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Use and management of pasture in the cerrado biome: Impacts on aggregation of an oxisol

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The objective of this study was to evaluate the physical quality of a dystrophic Oxisol in the Cerrado biome, by means of its aggregation, after 19 years of use and management with pasture. The treatments were soil with natural vegetation (CERR); and soil with *Brachiaria decumbens* cultivar Basilisk pasture, under the following four types of management: soil with maintenance-level fertilization, every two years, and with legumes (PAML); soil with maintenance-level fertilization, every two years (PAM); soil with fertilization only at implantation (PAI); and soil with degraded pasture without fertilization (PD). In November 2012, after 19 years of land use in the treatments, soil samples were collected at four locations per plot, and at two depths, 0 to 10 and 10 to 20 cm. The study evaluated the size distribution of air-dried aggregates and the distribution of water-stable aggregates, determining the water-stable weighted mean diameters (WMD_{ws}), the efficiency ratio of aggregates (ERA) and organic matter content of soil. The management of grassland with fertilizer favors the formation of larger aggregates in the soil, as well as WMD_{sw}, ERA and the content of organic matter, improving soil physical quality, both in the 0 to 10 cm and in the 10 to 20 cm layer. Impacts on soil aggregates caused by the removal of native vegetation can be improved with the use of soil under pasture and managed with fertilization in the 10 to 20 cm layer.

Key words: Soil physics, sustainability, organic matter.

INTRODUCTION

The use of the soil for pasture in the Cerrado, Brazil's highland savanna, is of great importance for the Brazilian agribusiness sector. Since the expansion of the agricultural frontier in the 1970s, boosted by the opening of new areas, the Cerrado soils have undergone significant transformations, occasioned by the use of various technologies, especially alterations in fertilization and soil management, breeding and diversification of crops (Macedo, 2009).

In Brazil, extensive systems of exploitation for animal

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production, mainly for beef cattle, are carried out principally in pastures, either native or cultivated. However, more than half of the cultivated pastures in the Cerrado are degraded or in the process of degradation, with reduced soil fertility, increased invasive plants, pests, soil compacted by animal hooves and erosive processes, culminating in the loss of pasture to sustain the levels of production and quality demanded by stock (Souza et al., 2008; Macedo, 2009; Parente and Maia, 2011).

The effects of pasture degradation include an alteration in the physical quality of the soil, an increase in density, reduction in porosity and more resistance to penetration when conditions are dry (Mapfumo et al., 2000; Fidalski et al., 2008). Well-managed pasture, be it continuous pasture or integrated with crops, avoids physical degradation of the soil and protects against the impact of raindrops. It also prevents the soil surface structure from deteriorating and increases the infiltration of water into the soil; furthermore, the root system promotes improvements in soil structure (Salton et al., 2008; Bono et al., 2012).

The physical quality of the soil can be evaluated by soil properties, such as total porosity, soil density and aggregation, and the availability of water for plants. These properties influence the growth and development of plants and maintain the diversity of organisms that inhabit the soil (Bono et al., 2013; Carneiro et al., 2009). When the soil is submitted to the productive process its physical characteristics undergo alterations, and because there is then a tendency to lose structural quality and increase the susceptibility to erosion, it is vital to evaluate these characteristics after the introduction of anthropic activities, to look for more sustainable management strategies (Wendling et al., 2012).

A parameter that has been used in the evaluation of sustainability of use and management systems is the physical quality of the soil. Aggregation is one of the ways of checking this quality, and it is measured by distribution of aggregated classes, weighted mean diameter (WMD), geometric mean diameter (GMD) and Aggregate Stability Index (ASI) (Wendling et al., 2012; Demarchi et al., 2011).

The objective of this study was to verify the influence of different management systems for soil under pasture on the physical quality of a dystrophic oxisol in the Cerrado biome, in the municipality of Campo Grande in Brazil's Mato Grosso do Sul state.

MATERIALS AND METHODS

The experimental area used in this long-term experiment is located within the National Center for Beef Cattle Research (Embrapa Gado de Corte), in the municipality of Campo Grande, Mato Grosso state, at geographical coordinates: latitude 20°25'03" and longitude 54°42'20" at an altitude of 559 m. The soil was described as a dystrophic oxisol (Embrapa, 2013), and its natural vegetation, which was cut down in the agricultural year of 1972/73, was typical of 'cerradão', which is forested savanna. In October 1987, the area was heavily tilled, roots were removed, and there was an application of lime (1.0 t ha^{-1} - PRNT-100%) and fertilizer (350 kg ha^{-1} of simple superphosphate, 100 kg ha^{-1} of potassium chloride and 40 kg ha^{-1} of FTE), incorporated with a harrow. It was used in the general maintenance of the herd of the Beef Cattle Center at Embrapa Gado de Corte until August, 1993, and in July 1994 the soil was prepared for the start of the experiment.

