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Quality of Soil in the function of biological fertilization and plant covering

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The yield of soybean was influenced by the chemical and microbiological properties of the soil, which was favored by management techniques that promote improvement in soil quality. The objective of this study was to evaluate soybean yield, chemical and microbiological quality of the soil as a function of biological fertilization and soil cover conditions. The experiment was conducted in both crops seasons 2015/16 and 2016/17 with experimental design in randomized blocks, with the agronomic characteristics of the soybean analyzed as a function of the factors of biological fertilization and soil cover conditions, as well as the chemical and microbiological indicators of the soil, besides the two factors mentioned earlier, fragment of forest. It was observed higher height of plants, pods with three grains, leaf area and yield of soybean cultivated on *Crotalaria ochroleuca*, followed by *Pennisetum glaucum*. Biological fertilizer, *P. glaucum* and *C. ochroleuca* promoted increases in the fertility of soil cultivated with soybean, mainly potassium, and contributed to reduce carbon losses, indicated by lower basal respiration and soil metabolic quotient. Based on the results, we conclude that the soybean presented highest grain yield with *C. ochroleuca*, and the biological fertilization and cover plants increased the chemical and microbiological quality of the soil. These techniques can be implemented in the soybean farming system.

Key words: Fertility of soil, microbiological quality, *Glycine max*, yield, management.

INTRODUCTION

The soybean (*Glycine max* (L.) Merrill) was one of the most economically important crops of Brazilian agriculture, on a world scale, Brazil is the second largest producer of this oilseed, with production and average yield in the 2016/2017 crop season of 113,930.2 Mg and of 3,362.0 kg ha^{-1}, respectively (Companhia Nacional de Abastecimento, 2017). In order to meet the productive demands of the national and international market, it was necessary to adopt techniques that contribute to increase the quality of the soil, and that allow adequate development of the crop, since, correct managements increased the levels of soil fertility, consequently,

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obtaining higher production (Sousa and Lobato, 2004).

Inadequate soil using produces negative effects on its chemical and microbiological properties and may lead to imbalances in pedogenetic formation processes, intensifying losses of soil, organic matter, organic carbon and soil nutrients (Ebeling et al., 2011; Cunha et al., 2012). The microorganisms are directly linked to the process of organic matter decomposition, nutrient cycling and energy flow. The microbial biomass of the soil was constituted basically by fungi and bacteria, and were considered very sensitive the changes caused in the environment (Trannin et al., 2007; Fidelis et al., 2016; Goenster et al., 2017).

Changes in the dynamics of organic carbon, degradation of organic matter, changes in fertility, among others, were monitored from soil quality indicators. Among the most used microbiological properties were basal respiration, microbial biomass carbon, soil metabolic and microbial quotient (Jenkinson and Powlson, 1976; Vance et al., 1987; Anderson and Domsch, 1993; Matias et al., 2009). For the chemical properties, were applied some indicators that represent macro and micronutrients, pH, hydrogen and aluminum (Ebeling et al., 2011; Cunha et al., 2012).

As a practice of agricultural management, the introduction of plant covering increased the production of plant residues, and thus contribute to the increase of microbial activity, fixation and cycling of nutrients in the soil. Among the most used cover crops in the farming system, we mention millet (*Pennisetum* sp.) and Crotalaria (*Crotalaria* sp.), both with high potential of dry mass production and nutrient cycling (Pacheco et al., 2011; Cunha et al., 2012; Rossetti et al., 2012; Cherubin et al., 2015).

With the decomposition process, the minerals fixed in the plant residues were released into the soil and/or fixed by the microorganisms, which after the dead minerals were mineralized again, contributing to the aggregation of the particles and increase soil fertility (Carneiro et al., 2008; Gomide et al., 2011; Vezzani and Mielniczuk, 2011).

The microorganisms benefited from the presence of diversified organic residues in the soil, due to the utilization of the substrate for increased microbial biomass. Studies has indicated a reduction of the biodiversity of the ecological relations in the soil. Thus, biological fertilizer contributed to the multiplication and development of microbial populations, since it was composed of water, organic manure, organic compound enriched with macro and micronutrients, enzymes and vitamins (Medeiros and Lopes, 2006; Muñoz et al., 2017). In the search for sustainability in farming systems, the application of biological fertilizer and cover crops, minimize the impacts caused by farming practices on the chemical and microbiological properties of the soil, having a better vegetative development and increases in crop yield (Saeed et al., 2015).

Therefore, the objective of this study was to evaluate the soybean yield, the chemical and microbiological quality of the soil as a function of biological fertilization and soil cover conditions.

