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Biological and physical quality of a mined soil under revegetation with perennial grasses

Lizete Stumpf[1], Eloy Antonio Pauletto[2], Luiz Fernando Spinelli Pinto[2], Luciano Oliveira Geissler[2], Danilo Dufech Castilhos[2], David de Lima de Souza[2], Jeferson Pras Pimentel[2], Leonir Aldrigui Dutra Junior[2]

[1] Universidade Tecnológica Federal do Paraná/Campus Dois Vizinhos. Dois Vizinhos, PR, Brasil. E-mail: zete.stumpf@gmail.com (ORCID: 0000-0001-7760-0803)
[2] Universidade Federal de Pelotas/Faculdade de Agronomia Eliseu Maciel/Departamento de Solos. Pelotas, RS, Brasil. E-mail: pauletto_sul@yahoo.com.br (ORCID: 0000-0001-9679-3081); lfspin@uol.com.br (ORCID: 0000-0001-6582-7509); luciano.geissler@gmail.com (ORCID: 0000-0003-2580-9140); danilodc@ufpel.tche.br (ORCID: 0000-0003-3739-064X); david.lima@ufpel.edu.br (ORCID: 0000-0003-4318-9037); jefersonprass@gmail.com (ORCID: 0000-0002-2191-3533); leonirdutrajr@gmail.com (ORCID: 0000-0002-4658-0683)

ABSTRACT: The objective of this work was to evaluate a population of mites and springtails and a physical condition of a mined soil revegeted with different species of perennial grasses. The treatments evaluated were: *Urochloa brizantha*, *Hemarthria altissima*, *Paspalum notatum*, *Cynodon dactylon* and *Spontaneous vegetation*. For comparative effects a natural soil were used as reference. In 2014, 56 soil samples were collected in the 0.00-0.10 m layer for the determination of the population of mites and springtails, the physical attributes and the organic carbon content. The *Hemarthria altissima* was the most prominent plant species among perennial grasses, to date, providing an average density of mites and springtails very close to the natural soil. Among the physical attributes, bulk density showed the most sensitive variable the changes promoted by plant species, after 11 years of revegetation.

Key words: edaphic mesofauna; organic carbon; physical attributes

Qualidade biológica e física de um solo minerado sob revegetação com gramíneas perenes

RESUMO: O objetivo do trabalho foi avaliar a população de ácaros e de colêmbolos e a condição física de um solo minerado e revegetado com diferentes espécies de gramíneas perenes. Os tratamentos avaliados foram: a *Urochloa brizantha*, a *Hemarthria altissima*, o *Paspalum notatum*, o *Cynodon dactylon* e a vegetação espontânea. Para efeitos comparativos foi utilizado o solo natural como tratamento referência. Em 2014, oram coletadas 56 amostras de solo na camada de 0,00-0,10 m para a determinação da população de ácaros e colêmbolos, dos atributos físicos e do teor de carbono orgânico. A *Hemarthria altíssima* foi a espécie vegetal que mais se destacou entre as gramíneas perenes, até o presente momento, proporcionando uma densidade média de ácaros e colêmbolos muito próximos aos do solo natural. Entre os atributos físicos, a densidade do solo mostrou-se a variável mais sensível as alterações promovidas pelas espécies vegetais, decorridos 11 anos de revegetação.

Palavras-chave: mesofauna edáfica; carbono orgânico; atributos físicos

Introduction

Environmental degradation generated by coal mining is not an irreversible process, but recovery is slow because the correction of its chemical and physical attributes has to take place first, to only later have functional biological attributes recovered (Pauletto et al., 2016). In this sense, several studies have already been developed in mining soils to evaluate the effect of revegetation on their chemical (Bitencourt et al., 2015; Stumpf et al., 2016a; Leal et al., 2016), physical (Reis et al., 2014; Stumpf et al., 2016b; Pauletto et al., 2016) and biological (Menta et al., 2014; Oliveira Filho et al., 2015; Frasson et al., 2016; Majumder & Palit, 2017) attributes. Plants play a key role in the recovery of degraded areas, since they promote the increase of organic matter and the improvement of other soil attributes such as aggregation, aeration and water retention, thus creating favorable conditions for increasing the diversity of edaphic organisms, which in turn, influence nutrient recycling and consequently improve soil fertility and ecological balance (Hernani & Padovan, 2014).

