Soil chemical properties affected by cover crops under no-tillage system

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ABSTRACT

The use of cover crops in no-tillage systems (NTS) can significantly improve the soil's fertility. Thus, a study was performed to evaluate changes in chemical properties of soil caused by cover crops in a no-tillage system. The field experiment consisted of the following crop rotation: cover crops/rice/cover crops/rice. The experimental design was in randomized blocks with three replications. Treatments consisted of four cover crops (*Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf. cv. Marandu, *Brachiaria ruziziensis* R. Germ. and C.M. Evrard, *Panicum maximum* Jacq. cv. Colonião, and *Pennisetum glaucum* (L.) R. Br. cv. BN-2) and fallow (control treatment). Soil samples were collected at the beginning of the summer crop in Oct 2007, Oct 2008 and Oct 2009 at 0-5 cm soil depth. The use of cover crops provided for a significant increase in the level of nutrients, soil organic matter, cation exchange capacity, and base saturation in the soil. Soil fertility improved from the first to second year with the growing of cover crops. The soil under cover crops *P. glaucum*, *B. ruziziensis*, and *B. brizantha* showed higher fertility than the area under fallow.

Key words: *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf. cv. Marandu, *Brachiaria ruziziensis* R. Germ. and C.M. Evrard, *Panicum maximum* Jacq. cv. Colonião, *Pennisetum glaucum* (L.) R. Br. cv. BN-2, soil management.

RESUMO

Propriedades químicas do solo afetadas por plantas de cobertura no sistema plantio direto

O uso de plantas de cobertura no sistema de plantio direto (SPD) pode melhorar significativamente a fertilidade do solo. Assim, um estudo foi realizado para avaliar as alterações nas propriedades químicas do solo causadas pelas culturas de cobertura em sistema de plantio direto. O experimento de campo consistiu na rotação das seguintes culturas: plantas de cobertura/ arroz/ plantas de cobertura/ arroz. O delineamento experimental foi em blocos casualizados com três repetições. Os tratamentos consistiram de quatro espécies de plantas de cobertura (*Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf. cv. Marandu, *Brachiaria ruziziensis* R. Germ. and C.M. Evrard, *Panicum maximum* Jacq. cv. Colonião and *Pennisetum glaucum* (L.) R. Br. cv. BN-2) e pousio (tratamento controle). As amostras foram coletadas no início da safra de verão, em outubro de 2007, 2008 e 2009, a 0-5 cm de profundidade. O uso de plantas de cobertura proporcionou aumento significativo na concentração de nutrientes, matéria orgânica do solo, capacidade de troca catiônica e saturação por bases. A fertilidade do solo melhorou do primeiro para o segundo ano com o cultivo de plantas de cobertura. O solo sob as plantas de cobertura *P. glaucum*, *B. ruziziensis* e *B. brizantha* apresentou maior fertilidade do que a área mantida sob pousio.

Palavras-chave: *Brachiaria brizantha* (Hochst. ex A. Rich.) Stapf. cv. Marandu, *Brachiaria ruziziensis* R. Germ. and C.M. Evrard, *Panicum maximum* Jacq. cv. Colonião, *Pennisetum glaucum* (L.) R. Br. cv. BN-2, manejo do solo.

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INTRODUCTION

The use of no-tillage systems (NTS) is growing in all regions of Brazil, occupying an area of 25 million hectares, about 10 million of which are located in soils under Cerrado (CONAB, 2012). These soils are characterized by low soil fertility and low pH (Boer *et al.*, 2007). Using cover crops in NTS could be an important alternative to increase the sustainability of agricultural systems, which may favor increasing soil fertility, and restoring considerable amounts of nutrients to crops. Cover crops with large root systems can uptake nutrients from deep soil layers and after chemical desiccation, during straw degradation, release these nutrients in the soil surface (Duda *et al.*, 2003; Boer *et al.*, 2007; Torres & Pereira, 2008; Pacheco *et al.*, 2011; Cunha *et al.*, 2011). Therefore, vegetation at the soil surface in the NTS can significantly change the chemical properties of the soil (Torres *et al.*, 2005; Crusciol *et al.*, 2005; Rosolem *et al.*, 2006; Boer *et al.*, 2007; Carpim *et al.*, 2008, Garcia *et al.*, 2008; Reddy *et al.*, 2009, Carneiro *et al.*, 2009; Rosolem *et al.*, 2010; Cunha *et al.*, 2011).