MATERIALS AND METHODS

Study site and sampling design

The experiment was conducted for two years - crops seasons 2015/2016 and 2016/2017, in the experimental field of the State University of Mato Grosso, Tangara da Serra - MT, at the geographic coordinates 14°39'53"S and 57°25'46"W. A forest fragment located geographically at 14°39'07"S and 57°25'21"W was considered as control area. The soil of both sites was classified as Dystrophic RED LATOSOL (Oxisol) (Embrapa, 2013).

For the chemical and microbiological characteristics of the soil, a randomized complete block design was used in a double factorial with additional control (2 x 3 + 1), with two conditions of biological fertilizer (with and without), three soil cover conditions (millet (*Pennisetum glaucum* LR Br.); crotalaria (*Crotalaria ochroleuca* G. Don.); clean fallow) and a control in the forest fragment with four replications. The biological fertilizer and soil cover for the vegetative and productive characteristics of the soybean crop was considered. The plots were constituted from five meters long by five meters wide.

Before the implantation of this experiment, the field was cultivated with *Gossypium hirsutum* for five consecutive years in the conventional farming (two soil plows). Chemical analysis of the soil in the layer from 0 to 0.20 m depth in the month of July of 2015, with the results (Table 1) was applied to 1,300 kg ha^{-1} of dolomitic limestone for soil correction (Sousa and Lobato, 2004). Monitoring of climatic data during the development of the study in an automatic meteorological station (Figure 1) was carried.

The sowing of millet (Cv. ADR 500 - 25 kg ha^{-1}) and crotalaria (Cv. Common - 15 kg ha^{-1}) was carried out on October 3 of the years 2015 and 2016, and incorporated with leveling grid closed, being dried at 50 and 65 days after sowing of millet and crotalaria, respectively (Pacheco et al., 2013).

The seeding in straw of the soybean was performed on December 20, 2015 and 2016, using cultivar 98Y30, with spacing between 0.5m lines and density of 14 plants per meter. As the useful area of the plot, the four central lines were considered, disregarding 0.5 m at each end as edge effect. In both crop season, the fertilization was performed with 280 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of K_2O. At 30 and 50 days after sowing (DAS) was applied 50 + 50 kg ha^{-1} of K_2O, respectively. The sources of nutrients were Mono-ammonium phosphate (52% P_2O_5 + 9% N) and Potassium Chloride (60% K_2O).

Leaf fertilization with micronutrients was performed 30 DAS (Sousa and Lobato, 2004). The biological fertilizer was prepared in 100 L drum in the proportion of 20 L of water, 4 L of bovine manure and 1 kg of biological compound enriched with minerals, 30 days before its application. The mineral characteristics of the organic fertilizer was presented in Table 1, with microorganisms responsible for aerobic and anaerobic fermentation, such as bacteria and fungi. The biological fertilizer was filtered and applied 24 h after sowing the soybean, in the dose of 150 l ha^{-1} (Medeiros and Lopes, 2006).

Agronomic characteristics of soybean

In relation to the vegetative characteristics of soybean, was considered the leaf area measured at the phenological stage R_1 (Adami et al., 2008). The plant height, height of insertion of the first

Table 1. Result of soil chemical analysis of the layer 0 to 0.20 m performed in July 2015, and mineral quality of biological fertilizer.

Soil chemical quality											
pH	**P**	**K**	**Ca**	**Mg**	**Al**	**H**	**Al + H**	**T**	**V**	**OM**	
$CaCl_2$	**mg dm^{-3}**		**-------------------------------- cmol$_c$ dm^{-3} ---------------------**						**%**	**g dm^{-3}**	
5.52	1.03	0.20	2.17	1.37	0.00	4.33	4.33	8.07	46.34	32.67	
Ca	Mg	K	Zn	Cu	Fe	Mn	B	S	Clay	Sand	Silt
------------- % -----------				**------------------------- mg dm^{-3} --------------------**					**------------ g kg^{-1} -------**		
26.93	17.10	2.47	1.33	3.53	43.67	30.60	0.28	13.13	544	86	370
Mineral quality of biological fertilizer											
pH	**N**	**P**	**K**	**Ca**	**Mg**	**S**	**Zn**	**Cu**	**Fe**	**B**	**OM**
H_2O		**---------------------- g L^{-1} ------------------**				**---------------------- mg L^{-1} ------------------**					**%**
6.2	0.71	0.3	0.02	0.06	0.01	0.04	4.7	2.8	175	14.4	5.2

Potential hydrogen (pH), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), aluminum (Al), hydrogen (H), cation exchange capacity (T), base saturation (V), organic matter (OM), calcium saturation (% Ca), magnesium saturation (% Mg), potassium saturation (% K), zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), boron (B), sulfur (S) and nitrogen (N).

