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Research Article

Microbiological and structural quality of Oxisol under pasture renewal systems[1]

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ABSTRACT

The central Brazilian Savanna biome, known as Cerrado, has a vast area of pastures affected by some degree of degradation, where one of the main challenges is incorporating these areas into a crop production system. This study aimed to evaluate the effect of pasture renewal systems on the microbiological and structural quality of a medium-texture Oxisol. A randomized blocks design was adopted, with four replications and eight pasture renewal systems: 1) soybean/off-season maize/soybean; 2) soybean/maize-grass intercropping/soybean; 3) grass for 10 months and then one soybean crop; 4) grass + rattlepod for 10 months and then one soybean crop; 5) grass for 13 months and then one soybean crop; 6) grass + rattlepod for 13 months and then one soybean crop; 7) one soybean crop; 8) original pasture (control). The microbiological quality was assessed based on soil microbial biomass carbon, soil microbial activity, microbial metabolic quotient - qCO_2 and activity of the β-glucosidase enzyme; and the structural quality based on the soil structural quality index. The implementation of pasture renewal systems with grass as a single crop (systems 3 and 5) or intercropped with rattlepod (systems 4 and 6) improves the soil microbiological and structural quality. The pasture renewal system beginning with soybean/off-season maize succession (system 1) is not indicated for the medium-texture soil evaluated in this study.

KEYWORDS: Rapid soil structure diagnosis, β-glucosidase, soil microbial biomass.

RESUMO

Qualidade microbiológica e estrutural de Latossolo submetido a sistemas de renovação de pastagem

O Cerrado brasileiro possui vasta área ocupada por pastagens com algum grau de degradação, e um dos principais desafios está na incorporação dessas áreas a um sistema produtivo. Objetivou-se avaliar o efeito de sistemas de renovação de pastagem na qualidade microbiológica e estrutural de um Latossolo de textura média. O delineamento experimental foi em blocos ao acaso, com quatro repetições e oito sistemas de renovação de pastagem: 1) soja/milho safrinha/soja; 2) soja/consórcio milho-capim/soja; 3) 10 meses de capim e uma safra de soja; 4) 10 meses de capim + crotalária e uma safra de soja; 5) 13 meses de capim e uma safra de soja; 6) 13 meses de capim + crotalária e uma safra de soja; 7) uma safra de soja; 8) pasto original (testemunha). A qualidade microbiológica foi avaliada por meio do carbono da biomassa microbiana do solo, atividade microbiana do solo, quociente metabólico - qCO_2 e atividade da enzima β-glucosidase, e a qualidade estrutural por meio do índice de qualidade estrutural do solo. A implantação de sistemas de renovação de pastagem com capim solteiro (sistemas 3 e 5) ou consorciado com crotalária (sistemas 4 e 6) melhora a qualidade microbiológica e estrutural do solo. A renovação de pastagem iniciada com sistema de sucessão soja-milho safrinha (sistema 1) não é indicada para o solo de textura média avaliado neste estudo.

PALAVRAS-CHAVE: Diagnóstico rápido da estrutura do solo (DRES), β-glucosidase, biomassa microbiana do solo.

INTRODUCTION

In recent decades, advances have been made for agriculture in the Brazilian Savanna, known as Cerrado, a biome that occupies 204 million hectares and corresponds to approximately 24 % of the national territory, a fact that illustrates its importance for the Brazilian agribusiness. Of its total area, 1.5 % is occupied by forestry, 11.7 % by agricultural crops and 29.5 % by cultivated pastures (Brasil 2015).

Most of the pasture areas show some degree of degradation; therefore, it is important to know the limitations and potential of their soils before they can be incorporated into a crop production system. The purpose of such incorporation is to intensify the agricultural production in the Cerrado without the need to open new areas (Victoria et al. 2020).

Based on these precepts, pasture renewal systems combined with soil conservation practices, such as the no-tillage system, crop rotation and

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integrated crop-livestock farming, among others, are crucial to maintaining the soil quality and enhancing the performance of agricultural activities in this region (Carvalho et al. 2016, Salton et al. 2017, Forte et al. 2018).