In this sense, it is essential to be aware of the changes caused by cover crops, for understanding the process, which could result in more efficient use of nutrients for subsequent crops (Fabian, 2009). Sá (1993) reported that soils under NTS for 4, 9, and 16 years had values of 29, 79, and 129 mg kg^{-1} of P, respectively, in the 0-2.5 cm layer. Sá (1993), Crusciol *et al.* (2008), and Crusciol *et al.* (2010) reported an increase in the contents of K^+ in the 0-5 cm soil layer by using cover crops in NTS. Other studies have also described accumulation in the soil surface of Ca^{2+} and Mg^{2+} (Falleiros *et al.*, 2003), and Zn^{2+}, Mn^{2+}, Fe^{2+}, and Cu^{2+} (Franzluebbers & Hons, 1996), increases in cation exchange capacity, organic matter content, P and K^+ (Santos & Tomm, 2003; Bernardi *et al.*, 2005; Crusciol *et al.*, 2010), as well as changes in pH and reduced Al saturation (Cunha *et al.*, 2011).

Additionally, according to Santi *et al.* (2003), Bernardi *et al.* (2005), and Fabian (2009), after a while, in NTS there is a tendency to increase the efficiency of the applied fertilizers and the availability of nutrients by the action of microorganisms (N), decrease fixation of nutrients (P) and movement of cations in the soil profile (Ca^{2+}, Mg^{2+}, and K^+). In this sense, it is important to develop studies to assess the contributions of cover crops in soil fertility, aiming to increase crop yield, reducing production costs and increasing the overall sustainability of the system (Bernarndi *et al.*, 2005; Torres & Pereira, 2008; Crusciol *et al.*, 2010). Thus, a study was performed to evaluate changes in the soil's chemical properties caused by cover crops in NTS.

MATERIAL AND METHODS

Site descriptions

The field experiment was conducted in Santo Antônio de Goiás, in the Brazilian state of Goais (16° 27' latitude, 49º 17' longitude, and 823 m local elevation). The regional climate is tropical savanna, classified as Aw according to the Köppen classification. There are two well defined seasons, normally dry from May to September (autumn/winter) and wet from October to April (spring/summer), annual mean rainfall is between 1500 mm and 1700 mm. Local annual mean temperature is 22.7°C, varying annually from 14.2° C to 34.8° C.

The soil was a Brazilian Oxisol (Embrapa, 1999) found in a gently undulating topography. Soil texture was clayey (540 g kg^{-1} clay, 110 g kg^{-1} silt, and 350 g kg^{-1} sand). The research was conducted in an area that had been under NTS for six years (2001/2002 - 2006/2007) in rotations with corn (2001/2002, 2003/2004, and 2005/2006) and soybean (2002/2003, 2004/2005, and 2006/2007) in the summer and fallow in the winter.

Experimental design and treatments

The experiment consisted of cover crops in the first summer (November - 2007) and rice in the second summer (November - 2008). After the rice harvesting, it was sowed with the same cover crops in the off-season (March - 2009) and followed by rice again in the third summer (November - 2009). Cover crops used were: 1. *Panicum maximum*, 2. - *Brachiaria ruziziensis*, 3. - *Brachiaria brizantha* - cultivar Marandu and 4. - millet (*Pennisetum glaucum* - cultivar BN-2) and 5. Fallow (spontaneous vegetation, predominantly *Bidens pilosa* L., *Commelina benghalensis* L., *Conyza bonariensis* L. Cronquist, and *Cenchrus echinatus* L.). The experimental design was randomized blocks in a split plot scheme. In the main plots there were five cover crops and in the subplots there were two years (2008 and 2009) of evaluation, with three replications.