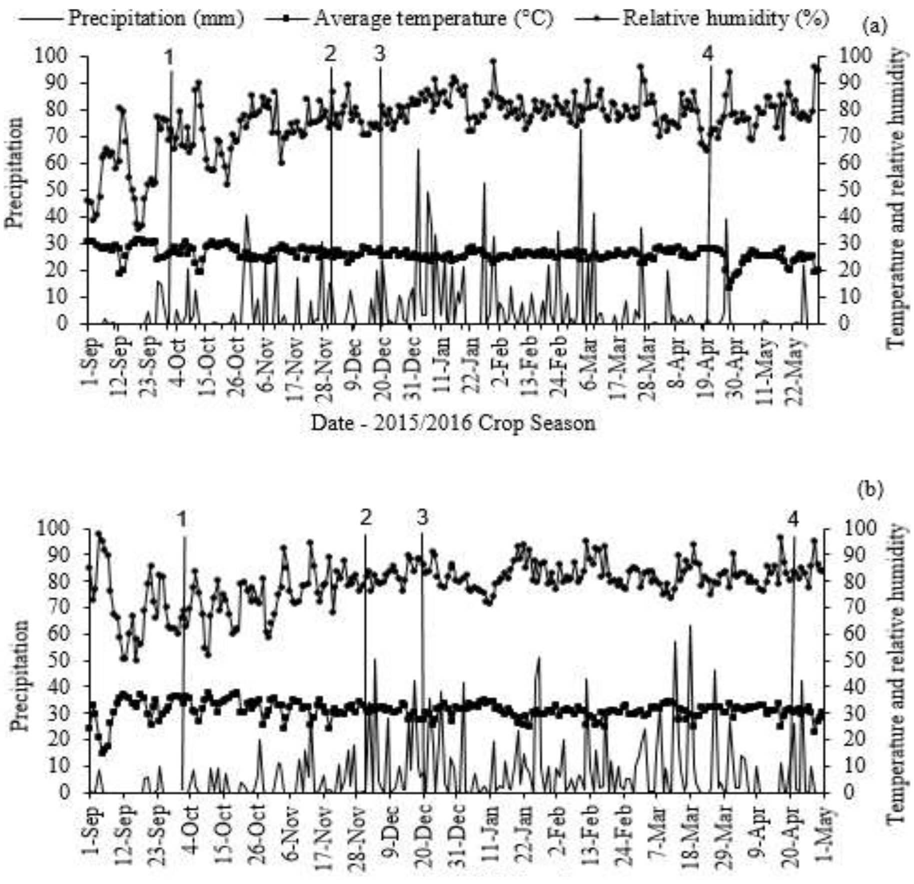

Figure 1. Accumulated precipitation (mm^{-1}), average temperature (T ºC) and relative air humidity (%) of the experimental area in the 2015-2016 (a) and 2016-2017 (b) crop seasons. 1 - sowing of millet and crotalaria; 2 - desiccation of plants; 3 - soybean sowing; 4 - soybean harvesting, soil sampling and evaluation of the soil chemical and microbiological quality.

pod and number of nodes of plant were considered. For the productive characteristics, it was considered the number of pods with one, two, three and four grains. At harvesting, all the plants present in the plot area were evaluated, with the grain moisture corrected to 13%. Mass of one thousand grains and the yield in kg ha^{-1} was determined (Souza et al., 2010).

Soil chemical characteristics

The soil quality was determined in each plot after the physiological maturity of the soybean, and in the forest fragment. Soil was collected in the space between soybean sowing lines at five points per plot. The chemical characteristics were determined in the 0 to 0.20 m depth layer, considering organic matter (OM), hydrogenation potential (pH), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), aluminum (Al), cation exchange capacity (T) and potassium saturation (% K) (Embrapa, 2011).

Soil microbiological characteristics

The soil microbial biomass carbon by the fumigation-extraction method (Vance *et al*., 1987), basal respiration of the soil obtained by the quantification of CO_2 released after the soil microbiological analysis, from 0 to 0.10 m depth (Jenkinson and Powlson, 1976), a microbial quotient determined by the relationship between soil microbial biomass carbon and total organic carbon, the metabolic quotient obtained by the relationship between basal respiration of the soil and the carbon of the microbial biomass of the soil were evaluated (Anderson and Domsch, 1993).

Statistical analyses

Shapiro Wilk normality tests and homogeneity by the Bartlett test was performed. The chemical and microbiological characteristics of the soil were submitted to the Dunnett test ($p \leq 0.05$), considering an additional plot in the forest fragment. Soil chemical and microbiological indicators, vegetative and productive characteristics of soybean were compared by Tukey's test ($p \leq 0.05$), using ASSISTAT software (Silva and Azevedo, 2016).