Soil quality bioindicators such as microbial biomass carbon and microbial activity are widely used to assess the short-term response of soil management practices (Maharjan et al. 2017, Mendes et al. 2019a). More recently, enzymes have been part of these bioindicators, which therefore allow accessing the "memory" left in the soil throughout the use of production systems (Mendes et al. 2019b, Mendes et al. 2020). Both chemical and physical attributes also exert a great influence on soil biology (Mendes et al. 2019a).

The main attributes used to characterize the microbiological quality of soils are microbial biomass carbon, microbial activity, microbial metabolic quotient, β-glucosidase activity (carbon cycle), acid phosphatase (phosphorus cycle) and arylsulfatase (sulfur cycle) (Lourente et al. 2011, Balota et al. 2013).

Similarly to soil microbial biomass, the enzyme activity is a sensitive indicator and may be used to monitor changes in soils, owing to its use and management, as a tool for better planning and assessing agricultural practices in the short and long term, aiming at soil conservation.

Another way of assessing the soil quality in each management system is using the rapid soil structure diagnosis method, which characterizes the soil surface layer at a depth of up to 25 cm, based on visual assessment of size and form of aggregates, presence or absence of compaction, evidence of biological activity and distribution of root system, among others (Ralisch et al. 2017).

Structure is an extremely important component in soil quality assessment (Jensen et al. 2020, Mamedov et al. 2021), especially when pasture renewal includes annual grain crops deprived of an efficient root system, such as that of grasses, capable of maintaining soil aggregation. Soil structure directly affects the soil permeability, aeration, root growth and soil biota, among others, which should be considered to assess the production systems' ability to maintain the soil quality (Salton et al. 2013, Salton & Tomazi 2014, Rabot et al. 2018).

Despite the individual nature of each assessment, the integration of these indicators can provide a greater sensitivity in detecting changes in soil quality. Thus, the present study aimed to evaluate the effect of pasture renewal systems on the microbiological and structural quality of a medium-texture Oxisol.

MATERIAL AND METHODS

The experiment was carried out in Nova Andradina, Mato Grosso do Sul state, Brazil (22º27'04"S, 53º18'13"W and 292 m of altitude), from October 2018 to March 2020. The climate in the region, according to the Köppen-Geiger classification, is Cwa (humid mesothermal), with hot summers and dry winters.

The soil in the region is classified as a medium-texture Latossolo Vermelho-Amarelo distrófico (Santos et al. 2018) or Oxisol (USDA 1999), with the following characteristics at the 0-20 cm depth: pH ($CaCl_2$) = 4.3; P Mehlich^{-1} (mg dm^{-3}) = 1.79; Ca (cmol$_c$ dm^{-3}) = 0.79; Mg (cmol$_c$ dm^{-3}) = 0.29; K (cmol$_c$ dm^{-3}) = 0.25; Mn (mg dm^{-3}) = 28.4; Cu (mg dm^{-3}) = 1.32; Fe (mg dm^{-3}) = 37.47; Zn (mg dm^{-3}) = 0.72; Al (cmol$_c$ dm^{-3}) = 0.3; V (%) = 24.5; SB (cmol$_c$ dm^{-3}) = 1.32; effective CEC (cmol$_c$ dm^{-3}) = 1.62; OM (g kg^{-1}) = 148; sand (g kg^{-1}) = 729; silt (g kg^{-1}) = 43; and clay (g kg^{-1}) = 228.

A randomized blocks design was used, with four replications and eight pasture renewal systems: 1) soybean/off-season rainfed maize/soybean; 2) soybean/maize-grass intercropping/soybean; 3) grass for 10 months and then one soybean crop; 4) grass + rattlepod for 10 months and then one soybean crop; 5) grass for 13 months and then one soybean crop; 6) grass + rattlepod for 13 months and then one soybean crop; 7) one soybean crop; 8) original pasture (control).

Dolomitic limestone was used to increase the base saturation to 60 % (0-20 cm layer), in addition to phosphorus, with single superphosphate fertilizer incorporated into the 0-15 cm layer in all pasture renewal systems.