Crop management

Tropical forages are sown in November 2007 and March 2009, and millet was sown in March 2008 and March 2009. It used 0.20 m row spacing with a mechanical planter set to distribute 10 kg of seeds per ha^{-1} as recommended by Crusciol *et al.* (2010).

Rice was sown in November of 2008 (second summer) and November of 2009 (third summer) using the cultivar "BRS Sertaneja" spaced at 0.35 m with 80 seeds per meter. The sowing fertilization was 400 kg ha^{-1} of the 04-30-16 NPK formula. Immediately after sowing, fertilization of 45 kg ha^{-1} of N as urea was made. Cultural practices were performed in accordance with the recommendations of the culture (EMBRAPA Arroz e Feijão, 2003).

Soil sampling

Three replications (composite sample) of 16 single samples each in the layer 0-5 cm depth for chemical analysis of the soil were collected before installation of the experiment to evaluate the initial fertility, one month after the application of limestone (1 t ha^{-1}). To evaluate changes caused by cover crops in the soil's chemical properties, samples were collected in October 2008 and October 2009. Eight single soil samples were collected from each plot in the layers of 0-5 cm. Single samples were manually mixed and homogenized to form a composite sample of each plot. These samples were packed separately in plastic bags and sent for chemical analysis, according to the methodology of Embrapa's manual of methods (Claessen, 1997).

Soil analysis

The pH was determined in water, using a soil:solution ratio of 1:2.5. P and K^+ were extracted by Mehlich 1, and Ca^{2+}, Mg^{2+} and Al^{3+} with 1 mol L^{-1} KCl. In the extracted solution, P was determined by colorimetry and K^+ by flame photometry. Ca^{2+} and Mg^{2+} were determined by EDTA titration and Al^{3+} by titration of NaOH from the extract. Micronutrients were determined on a portion of the extract for P by atomic absorption spectrophotometry. Soil organic matter was determined by Walkley & Black's method and the cation exchange capacity at pH 7.0 and base saturation were also calculated.

Statistical analysis

The analysis of variance (ANOVA) and LSD tests at $p<0.05$ were carried out using the SAS system statistical package (SAS, 1999). First, we performed an ANOVA and means test between the five cover crops (main plot) and the years 2008 and 2009 (subplots) at $p<0.05$. Then, we performed another ANOVA to compare each year (2008 and 2009) with the initial fertility (2007), using Dunnett's test at $p < 0.05$.

RESULTS AND DISCUSSION

It was possible to observe that cover crops significantly affected contents of nutrients in the soil (Tables 1 and 2). There was interaction between cover crops and years for pH. In the year 2008, soil under the cover crops *P. maximum* (6.8), *B. ruziziensis* (6.8) and *P. glaucum* (6.7) provided the highest values and differed from soil under fallow (6.3). However, in 2009, the pH of the soil under fallow was higher than that of the soil under *P. maximum* and did not differ from those under other cover crops. Guimarães (2000) and Moreti *et al.* (2007) reported that cover crops could significantly affect the soil pH. Plants have exudation of acids to the soil from their roots that could act directly on the soil pH (Moreti *et al.*, 2007). Almost all cover crops provided for a reduction of the soil pH, from 2008 to 2009, the only exception was *B. brizantha*, which did not allow for differences between the years. According to Sá (1993), Franchini *et al.* (2000) and Fabian (2009) not tilling the soil favors nutrient accumulation at the surface, increased contents of soil organic matter and reduction in pH values. In addition, when soil organic matter is mineralized there is production of organic acids that could contribute to increased soil acidity (Garcia & Rosolem, 2010).

The pH values were different and lower than the initial fertility at 2007 in the second year of evaluation under all cover crops (2009) (Table 3). This may be due to the removal of bases by the plants grown in this area. According to Oliveira & Pavan (1996), Mello *et al.* (2003), Caires *et al.* (2006), and Soratto & Crusciol (2007), in a no-tillage system the effect of limestone lasts longer than under conventional tillage, however, after the limestone application and with growing plants there is continued base (K^+, Mg^{+2}, and Ca^{+2}) removal that normally provides for a reduction in the soi pH. Because of this, it is normally necessary to apply limestone again after seven years.