Treatments

For this study the following treatments for soil management were considered:

1. CERR – soil with natural vegetation.
2. PAML – soil with pasture of *B. decumbens* cultivar Basilisk, with maintenance-level fertilization every two years and with legumes.
3. PAM - soil with pasture of *B. decumbens* cultivar Basilisk, with maintenance-level fertilization every two years;
4. PAI - soil with pasture of *B. decumbens* cultivar Basilisk, with fertilization at implantation;
5. PD - soil with degraded pasture of *B. decumbens* cultivar Basilisk, without fertilization.

All the pasture areas had animal management controlled by means of a supply of uniform forage.

Description of treatments

In treatments of PAML, PAM, PAI and PD, implantation of the *B. decumbens* cv. Basilisk pasture was done in plots measuring 140 m x 50 m (7000 m^2). In treatments PAML and PAM the areas were corrected with lime to maintain saturation at bases from 40 to 45%, with an application of dolomitic limestone with TNP of 80%. Maintenance-level fertilizer was applied every two years, using 400 kg ha^{-1} of machine-spread 0-20-20 formula. These applications took place each November, and in the PAM treatment, there was also an annual application of 50 kg ha^{-1} of N, based on urea, which took place between December and January. In the PAML treatment, legumes were introduced every two years, composed of a mixture of calopo (*Calopogonium mucunoides*) and *stylosanthes* (cultivar Campo Grande) directly on the *B. decumbens* pasture, using a pasture planter. The stocking rate in these treatments was 1.6 Animal Units (AU) ha^{-1}.

In the PAI treatment, the area was corrected with 1500 kg ha^{-1} of dolomitic limestone (TNP 80%) and fertilized only at implantation stage with 80 kg ha^{-1} of P_2O_5 using simple superphosphate as source, 100 kg ha^{-1} of K_2O using potassium chloride as source and 50 kg ha^{-1} of N from animal urea ha^{-1}. The stocking rate in this treatment was 0.8 AU ha^{-1}. In the PC treatment, the pasture was implanted without correction or fertilizer and the stocking rate was 0.6 AU ha^{-1}. In the CERR treatment, plots of 140 m x 50 m (7000 m^2) of native vegetation beside the experiment were considered.

Parameters evaluated

In November 2012, after 19 years of soil use, samples were collected from the treatments, from four places in each plot and at two depths, at 0 to 0.10 and 0.10 to 0.20 m. The samples, under friable conditions in the field (soil consistency when damp), were put through a sieve with a mesh of 8 mm and collected in a 4 mm sieve, in accordance with Guedes et al. (1996). Next, the analysis took place to calculate the size distribution of air-dried aggregates and water-stable aggregates, shaken as described by Veiga (2011). For this, 100 g of air-dried aggregates were used, placed in the upper part of a set of five sieves with mesh of 2.00; 1.00; 0.50; 0.25 and 0.105 mm, and shaken vertically with 46 oscillations per minute in the water, for 10 min. In the samples of air-dried aggregates, moisture was determined by the gravimetric method (Embrapa, 2011), to correct the humidity in aggregates submitted to shaking. By means of the sieves used, the aggregates were distributed in the following classes: 8 to 2; 2 to 1; 1 to 0.5; 0.5 to 0.21 and 0.21 to 0.105 mm. From the different sizes of aggregates separated in water, the organic matter (OM) content in the soil was determined, in accordance with Embrapa (2011). From the values of the size distribution of air-dried and water-stable aggregates the weighted mean diameters were determined for air-dried (WMD_{ad}) and water-stable (WMD_{ws}) aggregates to obtain their efficiency ratio (ERA) in accordance with Veiga (2011), by means of the equations below (equation 1 and equation 2):