The renewal systems 1 (soybean/off-season rainfed maize/soybean) and 2 (soybean/maize-grass intercropping/soybean) began in September 2018, with the application and incorporation of limestone with a harrow. Later, in October 2018, the soil was prepared for the sowing of the 2018/2019 soybean crop with a harrow and a leveler. After the harvest in 2019, maize was directly sown (system 1), maize was intercropped with brachiaria grass (system 2) and, finally, in the 2019/2020 crop, soybean was directly sown.

The management of the systems 3 (grass for 10 months and then one soybean crop), 4 (grass + rattlepod for 10 months and then one soybean crop), 5 (grass for 13 months and then one soybean crop) and 6 (grass + rattlepod for 13 months and then one soybean crop) also began in September 2018, with the application and incorporation of limestone with a harrow. In October 2018 (systems 5 and 6) and February 2019 (systems 3 and 4), the soil was prepared for the sowing of grass (as a single crop) and maize intercropped with rattlepod (crotalaria), with a harrow and a leveler, remaining with grass until the 2019/2020 crop, when soybean was directly sown. In the system 7 (one soybean crop), limestone was applied and incorporated to the soil in September 2019, with two harrows and one leveler, and then the 2019/2020 soybean crop was sown. The system 8 (original pasture) remained unchanged, as it was the control.

The crops, starting from 2018/2019, were mechanically planted with 0.50 m inter-row spacing, in plots of seven 6-m-long rows. The crops comprised the maize hybrid K9606 VIP3, with a planned population of 50,000 plants ha^{-1}; the soybean cultivar BRS 1003 IPRO, with 240,000 plants ha^{-1}; and *Urochloa ruziziensis* intercropped with maize, with a population of 100,000 plants ha^{-1}. The grass used in the pasture renewal systems was *Panicum maximum* cv. BRS Zuri, as a single crop and intercropped with rattlepod (*Crotalaria ochroleuca*).

The soil samples were collected at the soil level for the analysis of microbiological attributes on January 30, 2020, approximately 60 days after emergence (DAE), during the soybean flowering stage (R2), with the aid of a one-piece Dutch auger, at a 0-10 cm depth, as there is a higher concentration and activity of microorganisms at this depth (Silva et al. 2010). Sub-samples were collected at four points per plot, alternating between the two central sowing rows. At each point, five portions of soil at an equal distance of 10 cm were removed, with one pit in the middle and two pits on each side up to the middle of the inter-row, perpendicularly to the sowing row. The four subsamples were homogenized to form a single sample consisting of one plot. In the laboratory, the soil sample for each treatment was sieved (4 mm mesh) and stored in a cold chamber at ± 7 ºC, until analyzed, one day after the samples had been collected.

The soil microbial biomass carbon (SMB-C) analysis was carried out using the fumigation-extraction method proposed by Vance et al. (1987) and Tate et al. (1988); the soil microbial activity (C-CO_2) according to Alef & Nannipieri (1995); and the microbial metabolic quotient ($q CO_2$) determined by the ratio between the C-CO_2 flow from the soil and the SMB-C content (Anderson & Domsch 1990).

Soil samples were also collected after the soybean harvest in March 2020, using a one-piece Dutch auger at a 0-10 cm depth, following the same sampling recommendations used for the soil microbial biomass assessment. However, this time, the samples were air-dried to determine the β-glucosidase activity (Tabatabai 1994).

On the same date, soil blocks were collected to perform the rapid soil structure diagnosis proposed by Ralisch et al. (2017). Scores from 1 to 6 were assigned, with 1 being the worst and 6 being the best soil structure quality of each layer (SqL), used as a basis for calculating the soil structure quality index of the samples {$SSQIs = [(Th_{L1} \times Qe_{L1}) + (Th_{L2} \times Qe_{L2}) + (Th_{L3} \times Qe_{L3})]/Th_{total}$, where SSQIs is the soil structure quality index of the sample; Th_L the thickness of each layer, in cm (the number of layers may vary from 1 to 3); Qe_L the soil structure quality score assigned to each layer; and Th_{total} the total thickness/total depth of the sample (25 cm)} and the soil structure quality index of the evaluated area [$SSQIa = (SSQIs_1 + SSQIs_2 + \cdots + SSQIs_n)/n$, where SSQIa is the soil structure quality index of the evaluated area; n the total number of samples; and SSQIs the soil structure quality index of the samples, from 1 to n].