RESULTS

Agronomic characteristics of soybean

The vegetative and productive characteristics of the soybean crop in the 2015/16 crop season did not present significant differences in relation to the biological fertilization and soil cover, except the number of pods with three grains, which was higher in the soil maintained in clean fallow. Different behavior occurred in the 2016/17 crop season. When the biological fertilizer was applied, the soybean had higher insertion height of the first pod, the soil cover increased the plant height, leaf area and grain yield (Table 2). In the 2016/17 crop season, with soil cover there was a considerable influence on soybean grain yield, when grown on plant remains of millet and crotalaria presented increases of 10 and 16% yield, respectively, in relation to the soil in fallow clean. In this crop season, there were increases of 27, 31 and 17% of the yield of soybean cultivated on millet, crotalaria and soil in clean fallow, respectively, in relation to the 2015/16 crop season (Table 2). The increase in soybean yield reveals the importance of the practices proposed in this study, because in two years of management with soil cover increased grain yield in relation to the clean fallow (Table 2). In addition, the higher precipitation recorded in the 2016/17 crop season may also has contributed to a better productive development of soybean in relation to the 2015/16 crop season (Figure 1).

Soil chemical characteristics

The deposition of vegetable material in the soil provided conditions for the no-tillage of soybean, protection of the soil, organic matter production and fertility increments. Significant effects of the biological fertilizer and plant covering on soil chemical properties in both crops seasons was observed (Tables 3 and 4).

Highest concentration of potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg) and pH of the soil cultivated with soybean in the 2015/16 and 2016/17 crops seasons was observed. In the cultivated field with soil correction, mineral and biological fertilization presented higher chemical quality than the soil of the forest fragment, which presented lower fertility, but higher levels of organic matter in the soil (Tables 3 and 4).

The organic material was important for the quality of the chemical and microbiological properties of the soil. The soil of the forest fragment presented 27 and 31% more organic matter than the cultivated field with soybeans in the 2015/16 and 2016/17 crop seasons, respectively (Tables 3 and 4). The presence of organic matter was important for the maintenance of the productive capacity of the soil, therefore, there is need for the production of straw of millet and crotalaria, or other plant covering, on the agricultural soil.

There was also an increase of concentration of the K in the soil with application of the biological fertilizer and the use of millet in the 2015/16 crop season. The response in the 2016/17 crop season only for biological fertilization (Tables 3 and 4) was repeated. This is due to the ability of the millet to cycle a large quantity of K in the dry matter, which was also present in the mineral composition of the biological fertilizer, later mineralized in the soil through the organic matter decomposition process.

The soil of the forest fragment showed a higher cation exchange capacity, but with a higher acidity on the soil in the 2016/17 crop season (Table 4). The lowest P levels occurred in the soil with use of biological fertilizer, behavior not observed in the previous crop season. With crotalaria followed by millet, the concentration of P was higher than the clean fallow, which may be related to the nutrient cycling promoted by these plants covering.

Increased fertility of soil - mainly of the K and P, higher levels of organic matter in the soil, residues of millet and crotalaria and higher precipitation volume (Figure 1) were characteristics that contributed to the increases in soybean yield in 2016/17 crop season (Table 2).

Table 2. Soybean crop responses to biological fertilization (BF) and plant covering (COV) in the 2015/16 and 2016/2017 crop seasons.

	2015/2016 crop season									
BF	**PH**	**HIFP**	**NN**	**P1**	**P2**	**P3**	**P4**	**LA**	**1000-GW**	**GY**
	------- cm -------			**-------------------- un --------------------**				**cm^2**	**g**	**kg ha^{-1}**
With	66.3	16.5	13.8	11.2	22.3	20.0	0.4	1450.3	140.5	3020.3
Without	65.4	15.9	14.1	10.9	24.5	24.0	0.5	1720.1	137.9	3039.8
COV										
Millet	66.1	16.2	13.7	10.9	21.5	18.1^{b}	0.3	1637.7	141.1	3028.9
Crotalaria	68.2	16.6	14.1	10.6	22.5	20.8^{ab}	0.5	1613.8	141.0	3080.2
Clear Fallow	63.3	15.7	14.1	11.6	26.3	27.1^{a}	0.6	1503.9	135.6	2981.0
CV (%)	6.0	13.6	5.5	18.7	16.17	25.5	68.1	26.4	4.4	10.0
	2016/2017 crop season									
BF										
With	67.7	18.8^{a}	14.4	8.5	17.0	14.6	0.2^{b}	1981.7	176.2	3890.6
Without	67.8	16.3^{b}	14.7	9.3	19.2	17.2	0.4^{a}	2114.8	173.4	3688.6
COV										
Millet	68.9^{a}	18.6	14.7	8.2	16.6	15.1	0.2	2114.9^{ab}	176.2	3833.3^{ab}
Crotalaria	69.9^{a}	17.0	14.9	10.3	18.8	16.3	0.3	2260.0^{a}	173.5	4047.0^{a}
Clear fallow	64.4^{b}	17.0	14.1	8.0	18.9	16.4	0.3	1769.9^{b}	175.2	3488.5^{b}
CV (%)	5.0	9.4	4.5	29.5	24.4	21.4	77.5	14.7	5.1	10.5

Means followed by the same letters in the column do not differ statistically by the Tukey's test ($p \leq 0.05$). Plant height (PH), height insertion of the first pod (HIFP), number of nodes (NN), pods with 1, 2, 3 and 4 grains (P), leaf area (LA), 1,000-grain weight (1000-GW) and grain yield (GY).