$$WMD_{ad} = \sum_{i=1}^{n} (\mathrm{pi} * \mathrm{di}) \tag{1}$$

$$WMD_{ws} = \sum_{i=1}^{n} (\mathrm{pi} * \mathrm{di}) \tag{2}$$

i represents the class of aggregates (8 to 4; 4 to 2; 2 to 1; 1 to 0.5; and < 0.5 mm); ***pi*** is the proportion of aggregates present in the respective class in relation to the total mass of aggregates; and ***d*** is the mean diameter of the class (respectively 6; 3; 1.5; 0.75 and 0.25 mm). With the values of WMD_{ad} and WMD_{ws} the Efficiency Ratio of Aggregation (ERA) was calculated with equation 3 (eq. 3):

$$ERA = \frac{WMD_{ws}}{WMD_{ad}} \tag{3}$$

Statistical analyses

A randomized block design with four repetitions was used. The values obtained for size distribution of the water-stable aggregates, WMD_{ad}, WMD_{ws}, ERA and OM, were submitted to analysis of variance, and to compare means between treatments. The Waller-Duncan test was run at 5% of probability. The levels of sizes of aggregates and organic matter, were Submitted for linear regression analysis to establish the mathematical models.

RESULTS AND DISCUSSION

Table 1 shows the values obtained for classes of water-stable aggregates (AG), weighted mean diameter (WND_{ws}) of the aggregates' stability, efficiency ratio of aggregation (ERA), and organic matter in the classes of aggregates for various systems of pasture management, at layers from 0 to 10 and from 10 to 20 cm. At both depths, both for the sampling site and for the site-treatment interaction, there was no significant effect (P<0.05). In the layers from 0 to 10 cm and from 10 to 20 cm, there was a significant effect of the treatments for all the analyzed parameters (P<0.05), with the exception of the aggregates in class AG 1 to 0.5 mm in the 10 to 20 cm layer, which was not significant (P>0.05). The mean percentage values of the water-stable aggregates under the different pasture management systems in a Cerrado dystrophic oxisol are presented in Table 2.

The treatments with pasture fertilized every two years, in aggregate classes 8 to 2 mm and 2 to 1 mm, and pasture fertilized every two years and with legumes, in aggregate classes 8 to 2 mm, presented water-soluble aggregate percentages equal to those from the soil with native vegetation in both layers studied, showing the effect of this pasture management on soil aggregation.

The beneficial effects of greater aggregation in the soil are greater water infiltration capacity, lower soil density, greater aeration space and improvements in hydraulic conductivity. This means that water can infiltrate and move better within the soil profile, the characteristic curve for water retention improves and there is less resistance to root system penetration, as discussed in the works of Carvalho et al. (2004) and Bono et al. (2012).

According to Conte et al. (2011) and Salton et al. (2008), the stability of aggregates can increase the OM content and consequently the carbon content. The presence of the root system is fundamental for the existence of larger aggregates.

Bono et al. (2013) and Salton et al. (2008) worked in the same experimental area and also noted the positive effect on soil management of pasture managed with fertilizer and legumes. This also corroborates the results of Ayarza et al. (1993) and Alvarenga and Davide (1999), reporting that soil cultivated with pasture showed the same percentage of aggregates as soil with natural vegetation. Stable aggregates provide good structure for the soil, with porous spaces occurring within the soil. These allow roots to develop without interference, fauna to increase and air and water to circulate (Ferreira et al., 2010).

This aggregation in the pasture fertilized every two years, as well as in pasture with legumes, is attributed to soil fertilization, which favors intense growth. The root biomass will consequently renew itself and will contribute to the formation of larger aggregates (Corazza et al., 1999; Six et al., 2004; Marchão et al., 2007). More plant residue over the soil will also protect it from compression and fracturing by animal hooves, thus preparing it for a greater stocking rate (Fidalski et al., 2008; Bono et al., 2013).

Table 3 shows the greater percentage of aggregation in the classes from 8 to 2 mm and 2 to 1 mm, for both depths. In this table, WMD_{ad} is compared with WMD_{ws}, evidencing a significant effect of treatments only for WMD_{ws}, which indicates that water is the main agent in reducing the diameter of aggregates, as reflected in the efficiency rate of aggregation (ERA). The WMD_{ws} and the ERA for pasture fertilized every two years and pasture fertilized every two years with legumes, at both depths, follow the same tendency for the percentage of soil aggregation as they did under native vegetation, not differing statistically.

The pasture without fertilizer presented the lowest percentage of ERA among the studied systems, demonstrating the effect of fertilizer on soil aggregation.

