Research, Society and Development, v. 9, n. 6, e143963490, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i6.3490

Plantas de cobertura e efeito residual do calcário e gesso nos atributos físicos do solo em subsuperfície

Cover crops and residual effect of lime and gypsum on soil subsurface physical attributes

Plantas de cobertura y efecto residual de la caliza y el yeso sobre los atributos físicos del suelo en subsuperface

Recebido: 04/04/2020 | Revisado: 07/04/2020 | Aceito: 19/04/2020 | Publicado: 20/04/2020

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Resumo

O uso do calcário e gesso agrícola e diferentes plantas de cobertura podem influenciar os atributos físicos do solo. Dessa forma, objetivou-se avaliar as alterações dos atributos físicos do subsolo, influenciadas por diferentes plantas de cobertura combinadas a aplicação de calcário e gesso agrícola em sistema de semeadura direta na região de Cerrado. O experimento foi conduzido em Chapadão do Sul, estado de Mato Grosso do Sul, disposto no delineamento de blocos casualizados em esquema de parcela subsubdivididas. As parcelas foram constituídas das plantas de cobertura (*Urochloa ruziziensis*, e *Pennisetum glaucum)* e pousio, as subparcelas as quantidades de gesso (0; 2,3 e 4,6 Mg ha^{-1}) e as subparcelas de calcário (0, 2, 4 e 6 Mg ha^{-1}), com três repetições. A microporosidade, porosidade total e resistência a penetração sofreram efeitos das plantas de cobertura e doses de gesso. A macroporosidade e porosidade total foram influenciadas pelas plantas de cobertura e doses de calcário. O efeito residual da aplicação de calcário dose 2 Mg ha^{-1} sem aplicação de gesso agrícola proporcionou maior porosidade total na camada 0,30 - 0,40 m.

Palavras-chave: Densidade; Compactação do solo; Macroporosidade.

Abstract

The use of lime, gypsum, and different cover crops may influence the soil physical attributes, the formation of soil coverage before the crop implantation is crucial for the consolidation of the No-Tillage System. This work aimed to evaluate the alterations in the subsoil physical attributes, influenced by different cover crops combined with the application of lime and gypsum, in a no-tillage system in the Cerrado region, the soil of the experiment area was classified as Dystrophic Red Latosol. The experiment was carried out in Chapadão do Sul, state of Mato Grosso do Sul, Brazil, in a complete randomized block design, in a split-plot scheme. Plots consisted of cover crops (*Urochloa ruziziensis* and *Pennisetum glaucum*) and fallow; the subplots were formed by gypsum rates (0, 2.3, and 4.6 Mg ha-^{1}); and the sub-sub-plots consisted of lime rates (0, 2, 4, and 6 Mg ha^{-1}), with three replications. The cover crops, *Uruchloa ruziziensis, Pennisetum glaucum* and the rates of limestone and gypsum do not interfere with the density of the soil. The *Uruchloa ruziziensis* cover crop provides increased microporosity and total soil porosity. The cover crops *Uruchloa ruziziensis* and *Pennisetum glaucum* were not efficient in decompressing the soil in the layers of 0.20 - 0.30 and 0.30 - 0.40 m in depth. The residual effect of the lime rate of 2 Mg ha^{-1} without gypsum application provided higher total porosity the 0.30 - 0.40 m layer.

Keywords: Density; Soil compaction; Macroporosity.

Resumen

El uso de calcáreo, yeso y diferentes coberturas vegetales puede influir en las caractersiticas físicos del suelo, la formación de la cobertura del suelo antes de la implantación del cultivo es fundamental para la consolidación del Sistema Siembra directa. Este trabajo tuvo como objetivo evaluar los cambios en los atributos físicos del subsuelo, influenciados por diferentes culturas de cobertura combinadas con la aplicación de cal y yeso, en un sistema de siembra directa en la región del Cerrado, siendo el suelo del área experimental clasificado como Latosol Rojo distrófica. El experimento fue conducido em Chapadão do Sul, estado de Mato Grosso do Sul, Brasil en disenõ de bloques al azar, en esquema de parcelas subdivididas. Las parcelas consistieron de plantas de cobertura (*Urochloa ruziziensis* y *Pennisetum glaucum*) y barbecho; las subparcelas fueron formadas por dosis de yeso (0, 2,3 y 4,6 Mg ha-1); y las sub-subparcelas consistieron de dosis de cal (0, 2, 4 y 6 Mg ha-1), con tres repeticiones. Las plantas de cobertura, Uruchloa ruziziensis, Pennisetum glaucum y las dosis de piedra caliza y yeso no interfieren con la densidad del suelo. La planta de cobertura de Uruchloa ruziziensis proporciona una mayor microporosidad y una porosidad total del suelo. Los cultivos Uruchloa ruziziensis y Pennisetum glaucum no fueron eficientes en descomprimir el suelo en las capas de 0.20 - 0.30 y 0.30 - 0.40 m de profundidad. El efecto residual del encalhado de 2 Mg ha-1 sin aplicación de yeso proporcionó mayor porosidad total en la capa de 0,30 a 0,40 m.