Table 3. Chemical quality of soil layer 0 to 0.20 m in the 2015/16 crop season as a function of biological fertilization (BF) and plant covering (COV), and control in the forest fragment.

		Dunnett's test (p≤0,05)									
BF	**COV**	**OM**	**pH**	**P**	**K**	**K**	**Ca**	**Mg**	**H+Al**	**T**	**K**
		g kg^{-1}	**$CaCl_2$**	**---- mg dm^{-1} ----**		**---------------- $cmol_c$ dm^{-3} --------------**					**Percentage**
With	Millet	22.8^{b}	6.5^{a}	5.3^{a}	195.5^{a}	0.5^{a}	4.2^{a}	2.3^{a}	1.6^{b}	8.6^{a}	7.1^{a}
	Crotalaria	25.5^{a}	6.6^{a}	3.6^{a}	147.6^{a}	0.4^{a}	4.2^{a}	2.1^{a}	1.4^{b}	8.1^{b}	5.4^{a}
	Clear fallow	26.8^{a}	6.4^{a}	3.4^{b}	97.7^{b}	0.2^{b}	4.3^{a}	2.1^{a}	1.6^{b}	8.3^{b}	3.6^{b}
Without	Millet	21.5^{b}	6.6^{a}	4.5^{a}	157.4^{a}	0.4^{a}	3.7^{a}	2.1^{a}	1.4^{b}	7.7^{b}	5.7^{a}
	Crotalaria	23.8^{b}	6.6^{a}	3.9^{a}	124.1^{a}	0.3^{a}	4.3^{a}	2.3^{a}	1.4^{b}	8.3^{b}	4.5^{a}
	Clear fallow	24.2^{b}	6.7^{a}	4.1^{a}	85.0^{b}	0.2^{b}	2.8^{a}	2.3^{a}	1.4^{b}	7.8^{b}	3.1^{b}
Forest fragment		30.6^{a}	5.0^{b}	0.7^{b}	55.7^{b}	0.1^{b}	2.3^{b}	1.1^{b}	3.3^{a}	6.9^{b}	2.0^{b}
FB		**Tukey's test (p≤0.05)**									
With		25.1	6.5^{b}	4.1	146.9^{a}	0.4^{a}	4.2	2.2	1.5	8.3	5.4^{a}
Without		23.2	6.6^{a}	4.2	122.2^{b}	0.3^{b}	4.0	2.2	1.4	7.9	4.5^{b}
COV											
Millet		22.1	6.5	4.9	176.4^{a}	0.5^{a}	4.0	2.2	1.5	8.1	6.4^{a}
Crotalaria		24.6	6.6	3.7	135.9^{b}	0.3^{b}	4.2	2.2	1.4	8.2	5.0^{b}
Clear fallow		25.5	6.6	3.8	91.4^{c}	0.2^{c}	4.1	2.2	1.5	8.0	3.3^{c}
CV (%)		10.6	2.3	39.5	20.3	20.3	16.1	19.8	11.1	10.1	20.3

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 ($p \leq 0.05$). Organic matter (OM), potential hydrogen (pH) phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), hydrogen + aluminum (H + Al), cation exchange capacity (T), and potassium saturation (%K) at pH 7.

Table 4. Chemical quality of soil layer 0 to 0.20 m in the 2016/17 crop season as a function of biological fertilization (BF) and plant covering (COV), and control in the forest fragment.