Table 1. Values of the F statistic and its significance for the classes of water-stable aggregates (AG), weighted mean diameter (WND_{ws}) of the aggregates' stability, efficiency ratio of aggregation (ERA), and organic matter in aggregate classes for various management systems in a dystrophic red oxisol in the Cerrado region of Campo Grande, Mato Grosso do Sul, under pasture at the layers of 0 to 10 cm and 10 to 20 cm. Campo Grande, MS, 2014.

Properties evaluated	Cause of variation		CV%	Cause of variation		CV%
	Block	Treatments		Block	Treatments	
	Value of F			Value of F		
	0 to 10 cm			10 to 20 cm		
AG 8 to 2 mm	0.01[ns]	29.47**	20.8	0.05[ns]	11.62**	29.9
AG 2 to 1 mm	0.05[ns]	12.90**	23.0	0.04[ns]	7.42*	22.9
AG 1 to 0.5 mm	0.03[ns]	11.22**	35.8	0.32[ns]	0.79[ns]	35.8
AG 0.5 to 0. 25 mm	0.32[ns]	7.27**	22.5	1.53[ns]	10.95**	22.5
AG 0.25 to 0.105 mm	0.57[ns]	4.40*	37.4	1.67[ns]	4.66*	37.4
WMD_{ad}	0.79[ns]	3.61*	5.2	0.80[ns]	57.47**	5.2
WMD_{ws}	0.01[ns]	39.91**	17.1	0.10[ns]	14.28**	17.1
ERA	0.02[ns]	29.53**	17.9	0.24[ns]	23.19**	17.9
OM 8 to 2 mm	0.22[ns]	56.00**	10.6	1.27[ns]	15.19**	10.6
OM 2 to 1 mm	0.76[ns]	54.12**	5.0	1.78[ns]	71.37**	5.2
OM 1 to 0.5 mm	0.05[ns]	72.78**	5.6	1.09[ns]	51.60**	5.8
OM 0.5 to 0. 25 mm	0.51[ns]	53.50**	4.1	1.27[ns]	84.26**	4.2
OM 0.25 to 0.105 mm	0.34[ns]	45.18**	10.0	1.08[ns]	54.84**	8.9

ns= non significant * = significant at 5% and **=significant at 1% AG= Class size of water-stable aggregates; OM= organic matter in the aggregates.

Table 2. Mean values of the percentage of water-stable aggregates for different pasture management systems for a dystrophic red oxisol in the Cerrado biome of Campo Grande-MS, under pasture, at the layers from 0 to 10 cm and 10 to 20 cm. Campo Grande, MS, 2014.

Treatments	Classes dos agregados estáveis em água (mm)				
	8 to 2	2 to 1	1 to 0,5	0,5 to 0,21	021 to 0,105
	%				
	0 to 10 cm				
CERR	31.04[a]	27.11[a]	21.75[b]	15.29[c]	4.81[c]
PAI	20.02[b]	13.73[c]	25.15[b]	27.69[a]	13.41[a]
PAM	30.32[a]	28.62[a]	16.69[c]	16.79[c]	7.59[b]
PAML	29.49[a]	25.50[a]	13.50[c]	23.35[b]	8.15[b]
PC	8.79[c]	17.37[b]	32.56[a]	30.63[a]	10.65[a]
	10 to 20 cm				
CERR	26.38[a]	22.57[a]	23.02[a]	21.02[c]	7.01[a]
PAI	17.20[b]	13.49[c]	25.11[a]	34.34[b]	9.86[a]
PAM	26.43[a]	20.95[ab]	25.79[a]	22.27[c]	4.57[b]
PAML	25.85[a]	14.44[c]	19.33[b]	30.44[b]	9.94[a]
PC	9.47[c]	18,99[b]	22.34[a]	39,64[a]	9.56[a]

Means followed by the same letter in the column do not differ among themselves by the Waller-Duncan test at 5% probability.

This effect was also seen over time, when the pasture that received fertilizer only at implantation showed higher values for WMD_{ws} at the 0 to10 cm layer and the ERA at both depths than the unfertilized pasture. These data support those obtained by Reichert et al. (2004), Ayarza et al. (1993) and Salton et al. (1999), which reported similar WMD_{ws} and ERA for well-managed pasture and native vegetation.

The greater the $WMD_{ws,}$ the higher the percentage of aggregates in classes from 8 to 2 mm and 2 to 1 mm.