Palabras clave: Densidad; Compactación del suelo; Macroporosidad.

1. Introduction

The formation of soil coverage before the crop implantation is crucial for the consolidation of the No-Tillage System (NTS). This coverage provides several benefits to the soil, such as higher water use efficiency when compared with the conventional tillage system (Silva et al., 2015). These benefits are essential to soybeans, which is the most cultivated crop in Brazil regarding planted area (CONAB, 2017).

However, maintaining the NTS in the Brazilian Cerrado is difficult due to the high rate of plant residues decomposition (Torres et al., 2008). Therefore, using cover crops with high dry matter yield and longevity is fundamental to soybean succession. Grass crops, such as and *Pennisetum glaucum*, have become an alternative to overcome this problem owing to their high dry biomass yield and longevity (Veronese et al., 2012). Thus, the increment of cover crops in the soil leads to higher carbon incorporation indices into the system, directly affecting the soil physical attributes (Vasconcelos et al., 2010).

According to (Rosa et al., 2011), despite the several benefits of the NTS, this system can result in the compaction of the soil subsurface layers. Moreover, the soil compaction has been shown to reduce soil porosity and soil water infiltration. Moreover, it prevents the crop's root development (Bodner et al., 2010; Chen & Weil, 2011; Tolon-Becerra et al., 2011).

The decomposition of plant residues from cover crops produces organic compounds that can increase soil pH and nutrient availability. However, this is a short-term effect, and may not be detected when the subsoil acidity decreases, especially in an NTS (Caires et al., 2008; Pavinato & Rosolem, 2008).

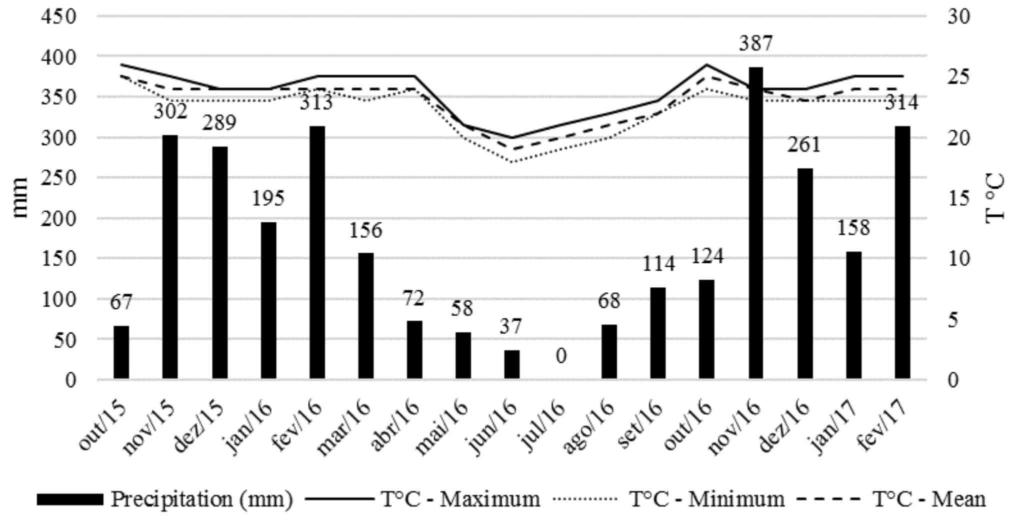
Thus, the use of lime and gypsum is the most efficient way of correcting soil acidity and profile formation owing to the ability of gypsum to carry elements in the deep layers (Bertollo, 2015). Few studies have reported the interference of lime and gypsum in the soil physical attributes. Several works have attributed the soil structural alterations to indirect effects of gypsum and lime application because the root system of the crops can develop better due to better soil chemical conditions (Medeiros et al., 2009).

