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Influence of biological fertilizer and plant cover in the physical properties of soil

Influência do fertilizante biológico e plantas de cobertura nas propriedades físicas do solo

João Paulo Ascari[1], Dejânia Vieira de Araújo[1], Inês Roeder Nogueira Mendes[1], Rafael Sbruzzi Prieto[1], Marco Antonio Camillo de Carvalho[1]

[1]Universidade do Estado de Mato Grosso (UNEMAT), Departamento de Agronomia, Campus Universitário de Tangará da Serra – MT, Brasil. *E-mail*: joaoascari@hotmail.com

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Abstract: The physical properties of the soil affect the root growth of the plants, which depending on the restriction level, the culture yield is reduced. The goal of this study was to identify the effects of biological fertilizer and soil cover on soil physical properties. This study was carried out in two crop seasons (2015/16 and 2016/17), where the experimental design was in randomized blocks arranged in factorial scheme: biological fertilizer (with and without) and soil cover plants (millet, crotalaria and fallow clean), and a forest fragment as a control. Biological fertilization and soil cover plants promoted significant increases in the soil moisture, macroporosity, and total porosity, as well as reducing microporosity and soil resistance to penetration. Thus, the physical properties of the soil were increased with the use of biological fertilizer, millet, and crotalaria as soil cover. The biological fertilizer did not promote soybean and maize yield increases, however, their yields were increased with millet and crotalaria

Keywords: Physical properties of the soil, soil management, soil quality

Resumo: As propriedades físicas do solo exercem influencia no crescimento radicular das plantas, que dependendo do nível de restrição, a produtividade da cultura é reduzida. O objetivo deste estudo foi verificar os efeitos da adubação biológica e plantas de cobertura sobre as propriedades físicas do solo. O estudo foi desenvolvido em duas safras (2015/16 e 2016/17), onde o delineamento experimental foi em blocos casualizados em esquema fatorial duplo: adubo biológico (com e sem) e condições de cobertura vegetal do solo (milheto, crotalária e pousio limpo), e um fragmento de floresta como testemunha. A adubação biológica e as plantas de cobertura do solo promoveram incrementos significativos na umidade do solo, macroporosidade e porosidade total, além de reduzir a microporosidade e a resistência do solo a penetração. Deste modo, as propriedades físicas do solo foram incrementadas com o uso de adubo biológico, milheto e crotalária como cobertura do solo. O adubo biológico não promoveu incrementos de produtividade da soja e do milho, entretanto, estas apresentaram incrementos significativos com o uso de milheto e crotalária.

Palavras-chave: Propriedades físicas do solo, manejo do solo, qualidade do solo

Introduction

Soybean [*Glycine max* (L.) Merrill] is important crop for Brazilian agribusiness, in the 2016/17 crop season, the Mato Grosso state had an area of 9,322.8 thousand hectares with cultivation, and average yield of 3,273.0 kg ha^{-1} of grains, increases of 2% and 14.9%, in relation to the previous crop season. The maize (*Zea mays* L.) generally grown in succession to soybean, and it occupied an area of 4,455.0 thousand hectares, with a grain yield of 5,962.0 kg ha^{-1}, and increase of the 18.2% and 49.1% in relation to the previous crop season (CONAB, 2017).

Considering the large extension of soils grown with these crops, the soil physical properties should be adequate, because of the presence of compacted layers in the soil results in problems with gas exchange, less physical space for water and reduction nutrient absorption. The compaction interferes in the plant's root growth, and it is the main physical cause of the less crop yield. Due to the extensive commercial fields cultivated with soybean and maize, it is important

that the physical properties of the soil are favorable to the root system development. Therefore, the better the physical quality of the soil, under appropriate both chemical and weather conditions, the higher the root development of the crops, also increasing the grain yield (Chioderoli et al., 2011). To monitor the soil's physical properties, some indicators are used, as soil resistance to penetration, porosity, density and moisture of the soil (Chioderoli et al., 2011; Cherubin et al., 2015).

The cultivation system and inadequate fertilization change the cultivated soil characteristics compared to the soil natural condition, as reduction of macroporosity, an increase of density and soil penetration resistance (Cunha et al., 2012; Cherubin et al., 2015). Such modifications of the soil structure are reflections of the compaction promoted by the transit of agricultural machines and implements (Beutler et al., 2005).

The balanced fertilization and organic matter maintenance is a good management practice for minimizing and correcting the negative reflexes on the soil's physical properties promoted by agricultural operations. Among the several known techniques, the integration of the biological fertilization with the use of plant cover can contribute to the improvement of the system (Medeiros & Lopes, 2006; Rossetti et al., 2012).

The biological fertilizer contributes to increasing the abundance of the soil saprophytic and decomposing microorganisms, that is responsible for the plant residues decomposition processes, therefore, it is necessary to opt for soil plant cover with high potential to produce dry matter, such as millet (Pennisetum sp.) and crotalaria (Crotalaria sp.). Plant residues serve as a substrate for soil microbial development, promoting increased aggregate stability, moisture content, protection, and maintenance of organic residues, the latter being one precept of no-tillage practice (Boer et al., 2008; Cunha et al., 2012).

The microbial action contributes to the straw decomposition rate, thus greater release of nutrients, production of organic matter in the superficial and subsurface layers of the soil, besides increasing the aggregation of the particles (Teixeira et al., 2011; Rossetti et al., 2012). Because of the higher carbon/nitrogen ratio, grasses usually have a longer half-life compared to legumes plants, which decompose faster due to the higher concentration of nitrogen in its composition. However, this condition does not always repeat itself, since the decomposition is influenced by climatic conditions, such as high temperatures and rainfall, soil texture and management practices adopted in the crop system (Boer et al., 2008; Carneiro et al., 2008).

The introduction of microorganisms and plant residues are management strategies that improve the soil physical properties. Therefore, the goal of this study was to identify the effects of biological fertilizer and soil cover on soil physical properties.

Material and Methods

The study was conducted over two crop season, in 2015/16 and 2016/17, in the experimental area of the University of Mato Grosso State, Campus of Tangara da Serra - MT. The soil was classified as LATOSSOLO VERMELHO Distroférrico (Oxisol) (SANTOS et al., 2018). The mean temperature (T °C) and relative humidity (%), and accumulated precipitation (mm) were recorded in both crop seasons studied (Figure 1).