Table 3. Mean values for the weighted mean diameter of air-dried aggregates (WMD_{ad}) and water-stable aggregates (WMD_{ws}) and the efficiency rate of aggregation (ERA) for different pasture management treatments in a dystrophic oxisol in the Cerrado biome in Campo Grande-MS, under pasture at depths of 0 to 10 cm and 10 to 20 cm. Campo Grande, MS, 2014.

Treatments	WMD_{ad}	WMD_{ws}	ERA
	0 to 10 cm		
	mm		
CERR	4.67[a]	2.18[a]	0.47[a]
PAI	4.49[a]	1.51[b]	0.34[b]
PAM	4.70[a]	2.14[a]	0.46[a]
PAML	4.66[a]	2.05[a]	0.44[a]
PC	4.57[a]	1.07[c]	0.20[c]
	10 to 20 cm		
CERR	4.27[a]	1.92[a]	0.45[a]
PAI	4.43[a]	1.39[b]	0.32[b]
PAM	4.61[a]	1.92[a]	0.42[ab]
PAML	4.50[a]	1.78[a]	0.39[b]
PC	4.32[a]	1.08[b]	0.18[c]

Means followed by the same letter in the column do not differ among themselves by the Waller-Duncan test at 5% probability.

These aggregates will be physically protected as OM adheres to the soil mineral particles, while smaller aggregates will be chemically protected, since they also adhere to mineral particles (Resck, 1996). Larger aggregates will be more likely to undergo disaggregation and other processes linked to soil degradation. Table 4 shows OM content found in the aggregate classes. The highest content was found at both depths in classes from 2 to 1 mm and 1 to 0.5 mm. Soil with native vegetation presented OM in the aggregates that was significantly higher than in other treatments in the classes from 2 to 1 mm and 1 to 0.5 mm at the layer from 0 to 10 cm. However, in the layer from 10 to 20 cm, the pastures managed with fertilizer and with legumes presented the highest OM content in each class, showing the effect of organic carbon on depth.

The largest aggregates, which have temporary binding agents (roots or fungal hyphae), are closely related to the present of plants and addition of residues to the soil. They become unprotected from the moment at which the soil becomes uncovered or left fallow, reducing the quantity and stability of these aggregates, and decreasing OM in the soil (Pillon et al., 2002). This may explain the effect of management without fertilizer, where the production of less plant matter exposes the soil surface to the impact of raindrops, favoring the disaggregation process.

Pasture with fertilizer every two years, pasture with fertilizer every two years and legumes, and pasture with fertilizer at implantation all act on soil aggregation through the root system. They promote an increase in OM, boost the soil carbon content and lead to root growth (Salton et al., 2008; Conte et al., 2011; Costa et al., 2012). In the treatment without fertilizer, the OM content was lower than in other treatments, in all aggregate classes, indicating that pastures managed with fertilizer have higher OM in the aggregates. Costa et al. (2012) state that OM is needed for carbon accumuluation and to favor the activity of soil microbiota, such as fungi that help to aggregate soil particles.

The root system in rapid-cycle pasture provokes an increase in the appearance of plant material in the most superficial layers, and also boosts carbon storage when the soil is not dressed. In well-managed pasture, in which OM is conserved in the soil, the carbon stocks in the soil can thus be higher than under native vegetation, according to Jakelaitis et al. (2008), Ferreira et al. (2010) and Wendling et al. (2012).

Jakelaitis et al. (2008) mention that in the literature, there are works that are contradictory in relation to differences in carbon found in soils under native vegetation and under pasture. It is known that carbon content can vary from soil to soil, even with a single production and deposition of biomass in the soil, depending on the quality of the material and the influence of various factors on the soil microbiota and the decomposition rate. The contribution of carbon to the soil, via the roots, is vital for the existence of larger aggregates, as has been seen in systems with permanent pasture, which present significantly higher WMD than systems with pasture that is unfertilized and receives no legumes, according to Salton et al. (2008).

Soil aggregation is related to the OM content up to a certain size, after which the values drop. In this study, OM content was highest in classes from 2 to 1 and 1 to 0.5 mm, at both depths (Figure 1). Soil aggregation in pasture is due to root growth, which helps the process by stimulating microbial activity, increasing the quantity of exudates that work as agents for soil aggregation, fostering the grouping of smaller aggregates, and resulting in the formation of larger ones (Costa et al., 2012).

The OM content of soil falls when there are fewer organisms decomposing. When decomposition rates rise, due to alterations in natural factors, the soil structure is damaged and degradation results. Soil management will impact on OM, which is one of the main agents in aggregate formation and stability, as reported also by Resck (1998), Ferreirra et al. (2010) and Demarchi et al. (2011). Fertilization of pastures thus increases soil aggregation and water-stability of aggregates, contributing to better physical quality for the soil and reaching levels comparable to those seen under natural vegetation.