Cover crops and year did not affect P contents in the soil (Table 1). In the year 2008, soil under fallow (10.8 mg dm^{-3} of P) and *P. glaucum* (11.2 mg dm^{-3} of P) differed from the initial fertility (2007) (13.8 mg dm^{-3} of P) (Table 3). This seems that fallow and millet did not cycle enough P and provided for a decrease in the level of this nutrient in the soil. In the year 2009, cover crops did not provide any differences in the soil's P contents in relation to the initial fertility (2007).

There was interaction between cover crops and years for calcium concentrations in the soil (Table 1). In the year 2008, soil under millet, fallow and *B. ruziziensis* provided the highest values and differed from the treatment with *B. brizantha*. In the year 2009, soil under *P. maximum* provided the lowest values of Ca and differed from fallow, *B. ruziziensis* and *B. brizantha*. According to Pacheco *et al*. (2014) cover crops can significantly change the soil attributes and depends on many factors, especially the species. Values of Ca in the soil with cover crops, increased from 2008 to 2009, however soil under fallow and millet did not differ significantly between the years. These increased in the values of Ca could be because during the process of cover crop degradation the release of this nutrient could occur, since we did not apply liming or fertilizer with calcium after installation of the experiment.

In the year 2008, calcium values in the soil with cover crops were similar to the initial fertility seen in 2007 (Table 3). However, in 2009 soil under the cover crops *B. ruziziensis* and *B. brizantha* provided the highest values and differed from the initial fertility. According to Kluthcouski *et al.* (2000), *Brachiaria* species, due to their large and depth root systems, have greater ability to mobilize nutrients from deep soil layers to the topsoil. In this regard, soil under the cover crops evaluated provided higher cycling of magnesium and in the year 2009 soils under all cover crops were different from the initial fertility seen in 2007 (Table 3). Additionally, it was observed that there was an increase in the mean of soil magnesium contents from 2008 to 2009, provided by the use of all the cover crops evaluated (Table 1). From these results, it could be inferred that there is a great importance of using cover crops to cycle these nutrients.

Regarding potassium concentration in the soil, there was only the effect of cover crops (Table 1). On average, soil under fallow allowed the lowest K^+ concentration and it differed from soil under all cover crops, with the exception of *P. glaucum* and *B. ruziziensis*. According to Crusciol *et al.* (2010), forage grasses have great potential for the absorption and accumulation of K^+, which is returned to the ground after their desiccation. Garcia *et al.* (2008) added that these forages provide non exchangeable K^+ to the soil, and this can lead to a reduction in spending for fertilizers in crop cultivation and, consequently, reduces the cost of production.

It was also observed that soil under *P. maximum* and *B. brizantha* in the first year (2008) and soil under all

Table 1: Soil's chemical attributes (pH, P, Ca^{2+}, Mg^{2+}, K^+, and SOM) in the 0-5 cm depth, as a function of the cover crops (plot) and year (subplot), Santo Antônio de Goiás, 2008/2009 and 2009/2010