Thus, this work aimed to evaluate the changes on soil subsurface physical attributes (density, total porosity, microporosity, macroporosity resistance to penetration, volumetric moisture), influenced by different cover crops combined with the lime and gypsum application, in a no-tillage system in the Cerrado region.

2. Material and Methods

The experiment was carried out in the municipality of Chapadão do Sul, MS (18°41'33"S; 52°40'45"W; 810 m asl). The Cerrado has a tropical wet and dry climate (Aw), according to the Köppen's classification, with well-defined seasons, characterized by dry winter (May-September) and rainy summer (October-April). The region has an average annual temperature of 13 °C-28 °C, average annual rainfall of 1,850 mm, and average annual relative humidity of 64.8% (Castro et al., 2012). Rainfall and air temperature data were recorded over the experiment period (Figure 1).

Figure 1 - Rainfall (mm) and average monthly temperature (ºC) over the experiment period.



The soil of the experiment area was classified as dystrophic Red Oxisol (Santos, 2018). The soil texture was characterized using the densimeter method (EMBRAPA, 1997), resulting in 46% of clay, 51.5% of sand, and 2.5% of silt, in the 0.2-0.4 m layer. Table 1 shows the chemical analysis of the experimental area before the experiment installation. Samples were taken at the 0.0-0.20 and 0.20-0.40 m layer.

Table 1 - Soil chemical analysis before the experiment installation.

Depth	pH	Ca	Mg	Al	H+Al	K	P(res)	S	OM	CEC	V	M
(m)	$CaCl_2$	---------cmol$_c$ dm^3-------				-------mg dm^3-----			g dm^3	cmol$_c$ dm^3	-----%----	
0-0.20	4.2	.0	.3	3	5.5	157	37.3	7	6.9	.3	33.5	11.6
0.20-0.40	4.3	.3	.2	2	5.2	94	5.70	.8	4.0	.9	25.1	.8

Depth	B	Cu	Fe	Mn	Zn
(m)	--mg dm^{-3}--				
0-0.20	0.14	1.30	44.0	16.4	5.2

OM: Organic matter; CEC: Cation exchange capacity; P(res): resin Phosphorus; V: vase saturation; M: saturation by aluminiu.

The experimental area had been under NTS for six years. Lime was used to increase the base saturation to 50%, whereas gypsum was applied at the NTS implantation, following the recommendation for the region. Lime and gypsum were incorporated with an intermediate grid. In the 2009/2010 crop year, the NTS was implemented, using soybean (*Glycine max)* in the first crop, corn in the second crop, and cover crops in the inter-crop.The same crop sequence was used in the 2010/2011 crop year. Cotton was sown in the 2011/2012 crop year.After its harvest, lime and gypsum were applied, without incorporation. Beans (*Phaseolus vulgaris)* and corn (*Zea mays)* were cultivated in the first and second crops of the 2012/2013 crop year, respectively. In October, lime and gypsum were applied, without incorporation. Cotton (*Gossypium sp.*) was sown in the 2013/2014 crop year, and in October, the cover crops were planted. In the 2014/2015 crop year, corn was sown as the second crop. In the 2015/2016 crop year, the present experiment was installed with the application of lime and gypsum rates in October 2015, without incorporation.

Cover crops were sown in October 2015 (5 kg ha^{-1} of *Urochloa ruziziensis* seeds and 15 kg ha^{-1} of *P. glaucum* seeds - cv ADR 300), using a mismatched disk seeder, spaced at 0.17 m between rows. Seeds remained in development until January 30, 2016, when they were manipulated with the aid of a horizontal plant residue crusher (Triton). On February 17, 2016, the material was dried using the Glyphosate (Roundup WG®, 1.98 kg ha^{-1}of active ingredient.) and Carfentrazone-ethylenic (Aurora®, 20g ha^{-1} of active ingredient).

The method described by Raij et al., (1996) of increase of base saturation was applied to estimate the need for lime application, aiming at values of 33.5, 56.4, 79.3, and 102.2%, corresponding to 0, 2, 4, and 6 Mg ha^{-1} of dolomitic limestone, respectively, which had 32% CaO, 17% MgO, 95% total neutralizing potential (TNP), and 98% neutralizing potential (NP). The necessity for gypsum application was calculated using the percentage of soil clay (30, and the recommended gypsum rate (GD) was of 2.3 Mg ha^{-1}, with 18% CaO and 15g % S.