After satisfying the assumptions of the analysis of variance (normality and homoscedasticity), the procedure was continued and, when a significant effect of the treatments was observed (pasture renewal systems), the means were compared using the Tukey test ($p \leq 0.05$). In a complementary way, the similarity among the pasture renewal systems was analyzed by cluster analysis. For this purpose, the unweighted pair group method with arithmetic mean (UPGMA) was used, with the Mahalanobis distance as a measure of similarity, using the GENES software (Cruz 2013).

RESULTS AND DISCUSSION

The soil microbial biomass carbon (SMB-C) and microbial activity ($C\text{-}CO_2$) were higher in the pasture renewal systems 5 (grass for 13 months and then one soybean crop), 6 (grass + rattlepod for 13 months and then one soybean crop) and 8 (original pasture), when compared to the system 1 (soybean/off-season rainfed maize/soybean); and the other systems did not differ from each other (Table 1). The microbial metabolic quotient ($qC\text{-}CO_2$) did not show any significant difference among the evaluated systems (Table 1).

The β-glucosidase activity values were significantly lower in the system 1 (soybean/off-season rainfed maize/soybean), when compared to the systems 3 (grass for 10 months and then one soybean crop), 4 (grass + rattlepod for 10 months and then one soybean crop) and 7 (one soybean crop), without statistically differing from the systems 2, 5, 6 and 8 (Table 1).

The pasture renewal systems 3 (grass for 10 months and then one soybean crop), 4 (grass + rattlepod for 10 months and then one soybean crop), 5 (grass for 13 months and then one soybean crop), 6 (grass + rattlepod for 13 months and then one soybean crop) and 8 (original pasture - control) yielded the largest SSQI, in comparison to the systems 1 (soybean/off-season rainfed maize/soybean), 2 (soybean/maize-grass intercropping/soybean) and 7 (one soybean crop), i.e., those whose pasture renewal began with a soybean crop (Table 1).

The cultivation of grasses and leguminous plants provide a greater diversity of residues and root systems, favoring the maintenance of the soil microbial biomass carbon (SMB-C) and microbial activity ($C\text{-}CO_2$) (Laroca et al. 2018, Fontana et al. 2020, Sousa et al. 2020). The off-season maize single crop in succession to soybean did not show such diversity and resulted in significant reductions in SMB-C and $C\text{-}CO_2$, when compared to the other pasture renewal systems. This is because the soil microbiological attributes are related to the quantity, quality and diversification of plant residues deposited in the soil in the long term, with higher values of microbial biomass in integrated production systems (Soares et al. 2019).

Overall, the soil microbiological attributes were influenced by the pasture renewal systems, and the systems with the presence of grass for 10 and 13 months yielded the highest values. This may be related to the greater quantity and quality of organic material present in the soil, which can be considered an alternative for achieving a higher level of environmental sustainability in agricultural activities.

The potential of soil enzyme activity as a highly sensitive indicator has been verified in Brazil (Mendes et al. 2003, Balota et al. 2004, Mendes et al. 2015). Β-glucosidase acts in the final stage of cellulose degradation, hydrolyzing cellobiose and releasing glucose as an end product, an important source of energy for soil microorganisms. This enzyme reflects the biological activity and the ability of the soil to stabilize organic matter, with its activity being influenced by soil management and pH (Tabatabai 1994).

Table 1. Mean values of soil microbial biomass carbon (SMB-C), soil microbial activity ($C\text{-}CO_2$), microbial metabolic quotient ($qC\text{-}CO_2$), β-glucosidase activity and soil structure quality index (SSQI) in pasture renewal systems, in a medium-texture soil.