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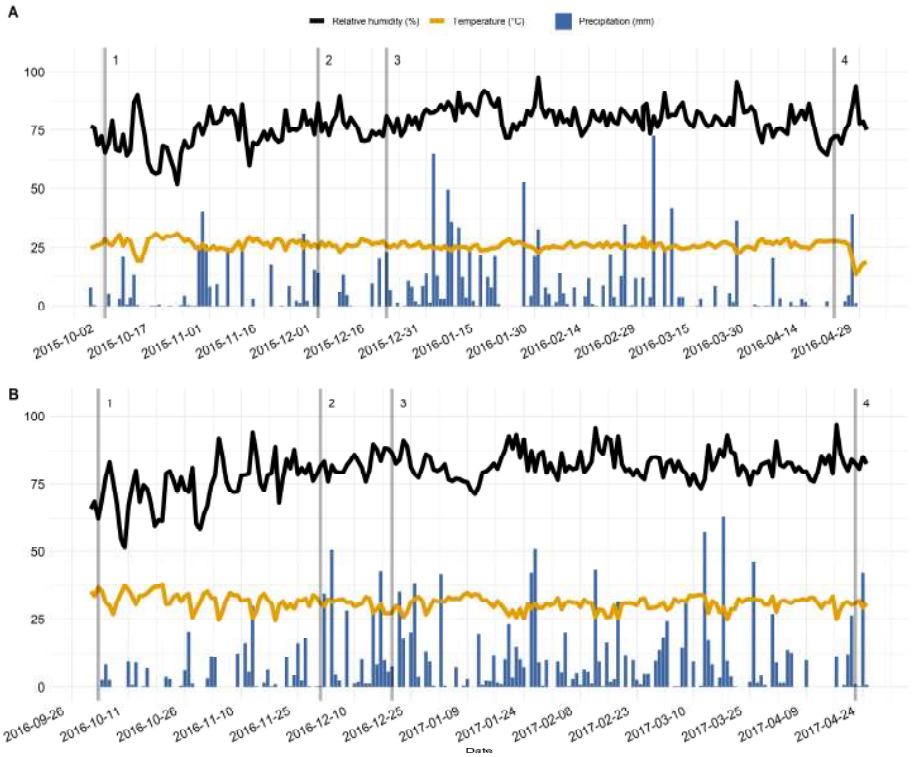

Figure 1. Accumulated precipitation (mm), average temperature (T ºC) and relative air humidity (%) of the experimental area in both 2015-2016 (A) and 2016-2017 (B) crop season. 1) sowing of millet and crotalaria; 2) desiccation of cover plants; 3) maize and soybean sowing; 4) maize and soybean harvesting, soil sampling and soil physical properties evaluation

For assess the soil physical properties, was used a randomized block design in a double factorial and additional control (2 x 3 + 1): two conditions of biological fertilizer (with and without), three soil cover plants (millet - *Pennisetum glaucum* (L.) R. Br.; Crotalaria - *Crotalaria ochroleuca* G. Don.; fallow clean) and a forest fragment as a control, and four replicates. To assess the soybean and maize yields were considered just the double factors biological fertilizer and soil cover.

The experimental field was previously cultivated with *Gossypium hirsutum* L. in the conventional system (two grid operations) for five years ago. The experimental soil has 54.4% of clay, 86.0% of sand and 37.0% silt (clay texture). The plots were constituted of 5 x 5 m, having a total area of 25 m^2. The sowing of millet (Cv. ADR 500 - 25 kg ha^{-1}) and crotalaria (Cv. Common - 15 kg ha^{-1}) was carried out on October 4th, of the years 2015 and 2016. The cover plants were dried before the reproductive stage.

Was carried out soybean and maize no-tillage on December 20th. The soybean and maize cultivars used were 98Y30 and AS1555, with a density of 280,000 and 55,000 plants ha^{-1}, respectively, both cultivated in 0.5m spacing The mineral fertilizer was according to soil analysis (data not shown).

The biological fertilizer was prepared in a 100 L plastic container by proportions of 20 L water, 4 L bovine manure and 1 kg of the biological compound. The microorganisms responsible for both aerobic and anaerobic fermentation are bacteria, fungi and yeasts as described by the manufacturer Medeiros & Lopes (2006). Was applied 150 L ha^{-1} of biological fertilizer 24 hours after sowing soybean and maize.

The soil's physical properties were evaluated at 120 days after the sowing of both soybean and maize. The samples were collected in three points per plot of the experimental field at the space between the crop lines, and also in the forest fragment. The material collected consisted of undisturbed soil samples with volumetric rings (Kopecky Ring), in the soil layers 0 to 0.10 m and 0.10 to 0.20 m. Following the established protocol

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by Teixeira et al. (2017), were evaluated volumetric moisture, soil bulk density, macroporosity, microporosity and total soil porosity in both crop seasons studied. The resistance to penetration was determined with the aid of the Stolf impact penetrometer (Stolf, 1991; Sá & Santos Junior, 2007), considering ten soil layers of 0.05 m, comprising the layer of 0.50 m depth. The samplings were carried out at ten points per plot in the space between the crop lines, having an average value by plot.

After the physiological maturity, the four central lines of soybean and maize plants were harvested and the mechanical track made. The grain moisture was corrected to 13% and grain yield was estimated in kilograms by a hectare (kg ha^{-1}).

Shapiro Wilk normality test and Bartlett test of variance homogeneity were performed for all variables. For the statistical analyses of the soil physical properties of both experimental and natural soil, the Dunnett test ($p \leq 0.05$) was applied. To compare the means of the soil's physical properties, soybean and maize grain yields were applied to the Tukey test ($p \leq 0.05$). All the statistical analyses were done using ASSISTAT software (Silva & Azevedo, 2016).

Results and Discussion

Analyzing the soil physical properties at the soybean field, it was observed the similarity among the results in both crop seasons 2015/16 and 2016/17, which differed statistically from the control area at the forest fragment. The natural soil had lower moisture, density and microporosity, higher macroporosity and total porosity. In the 2016/2017 crop season, soybean crop system influenced in higher values of soil density in relation to the previous crop season (Tables 1 and 2).

Table 1. Soil physical properties of the area cultivated with soybean in function of biological fertilizer and soil cover plants, and a forest fragment as a control, crop season 2015/16

Biological Fertilizer	Soil cover plants	Dunnett's test ($p \leq 0,05$)									
		Uv[1]		Ds[2]		Ma[3]		Mi[4]		Tp[5]	
		0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
		------- % ------		----- g cm^{-3} ----		---------- cm^3 cm^{-3} ----------					
With	Millet	24a	27a	1.25a	1.28b	0.06b	0.08a	0.42	0.40	0.48b	0.48a
	Crotalaria	22a	26a	1.21b	1.29a	0.07b	0.06a	0.43	0.40	0.50a	0.46b
	Clean Fallow	19b	23b	1.18b	1.32a	0.06b	0.03b	0.42	0.42	0.48b	0.45b
Without	Millet	23a	26a	1.19b	1.26b	0.09b	0.09a	0.40	0.38	0.48b	0.47b
	Crotalaria	21b	27a	1.22b	1.38a	0.08b	0.04b	0.41	0.39	0.49a	0.43b
	Clean Fallow	18b	23b	1.24a	1.31a	0.06b	0.05b	0.42	0.41	0.48b	0.46b
Forest fragment		17b	21b	1.14b	1.18b	0.14a	0.11a	0.38	0.42	0.53a	0.53a
Biological Fertilizer		Tukey's test ($p \leq 0.05$)									
With		22	25	1.21	1.30	0.07	0.05	0.42	0.41	0.49	0.46
Without		21	26	1.22	1.32	0.08	0.06	0.41	0.39	0.49	0.45
Soil cover plants											
Millet		24a	26a	1.22	1.27	0.08	0.08a	0.41	0.39b	0.48	0.47
Crotalaria		21b	27a	1.22	1.33	0.08	0.05ab	0.42	0.40ab	0.49	0.45
Clean Fallow		19b	23b	1.21	1.31	0.06	0.04b	0.42	0.42a	0.48	0.46
CV (%)		9.46	8.30	4.15	4.15	26.43	40.98	5.81	4.81	4.13	6.04

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$). [1]Volumetric moisture, [2]soil density, [3]macroporosity, [4]microporosity and [5]total soil porosity.