In turn, better physical quality for the soil improves root growth, according to Araújo et al. (2012); water and

Table 4. Mean values for organic matter content (OM) of water-stable aggregates for different pasture management treatments in a dystrophic oxisol in the Cerrado biome in Campo Grande-MS, under pasture at depths of 0 to 10 cm and 10 to 20 cm. Campo Grande, MS, 2014.

Treatments	Classes of water-stable aggregates (mm)				
	8 to 2	2 to 1	1 to 0.5	0.5 to 0.21	0.21 to 0.105
	%				
	0 to 10 cm				
CERR	30.16[a]	41.55[a]	42.06[a]	33.72[a]	27.16[a]
PAI	26.09[c]	24.07[c]	27.87[c]	21.17[c]	16.58[b]
PAM	27.95[b]	32.61[b]	35.53[b]	27.84[b]	27.15[a]
PAML	28.87[ab]	34.75[b]	27.96[c]	25.33[b]	25.43[b]
PC	19.25[d]	20.23[d]	14.00[d]	9.30[d]	13.58[c]
	10 to 20 cm				
CERR	18.67[b]	23.95[a]	18.64[bc]	16.56[bc]	16.76[b]
PAI	18.11[b]	20.22[b]	21.69[ab]	15.79[c]	15.40[b]
PAM	20.12[ab]	25.23[a]	24.56[a]	22.26[a]	21.65[a]
PAML	21.96[a]	23.23[a]	21.38[b]	18.15[b]	19.16[a]
PC	14.59[c]	17.06[c]	17.08[c]	16.29[bc]	10.10[c]

Means followed by the same letter in the column do not differ among themselves by the Waller-Duncan test at 5% probability.

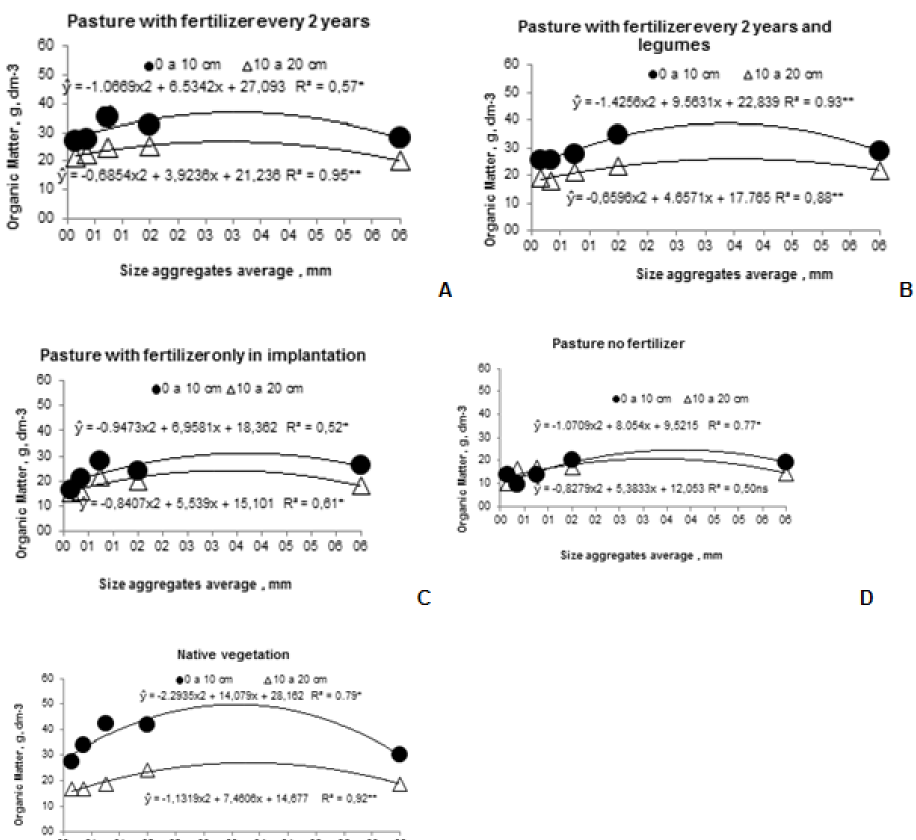

Figure 1. Organic matter in the water-stable aggregates for different pasture management treatments in a dystrophic oxisol in the Cerrado biome in Campo Grande-MS, under pasture at depths of 0 to 10 cm and 10 to 20 cm. Campo Grande, MS, 2014.

nutrients are stored and supplied to plants with greater efficiency, and gas exchange and biological activity also improve and contribute to sustainability. Alves et al. (2007) mention the use of pasture and legumes to recover degraded areas, improving OM content and boosting soil aggregation, as confirmed in this study.