Within the agricultural context, perennial grasses stand out. These plants have a dense root system whose action through several years in the same place closely binds particles and adds organic compounds throughout the soil matrix, resulting in improvements in the soil structural condition (Silva & Mielniczuck, 1997). In drastically altered soils, such as mining soils, the potential of perennial grasses to provide better physical conditions was demonstrated by Stumpf et al. (2016b), who observed that after 8.6 years of revegetation, the 0.00-0.10 m soil layer had the highest root biomass of the species (2.78 to 13.26 Mg m^{-3}) and, consequently, the lowest values of soil density (Ds) (1.22 to 1.45 Mg m^{-3}) and the highest macroporosity (Ma) (0.086 to 0.151 m^3 m^{-3}) in relation to the 0.10-0.20 m layer, where the root biomass was substantially lower (0.87 to 6.00 Mg m^{-3}) with Ds values ranging from 1.36 to 1.59 Mg m^{-3} and Ma ranging from 0.035 to 0.114 m^3 m^{-3}.

According to Souza et al. (2014), fresh organic matter such as decomposing plant residues acts intensely on the stability of aggregates due to the biological activities that are triggered. In this process, the presence of soil mesofauna is essential for fragmenting the decomposing material and regulating the fungi population, which together with the bacteria, are responsible for the catabolization of the organic matter of the soil and production of organic compounds that bind aggregates (Balota, 2017). Among the diversity of organisms belonging to the soil mesofauna, mites and springtails are noteworthy, making up 72 to 97% of the total population (Lins et al., 2007).

According to Silva et al. (2013), because mites are much more abundant than springtails, they decrease the surface area of plant residues, facilitating the continuation of decomposition by microorganisms, mainly bacteria. On the other hand, the main function of springtails is to regulate the edaphic microbiota, because although they feed on an extensive range of foods, the preference of the majority of the species is microorganisms and fungal hyphae associated with soil organic matter and litter (Oliveira Filho & Baretta, 2016).

The measurement of edaphic mesofauna in agricultural soils has already been used as a bioindicator of changes in soil quality caused by different uses and management (São José et al., 2013; Silva et al., 2014; Geremia et al., 2015). In this context, plants can exert a differentiated influence on the frequency of organisms in the edaphic mesofauna, either through the amount of nutrient concentration and lignin content of the aerial biomass added to the soil via litter (Balota, 2017), or by the influence of its underground biomass in soil structuring, which interferes with habitat conditions (habitable pore space volume, pore connectivity, and moisture and temperature regimes) of some organisms (Oliveira Filho & Baretta, 2016).

The objective of this work was to evaluate the population of mites and springtails and the physical condition of a mined soil revegeted with different species of perennial grasses.

Materials and Methods

The study was carried out in a coal mining area belonging to athe Mining Company of Rio Grande do Sul (CRM), located in Candiota/RS (31°33’56” S and 53°43’30” W). Open-cast coal mining takes place in this area and includes the following steps: (a) removal of A, B and/or C horizons from the original soil and rocks; (b) extraction of coal deposites; (c) deposition of esterile material (mixture of rocks and unused coal) in the pit open for extraction of the mineral, which is planed by crawler tractors; (d) replacement of a soil layer (A and/or B horizon) previously removed to mining the coal, thereby giving rise to the “constructed soil”. The soil layer returned to the experimental area comes from the B horizon of a typical Eutrophic Red Argisol, as indicated by the dark red color (2.5 YR 3.5/6), clayey textural class (466 g kg^{-1} of clay, 229.66 g kg^{-1} of silt, 304.33 g kg^{-1} of sand) in the 0.00-0.30m layer and with low organic matter content (1.15%).

The soil was prepared in the first quarter of 2003 and the experiment, with different plant species, was installed in November/December of the same year, in 20 m^2 (5m x 4m) plots in a randomized block design with four replicates. Treatments with the following perennial grasses were evaluated in the present study: *Urochloa brizantha, Hemarthria altíssima, Paspalum notatum* cv Pensacola, *Cynodon dactylon* cv Tifton 85 and spontaneous vegetation. Prior to planting the species, the area was scarified with a motor patrol at a depth of approximately 0.15 m, followed by liming corresponding to 10.4 Mg ha^{-1} of limestone (PRNT = 100%) and fertilization of 900 kg ha^{-1} of N-P_2O5-K_2O 5-20-20, based on results obtained in soil analysis. Fertilizations with 250 kg ha^{-1} of $NP_2O_5K_2O$ 5-30-15 and 250 kg ha^{-1} of ammonium sulfate were also carried out annually in all plots of the experimental area. The treatments did not receive any type of management related to the cutting of forage during the whole experiment.