The soil physical properties presented no significant differences when the biological fertilizer was used, however, it was observed higher moisture and macroporosity in the soybean area with residues of millet in the 2015/16 crop season (Table 1). In the crop season 2016/17,

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occurred no significant effects between or inside the factor analyzed in the soybean experimental field. Statistical differences of the physical properties were observed just when comparing by the Dunnett test's the biological fertilizer and soil cover plants with forest fragment (soil quality control) (Table 2).

When analyzing the physical properties of the soil cultivated with maize, it was verified changes in its properties in relation to the forest fragment soil. In the crop season 2015/16 the soil of the forest fragment had lower humidity, greater macroporosity and total porosity. Behavior slightly different occurred in the crop season 2016/2017, which in addition to the characteristics already mentioned, increased density and microporosity of the soil cultivated with maize

Table 2. Soil physical properties of the area cultivated with soybean in function of biological fertilizer and soil cover plants, and a forest fragment as a control, crop season 2016/17

Biological Fertilizer	Soil cover plants	Dunnett's test (p≤0,05)									
		Uv[1]		Ds[2]		Ma[3]		Mi[4]		Tp[5]	
		0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
		-------- % ------		---- g cm^{-3} ----		---------- cm^3 cm^{-3} ----------					
With	Millet	37	36a	1.31b	1.37b	0.12b	0.10a	0.40a	0.38a	0.52	0.48a
	Crotalaria	38	37a	1.34b	1.41a	0.09b	0.09b	0.41a	0.38a	0.50	0.47a
	Clean Fallow	36	36a	1.31b	1.36b	0.11b	0.10a	0.40a	0.38a	0.51	0.49a
Without	Millet	37	41a	1.35b	1.41a	0.11b	0.09b	0.39a	0.37a	0.50	0.47a
	Crotalaria	36	36a	1.32b	1.40a	0.12b	0.09b	0.39a	0.38a	0.51	0.47a
	Clean Fallow	36	34b	1.37a	1.41a	0.10b	0.10a	0.40a	0.36b	0.50	0.46a
Forest Fragment		36	42a	1.26b	1.29b	0.20a	0.15a	0.33b	0.40a	0.53	0.55b
Biological fertilizer		Tukey's test (p≤0.05)									
With		37	36	1.32	1.38	0.10	0.10	0.40	0.38	0.51	0.48
Without		36	37	1.35	1.41	0.11	0.10	0.39	0.37	0.50	0.46
Soil cover plants											
Millet		37	39	1.33	1.39	0.11	0.10	0.40	0.38	0.51	0.47
Crotalaria		37	36	1.33	1.41	0.10	0.10	0.40	0.38	0.50	0.47
Clean Fallow		36	35	1.34	1.39	0.11	0.10	0.40	0.37	0.50	0.47
CV (%)		5.19	11.26	3.26	3.13	15.57	22.66	3.17	4.79	2.85	3.65

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$). [1]Volumetric moisture. [2]soil density. [3]macroporosity. [4]microporosity and [5]total soil porosity

At the 2015/16 crop season all the physical properties were influencied by biological fertilizer or by soil cover plants. At the 2016/2017 crop season just the micropores of the soil was affected by treatments, which were higher in the absence of the biological fertilizer and in the clean fallow, not differing statistically from the crotalaria (Tables 3 and 4).

In the 2015/2016 crop season, the effect of the cover plants for maintaining the moisture of the soil cultivated with soybean and maize in the analyzed layers was significant. In the presence of millet, were observed the highest levels of soil moisture in relation to crotalaria and clean fallow, which did not differ statistically between each other (Tables 1 and 3).

Table 3. Soil physical properties of the area cultivated with maize in function of biological fertilizer and soil cover plants, and a forest fragment as a control, crop season 2015/16

Biological fertilizer	Soil cover plants	Dunnett's test ($p \leq 0.05$)									
		Uv[1]		Ds[2]		Ma[3]		Mi[4]		Tp[5]	
		0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
		----- % -----		----- g cm^{-3} ----		---------- cm^3 cm^{-3} ----------					
With	Millet	26a	28a	1.25b	1.37	0.04b	0.05	0.42a	0.37b	0.47a	0.42b

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	Crotalaria	20b	24b	1.26b	1.34	0.02b	0.04	0.44a	0.40a	0.47a	0.44a
	Clean Fallow	21b	24b	1.23b	1.30	0.03b	0.06	0.45a	0.40a	0.48a	0.46a
	Millet	25a	28a	1.29a	1.43	0.04b	0.03	0.41b	0.36b	0.46b	0.39b
Without	Crotalaria	19b	25a	1.25b	1.41	0.03b	0.03	0.44a	0.38b	0.47a	0.41b
	Clean Fallow	17b	22b	1.24b	1.41	0.02b	0.02	0.46a	0.38b	0.49a	0.40b
Forest Fragment		18b	21b	1.14b	1.33	0.15a	0.04	0.38b	0.43a	0.53a	0.48a
Biological Fertilizer					Tukey's test ($p \leq 0.05$)						
With		0.22a	0.25	1.25	1.33b	0.03	0.05a	0.44	0.39a	0.47	0.44a
Without		0.20b	0.25	1.26	1.42a	0.03	0.02b	0.44	0.37b	0.47	0.40b
Soil cover plant											
Millet		0.26a	0.28a	1.27	1.40	0.04	0.04	0.42b	0.37	0.46	0.41
Crotalaria		0.19b	0.24b	1.25	1.37	0.03	0.03	0.44ab	0.39	0.47	0.43
Clean Fallow		0.19b	0.23b	1.24	1.35	0.03	0.04	0.46a	0.39	0.48	0.43
CV (%)		10.25	7.16	5.70	4.95	58.55	58.31	4.45	5.01	6.72	5.69

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$). [1]Volumetric moisture. [2]soil density. [3]macroporosity. [4]microporosity and [5]total soil porosity

In the 2016/2017 crop season, the biological fertilizer and plant covering no influence the soil moisture on-field cultivated with both soybean and maize because was recorded higher rainfall near the evaluation period (Figure 1). This contributed to the maintenance and increase soil moisture, explaining the absence of the significant effects among the factors studied for this variable (Tables 2 and 4).