The experiment consisted of a randomized blocks design, with three replications, in a split-plot scheme. The main plot (3.15 m x 66 m) consisted of two cover crops (*Urochloa ruziziensis* and *Pennisetum glaucum*) and fallow; the subplots (3.15 x 22 m) were formed by gypsum rates (0, 2.3, and 4.6 Mg ha^{-1}); and the sub-sub-plot (3.15 m x 5.5 m) consisted of different lime rates (0, 2, 4, and 6 Mg ha^{-1}). The physical attributes evaluated were density, macroporosity, microporosity, total porosity and soil penetration resistance at depths of 0.20-0.30 and 0.30-0.40 m.

Soil density (Sd) was determined by the volumetric ring method; total porosity (Tp) was calculated by the soil water saturation percentage; soil microporosity (Mi) and macroporosity (Ma) were determined by the tension table (EMBRAPA, 1997). Samples were taken at the 0.20-0.30 and 0.30-0.40 m layer.

A digital electronic penetrometer (PenetroLOG, Falker) was used to determine the soil mechanical resistance to penetration (Pr). Pr data were classified (every 0.10 m) from 0.20 to 0.40 m depth, represented in Megapascal (MPa). Samples were randomly taken from each experimental plot. Soil moisture was measured at the same depths on the same day of the soil mechanical resistance to penetration test.

Data were subject to analysis of variance, followed by the means comparison between gypsum rates and cover crops by the Tukey's test ($P \leq 0.05$). Polynomial regression analysis was performed for the lime rates, using the Sisvar software.

3. Results

No significant differences were observed for microporosity (Mi) at the 0.20-0.30 m layer, macroporosity (Ma) at the 0.30-0.40 m layer, soil density (Sd), and volumetric moisture (Mv) in the two layers studied, in function of the residual effect of lime and gypsum, at the rates used in the experiment (Table 2).

Table 2 - Summary of analysis of variance for Macropority (Ma), Microporosity (Mi), Total porosity (Tp), Soil density (Sd), soil mechanical resistance to penetration (Pr), and Volumetric moisture (Mv) in function of cover crops and chemical conditioners, at the 0.20-0.30 and 0.30-0.40 m layers.

SV	DF	Ma	Mi	Tp	Sd	Pr	Mv
		----------------------------	0.20 – 0.30 m	----------------------------			
Block	2	0.0004	0.0002	0.0000	0.0575	0.0400	35.9694
Cover crop (C)	2	0.0001^{ns}	0.0012^{ns}	0.0061*	0.0138^{ns}	3.8200*	29.6237^{ns}
Gypsum (G)	2	0.0002^{ns}	0.0046^{ns}	0.0013^{ns}	0.0138^{ns}	0.7820*	44.2628^{ns}
Lime (Ca)	3	0.0021*	0.0023^{ns}	0.0020^{ns}	0.0013^{ns}	0.0232^{ns}	35.7904^{ns}
C x G	4	0.0007^{ns}	0.0021^{ns}	0.0040*	0.0081^{ns}	1.2386*	32.3099^{ns}
C x L	6	0.0021*	0.0010^{ns}	0.0077*	0.0036^{ns}	0.3480^{ns}	16.1147^{ns}
G x L	6	0.0005^{ns}	0.0006^{ns}	0.0026^{ns}	0.0129^{ns}	0.2533^{ns}	13.5543^{ns}