Cover crop	2008	2009	Average	2008	2009	Average
	pH (water)			P (mg dm^{-3})		
Fallow	6.3 cA§	5.8 abB	6.0	10.8	13.3	12.0
P. maximum	6.8 aA	5.6 cB	6.2	11.8	12.8	12.3
B. ruziziensis	6.8 aA	5.8 abB	6.3	13.8	15.6	14.7
B. brizantha	6.4 bcA	5.7 bcA	6.1	11.8	15.9	13.9
P. glaucum	6.7 abA	5.9 aB	6.3	11.2	16.7	13.9
Average	6.6	5.7	-	12.1	14.7	-
	Ca^{2+} (mol dm^{-3})			Mg^{2+}(mol dm^{-3})		
Fallow	2.57 aA	2.83 aA	2.70	0.87	1.27	1.10
P. maximum	2.33 abB	2.57 bA	2.45	0.97	1.40	1.20
B. ruziziensis	2.57 aB	2.90 aA	2.75	0.93	1.40	1.20
B. brizantha	2.17 bB	3.00 aA	2.60	0.90	1.57	1.25
P. glaucum	2.70 aA	2.90 abA	2.80	1.13	1.27	1.20
Average	2.51	2.80	-	0.96 B	1.38 A	-
	K^+ (mol dm^{-3})			SOM (g dm^{-3})		
Fallow	0.38	0.34	0.36 b	18.4 cB	22.9 bA	20.7
P. maximum	0.61	0.64	0.62 a	20.6 bB	23.0 bA	21.8
B. ruziziensis	0.51	0.54	0.53 ab	21.4 bA	22.9 bA	22.2
B. brizantha	0.60	0.62	0.61 a	21.8 aA	23.9 bA	22.8
P. glaucum	0.43	0.49	0.46 ab	21.6 aB	24.2 aA	22.9
Average	0.50	0.53	-	20.8	23.4	-
Factor	ANOVA (*Mean Square*)					
	pH	P	Ca^{+2}	Mg^{+2}	K^+	SOM
Block	0.012	14.281	0.008	0.002	0.011	0.085
Cover crop (CC)	0.089^{**}	7.848	0.115	0.024	0.076^{*}	4.938^{**}
Error (a)	0.011	2.422	0.039	0.029	0.001	0.214
Year	5.720^{**}	49.923	0.645^{**}	1.323^{**}	0.005	25.208^{**}
CC * Year	0.127^{**}	8.227	0.168^{*}	0.055	0.006	4.510^{**}
Error (b)	0.019	3.494	0.033	0.009	0.001	0.222
CV Plot (%)	1.71	11.64	7.47	14.37	6.89	2.10
CV Subplot (%)	2.26	13.98	6.85	19.99	6.16	2.14

§ Means followed by the same letter, lowercase vertically or upper cases horizontally, do not differ by the LSD at $p \leq 0.05$. pH: hydrogen potential, P: phosphorus; Ca^{2+}: calcium, Mg^{2+}: magnesium, K^+: potassium, SOM: soil organic matter. **,*Significant at p<0.05 and 0.01, respectively.

cover crops, with the exception of fallow, in the second year (2009), differed from the initial fertility in 2007 (Table 3). With this result, we could infer that cover crops in a no-tillage system allowed for increases in K^+ contents in the soil.

In relation to soil organic matter (SOM), there was interaction between cover crops and years (Table 1). It was possible to see that, in 2008, soil under fallow provided the lowest values of SOM and differed from the soil with all cover crops. The use of fallow in crop areas was not interesting because it can increase the weed infestation and, as our results showed, fallow could increase the SOM, but cover crops increased more. Therefore, the use of cover crops seems to be much more interesting than the use of fallow. In the second year (2009), soil under millet provided the highest value and differed from the others treatments. According to Nascente *et al*. (2013), millet is a cover crop that could increase soil organic matter and release nitrogen to the soil for the plants. Soil organic matter contents increased in value from 2008 to 2009, the only exceptions were treatments with *B. ruziziensis* and *B. brizantha*, these values did not significantly differ. The use of cover crops in no-tillage systems, due to keeping straw on the soil surface without plowing, normally provides for increases in the soil's organic matter through the years (Crusciol *et al*., 2010; Nascente *et al*., 2013).

Soil under all cover crops were different from initial fertility at 2007 in the second year (2009), showing the importance to use cover crops to increase SOM content (Table 3). Also Cunha *et al.* (2011) found an increase in SOM in soils under NTS cultivated with forage.