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Table 4. Soil physical properties of the area cultivated with maize in function of biological fertilizer and soil cover plants, and a forest fragment as a control, crop season 2016/17

		Dunnett's test ($p \leq 0.05$)									
Biological fertilizer	Soil cover plants	Uv[1]		Ds[2]		Ma[3]		Mi[4]		Tp[5]	
		0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
		------- % -----		----- g cm^{-3} ----		---------- cm^3 cm^{-3} ----------					
	Millet	34a	35b	1.36b	1.45a	0.10b	0.10b	0.38a	0.36a	0.49b	0.45b
With	Crotalaria	33a	33b	1.34b	1.42a	0.10b	0.09b	0.38a	0.36a	0.48b	0.46b
	Clean Fallow	33a	34b	1.33b	1.41a	0.07b	0.08b	0.43a	0.38a	0.51a	0.46b
	Millet	32a	32b	1.37b	1.46a	0.10b	0.08b	0.38a	0.36a	0.49b	0.44b
Without	Crotalaria	34a	32b	1.40a	1.46a	0.09b	0.08b	0.38a	0.35b	0.48b	0.43b
	Clean Fallow	31b	32b	1.39a	1.49a	0.09b	0.09b	0.39a	0.36a	0.48b	0.44b
Forest Fragment		36a	43a	1.26b	1.29b	0.20a	0.15a	0.33b	0.40a	0.53a	0.55a
Biological Fertilizer					Tukey's test ($p \leq 0.05$)						
With		33	34	1.34	1.43	0.09	0.09	0.40a	0.37	0.49	0.46
Without		32	32	1.39	1.47	0.10	0.09	0.38b	0.35	0.48	0.44
Soil cover plants											
Millet		33	34	1.36	1.45	0.10	0.09	0.38b	0.36	0.49	0.45
Crotalaria		34	33	1.37	1.44	0.09	0.09	0.38b	0.36	0.48	0.45
Clean Fallow		32	33	1.36	1.45	0.08	0.08	0.41a	0.37	0.49	0.45
CV (%)		6.13	7.66	4.15	4.05	17.14	21.90	4.14	6.72	3.80	4.95

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$). [1]Volumetric moisture. [2]soil density. [3]macroporosity. [4]microporosity and [5]total soil porosity

These results reveal the importance of straw for agricultural activities, with the aim of maintaining moisture and mitigating the effects of possible water stress on soybean and maize, as well as reducing soil impacts on agricultural machine traffic. Our findings corroborate with those obtained by Sousa Neto et al. (2008) and Zhao et al. (2009), who observed that the use of vegetable residues in the crop system, the soil water storage was increased.

Following the same reasoning, Jakelaitis et al. (2008) verified that the soil moisture losses are reduced by the increase of the organic matter layer. In addition, no-tillage for both crops studied contributed to the accumulation of dry mass on the soil, reduced the thermal amplitude and maintained moisture required for soil metabolic processes (Cunha et al., 2012).

The soil density was not influenced by biological fertilization and soil cover plants in soybean cultivation in the two crop seasons (Tables 1 and 2). However, with the application of biological fertilizer in the field of maize, 2015/2016 crop season, there was lower density but was not observed the continuity of this effect in the next crop season (Tables 3 and 4).

There was an increase in the density of the soil layers from the 2015/2016 crop season to 2016/2017 crop season, indicating that soybean and maize cultivation increased soil compaction, which was higher than those observed in the forest fragment (Tables 1, 2, 3 and 4). Cherubin et al. (2006) reported that crop cultivation promotes several changes in soil physical properties, such as compaction, which for Beutler et al. (2006), can be measured with soil density, which has a close relationship with the soil penetration resistance. Jakelaitis et al. (2008) also observed increased soil density when natural areas are modified for agricultural use.

The biological fertilizer and soil cover plants were analyzed in order to increase the quality of the soil cultivated, it is necessary to use this management overtime for an increase in the physical quality of the soil. Rossetti et al. (2012), have reported that even with the adoption of conservation practices, agricultural systems alter soil attributes due to machine traffic and other necessary practices to a specific crop system. In addition, there is uniformity in the vegetal stratum with the use of species of the annual cycle, causing the soil to remain for a period of the year without vegetal cover. Therefore, in order to reduce the negative effects on soil properties and increase the soil organic matter, it should be adopted long-term integrated management, as crop diversification, no-tillage, equilibrated fertilization

The benefit of these practices has been proven by Zhao et al. (2009), who tested liquid organic manure of pig in the wheat, maize and soybean cultivation, and associated it with mineral fertilization. The authors observed a decrease in soil density. In addition, soil total porosity and organic matter were increased, resulting in larger soil aggregation.

The lowest soils densities were recorded in the 0 to 0.10 m layer in relation to 0.10 to 0.20 m layer. This findings must have been result by the soil cover plants use, which due to the aggressive root development form galleries in the soil that facilitates the gas exchange with the atmosphere, consequently, increasing the water infiltration by the same galleries, which justifies the larger humidity of the soil when it is covered by the millet straw (Tables 1, 2, 3 and 4).

In the Sousa Neto et al. (2008) study, were observed lower density in the soil surface layer due to the production of organic matter by the cover plants, responsible for improving soil aggregation. Rossetti et al. (2012) observed that fields with a density larger than 1.30 g cm^{-3} must be introduced plants with high straw production capacities, such as millet and crotalaria, to avoid restricting the crops root growth.

The soil macroporosity is responsible for the aeration process, which in the cultivated areas it was smaller than that observed at the forest fragment. But in the short time of the management application proposed in this study, both 2015/2016 and 2016/2017 crop seasons, the soil macropores were increased, characterizing an improvement in this soil property. Higher macroporosity was observed with millet in soybean cultivated field (Table 1), and biological fertilizer at the maize area (Table 3).

The physical properties of the cultivated areas with soybean and maize differs when compared with the soil characteristics of the forest fragment, which presented lower density, higher macroporosity, and lower microporosity. Jimenez et al. (2008) observed a relationship between

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macroporosity and soil density, as the increase in compaction decreases the space occupied by air in the soil. For Andrade & Stone (2009), the ideal for cultivated soils is to present total porosity close to 50%, being this percentage distributed in 34% of macropores and 66% of micropores.

In the 2015/2016 crop season, the soil cultivated with maize and soybean presented critical values of macropores (Tables 1 and 3). According to Silva et al. (2004), even with macropores' critical values of the soil (0.10 cm^3 cm^{-3}), the plant can still develop, however, with restriction to root growth. In the Valicheski et al. (2016) study, was observed a reduction in the grain yield, it is because of the physical restriction, poor aeration of the soil and low soil macroporosity. The soil macroporosity is agreement correlated with soybean grain yield, where low soil microporosity results in crop yield loss (Queiroz et al., 2011).