Error 1	4	0.0002	0.0008	0.0005	0.0066	0.0770	11.1660
Error 2	8	0.0000	0.0007	0.0008	0.0029	0.0903	10.1695
CV 1	-	14.52	7.08	4.56	6.11	9.65	9.33
CV 2	-	7.14	6.94	5.83	4.00	10.45	8.90
CV 3	-	21.20	6.32	8.28	6.89	9.29	9.91
Mean	-	0.09	0.39	0.47	1.33	2.88	35.82
		Ma	Mi	Tp	Sd	Pr	Mv
		------------------------------- 0.30 – 0.40 m -------------------------------					
Block		0.0001	0.0055	0.0013	0.0633	0.0263	146.5067
Cover crop (C)		0.0002^{ns}	0.0080*	0.0152*	0.0168^{ns}	2.3016*	25.0627 ^{ns}
Gypsum (G)		0.0004^{ns}	0.0009^{ns}	0.0007^{ns}	0.0031^{ns}	0.3845^{ns}	40.5356 ^{ns}
Lime (Ca)		0.0010^{ns}	0.0026^{ns}	0.0035*	0.0007^{ns}	0.9296^{ns}	12.8828 ^{ns}
C x G		0.0004^{ns}	0.0016*	0.0020*	0.0071^{ns}	1.2225*	10.7904 ^{ns}
C x L		0.0008^{ns}	0.0008^{ns}	0.0012^{ns}	0.0023^{ns}	0.1468^{ns}	11.1355 ^{ns}
G x L		0.0003^{ns}	0.0012^{ns}	0.0017*	0.0023^{ns}	0.1595^{ns}	12.1941 ^{ns}
Error 1		0.0002	0.0002	0.0003	0.0124	0.0993	14.3490
Error 2		0.0003	0.0010	0.0011	0.0085	0.1187	12.6362
CV 1		12.53	4.14	3.65	8.77	11.71	11.25
CV 2		17.81	8.89	7.47	7.27	12.80	10.56
CV 3		16.73	7.60	6.66	4.62	11.91	9.93
Mean		0.10	0.35	0.45	1.27	2.69	33.67

*, ns: ($P \leq 0.05$) and not significant, respectively. CV: coefficient of variation.

Total porosity (Tp) and soil mechanical resistance to penetration (Pr) at the two depths (0.20-0.30 and 0.30-0.40 m) and Mi at the 0.30-0.40 m depth had cover crops x gypsum rate interaction (Table 3). Mi showed higher values at the gypsum rate of 2.3 Mg ha^{-1} combined with fallow. These results were also found when applying a gypsum rate of 4.6 Mg ha^{-1} associated with fallow and *U.ruziziensis*.

The use of *Urochloa ruziziensis* without gypsum application at the 0.20-0.30 m layer let to high Tp values (Table 3).

Table 3 - Unfolding of the cover crops x gypsum rates interaction obtained for microporosity (Mi), total porosity (Tp), and soil mechanical resistance to penetration (Pr), according to the soil layer.

	Gypsum rate (Mg ha^{-1})		
	Mi (m^3 m^{-3})		
	0,30 – 0,40 m		
Cover Crop	0	2.3	4.6
Urochloa ruziziensis	0.35 aA	0.34 bA	0.36 aA
Fallow	0.37 aA	0.38 aA	0.37 aA
Pennisetum glaucum	0.36 aA	0.34 bAB	0.33 bB
	Tp (m^3 m^{-3})		
	0.20 – 0.30 m		
Urochloa ruziziensis	0.50 aA	0.47 abB	0.47 aB
Fallow	0.46 bA	0.48 aA	0.48 aA
Pennisetum glaucum	0.45 bA	0.45 bA	0.48 aA
	Tp		
	0.30 – 0.40 m		
Urochloa ruziziensis	0.45 abA	0.44 bA	0.46 aA
Fallow	0.47 aA	0.48 aA	0.45 aA
Pennisetum glaucum	0.43 bA	0.42 bA	0.43 bA
	Pr (MPa)		
	0.20 – 0.30 m		
Urochloa ruziziensis	3.36 aA	3.10 aA	3.01 bA
Fallow	2.59 bA	2.46 bA	2.51 cA
Pennisetum glaucum	2.76 bB	2.59 bB	3.50 aA
	Pr		
	0.30 – 0.40 m		
Urochloa ruziziensis	2.90 aA	3.04 aA	2.44 bB
Fallow	2.41 bA	2.44 bA	2.37 bA
Pennisetum glaucum	2.49 abB	2.93 aAB	3.22 aA

Means followed by uppercase letters in the row and lowercase letters in the column do not statistically differ from each other by the Tukey's test at 5%.

Pr had similar values in both layers. At all gypsum rates, fallow led to the lowest Pr values (Table 3). *Urochloa ruziziensis* at the 0.30-0.40 m layer combined with the gypsum rate of 4.6 Mg ha^{-1} led to a higher Pr value

Ma and Tp at the 0.20-0.30 m layer were influenced by the cover crops x lime rates interaction (Table 4). A significant difference was detected at the lime rate of 6 Mg ha^{-1}, in which *Urochloa ruziziensis* showed a higher value of macropores.