BF	COV	Dunnett's test ($p≤0,05$)									
		OM	pH	P	K	K	Ca	Mg	H+Al	T	K
		g kg^{-1}	$CaCl_2$	------ mg dm^{-1} -----			---------------- cmol$_c$ dm^{-3} ------------				Percentage
With	Millet	30.7^{b}	5.8^{a}	2.7^{b}	202.0^{a}	0.5^{a}	4.2^{a}	1.4^{b}	1.7^{b}	7.9^{b}	7.4^{a}
	Crotalaria	29.3^{b}	5.9^{a}	4.2^{a}	194.2^{a}	0.5^{a}	4.4^{a}	1.4^{b}	1.1^{b}	7.4^{b}	7.1^{a}
	Clear fallow	30.7^{b}	6.1^{a}	2.8^{b}	152.5^{a}	0.4^{a}	4.5^{a}	1.3^{b}	1.3^{b}	7.5^{b}	5.6^{a}
Without	Millet	30.3^{b}	5.9^{a}	7.3^{a}	157.7^{a}	0.4^{a}	4.7^{a}	1.3^{b}	1.6^{b}	8.0^{b}	5.8^{a}
	Crotalaria	29.0^{b}	5.9^{a}	9.2^{a}	155.1^{a}	0.4^{a}	4.4^{a}	1.2^{b}	1.7^{b}	7.7^{b}	5.7^{a}
	Clear fallow	30.0^{b}	6.1^{a}	3.5^{b}	122.5^{a}	0.3^{a}	4.4^{a}	1.5^{a}	1.6^{b}	7.8^{b}	4.5^{a}
Forest fragment		39.3^{a}	5.0^{b}	0.7^{b}	45.6^{b}	0.1^{b}	3.7^{b}	1.2^{b}	4.3^{a}	9.3^{a}	1.7^{b}
BF		Tukey's test ($p≤0.05$)									
With		30.2	5.9	3.2^{b}	182.9^{a}	0.5^{a}	4.4	1.4	1.4	7.6	6.7^{a}
Without		29.8	6.0	6.6^{a}	145.1^{b}	0.4^{b}	4.5	1.3	1.6	7.8	5.3^{b}
COV											
Millet		30.5	5.8^{b}	5.0^{ab}	179.7	0.5	4.4	1.4	1.6	7.9	6.6
Crotalaria		29.2	5.9^{b}	6.7^{a}	174.6	0.4	4.4	1.3	1.4	7.6	6.4
Clear fallow		30.3	6.1^{a}	3.2^{b}	137.5	0.3	4.5	1.4	1.4	7.6	5.0
CV (%)		4.7	1.2	39.16	22.9	22.9	4.4	10.2	23.2	6.6	22.9

Means followed by the same letter in the column do not differ statistically by the Dunnett's test ($p≤ 0.05$) and Tukey's test ($p≤0.05$). Organic matter (OM), potential hydrogen (pH) phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), hydrogen + aluminum (H + Al), cation exchange capacity (T), and potassium saturation (%K) at pH 7.

Soil microbiological characteristics

There was a lower microbiological indicators quality of the soil in the cultivated field with soybeans in both the 2015/16 and 2016/17 crop seasons, compared to the soil of the forest fragment, where was observed greater total organic carbon, microbial biomass carbon, microbial quotient and basal respiration (Table 5). There were no observed effects of the biological fertilizer on the microbiological properties of the soil in the crop season 2015/16. The implementation of the management proposed in this study in the 2016/17 crop season showed higher carbon fixation efficiency, lower soil CO_2 losses and soil metabolic quotient by microbial biomass (Table 5). The climatic conditions of this last crop season may have favored the development of microbial biomass in relation to the 2015/16 crop season, as there was frequent rainfall before soil collection for analysis (Figure 1). The mean values of total organic carbon, microbial biomass carbon, microbial quotient, basal respiration and metabolic quotient of soil cultivated with soybean increased (25, 45, 18, 117 and 47%, respectively) in the 2016/17 crop season in relation to the 2015/16 crop season. However, the metabolic quotient indicates that the microbial biomass is under stress condition (Table 5). The management with biological fertilizer and plant covering reduced the impacts resulting from agricultural practices in the soil, and the microbiological indicators were sensitive tools to monitor such modifications. The results observed in the area cultivated with soybean with application of the biological fertilizer and plant residues remaining of millet and crotalaria, had lower soil metabolic quotient in the both crop season, when compared to the absence of biological fertilizer and clear fallow (Table 5).

DISCUSSION

Agronomic characteristics of soybean

In this study, there were no effects of the biological fertilization on the grain yield of soybean crop. However, in other crops such as *C. sativus*, the biofertilizer or the combination of biofertilizer with mineral fertilizer promoted an increase in the number of fruits per plant, fruit weight, fruit size and yield per green house/kg (Saeed et al., 2015). Increase in soybean yield when cultivated on plant

Table 5. Microbiological quality of the soil layer 0.00 to 0.20 m in the 2015/16 and 2016/17 soybeans crop seasons as a function of biological fertilization (BF) and plant covering (COV), using a forest fragment as control.