In the 2016/17 crop season was increase the soil macroporosity (Tables 2 and 4), however, the average value of microporosity observed is very close to that critical value reported by Silva et al. (2004). According to the same authors, the macroporosity below 0.10 cm^3 cm^{-3} of soil impairs the gas exchange of the soil with the atmosphere, and as a consequence, interferes in the root development of the crops. In the study of Zhao et al. (2009), it was observed elevation of soil macroporosity using plant residues and organic manure in a crop rotation system.

Was observed higher soil microporosity in the cultivated area with maize and soybean in relation to the forest fragment soil. When was used millet and crotalaria, were observed lower microporosity in the 0 to 0.10 m layer in relation to the clean fallow. In the 2015/16 crop season, the millet reduced the microporosity at the cultivated area of soybean and maize. In the 2016/17 crop season, the micropores percentage was smaller with millet and crotalaria only in maize cultivated soil (Tables 1, 2, 3, and 4).

Table 5. Soil resistance to penetration of area cultivated with soybean in function of biological fertilizer and soil cover plants, and a forest fragment as a control at the 2015/16 crop season

Biological fertilizer	Soil cover plants	Dunnett's test ($p \leq 0.05$)									
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
		Soil resistance to penetration (MPa)									
With	Millet	3.76a	4.08a	4.83a	4.30b	3.55	3.55	3.02	2.59	2.27	2.05
	Crotalaria	3.55a	4.19a	4.62a	4.51b	3.76	3.55	2.91	2.48	2.37	2.16
	Clean Fallow	4.19a	4.51a	5.05a	4.62b	3.76	3.55	3.12	2.69	2.48	2.16
Without	Millet	3.12a	3.02b	3.98b	5.05a	3.34	3.12	3.02	2.69	2.27	2.05
	Crotalaria	3.02a	3.02b	3.55b	3.76b	3.44	3.27	2.91	2.80	2.59	2.16
	Clean Fallow	5.69a	4.30a	5.26a	4.83b	3.76	3.76	3.44	2.59	2.48	2.27
Forest Fragment		1.20b	1.41b	2.34b	3.23b	3.12	3.02	2.80	2.69	2.05	2.16
Biological fertilizer		Tukey's test ($p \leq 0.05$)									
With		3.84	4.26	4.83	4.48	3.69	3.55	3.02	2.59	2.37	2.12
Without		3.92	3.44	4.26	4.55	3.51	3.57	3.12	2.69	2.45	2.16
Soil cover plants											
Millet		3.44b	3.55	4.41	4.67	3.44	3.34	3.02	2.64	2.27	2.05
Crotalaria		3.28b	3.60	4.08	4.14	3.60	3.39	2.91	2.64	2.48	2.16
Clean Fallow		4.94a	4.41	5.15	4.73	3.76	3.66	3.28	2.64	2.48	2.21
CV (%)		25.80	36.51	20.23	19.91	14.48	13.38	20.26	17.01	16.02	13.17

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$)

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The highest values of soil micropores occurred in the clean fallow, justifying the highest levels of soil compaction, as reported by Sousa Neto et al. (2008), where they observed that higher microporosity is a strong indicator of soil compaction. This explains the fact that this property had lower values in the forest fragment and in the millet and crotalaria experimental area, in relation to the soil of clean fallow.

The soil total porosity did not suffer the effects of the biological fertilizer and soil cover plants, except for the maize 2015/16 crop season (Table 3), which presented higher porosity with biological fertilizer. In the two crop seasons, the forest fragment presented the highest values of this property in relation to the experimental field cultivated with soybean and maize (Tables 1, 2, 3, and 4). Similar behavior was observed by Jakelaitis et al. (2008), where they obtained the highest soil porosity in the natural environment, followed by a cultivation system with maize, soybean and *Brachiaria brizantha*. Rossetti et al. (2012) verified higher porosity of the soil using millet and lower porosity with crotalaria, when compared to other coverages.

The physical properties are efficient tools to show the soil quality, mainly the impacts caused by the traffic of machines in agricultural fields. Jakelaitis et al. (2008) reported that various soil physical properties, such as soil resistance to penetration, are sensitive to indicate the changes from a natural environment to agricultural environment.

The forest fragment presented lower soil resistance to penetration than the cultivated field with soybean in the 2015/16 and 2016/17 crop seasons. In the last crop season, the effect of the soil cover plants was more evident, when using millet and crotalaria the soil resistance to penetration was similar to observed in the forest fragment soil (Tables 5 and 6).

Table 6. Soil resistance to penetration of area cultivated with soybean in function of biological fertilizer and soil cover plants, and a forest fragment as a control at the 2016/17 crop season

Biological fertilizer	Soil cover plants	Dunnett's test ($p \leq 0.05$)									
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
		Soil resistance to penetration (MPa)									
With	Millet	0.52b	2.00b	2.53b	2.80b	2.91b	2.69b	2.59b	2.21b	2.16	1.73b
	Crotalaria	0.41b	2.21a	2.64b	2.91b	2.96b	2.64b	2.80a	2.59a	2.27	1.89b
	Clean Fallow	2.21a	2.75a	3.23a	3.44a	3.23a	2.91a	2.64b	2.27b	2.27	1.95b
Without	Millet	1.52b	1.63b	2.53b	2.80b	2.85b	2.80a	2.86a	2.53b	2.21	1.89b
	Crotalaria	1.79a	2.05b	2.48b	2.96b	3.02a	2.80a	2.91a	2.53b	2.32	2.00b
	Clean Fallow	2.80a	2.53a	2.75a	2.85b	3.12a	3.07a	2.69b	2.43b	2.59	2.75a
Forest Fragment		1.20b	1.57b	2.00b	2.27b	2.48b	2.37b	2.32b	2.21b	2.27	2.00b
Biological Fertilizer		Tukey's test ($p \leq 0.05$)									
With		1.63b	2.32a	2.80	3.05	3.03	2.75	2.68	3.36	2.23	1.86b
Without		2.04a	2.07b	2.59	2.87	3.00	2.89	2.82	2.50	2.37	2.21a
Soil cover plants											
Millet		1.39b	1.81b	2.53	2.80	2.88	2.75ab	2.72	2.37	2.19	1.81b
Crotalaria		1.60b	2.13b	2.56	2.94	2.99	2.72b	2.86	2.56	2.29	1.95b
Clean Fallow		2.51a	2.64a	2.99	3.15	3.18	2.99a	2.67	2.35	2.43	2.35a
CV (%)		12.71	12.38	13.74	14.37	9.04	7.55	7.60	7.56	12.14	11.31

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$)

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Analyzing the soil resistance to penetration of the cultivated area with maize, it was noticed that the plant covering had a notable influence on this property. When comparing the maize crop cultivated in soil with millet and crotalaria straw were observed not differ statistically if compared to forest fragment soil in the 0 to 0.05 m layer. Due to the short time of the evaluations, not effect of the biological fertilizer was observed. The management influences proposed in this study were evident in the soil layers that comprise 0 - 0.30 meters and 0 - 0.10 meters in the 2015/2016 (Table 7) and 2016/2017 (Table 8) crop seasons, respectively.