Table 4 - Unfolding of the cover crop x lime rates interaction obtained for macroporosity (Ma) and total porosity (Tp), according to the soil layer.

	Lime rates (Mg ha^{-1})					
	Ma (m^3 m^{-3})					
Cover crop	0,20 – 0,30 m				Equation	R²
	0	2	4	6		
Urochloa ruziziensis	0.08 a	0.11 a	0.07 a	0.11 a	---	--
Fallow	0.09 a	0.09 a	0.09 a	0.09 b	---	--
Pennisetum glaucum	0.09 a	0.11 a	0.08 a	0.07 b	0.103111-0.000005x	0.62
	Tp (m^3 m^{-3})					
	0.20 -0.30 m					
Urochloa ruziziensis	0.48 a	0.52 a	0.43 b	0.50 a	---	--
Fallow	0.45 a	0.47 b	0.49 a	0.49 a	0.454556+0.00006x	0.80
Pennisetum glaucum	0.47 a	0.45 b	0.46 ab	0.45 b	---	--

Means followed by lowercase letters in the column do not statistically differ from each other by the Tukey’s test at 5%.

The use of 2 Mg ha^{-1} lime resulted in a higher Tp value when *Urochloa ruziziensis* was used as a cover crop (Table 4). For the lime rate of 4 Mg ha^{-1}, fallow had a better Tp value, but it did not differ from that of the *Pennisetum glaucum*. Conversely, the lime rate of 6 Mg ha^{-1} had the best result when using *Urochloa ruziziensis* and fallow.

Lime rates affected Tp in treatments with fallow. The equation shown in Table 4 was positively influenced by the increase in the agricultural lime. Tp at the 0.30-0.40 m layer was affected by the lime and gypsum rates, and Table 5 shows the unfolding of this interaction. The lime rate of 2 Mg ha^{-1} without gypsum application resulted in a higher Tp value, not differing from the gypsum rate of 2.3 Mg ha^{-1}.

Table 5 - Unfolding of the gypsum rates x lime rates interaction obtained for the evaluation of the total porosity (Tp) at the 0.30 - 0.40 m layer.

	Lime rates (Mg ha^{-1})			
Gypsum (Mg ha^{-1})	0	2	4	6
	Tp (m^3 m^{-3})			
	0.30 – 0.40 m			
0	0.42 a	0.48 a	0.46 a	0.44 a
2.3	0.44 a	0.45 ab	0.44 a	0.45 a
4.6	0.45 a	0.45 b	0.43 a	0.44 a

Means followed by lowercase letters in the column do not statistically differ from each other by the Tukey’s test at 5%.

4. Discussion

As the rates are calculated and plastered at the same time, in general, they do not affect the physical attributes of the soil (Table 2). Data obtained in this work corroborate those reported by (Tormena et al., 1998), who verified no changes in soil density, macroporosity, and microporosity at the layers of 0.20, 0.35, and 0.60 m, in function of the lime application, in a Clayey Dark Red Latosol.

According to (Pessoni, 2012), the fact that the rates did not differ for their levels for Sd can be explained by the slower reaction of the lime, which keeps the Al in the exchange complex by modifying the soil structure more slowly. In the no-tillage system, the organic material decomposes gradually and over time after applying the correctives.

The history of the area must also be considered since it had been under NTS for over 60 months. Therefore, it takes longer for the area to show relevant changes in the subsurface physical attributes (0.20-0.40 m) in function of the treatments. (Oliveira & Pavan, 1996) state that, in the NTS, the input of organic matter over time on the soil surface reduces the temperature and moisture variation. This phenomenon explains the absence of response of the Mv, contributing to the development of organisms that will open the channels through which the lime and gypsum will move.

These channels, created by dead roots, soil microorganisms, and the natural cracking of the soil, help the movement of fine particles due to the descending water flow, consequently allowing the movement of lime and gypsum in deep layers (Alleoni et al., 2005; Pessoni, 2012).

Cover plants combined with rates of gypsum, showed specific effects in soil improvements, mainly the porosity and Pr (Table 3). The similar values found for treatments under fallow and *Urochloa ruziziensis* can be explained by the action of the root system, which forms biopores when decomposing. Moreover, the root system of grasses is denser and better-distributed, favoring the bonding of particles (Eltz et al., 1989; Fabian, 2009). This fact also justifies the result reported for *Pennisetum glaucum*, in which Mi values were higher at the gypsum rates of zero and 2.3 Mg ha^1. Another possible explanation is the fact that the continuous use of NTS increases soil density and microporosity and reduces the soil macroporosity and total porosity (Silveira et al., 2008). Although micropores are hardly influenced by the soil management, unlike macropores, the effect observed in this work might have been the result of the organization of isolated primary mineral particles and microaggregates (Silva & Kay, 1997; Lal & Shukla, 2004).