BF	COV	Dunnett's test (p≤0.05)									
		2015/2016 crop season					2016/2017 crop season				
		TOC	SMBC	*q*MIC	C-CO_2	*q*CO_2	TOC	SMBC	*q*MIC	C-CO_2	*q*CO_2
With	Millet	13.2[b]	102.6[b]	0.7[b]	0.2[b]	1.4	17.8[b]	135.2[b]	0.6[b]	0.4	2.7[b]
	Crotalaria	14.8[a]	104.7[b]	0.7[b]	0.3[b]	2.9	17.0[b]	129.2[b]	0.6[b]	0.4	3.2[a]
	Clear fallow	15.6a	95.6[b]	0.6[b]	0.2[b]	2.7	17.8[b]	157.4[b]	0.9[b]	0.6	4.0[a]
Without	Millet	12.5[b]	87.3[b]	0.7[b]	0.2[b]	2.6	17.6[b]	151.8[b]	0.9[b]	0.6	4.1[a]
	Crotalaria	13.8[b]	91.2[b]	0.7[b]	0.3[b]	2.6	16.8[b]	131.4[b]	0.8[b]	0.4	3.2[a]
	Clear fallow	14.0[b]	85.3[b]	0.7[b]	0.3[b]	3.3	17.4[b]	118.2[b]	0.7[b]	0.6	5.7[a]
Forest fragment		17.7[a]	439.3[a]	2.6[a]	0.8[a]	1.9	21.4[a]	324.7[a]	1.5[a]	0.5	1.5[b]
BF		Tukey's test (p≤0.05)									
With		14.5	101.0	0.7	0.2	2.4	17.5	140.6	0.8	0.5	3.3[b]
Without		13.4	88.0	0.7	0.2	2.8	17.3	133.8	0.8	0.6	4.3[a]
COV											
Millet		12.8	95.0	0.7	0.2	2.0[b]	17.7	143.5	0.8	0.5[ab]	3.4[b]
Crotalaria		14.3	98.0	0.7	0.3	2.8[ab]	16.9	130.3	0.8	0.4[b]	3.2[b]
Clear fallow		14.8	90.4	0.6	0.3	3.0[a]	17.6	137.8	0.8	0.6[a]	4.9[a]
CV (%)		10.6	13.0	15.4	18.3	24.3	7.75	24.8	27.2	25.4	18.[6]

Means followed by some letter in column not differ statistically for Dunnett's test (p≤0,05) and Tukey's test (p≤0,05). Total organic carbon (TOC – g kg^{-1}), soil microbial biomass carbon (SMBC – mg C microbial kg^{-1} solo), microbial quotient (qMIC – %), soil basal respiration (C-CO_2 – mg de C-CO_2 kg^{-1} soil $hour^{-1}$) and metabolic quotient (qCO_2 – mg C-CO_2 g^{-1} SMBC h^{-1}).

residues of millet and crotalaria in the 2016/17 crop season was recorded. In the soybean cultivated in soil with plant covering and low water availability, greater grain yield of soybean occured, because the dry matter of *Avena strigosa*, *Vicia sativa* and *Raphanus sativus* deposited on the soil contributed to the maintenance of moisture (Debiasi et al., 2010). On the other hand, whit *Brachiaria ruziziensis, Pennisetum glaucum, Cajanus cajan* and *Cenchrus echinatus* and uniform distribution of rainfall throughout the crop cycle, did not record effects of plant covering on soybean grain yield (Pacheco et al., 2011; 2013).

Soil chemical characteristics

There was an increase of K concentration in the soil with millet. Among all the coverages tested, the millet was the one with the highest concentration of K remaining in the dry matter in relation to the other cover plants, being 58 kg ha^{-1} of K, besides contributing 70 kg ha^{-1} of N and 12 kg ha^{-1} of P (Pacheco et al., 2011).

The fertility of soil of the Cerrado Region was low naturally, with the forest fragment analyzed in this study. It was necessary to adopt management that increases the concentration of nutrients in the soil of the areas submitted to agricultural crops (Lopes et al., 2013). In this way, the needs of the crop were made available and the nutrients of the soil were replenished (Sousa and Lobato, 2004).

In the present study, the organic matter was lower in soil cultivated with soybean in relation to the forest fragment. Cherubin et al. (2015) also observed losses of organic material in agricultural areas in relation to the natural environment. The organic matter was an important indicator of soil changes in microbiological quality. The loss of organic material was intensified in the conventional farming system in relation to no-tillage, which was considered a soil conservation practice that allows the accumulation of vegetable dry matter (Vezzani and Mielniczuk, 2011).

The efficiency of the biological fertilizer depends on the presence of organic matter in the soil, because the introduction of decomposing microorganisms, mainly bacteria and fungi, use it as a substrate for its growth. These biological agents benefit the soil by decomposing organic matter, promoting the cycling of nutrients and improving the efficiency in the use of mineral fertilization, used to supply the nutritional needs of crops (Medeiros and Lopes, 2006).

Soil microbiological characteristics

The soil microbial biomass carbon was lower in the cultivated field compared to the forest fragment. In the municipality of Primavera do Leste - MT, a reduction in the area used for agricultural practices in relation to native vegetation was noticed (Matsuoka et al., 2003). The soil microbial biomass carbon positively correlates with the total organic carbon, this justifies the greater soil microbial biomass of the forest fragment observed in this study (Lisboa et al., 2012; Lopes et al., 2013).