Natural soil belonging to the mining area was used as reference treatment, with a predominance of white broom (*Baccharis dracunculifolia* Dc), macega estaladeira - (*Saccharum angustifolium* (Ness) Trin), chirca (*Eupatorium huniifolium* Hook. Ex Arn.), carqueja (*Baccharis trimera* (Less) Dc) and Caraguatá (*Eryngium horridum* Malne).

In October 2014, 56 soil samples were collected in the 0.00-0.10 m layer (4 blocks × 2 subsamples per treatment × 7 treatments) using stainless steel cylinders 0.08 m in height and 0.085 m in diameter for determination of organisms of the edaphic mesofauna, represented by mites and springtails. After the collection, the mesofauna (number of mites and springtails) was determined using the Tullgren Funnel Extractor method, proposed by Bachelier (1978). The procedure consisted of placing the samples carefully in 2mm mesh sieves on top of each funnel. At the base of the funnels were placed collecting cups containing 80% alcohol plus four drops of glycerin in order to avoid the rapid evaporation of the alcohol. Then, 25 watt bulbs were attached to each funnel. The lamps remained on for 48 hours so that the light and heat made the organisms to move downwards, thus being captured by the collecting cup with a capacity of 50 mL. Subsequently, these collected organisms were packed in closed containers and with the help of a binocular estereomicroscope were observed, classified and quantified according to the methodology described by Bachelier (1978).

In addition, 56 soil samples with a preserved and non-preserved structure (4 blocks × 2 subsamples per treatment × 7 treatments) were collected for determination of soil density, total porosity, macroporosity and microporosity, stability of water-stable aggregates, weighted average diameter of aggregates, and soil organic carbon content. Samples with preserved structure after washed were saturated in water by capillarity for 48 h to ensure complete saturation and then weighed on a precision scale and placed on a tension table where they were equilibrated at a tension of 6 kPa for determination of macroporosity. After equilibration, the samples were dried in an oven at 105 °C to constant weight for determination of microporosity and bulk density. Total porosity was calculated by summing the macroporosity and microporosity, and bulk density was calculated as the dry soil mass-to-volume ratio (Embrapa, 2011). The samples with non-preserved structure were placed in shaded and air dried trays until the soil reached the point of friability, when they were carefully dismantled manually, observing the points of weakness of the aggregates and passed in a 9.52 mm mesh sieve. After air dried for a period of approximately two weeks, the samples were submitted to wet sieving (Yoder, 1936), following a methodology presented by Palmeira et al. (1999) which follows the principle of determining the stability of aggregates in water, according to Kemper (1965). The intervals of the classes of the aggregates were: C1: 9.52-4.76 mm; C2: 4.75-2.0 mm; C3: 1.99-1.00 mm; C4: 0.99-0.25 mm; C5: 0.24-0.105 mm and C6: <0.104 mm. Based on these classes, the aggregates were separated into macroaggregates, that is, aggregates larger than 0.25 mm, and microaggregates, in case of aggregates smaller than 0.25 mm, according to Tisdall & Oades (1982). The data obtained was the basis to calculate the weighted mean diameter (WMD) of the aggregates in each soil layer evaluated.

Part of the air-dried and shade samples was stripped and passed in a 2.00 mm mesh sieve to determine the total organic carbon (OC) content through to the modified Walkey-Black method, according to Tedesco et al. (1995).

The data were submitted to analysis of variance by the F test at a significance level of 5% and pairwise comparisons of means were made by the Tukey test ($p < 0.05$). A principal component analysis (PCA) was applied in order to check the relationship between the population of mites and springtails and the condition of the constructed soil structure, to detect clusters, and to analyze the relation of groups of variables with each species of grass. All analyses were performed using the statistical software SAS (Statistical Analysis System).