Conclusions

Pasture with fertilization favors the formation of larger soil aggregates, improving the physical quality of the soil at depths of not only 0 to 10 cm but also 10 to 20 cm. The impacts of removing native vegetation on soil aggregates can be reduced by covering soil with pasture, fertilizing it appropriately and controlling stock levels.

Conflicts of interest

The authors have none to declare.

REFERENCES

Alvarenga MIM, Davide AV (1999). Características físicas e químicas de um Latossolo Vermelho-Escuro e a sustentabilidade de agroecossistemas. Rev. Bras. Ciênc. Solo. 23:933-942.

Alves MC, Suzuki LGAS, Suzuki LEAS (2007). Densidade do solo e infiltração de água como indicadores da qualidade física de um latossolo vermelho distrófico em recuperação. Rev. Bras. Ciênc. Solo 31:617-625.

Araújo EA, Ker JC, Neves JCL, Lani JL (2012). Qualidade do solo: conceitos, indicadores e avaliação. Revista Brasileira de Tecnologia Aplicada Ciênc. Agr. 5(1):187-206.

Ayarza M, Vilela L, Rauscher F (1993). Rotação de culturas e pastagens em um solo de Cerrado: Estudo de caso. In: Congresso Brasileiro De Ciência Do Solo. P 24.

Bono JAM, Macedo MCM, Tormena CA, Nanni MR, Gomes EP, Muller MML (2012). Infiltração de Água no solo em um Latossolo Vermelho da região sudoeste dos cerrados com diferentes sistemas de uso e manejo. Rev. Bras. Ciênc. Solo 36(6):1845-1853.

Bono JAM, Macedo MCM, Tormena CA (2013). Qualidade física do solo em um Latossolo Vermelho da região sudoeste dos cerrados sob diferentes sistemas de uso e manejo. Rev. Bras. Ciênc. Solo 37(3):743-753.

Carneiro MAC, Souza ED, Reis EF, Pereira HS, Azevedo WR (2009). Atributos físicos, químicos e biológicos de solo de cerrado sob diferentes sistemas de uso e manejo. Rev. Bras. Ciênc. Solo 33(1):147-157.

Carvalho JRP, Dechen SCF, Dufranc G (2004). Variabilidade espacial da agregação do solo avaliada pela geometria fractal e geoestatística. Rev. Bras. Ciênc. Solo 28(1):1-9.

Conte O, Flores JPC, Cassol LC, Anghinoni I, Carvalho PCF, Levien R, Wesp CL ((2011). Evolução de atributos físicos de solo em sistema de integração lavoura-pecuária. Pesq. Agropec. Bras. 46(10):1301-1309.

Corazza EJ, Silva JE, Resck DVS, Gomes AC (1999). Comportamento de diferentes sistemas de manejo como fonte ou depósito de carbono em relação à vegetação de Cerrado. Rev. Bras. Ciênc. Solo 23(2):425-432.

Costa Jr C, Píccolo MC, Siqueira Neto M, Camargo PB, Cerri CC, Bernoux M (2012). Carbono em agregados do solo sob vegetação nativa, pastagem e sistemas agrícolas no bioma Cerrado. Rev. Bras. Ciênc. Solo 36(4):1311-1321.

Demarchi JC, Perusi MC, Piroli EL (2011). Análise da estabilidade de agregados de solos da microbacia do Ribeirão São Domingos, Santa Cruz do Rio Pardo – SP, sob diferentes tipos de uso e ocupação. Rev. Bras. Tecnol. Apl. Ciênc. Agr. 4(2):07–29.

EMBRAPA (2013). Sistema Brasileiro de Classificação do Solo, 3ª ed. Rev. Ampl. Bras. P 353.

EMBRAPA (2011). Manual de método de análise de solo, org. Kangussu, G. D., Rio de Janeiro P 230.

Ferreira RRM, Tavares Filho J, Ferreira VM (2010). Efeitos de sistemas de manejo de pastagens nas propriedades físicas do solo. Semina: Ciênc. Agr. 31(4):913-932.