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Table 7. Soil resistance to penetration of area cultivated with maize in function of biological fertilizer and soil cover plants, and a forest fragment as a control at the 2015/16 crop season

Biological fertilizer	Soil cover plants	Dunnett's test ($p \leq 0.05$)									
		0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
		---------- Soil Resistance to Penetration (Mpa) ----------									
With	Millet	2.37b	3.01a	3.87b	3.66b	3.55b	3.76b	3.55	2.69	2.27	1.84
	Crotalaria	2.37b	3.23a	3.98b	4.19b	4.08a	3.98a	3.34	2.91	2.59	2.16
	Clean Fallow	2.91a	3.12a	4.41a	4.83a	4.08a	3.98a	3.44	3.02	2.48	2.27
Without	Millet	2.16b	2.16b	2.80b	4.08b	3.76b	3.34b	3.12	2.80	2.48	2.16
	Crotalaria	2.05b	2.37b	3.76b	4.62a	3.87b	3.55b	3.44	2.80	2.37	1.84
	Clean Fallow	3.12a	3.34a	4.62a	3.98b	3.87b	3.66b	3.02	2.80	2.48	2.27
Forest Fragment		1.20b	1.41b	2.37b	3.23b	3.12b	3.02b	2.80	2.69	2.05	2.16
Biological Fertilizer		Tukey's test ($p \leq 0.05$)									
With		2.55	3.12	4.08	4.23	3.91	3.91a	3.44	2.87	2.45	2.09
Without		2.45	2.62	3.73	4.20	3.83	3.51b	3.19	2.80	2.45	2.09
Soil cover plants											
Millet		2.27ab	2.59	3.34	3.87	3.66	3.55	3.34	2.75	2.37	2.00
Crotalaria		2.21b	2.80	3.87	4.41	3.98	3.76	3.39	2.86	2.48	2.00
Clean Fallow		3.01a	3.23	4.51	4.41	3.98	3.82	3.23	2.91	2.48	2.27
CV (%)		26.45	27.68	26.03	15.85	10.95	10.88	12.53	12.68	18.49	21.08

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$)

The benefits that the plant covering promote in the soil are listed by Foloni et al. (2006) and Jimenez et al. (2008), where they commented that millet has the capacity to develop the root system in-depth, breaking the compacted layers of the soil, forming galleries after root decomposition, which besides fixing carbon, depositing organic material, facilitates the infiltration of water and the gas exchanges between the soil and the atmosphere. Organic matter production and nutrient cycling are among the main characteristics of soil cover plants. The highest dry mass production was observed in the millet, followed by the crotalaria, in both soybean and maize crop seasons.

Due to the traffic of machines and implements in the agricultural field, increase soil compaction, mainly in the more superficial layers of the soil, which is not the case in the soil in natural conditions, as at the forest fragment. One of the great problems in agricultural crop systems is the formation of compacted layers in the soil profile, which impose a restriction on the development and growth of the plant's root system, leading to a decrease in the absorption of water and nutrients.

A According to Beutler et al. (2005), a soil penetration resistance of 0.80 MPa is great for the development of soybean in the field. And as limiting values, Beutler et al. (2006) verified that

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2.24 to 2.97 MPa in LATOSSOLO VERMELHO reduced of soybean grains yield, because it prevented the root development, due to factors such as lower macroporosity, low availability of nutrients and water. By the strong relationship that the resistance to penetration has with soil compaction, values above 2 - 3 MPa it is considered limiting to the root growth of the cultures (Silva et al., 1994; Sinnett et al., 2008; Moraes et al., 2014; Bartzen et ., 2019). In the study of Ramos et al. (2010), they observed shorter soybean roots grown in a soil with 3.5 MPa, as well as root morphological deformation. These findings indicated that the soybean root is sensitive to soil compacted layers.

Considering 2 MPa a critical value to soil resistance to penetration, the values obtained at the cultivated fields with soybean and maize in the 2015/2016 crop season were all high (Table 5 and 7). However, in the 2016/2017 crop season, the values of soil resistance to penetration had a considerable reduction, being below the limiting value of 2 MPa, mainly in the soil superficial layer (from 0 to 0.05m and 0.05 to 0.10m) using biological fertilizer, millet and crotalaria (Table 6 and 8). Based on these results, it was verified that in two crop season it was possible to increase the soil's physical quality.

The results observed in this study corroborate with Assis et al. (2014), which verified high values of soil resistance to penetration (above 2 MPa), where the use of millet promoted a lower restriction on the development of maize roots in a crop succession system

Table 8. Soil resistance to penetration of area cultivated with maize in function of biological fertilizer and soil cover plants, and a forest fragment as a control at the 2016/17 crop season

Biological vertilizer	Soil cover plants	Dunnett's test ($p \leq 0.05$) 0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50
		---------- Soil Resistance to Penetration (Mpa) ----------									
With	Millet	1.47b	1.73b	2.48	2.80	3.07a	2.69b	2.69b	2.27b	2.00	1.73
	Crotalaria	1.63b	2.00b	2.48	2.86	3.07a	3.02a	2.69b	2.64b	2.16	1.79
	Clean Fallow	1.95a	2.37a	2.64	3.02	3.07a	3.23a	3.02a	2.75a	2.43	1.89
Without	Millet	1.52b	1.84b	2.48	2.64	2.75b	2.80b	2.59b	2.48b	2.32	1.73
	Crotalaria	1.68b	2.16a	2.64	2.75	2.75b	2.48b	2.64b	2.16b	2.05	1.63
	Clean Fallow	1.79a	2.16a	2.43	2.96	2.53b	2.64b	2.69b	2.43b	2.27	1.73
Forest Fragment		1.20b	1.57b	2.00	2.27	2.48b	2.37b	2.32b	2.21b	2.27	2.00
Biological Fertilizer		Tukey's test ($p \leq 0.05$)									
With		1.68	2.04	2.53	2.89	3.07a	2.98a	2.80	2.55	2.20	1.80
Without		1,66	2.05	2.52	2.78	2.68b	2.64b	2.64	2.36	2.21	1.70
Soil cover plants											
Millet		1.49b	1.79b	2.48	2.72	2.91	2.75	2.64	2.37	2.16	1.73
Crotalaria		1.65ab	2.08ab	2.56	2.80	2.91	2.75	2.67	2.40	2.11	1.71
Clean Fallow		1.87a	2.27a	2.53	2.99	2.80	2.94	2.86	2.59	2.35	1.81
CV (%)		16.67	14.40	16.13	17.66	10.24	8.94	8.17	9.51	15.48	17.06

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p \leq 0.05$) and Tukey's test ($p \leq 0.05$)

In the 2015/16 crop season, the soybean did not present responses to biological fertilizer and soil cover plants, however, maize was more productive when grown on crotalaria. In the 2016/17 crop season, the crop yield was higher with plant cover. This indicates that, in addition to increasing the soil physical quality, this management with soil cover plants also promotes increases in crop grains yield. The use of the biological fertilizer no affected the grains yield of soybean and maize (Figure 2), maybe it needs to be studied in the long-term to see its influence on crop yields.