Results and Discussion

The treatments with the different plant species presented significant differences only in the population of mites and springtails and bulk density (BD). Notably, *Hemarthria altíssima* presented the highest average density of mites and springtails in relation to the other species, with 3000 and 1025 individuals m^{-2} respectively, and *Urochloa brizantha* and *Paspalum notatum* presented the lowest BD in relation to *Cynodon dactylon* (Table 1).

This notable distinction between plant species is due to the fact that the edaphic mesofauna depends on soil cover, litter deposition, higher humidity and lower temperature oscillation at the soil surface (Sautter et al., 1998; Oliveira Filho et al., 2014; Oliveira Filho et al., 2015), factors that should be measured in future studies in the study area to corroborate the oustading findings for *Hemartria altíssima* in this stage of regeneration of the mined soil. On the other hand, improvements in BD are rather dependent on root density of plant species, as shown by Stumpf et al. (2016a).

In relation to the reference soil, it is observed that the mined soil under revegetation of different plant species presented populations of mites and springtails, respectively, from 10 to 85% and from 18 to 92% smaller in relation to the natural soil (Table 1). This result is in line with the observations of Li et al. (2015) and Mukhopadhyay et al. (2014), who only observed a significant effect on the biological quality of the mined soils in China and India after, respectively, 18 and 17 years of revegetation. On the other hand, the Table 1 also shows that the amount of mites was greater than that of the springtails in all treatments in both treatments, i.e. in the natural soil under native vegetation and in the mined soil under revegetation. This result differs from those of Frasson et al. (2016) and Oliveira Filho et al. (2014) who observed a predominance of springtails over mites in coal mining areas under revegetation for 5 and 7 years, respectively, with different plant species (*Schinus.*

Table 1. Differences (Δtest) between mined soil under revegetation of perennial grasses and natural soil in relation to the mean density of mites and springtails, bulk density (BD), total porosity (TP), macroporosity (Ma), microporosity (Mi), percentage of macroaggregates (Macro) and microaggregates (Micro), weighted mean diameter of aggregates (WMD) and organic carbon (OC) content in the 0.00-0.10 m layer.

Treatments	Mites	Springtails	BD	PT	Ma	Mi	Macro	Micro	WMD	OC
	Individuals m^{-2}		$Mg\ m^{-3}$		$m^3\ m^{-3}$		%		Mm	$g\ kg^{-1}$
Urochloa brizantha	1400 b	300 c	1.18 b	0.49^{ns}	0.14^{ns}	0.35^{ns}	77.3^{ns}	12.6^{ns}	2.43^{ns}	12.6^{ns}
Δtest (+ or -)	-58%	-76%	-13%	+8%	+89%	-9%	-6%	-28%	-4%	-27%
Hemartria altissima	3000 a	1025 a	1.27 ab	0.48^{ns}	0.12^{ns}	0.34^{ns}	78.9^{ns}	13.0^{ns}	2.07^{ns}	13.0^{ns}
Δtest (+ or -)	-10%	-18%	-7%	+5%	+70%	-10%	-4%	-26%	-18%	-24%
Paspalum notatum	1400 b	550 b	1.21 b	0.49^{ns}	0.14^{ns}	0.35^{ns}	79.5^{ns}	14.2^{ns}	2.42^{ns}	14.2^{ns}
Δtest (+ or -)	-58%	-56%	-11%	+8%	+86%	-6%	-4%	-19%	-4%	-17%
Cynodon dactylon	500 c	100 c	1.38 a	0.51^{ns}	0.11^{ns}	0.36^{ns}	82.1^{ns}	12.6^{ns}	2.09^{ns}	12.6^{ns}
Δtest (+ or -)	-85%	-92%	+2%	+12%	+45%	-5%	-1%	-28%	-17%	-27%
Spontaneous vegetation	575 c	175 c	1.33 ab	0.40^{ns}	0.15^{ns}	0.28^{ns}	69.7^{ns}	15.6^{ns}	2.40^{ns}	15.6^{ns}
Δtest (+ or -)	-83%	-86%	-2%	-13%	+100%	-25%	-16%	-10%	-5%	-9%
Natural soil	3350	1250	1.36	0.45	0.07	0.38	82.5	17.5	2.82	17.2