Fidalski J, Tormena CA, Cecato U, Barbero LM, Lugão SMB, Costa MAT (2008). Qualidade física do solo em pastagem adubada e sob pastejo contínuo. Pesq. Agropec. Bras. 43(11):1583-1590.

Guedes HM, Resck MVS, Perreira IS, Silva JE, Catro LHR (1996). Caracterização da distribuição de tamanho de agregados de diferentes sistemas de manejo e seu conteúdo de carbono em Latossolo Vermelho-Escuro Brasil In: Perreira RC, Nasser LCB (1996). Simpósio Sobre O Cerrado, 7, International Symposium On Tropical Savannas, 1, Brasília, 1996. Anais... Planaltina: EMBRAPA-CPAC. 1:329-333.

Jakelaitis A, Silva AA, Santos JB, Vivian R (2008). Qualidade da camada superficial de solo sob mata, pastagens e áreas cultivadas. Pesq. Agropec. Trop. 38(2):118-127.

Macedo MCM (2009). Integração lavoura e pecuária: o estado da arte e inovações tecnológicas. Rev. Bras. Zootec. 38:133-146.

Mapfumo E, Chanasyk DS, Baron VS, Naeth MA (2000). Grazing impacts on selected soil parameters under short-term forage sequences. J. Range. Manage. USDA 53(5):466-470.

Marchão RL, Balbino LC, Silva EM, Santos Jr JDG, Sá MAC, Vilela L, Becquer T (2007). Qualidade física de um Latossolo Vermelho sob sistemas de integração lavoura-pecuária no Cerrado. Pesq. Agropec. Bras. 42:873-882.

Parente HN, Maia M (2011). Impacto do pastejo sobre a compactação dos solos com ênfase no Semiárido. Revista Trópica – Ciênc. Agr. Biol. 5(3):3-5.

Pillon CN, Mielniczuk J, Martin Neto L (2002). Dinâmica da material orgânico no ambiente. Embrapa Clima Temperado. Pelotas.: (EMBRAPA- Clima Temperado – Documento, 105).

Reichert JM, Reinert JD, Silva VR (2004). Compactação do solo em sistema de plantio direto: Limites críticos e mitigação, In: Couto. E.G. e Bueno, J.F., orgs. Reunião Brasileira de Manejo E Conservação do Solo e da Água, 14. Cuiabá, 2004. Anais... Cuiabá, SBCS/UFMT 1:167-198.

Resck DVS (1996). Manejo de solo e sustentabilidade dos sistemas agrossilvipastoris na região dos cerrados, In: Pereira, R. C.; Nasser, L. C. B. Simpósio Sobre o Cerrado, 8, 1996, Brasília, Anais..., Planaltina: CPAC. 1:81-89.

Resck DVS (1998). Agricultural intensification systems and their impact on soil and water quality in the Cerrados of Brazil. In: Lal, R. Soil quality and agricultural sustainability, Michigan. Ann. Arbor. Press 1:288-300.

Salton JC, Hernani LC, Broch DL, Fabrício AC (1999). Alterações em atributos físicos do solo decorrentes da rotação soja-pastagem, no sistema plantio direto. Dourados: Embrapa Agropecuária Oeste. 5p. (Comunicado Técnico, 10).

Salton JC, Mielniczuk J, Bayer C, Boeni M, Conceição PC, Fabrício AC, Carvalho A, Macedo M, Cláudio M, Broch, Lz D (2008). Agregação e estabilidade de agregados do solo em sistemas agropecuários em mato grosso do sul. Revista Brasileira de Ciência do Solo 32:11-21.

Six J, Bossuyt H, Degryze S, Denef K (2004). A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Till. Res. 79:7-31.

Souza ED, Carneiro MAC, Banys VL (2008). Atributos físicos e químicos de um Latossolo Amarelo e distribuição do sistema radicular da soja sob diferentes sistemas de preparo no cerrado maranhense. Acta Sci. Agron. 30(4):525-531.

Veiga M (2011). Metodologia para coleta de amostras e análises físicas de solo. Florianópolis: EPAGRI. 52p.

Wendling B, Vinhal-Freitas IC, Oliveira RC, Babata MM, Borges EN (2012). Densidade, agregação e porosidade do solo em áreas de conversão do cerrado em floresta de pinus, pastagem e plantio direto. Biosci. J. 28(1):256-265.