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The organic matter produced by the cover plants can mineralize essential nutrients at the soil after the decomposition process, such as nitrogen and potassium (Carneiro et al., 2008). Andreotti et al. (2008) observed higher grains yield of the maize cultivated over on crotalaria in relation to millet. The crotalaria can fix atmospheric nitrogen in the soil, and it is gradually mineralized and available throughout the maize cycle.

Thus, the benefits of this management proposal, biological fertilizer and soil cover plants, were evident. It improved the soil's physical properties and increased grains yield of soybean and maize. In this way, the agricultural soil conservation can be obtained by combining management techniques capable of increase the grains yield of the crops, in favor of the sustainability of the agroecosystem.

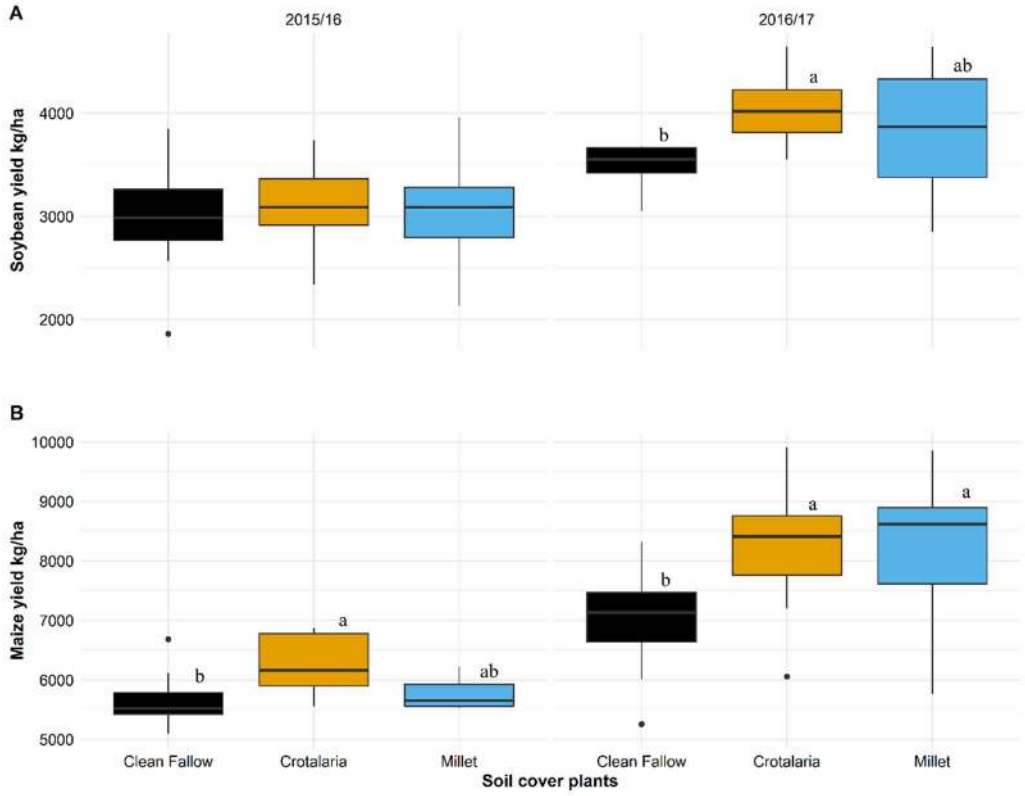

Figure 2. Grain yield of soybean (A) and maize (B) as a function of biological fertilizer and soil cover plants in both 2015/16 and 2016/17 crops seasons. Means followed by the same letter in the column do not differ statistically by the Tukey's test ($p \leq 0.05$)

Conclusion

The biological fertilizer and soil cover plants improved soil physical properties, as increasing soil macroporosity and decreasing microporosity, that is, reduced the soil compaction.

The soil resistance to penetration was larger on the soil cultivated with soybean and maize. In the experimental area, this property was lower at the soil with millet and crotalaria straws.

Millet and crotalaria increased the grains yield of soybean in the 2016/17 crop season, and of maize in the two crop seasons, but the biological fertilization did not interfere in the agronomic performance of both soybean and maize.

References

AANDRADE, R.S.; STONE, L.F. Índice S como indicador da qualidade física de solos. **Revista**

Brasileira de Engenharia Agrícola e Ambiental, v.13, n.4, p.382-388, 2009.

ANDREOTTI, M.; ARALDI, M.; GUIMARÃES, V.F.; JUNIOR, E.F.; BUZETTI, S. Produtividade do milho safrinha e modificações químicas de um Latossolo em sistema plantio direto em função de espécies de cobertura após calagem superficial. **Acta Scientiarum Agronomy**, v.30, n.1, p.109-115, 2008.

ASSIS, E.B.; NUNES, M.C.M.; BARELLI, M.A.A.; JUNIOR, S.S.J.; SERAFIM, M.E. Resistência à penetração em Argissolo Vermelho-Amarelo sob pousio e diferentes culturas de cobertura. **Enciclopédia Biosfera**, v.10, n.19, p.1668-1677, 2014.

BARTZEN, B.T.; HOELSCHER, G.L.; RIBEIRO, L.L.O.; SEIDEL, E.P. How the soil resistance to penetration affects the development of agricultural crops? **Journal of Experimental Agriculture International**, v.30, n5, p.1-17, 2019.

BEUTLER, A.N.; CENTURION, J.F.; ROQUE, C.G.; FERRAZ, M.V. Densidade relativa ótima de Latossolos Vermelhos para a produtividade de soja. **Revista Brasileira de Ciência do Solo**, v.29, n.6, p.843-849, 2005.

BEUTLER, A.N.; CENTURIUON, J.F.; CENTURION, M.A.P.C.; SILVA, A.P. Efeito da compactação na produtividade de cultivares de soja em Latossolo Vermelho. **Revista Brasileira de Ciência do Solo**, v.30, n.5, p.787-794, 2006.

BOER, C.A.; ASSIS, R.L.; SILVA, J.P.; BRAZ, A.J.B.P.; BARROSO, A.L.L.; FILHO, A.C.; PIRES, F.R. Biomassa, decomposição e cobertura do solo ocasionada por resíduos culturais de três espécies vegetais na região centro-oeste do brasil. **Revista Brasileira de Ciência do Solo**, v.32, n.2, p.843-851, 2008.