Treatments	SMB-C	$C\text{-}CO_2$	$qC\text{-}CO_2$	β-glucosidase	SSQI
	$mg\ g^{-1}$	$mg\ g^{-1}\ soil\ day^{-1}$		mg p-nitrophenol kg^{-1} of soil h^{-1}	
1	175.58 b[1]	15.01 b	40.12 a	62.04 c	3.22 b
2	195.83 ab	18.15 ab	40.06 a	71.99 abc	3.21 b
3	195.26 ab	16.98 ab	37.57 a	81.92 a	4.52 a
4	197.93 ab	17.57 ab	38.11 a	79.27 ab	4.97 a
5	249.85 a	19.93 a	33.30 a	75.18 abc	5.13 a
6	242.04 a	21.08 a	36.73 a	68.39 abc	5.14 a
7	227.62 ab	18.15 ab	34.08 a	78.57 ab	2.70 b
8	257.07 a	21.27 a	34.94 a	67.42 bc	5.21 a
Mean	217.64	18.59	36.87	73.10	4.26
CV (%)	16.09	16.15	25.55	7.80	7.17

[1] Means followed by the same letters do not differ by the Tukey test ($p \leq 0.05$). CV: coefficient of variation. 1) soybean/off-season rainfed maize/soybean; 2) soybean/maize-grass intercropping/soybean; 3) grass for 10 months and then one soybean crop; 4) grass + rattlepod for 10 months and then one soybean crop; 5) grass for 13 months and then one soybean crop; 6) grass + rattlepod for 13 months and then one soybean crop; 7) one soybean crop; 8) original pasture (control).

The low β-glucosidase activity observed in the renewal system 1 (soybean/off-season rainfed maize/soybean) indicates that the soybean-maize succession can reduce the activity of this enzyme. The β-glucosidase activity may be influenced by the quality of crop residues and soil management practices. Thus, the adoption of the no-tillage system may contribute to an increasing β-glucosidase activity, in comparison to the conventional tillage system (Pandey et al. 2014).

Regarding the soil structure, in the method proposed by Ralisch et al. (2017), scores between 5.0 and 6.0 indicate a very good soil structure quality, meaning that the management system used can be maintained. The scores for the renewal systems 5 (grass for 13 months and then one soybean crop), 6 (grass + rattlepod for 13 months and then one soybean crop) and 8 (original pasture - control) are within this range.

Ralisch et al. (2017) stated that the presence of roots favors the formation of larger and more resistant aggregates, with a lumpy appearance and porosity, receiving high scores on the rapid soil structure diagnosis. Thus, the presence of grass for 13 months in the renewal systems 5 and 6 and the unchanged pasture (control; system 8) contributed to the maintenance of the soil structure.

An SSQI score of 4.0-4.9 indicates a good soil structure quality (Ralisch et al. 2017). The scores of the systems 3 (grass for 10 months and then one soybean crop) and 4 (grass + rattlepod for 10 months and then one soybean crop) are within this range.

The pasture renewal systems 1 (soybean/off-season rainfed maize/soybean) and 2 (soybean/maize-grass intercropping/soybean) showed a regular SSQI, with scores of 3.0-3.9, demonstrating that the soil management should be improved with the adoption of conservationist practices, avoiding the traffic of agricultural machinery.

The renewal system 7 (one soybean crop) showed a poor soil structure quality, with SSQI score of 2.69, requiring intervention in the system. A solution to improve this SSQI is the use of soil recovery plants and an increase in the diversity of plant species (Ralisch et al. 2017). The recent soil preparation with a harrow for sowing soybean (2019/2020) of the renewal system 7 (one soybean crop) may have contributed to the low SSQI, given that soil disturbance contributes to reducing aggregate size (Salton et al. 2013, Salton & Tomazi 2014).

Bonetti et al. (2018) pointed out that the lesser the turning over, the better the soil structure, because of the greater input of material from crop residues and roots. However, when the soil is mechanically managed, changes in its characteristics may occur, as in the renewal systems 1 (soybean/off-season rainfed maize/soybean), 2 (soybean/maize-grass intercropping/soybean) and 7 (one soybean crop).