Equal lowercase letters in the column do not differ from each other (Tukey test, $p < 0.05$). Δtest (+ or -): differences of each treatment in relation to the reference soil (Natural soil)

terebinthifolius, Urochloas sp., Baccharis spp., Pseudobom baxgrandiflorum, Senna multijuga, Mimosa scabrella, Solanum pseudocapsicum, Eucalyptus spp., Eugenia spp., Taberna emontanacatharinensi) and in coal mining areas under revegetation for 4 years with *Urochloa decumbens.*

In spite of the fact that mined soil still presented biological and aggregation attributes below the natural condition, most of the perennial grasses showed to improve the recovery of BD and Ma, which were respectively 2 to 13% lower and 45 to 100% higher in contrast to the natural soil (Table 1). This result is probably due to the action of the roots of the different plant species, which presented the same pattern of root development at 8.6 years of revegetation, that is, a larger mass, volume, specific surface area and root length concentrated in the layer of 0.00-0.10 m, as demonstrated by Stumpf et al. (2016b). The aggressive root system of the species promoted the reorganization of the structure and network of soil pores, converging with the works of Perkons et al. (2014) and Vezzani & Mielniczuk (2011).

The positive behavior of the different plant species on the physical attributes of the mined soil was also evidenced through the principal components analysis, which considered the first two factors, which had an accumulated eigenvalue of 53.9%. The two components resulted from the linear combination of the 10 variables studied, where the first component explained 33.3% of the total variance, while the second explained 20.6%.

The first component had the highest positive correlations for the variables total porosity, macroporosity and macroaggregates, while the variables bulk density and microaggregates presented the highest negative correlations (Figure 1).

The behavior of these variables corroborates the positive performance of the majority of perennial grasses after 11 years of revegetation in terms of decreasing BD and increasing volume of macropores to the depth of 0.10 m. This result, as previously mentioned, may be a consequence of the higher concentration of roots in this soil layer, which was found to be around 64% at 8.6 years of revegetation (Stumpf et al., 2016b). This converges with the observations of Krummelbein & Raab (2012), who recommended the use of perennial species and with deeper rooting to increase the structuring of constructed soils in Germany, in order to obtain lower Ds and larger pore volume, mainly of macropores.

In the second component, the highest positive correlations were observed between the mite and springtail population and the variables microaggregates and microporosity, while the weighted mean diameter of the aggregates and macroaggregates showed the highest negative correlations with respect to these organisms (Figure 1). This result shows that mites and springtails also act on mined soils as precursors of the transformation of vegetal residues into organic matter, initially fragmenting the vegetal residues so that the soil microbiota be able to produce the organic compounds responsible for the bonding and cementing of small aggregates, as described by Balota (2017). Moreover, as mentioned by Oliveira Filho & Baretta (2016), springtails live and act on the same portion of the soil inhabited by fungi and are part of a complex of antagonistic and competing organisms that can positively influence fungus-plant interactions, as to maintain the mycorrhizae in an active state and consequently promoting the release of glomalin, a glycoprotein that exerts great influence on soil microaggregation.

The positive relation of the populations of mites and springtails with microporosity (Figure 1) should be better investigated because, due to size of these organisms (0.1 to 2 mm), they depend on air-filled pores, presenting at least the width of their body, tending to avoid narrow pores (Oliveira Filho & Baretta, 2016, Balota, 2017).

It is important to point out that the treatments presented differences in relation to BD, possibly due to the physical action of roots, but this effect was not repeated in relation to OC content (Table 1). This variable did not show to be an