CARNEIRO, M.A.C.; CORDEIRO, M.A.S.; ASSIS, P.C.R.; MORAES, E.S.; PEREIRA, H.S.; PAULINO, H.B.; SOUZA, E.D. Produção de fitomassa de diferentes espécies de cobertura e suas alterações na atividade microbiana de solo de Cerrado. **Bragantia**, v.67, n.2, p.455-462, 2008.

CHERUBIN, M.R.; EITELWEIN, M.T.; FABBRIS, C.; WEIRICH, S.W.; SILVA, R.F.; SILVA, V.R.; BASSO, C.J. Qualidade física, química e biológica de um Latossolo com diferentes manejos e fertilizantes. **Revista Brasileira de Ciência do Solo**, v.39, n.2, p.615-625, 2015.

CHIODEROLI, C.A.; MELLO, L.M.M.; GRIGOLLI, P.J.; FURLANI, C.E.A.; SILVA, J.O.R.; CESARIN, A.L. Atributos físicos do solo e produtividade de soja em sistema de consórcio milho e braquiária. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.16, n.1, p.37-43, 2012.

COMPANHIA NACIONAL DE ABASTECIMENTO. Acompanhamento da safra brasileira de grãos: Décimo levantamento, Safra 2016/2017. Brasília: CONAB, 2017. 170 p.

CUNHA, E.Q.; STONE, L.F.; FERREIRA, E.P.B.; DIDONET, A.D.; MOREIRA, J.A.A. Atributos físicos, químicos e biológicos de solo sob produção orgânica impactados por sistemas de cultivo. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.16, n.1, p.56-63, 2012.

FOLONI, J.S.S.; LIMA, S.L.; BULL, L.T. Crescimento aéreo e radicular da soja e de plantas de cobertura em camadas compactadas de solo. **Revista Brasileira de Ciência do Solo**, v.30, n.1, p.49-57, 2006.

JAKELAITIS, A.; SILVA, A.A.; SANTOS, J.B.; VIVIAN, R. Qualidade da camada superficial de solo sob mata, pastagens e áreas cultivadas. **Pesquisa Agropecuária Tropical**, v.38, n.2, p.118-127, 2008.

JIMENEZ, R.L.; GONÇALVES, W.G.; ARAÚJO FILHO, J.V.; ASSIS, R.L.; PIRES, F.R.; SILVA, G.P. Crescimento de plantas de cobertura sob diferentes níveis de compactação em um Latossolo Vermelho. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v.12, n.2, p.116-121, 2008.

MEDEIROS, M.B.; LOPES, J.S. Biofertilizantes líquidos e sustentabilidade agrícola. **Bahia Agrícola,** v.7, n.3, p.24-26, 2006.

MORAES, M.T.; SILVA, V.R.; ZWIRTES, A.L.; CARLESSO, R. Use of penetrometers in agriculture: a review. **Engenharia Agrícola**, Jaboticabal, v.34, n.1, p.179-193, 2014.

QUEIROZ, R.P.; LAZARINI, E.; SANTOS, M.L.; CARVALHO, M.P.; SANTOS, C. Inter-relation between soybean yield and soil

compaction under degraded pasture in Brazilian Savannah. **Revista Brasileira de Ciência do Solo**, v.35, n.5, p.1579-1588, 2011.

RAMOS, J.C.; IMHOFF, S.D.C.; PILATTI, M.Á,; VEGETTI, A.C. Morphological characteristics of soybean root apexes as indicators of soil compaction. **Scientia Agricola**, v.67, n.6, p.707-712, 2010.

ROSSETTI, K.V.; ANDRIOLI, I.; CENTURION, J.F.; MATIAS, S.S.R.; NÓBREGA, J.C.A. Atributos físicos do solo em diferentes condições de cobertura vegetal em área de plantio direto. **Revista Brasileira de Ciências Agrárias**, v.7, n.3, p.427-433, 2012.

SÁ, M.A.C.; SANTOS JUNIOR, J.D.G. Considerações teóricas sobre o cálculo de resistência mecânica do solo a penetração determinada com penetrômetros dinâmicos. Brasília: Embrapa Cerrados, 2007. 25 p.

SANTOS, H.G.; JACOMINE, P.K.T; ANJOS, L.H.C.; OLIVEIRA, V.Á.; LUMBRERAS, J.F.; COELHO, M.R.; ARAÚJO FILHO, J.C.; OLIVEIRA, J.B.; CUNHA, T.J.F. **Sistema brasileiro de classificação de solos**. 5º ed., Brasília: Embrapa, 2018. 356p.

SILVA, A.P.; IMHOFF, S.; KAY, B. Plant response to mechanical resistance and air-filled porosity of soils under conventional and no-tillage system. **Scientia Agricola**, v.61, n.4, p.451-456, 2004.

SILVA, A.P.; KAY, B.D.; PERFECT, E. Characterization of the least limiting water range. **Soil Science Society of America Journal**, v.58, n.6, p.1775-1781, 1994.

SILVA, F.A.S.; AZEVEDO, C.A.V. The Assistat Software Version 7.7 and its use in the analysis of experimental data. **African Journal of Agricultural Research**, v.11, n.39, p.3733-3740, 2016.

SINNETT, D.; MORGAN, G.; WILLIAMS, M.; HUTCHINGS, T.R. Soil penetration resistance and tree root development. **Soil Use and Management**, v.24, n.3, p.273-280, 2008.

SOUSA NETO, E.L.; ANDRIOLI, I.; BEUTLER, A.N.; CENTURION, J.F. Atributos físicos do solo e produtividade de milho em resposta a culturas de pré-safra. **Pesquisa Agropecuária Brasileira**, v.43, n.2, p.255-260, 2008.

STOLF, F. Teoria e teste experimental de fórmulas de transformação dos dados de penetrômetro de impacto em resistência do solo. **Revista Brasileira de Ciência do Solo**, v.15, p.229-235, 1991.

TEIXEIRA, M.B.; LOSS, A.; PEREIRA, M.G.; PIMENTEL, C. Decomposição e liberação de nutrientes da parte aérea de plantas de milheto e sorgo. **Revista Brasileira de Ciência do Solo**, v.35, n.3, p.867-876, 2011.

TEIXEIRA, P.C.; DONAGEMMA, G.K.; FONTANA, A.; TEIXEIRA, W.G. **Manual de Métodos de Análise de Solo.** 3º ed., Brasília: Embrapa Solos, 2017. 574 p.

VALICHESKI, R.R.; BRANDELERO, S.M.; MIQUELUTTI, D.J.; STÜRMER, S.L.K.; TRAMONTI, A.L.; FRANZÃO, M.C. Absorption of primary macronutrients and soybean growth at different compactation densities and moisture levels in a silt loam soil. **Revista Ceres**, v.63, n.2, p.223-231, 2016.

ZHAO, Y.; WANG, P.; LI, J.; CHEN, Y.; YING, X.; LIU, S. The effects of two organic manures on soil properties and crop yields on a temperate calcareous soil under a wheat–maize cropping system. **European Journal of Agronomy**, v.31, n.1, p.36-42, 2009.