Table 2: Soil's chemical attributes (CEC, BS, Fe^{3+}, Zn^{2+}, Mn^{2+}, Cu^{2+}), in the 0-5 cm depth, as a function of the cover crops (plot) and year (subplot), Santo Antônio de Goiás, 2008/2009 and 2009/2010

Cover crop	2008	2009	Average	2008	2009	Average
	CEC ($cmol_c$ dm^{-3})			BS (%)		
Fallow	7.75 abA	8.82 cA	8.29	48.4 bB	51.1 abA	49.76
P. maximum	7.33 cB	8.98 abA	8.16	55.2 aA	50.0 bA	52.34
B. ruziziensis	7.31 cB	8.91 abA	8.11	55.7 aA	54.7 abA	55.13
B. brizantha	8.00 aA	9.17 aA	8.48	48.6 bA	56.3 aA	50.73
P. glaucum	7.55 bcB	8.51 bcA	8.03	57.0 aA	53.6 abA	55.18
Average	7.59	8,88	-	52.99	52.52	-
	Fe^{3+} ($mg\ dm^{-3}$)			Zn^{2+} ($mg\ dm^{-3}$)		
Fallow	28.5	26.0	27.25 c	3.53 cdB	4.80 bA	4.17
P. maximum	27.7	29.8	28.71 bc	3.43 dA	4.27 cA	3.83
B. ruziziensis	25.6	31.8	28.67 bc	4.43 aA	4.73 cA	4.59
B. brizantha	32.2	35.2	33.69 a	4.17 abA	5.37 aA	4.78
P. glaucum	33.2	30.1	31.67 ab	3.87 bcB	5.10 abA	4.48
Average	29.43	30.58	-	3.89 B	4.85 A	-
	Mn^{2+} ($mg\ dm^{-3}$)			Cu^{2+} ($mg\ dm^{-3}$)		
Fallow	21.6 aA	21.0 cA	21.25	2.0	1.4	1.70
P. maximum	20.5 bA	21.7 cA	21.20	1.5	1.6	1.51
B. ruziziensis	20.6 bA	25.7 bA	23.15	1.2	1.5	1.32
B. brizantha	19.2 cB	31.0 aA	25.05	1.7	1.5	1.62
P. glaucum	22.4 aB	26.6 bA	24.45	1.8	1.7	1.72
Average	20.85	25.19	-	1,62	1.54	-
Factor	ANOVA (*Mean Square*)					
	CEC	BS	Fe^{3+}	Zn^{2+}	Mn^{2+}	Cu^{2+}
Block	0.265	21.218	0.722	0.013	0.032	0.128
Cover crop (CC)	0.291**	37.082	41.116*	0.791**	19.573**	0.151
Error (a)	0.161	3.214	0.253	0.044	0.421	0.084
Year	8.965**	17.941	9.976	7.008**	140.833**	0.048
CC * Year	0.611**	70.300**	23.253	0.254**	33.849**	0.159
Error (b)	0.084	6.617	0.651	0.042	1.193	0.067
CV Plot (%)	4.87	3.39	1.68	4.78	2.82	18.37
CV Subplot (%)	3.51	4.88	2.69	4.66	4.75	16.38

§ Means followed by the same letter, lowercase vertically or upper cases horizontally, do not differ by the LSD at $p \leq 0.05$. CEC: cation exchange capacity, BS: base saturation, Fe^{3+}: iron, Zn^{2+}: zinc, Mn^{2+}: manganese, Cu^{2+}: copper. **,*Significant at p<0.05 and 0.01, respectively.

It could be observed that cation exchange capacity (CEC) of the soil under *B. brizantha* showed the highest values in the two years, although it did not differ significantly from some other cover crops (Table 2), besides, the CEC was higher in the soil from 2008 to 2009 for the soil under *P. maximum*, *B. ruziziensis* and millet. In the year 2009, the CEC of the soil under all cover crops did not differ from the

Table 3: Comparison of the soil's chemical attributes (pH, P, Ca^{2+}, Mg^{2+}, K^{+}, SOM, CEC, V, Fe^{3+}, Zn^{2+}, Mn^{2+}, Cu^{2+}), in the 0-5 cm depth, as a function of the cover crops with the initial fertility, Santo Antônio de Goiás, 2007/2008 (initial fertility), 2008/2009 and 2009/2010