Figure 1 shows the dendrogram generated by the clustering method, based on the generalized Mahalanobis distance, which divided the pasture renewal systems into two groups, with group I being the smallest, with 3 systems, and group II being the largest one, with 5 systems. The statistical criterion used to determine the number of groups was the Mojena method (1977), based on the relative size of the fusion levels in the dendrogram. The cophenetic correlation coefficient (CCC) in the clustering

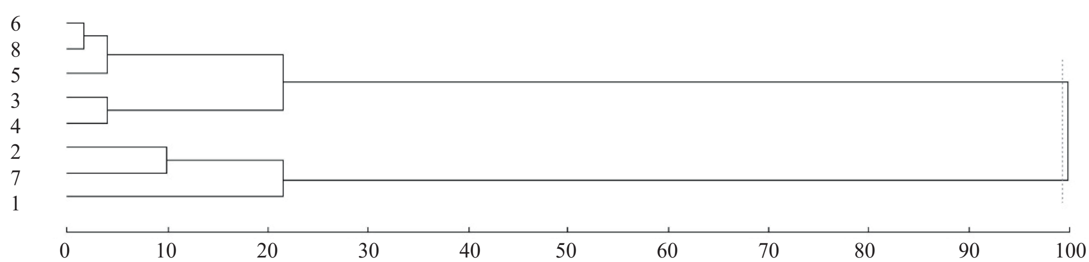

Figure 1. Similarity dendrogram using the unweighted pair group method with arithmetic mean (UPGMA) and the Mahalanobis distance, based on soil microbial biomass carbon (SMB-C), soil microbial activity (C-CO2), microbial metabolic quotient (*q*C-CO2), β-glucosidase activity and soil structure quality index (SSQI), as a function of the proposed pasture renewal systems, in a medium-texture soil. 1) soybean/off-season rainfed maize/soybean; 2) soybean/maize-grass intercropping/soybean; 3) grass for 10 months and then one soybean crop; 4) grass + rattlepod for 10 months and then one soybean crop; 5) grass for 13 months and then one soybean crop; 6) grass + rattlepod for 13 months and then one soybean crop; 7) one soybean crop; 8) original pasture (control).

examined by the UPGMA method was 93.39 %, indicating a good representation of the distances in the dendrogram.

In interpreting the similarity matrix among the pasture renewal systems, a cutoff point of 100 % was done in the Mahalanobis distance, allowing a clear division of the groups ordered by the variables SMB-C, C-CO2, *q*C-CO2, β-glucosidase and SSQI, constituting the group I, which comprises the representative data of the systems 3, 4, 5, 6 and 8; and the group II, formed by the systems 1, 2 and 7. These two groups did not show any similarity to each other, since their linkage distance was 100 %.

In the group I, two distinct clusters (subgroups) were formed. The first subgroup showed a linkage with 1.6 % of dissimilarity among the systems 6, 8 and 5, allowing to infer that the similarity among them is 98 %. Possibly, the clusters were formed due to the presence of grasses for a longer period. In the second subgroup, the systems 3 and 4 showed only 3.8 % of dissimilarity. This demonstrates that the systems with grass as a single crop or those intercropped with *Crotalaria ochroleuca* presented similar characteristics.

In the group II, two subgroups were formed from different clusters. The first subgroup showed 90 % of similarity (10 % of dissimilarity) between the systems 2 and 7. In the second subgroup, it was found that the system 1 showed 79 % of similarity with the systems 2 and 7. This soil, despite being classified as medium texture, has a high sand content (729 g kg^{-1}), which increases its susceptibility to erosion and degradation processes. The soybean/off-season maize succession (system 1), without the presence of other species producing satisfactory phytomass, coupled with the increased traffic of agricultural machinery, may have favored the clustering of the systems 1, 2 and 7, hence the use of soybean crop is not recommended at the beginning of the pasture renewal process, as it affects the soil quality.

CONCLUSIONS

1. Pasture renewal systems, either with grass as a single crop [systems 3 (grass for 10 months and then one soybean crop) and 5 (grass for 13 months and then one soybean crop)] or intercropped with rattlepod (*Crotalaria ochroleuca*) [systems 4 (grass + rattlepod for 10 months and then one soybean crop) and 6 (grass + rattlepod for 13 months and then one soybean crop)] improve the microbiological and structural soil quality;
2. Pasture renewal systems beginning with a soybean/off-season maize succession (system 1 - soybean/off-season rainfed maize/soybean) are not indicated for the medium-texture soil evaluated in this study.

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