In relation to Pr, the values are above those mentioned in the literature as limiting to the root development of the plants, however it was expected, because it is a no-tillage system. This result can be explained by the fact that, when gypsum is applied, gypsum sulfate causes the partial neutralization of aluminum ions, decreasing the total soil porosity (Rosa Junior et al., 1994). Another explanation would be the possible formation of minerals by the aluminum (Al) precipitation, or the occurrence of auto liming, which is the neutralization of aluminum ions by the gypsum application, resulting in the exchange of hydroxyls (OH^-) by sulfate (SO_4^{2-}) and the production of hydroxylated aluminum structures (Adams & Rawayfih, 1977).

The history of the study area should be considered because the cultivation of crops that have an aggressive root system, such as cotton (which was grown before the soybean crop), can result in lower Pr values. Nevertheless, all treatments and depths had values higher than 2 MPa, which is considered as limiting for the development of the crops (Taylor et al., 1966).

This increase can be explained by the increase in the calcium content in the subsoil, which forms larger aggregates by the increase in the aggregation strength. In the presence of larger aggregates, a higher amount of strength is required for the root to penetrate the soil. Therefore, the Pr measured by the penetrometer also increases with the gypsum rate (Miska et al., 1986). Conversely, the gypsum rate of 4.6 Mg ha^{-1} at the two depths resulted in lower Pr in *Pennisetum glaucum*.

Covering plants combined with the rates of limestone, modified the physical conditions of the soil (Table 4). This result was possibly due to the denser root system of this cover crop, causing a higher amount of biopores when the roots decompose (Eltz et al., 1989; Fabian, 2009).(Camargo & Alleoni, 1997) reported that the reduction in macroporosity impairs the root development since the macropores are the preferred paths for root growth.(Andrade et al., 2009) state that the roots cannot explore the deeper layers of the soil, causing less soil aeration. The root system is responsible for increasing aeration and decreasing soil density. With the lower root volume at the deep layers, soil compaction occurs.

(Castro, 2012; Castro et al., 2011) found different results. These authors tested different lime rates and reported a positive linear increase, which indicates that the lime improves the porous system of the soil and increases macroporosity. Studies have recommended the value of 0.10 m^3 m^{-3} of macropores as a critical limit for the non-restriction of soil gas exchange and aeration (Van Lier, 2010). The literature suggests that the soil of the present study has low values of macropores and requires management practices to increase Ma, aiming at improving soil aeration.

The benefits of cover crops can be attributed to the high root density and distribution, mainly of grass crops, which, due to the renewal of the root system, constant water absorption, and the distribution of soil exudates, increase soil microbial activity (Silva & Mielniczuk, 1997).

The lime increased the Pt values in the fallow area (Table 5), this result disagrees with those of (Bertollo, 2015; Calonego et al., 2012), who found no effects of soil management in subsurface layers on the porous system of the soil by the process of natural accommodation of subsurface particles, especially in an NTS. According to (Lal & Shukla, 2004), the effect observed for the lime application might have been related to the better soil aggregation provided by liming.

Very few studies have addressed the effect of cover crops on the soil physical attributes and the residual effect of lime and gypsum on the surface and subsurface layers under a no-tillage system.

5. Conclusions

The cover crops, *Uruchloa ruziziensis*, *Pennisetum glaucum* and the rates of limestone and gypsum do not interfere with the density of the soil.

The *Uruchloa ruziziensis* cover crop provides increased microporosity and total soil porosity.

The cover crops *Uruchloa ruziziensis* and *Pennisetum glaucum* were not efficient in decompressing the soil in the layers of 0.20 - 0.30 and 0.30 - 0.40 m in depth.

The residual effect of the application of the lime rate of 2 Mg ha^{-1} without gypsum application provided higher values of total porosity in the 0.30-0.40 m layer.

Funding

Work was supported by the Foundation for Support to the Development of Education, Science and Technology of the State of Mato Grosso do Sul.- FUNDECT [grant numbers 05/2016].

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