Cover crop	2008	2009	2008	2009	2008	2009
	pH (water)		**P (mg dm^{-3})**		**Ca^{2+} (cmol$_c$ dm^{-3})**	
Fallow	6.3 §	5.8 *	10.8 *	13.3	2.57	2.83
P. maximum	6.8 *	5.6 *	11.8	12.8	2.33	2.57
B. ruziziensis	6.8 *	5.8 *	13.8	15.6	2.57	2.90 *
B. brizantha	6.4	5.7 *	11.8	15.9	2.17	3.00 *
P. glaucum	6.7	5.9 *	11.2 *	16.7	2.70	2.90
Initial Fertility	6.4	6.4	13.8	13.8	2.5	2.5
Factors			**ANOVA (*Mean Square*)**			
Error	0.0249	0.01377	0.6859	5.99566	0.0406	0.0332
LSD	0.3852	0.2854	2.0221	5.9784	0.4917	0.4450
CV (%)	2.17	1.99	15.79	16.87	7.20	6.65
	Mg^{2+}(cmol$_c$ dm^{-3})		**K^{+} (cmol$_c$ dm^{-3})**		**SOM (g dm^{-3})**	
Fallow	0.87	1.27*	0.38	0.34	18.4*	22.9*
P. maximum	0.97	1.40*	0.61*	0.64*	20.6	23.0*
B. ruziziensis	0.93	1.40*	0.51	0.54*	21.4	22.9*
B. brizantha	0.90	1.57*	0.60*	0.62*	21.8 *	23.9*
P. glaucum	1.13*	1.27*	0.43	0.49*	21.6*	24.2*
Initial Fertility	0.8	0.8	0.25	0.25	20.4	20.4
Factors			**ANOVA (*Mean Square*)**			
Error	0.0092	0.0286	0.0142	0.0049	0.2082	0.0130
LSD	0.2345	0.4126	0.2912	0.1707	1.1141	0.2784
CV (%)	9.82	13.11	26.28	14.63	2.25	0.50
	CEC (cmol$_c$ dm^{-3})		**BS (%)**		**Fe^{3+} (mg dm^{-3})**	
Fallow	7.75 *	8.82	48.4	51.1	28.5	26.0
P. maximum	7.33	8.98	55.2	50.0	27.7	29.8
B. ruziziensis	7.31	8.91	55.7	54.7	25.6	31.8*
B. brizantha	8.00 *	9.17	48.6	53.3	32.2	35.2*
P. glaucum	7.55	8.51	57.0*	56.3	33.2	30.1
Initial Fertility	7.05	7.05	50.32	50.32	27.60	27.60
Factors			**ANOVA (*Mean Square*)**			
Error	0.1166	8.8726	8.2306	8.8726	7.5699	2.5463
LSD	0.8336	0.6843	7.0046	7.2726	6.7176	3.8961
CV (%)	4.36	5.62	5.28	3.30	9.63	5.30
	Zn^{2+} (mg dm^{-3})		**Mn^{2+} (mg dm^{-3})**		**Cu^{2+} (mg dm^{-3})**	
Fallow	3.53*	4.80	21.6*	21.0	2.0	1.4*
P. maximum	3.43*	4.27*	20.5*	21.7*	1.5	1.6*
B. ruziziensis	4.43	4.73	20.6*	25.7*	1.2	1.5*
B. brizantha	4.17*	5.37	19.2	31.0*	1.7	1.5*
P. glaucum	3.87*	5.10	22.4*	26.6*	1.8	1.7
Initial Fertility	5.1	5.1	18.1	18.1	1.9	1.9
Factors			**ANOVA (*Mean Square*)**			
Error	0.07956	0.1072	0.5306	1.6150	0.0950	0.0123
LSD	0.6887	0.7995	1.7784	3.1028	0.7525	0.2711
CV (%)	7.79	6.69	1.78	5.29	19.05	6.94

§ Means followed by * differed from control treatment (initial fertility) by Dunnet's test for $p \leq 0.05$. LSD: least significant difference.

initial fertility at 2007 (Table 3). Moreti *et al.* (2007), Garcia & Rosolem (2010), and Cunha *et al.* (2011) reported that the use of cover crops with a constant input of biomass on the soil surface can alter the contents of soil nutrients in a relatively short time. Crusciol *et al.* (2010), in only one harvest also observed a significant increase in soil CEC due to *B. brizantha* cultivation.