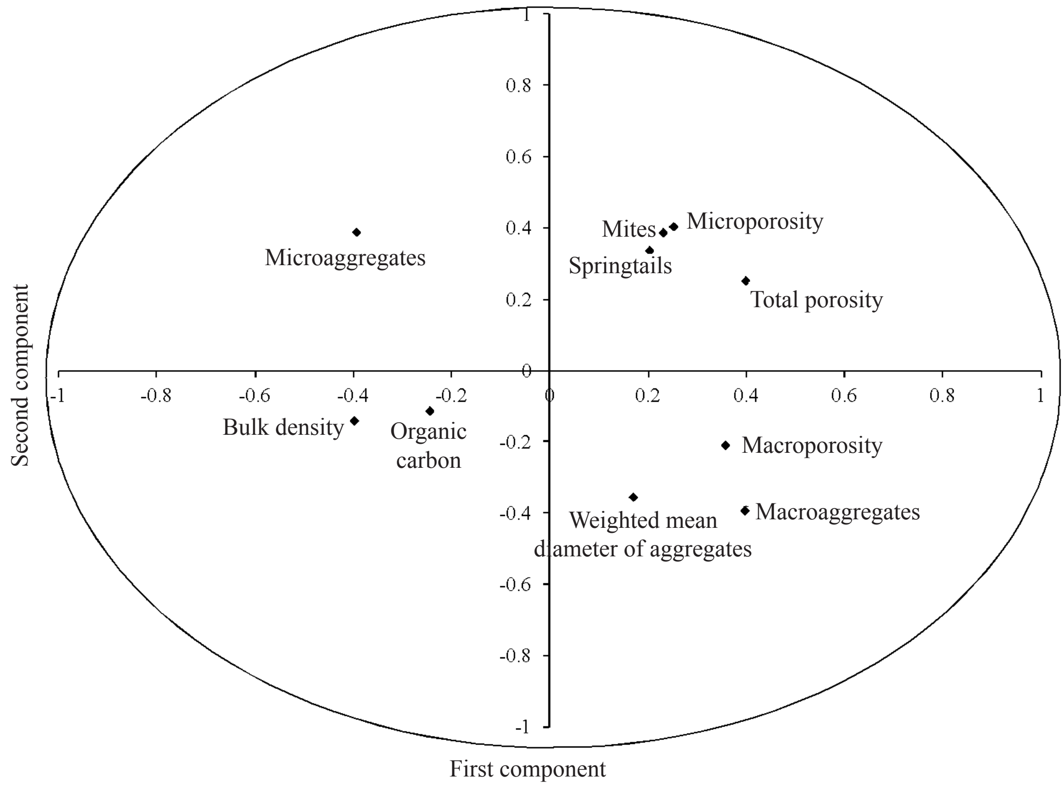

Figure 1. Eigenvectors of soil mesofauna variables (mites and springtails) and physical condition (bulk density, total porosity, macroporosity, microporosity, percentage of macroaggregates and microaggregates and weighted mean diameter of aggregates) and organic carbon content of the 0-0.10 m layer of a mined soil and revegeted with different perennial grasses for 11 years.

important factor for the presence of mites and springtails (Fig. 1), differing from what was reported Oliveira Filho & Bareta (2016), that is, that the organic matter content of the soil influences the density and activity of the mesofauna species, mainly springtails. This result shows that the increment of organic carbon in the soil is very slow in mined areas due to the intense degradation to which the soil is submitted. According to Maharana & Patel (2013) and Wick et al. (2009), carbon losses occur during the removal, storage and re-location of soil in mining areas, caused by both soil erosion and disintegration of natural soil aggregates. Furthermore, inadequate soil handling and distribution during topographical recomposition may cause compaction, hindering the early development of vegetation cover (Borůvka et al., 2012; Stumpf et al., 2016b), which is the main starting point for the recovery of the physical, chemical and biological quality of mining soils (Zhao et al., 2013). In this sense, Onweremadu (2007) observed that even after 30 years of revegetation, mined soils in southeastern Nigeria still had no O horizon below their surface when compared to natural soil. On the other hand, Akala & Lal (2001) observed that the accumulation of organic carbon began to occur between 5 and 10 years of revegetation in mined soils in the Midwest of the United States. In northern China, Zhao et al. (2013) verified that the organic matter of soils showed a significant increase during 13 years of evaluation, and that the root system of plants acted in a more significant way in the improvement of the aggregation of the soil between 5 and 10 years after revegetation of the area.

The initial difficulty to achieve coverage in soils constructed with the different plant species was observed in the first year of study, mainly due to the excessive compaction of the area, which remains below the 0.10 m layer until the present day, as discussed by Stumpf et al. (2016a). This indicates that there are many obstacles to be overcome over time to demonstrate the full potential of grasses.

Conclusions

The population of mites and springtails in the 0.00-0.10 m layer of mined soils under revegetation for 11 years is still lower in relation to the natural soil, except in the case of *Hemarthria altíssima* which had an average density of organisms very close to those of the reference soil.

Bulk density was the attribute of the mined soils that showed to be more sensitive to the improvements promoted by revegetation.

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