Therefore, the accumulation of organic matter in the cultivated areas resulting from management techniques such as the addition of liquid residues of pigs in the farming system contributed to increase the carbon levels of soil microbial biomass (Cherubin et al., 2015). In a study testing different forms of soil cover, the carbon of microbial biomass was larger using straw mulch in relation to plastic mulching of the soil (Muñoz et al., 2017).

Soil cover plants are important for soil management, where millet has been used in no-tillage systems due to high dry matter production. This characteristic paved way to increase carbon levels in soil cultivated for four years in no-tillage. From the implantation of this cultivation system, accumulation of carbon in the soil and increases in the carbon of the microbial biomass was recorded, in relation to the conventional system made with a rotation and without presence of straw on the soil (Matias et al., 2009).

To obtain reference values of the microbiological quality of farming field, Mendes et al. (2015) elaborated different levels of interpretation of soil quality bioindicators of soybean and maize crops. Considering the minimum value of 205 mg C kg^{-1} of soil based on the organic matter content proposed by the authors mentioned earlier, the soil microbial biomass carbon of the present study was found to be low in the 2015/16 and 2016/17 crop seasons (Mendes et al., 2015).

The microbial quotient was formed by the relationship between the soil microbial biomass carbon and the total organic carbon, and indicates the percentage of soil carbon immobilized by microorganisms with highest and lowest values indicating carbon gain and loss in the soil microbial biomass, respectively. Considering that 2.20% was considered an equilibrium level for this indicator, the values observed in the soybean cultivated soil in this study were lower, indicating low carbon fixation in the biomass (Jenkinson and Ladd, 1981).

The study reported values of microbial quotient higher than 1 in fields submitted to different farming systems, being higher in no-tillage system. Higher values of microbial quotients indicated that soil organic matter is more available to be processed and transformed by soil microbial biomass (Matias et al., 2009). Soil basal respiration, soil microbial biomass carbon and microbial quotient had the lowest values in the soybean cultivated soil in relation to the forest fragment. A similar relationship between bioindicators was observed by Cunha et al. (2012). Soils submitted to conventional tillage presented higher basal respiration in relation to no-tillage (Lisboa et al., 2012). Greater respiration of the soil was submitted for mechanical scarification (Cherubin et al., 2015). The release of CO_2 by respiration was related to the increase in the metabolic activity of microbial biomass, which is usually caused by stress conditions in the soil. The rapid carbon consumption allows greater release of nutrients to plants in the short term, but in the long term, indicates low efficiency of fixation in the biomass, generating losses of carbon in the form of CO_2 by microbial respiration (Cunha et al., 2012). The basal respiration of the soil was usually lower in natural areas or in equilibrium, and according to the classification levels of the bioindicators, all values of basal respiration observed in this study were low (Mendes et al., 2015).

The study also observed a low metabolic quotient with biological fertilizer, millet and crotalaria. The highest metabolic quotient, as observed in the soil without biological fertilizer and clean fallow, indicate unbalanced areas, which is due to the accelerated metabolic process of the microorganisms of the soil. The fast process of organic matter decomposition increased the losses of carbon in the form of CO_2 by soil microbial biomass (Cunha et al., 2012).

The quality of plant residues also influences the carbon fixation. The metabolic quotient was higher in soil with straw of *P. glaucum*, *C. spectabilis* and in fallow area. This indicates that the straw of these plants may have caused some type of stress to the microorganisms, which consume more energy, reducing the carbon fixation in the soil and increasing the losses by soil respiration (Carneiro et al., 2008). With low values of soil metabolic quotient, the biomass has greater efficiency in the fixation of carbon in the microbial cell, thus having less energy expenditure. With soils that present stress conditions, the microorganisms tend to spend more energy to survive, so the values of the metabolic quotient are higher (Gomide et al., 2011; Fidelis et al., 2016).The microorganisms were important for the functioning of the soil and its interactions with the root system of the crops, and can also influence the soil chemical attributes (Mendes et al., 2015). Works involving soil microorganisms require a longer evaluation time to obtain reliable results (Cherubin et al., 2015).

The soil quality indicators were tools used to monitor agricultural soils (Gomide et al., 2011). Based on the results of this study, it was recommended to make use of biological fertilization and plant covering, since this management improved the chemical and microbiological quality of soil cultivated with soybean, besides the significant effects on the vegetative development and the grain yield of the soybean crop.

CONCLUSIONS

The grain yield of the soybean was higher when cultivated in the plant residues of crotalaria in the 2016/2017 crop season. Effects of the biological fertilization on the agronomic performance of the soybean crop were not observed. The application of the biological fertilizer, the use of millet and crotalaria increased the fertility and microbiological quality of the soil in the 2015/16 and 2016/17 crop seasons.

CONFLICT OF INTERESTS

The authors had not declared any conflict of interests.

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