The base saturation (BS) of the soil under *P. maximum*, *B. ruziziensis* and millet showed the highest values in 2008, however soil BS under *P. maximum* was lower than under *B. brizantha*, in 2009 (Table 2). In addition, soil BS was higher from 2008 to 2009 only for the soil under fallow. In the year 2009, the soil BS under all cover crops did not differ from the initial fertility found in 2007 (Table 3).

Fabian (2009), working with *Brachiaria brizantha* and *Crotalaria juncea*, found that these cover crops provided for an increase in the contents of SOM, and reported that this feature can have positive effects on soil CEC and BS. According to Crusciol *et al.* (2010), CEC and BS are reflections of the organic matter content and soil nutrients. Additionally, they reported that due to crop residue on the soil surface, there is a greater amount of organic matter in the soil surface, especially in the 0-5 cm layer. Therefore, in our trial, observing the soil chemical changes under the majority of the cover crops used, it seems clear that the decomposition of the residues provided an extra amount of nutrients to the soil surface, as well as significant increases in the content of soil organic matter (Table 1) and soil CEC (Table 2). In this sense, it was observed that almost all the contents of nutrients showed increases from one year to the next (Table 1 and 2); it may be due the annual input of biomass in the system that contributes significantly to add nutrients to the soil. In other words, the longer the no-tillage system is used, the longer the benefits to the agricultural systems, mainly in terms of soil fertility (Bernardi *et al.*, 2003). Grasses like *P. maximum*, *B. ruziziensis*, and *B. brizantha* are normally related to produce high amounts of biomass (Kluthcouski *et al.*, 2000; Moreti *et al.*, 2007; Crusciol *et al.*, 2008; Rosolem *et al.*, 2010; Pacheco *et al.*, 2011; Nascente & Crusciol, 2012) and therefore, will probably contribute significantly to increased soil fertility as was observed in our trial.

Regarding micronutrients, soil under *B. brizantha*, on average, allowed the highest value of iron and differed from other cover crops, however it was similar to the soil under millet (Table 2). In relation to zinc, soil with *B. ruziziensis*, *B. brizantha* in the year 2008 and under *B. brizantha* and millet in the year 2009 provided the highest values. In soil under fallow and millet in 2008 and under *B. brizantha* in 2009 we observed the highest values of manganese. Regarding copper, there was no effect of cover crops or years. It is important to note that there was no fertilization with micronutrients in the area, and there were observed increases in the level of micronutrients in comparison to the initial fertility in 2007 (Table 3). Thus, there is an outstanding advantage of using cover crops in order to increase the contents of soil nutrients, especially for soils of the Cerrado, characterized as being nutritionally poor (Bernardi *et al.*, 2003). According to these authors, there has been an increase in micronutrient deficiencies in the Cerrado, mainly due to the low natural fertility of these soils. Therefore, the introduction of cover crops can increase the contents of these nutrients in the soil and reduce the application of fertilizers, leading to lower costs of production and contributing to the sustainability of the system. Cunha *et al.* (2011), worked with cover crops and reported that they were not able to maintain the same soil contents of Fe^{2+} and Mn^{2+}. In spite of that, in our trial, millet, B. ruziziensis, and P. maximum stood out for the increase in the soil content of Mn^{2+} in both years. *B. ruziziensis* also contributes to increase the soil content of Fe^{3+} (2009); *B. brizantha* provided for an increase in the soil contents of Fe^{3+} and Mn^{2+} (2009); and fallow provided for an increase in the Mn^{2+} (2008). In this sense, Franzluebbers & Hons (1996) also found increases in Zn^{2+}, Mn^{2+}, Fe^{3+}, and Cu^{2+} in soil under cover crops. Fallow did not show that it could maintain soil micronutrient contents in both years.

It is important to notice that although we had differences among some soil attributes, these differences, in the majority of attributes, were low because it was only two years of evaluation. The only exception was potassium, which is expected since this nutrient is very mobile in the soil (Malavolta, 1980). It is likely that if we had more years of evaluations the differences among the average of soil attributes would increase.

CONCLUSIONS

The use of cover crops provided significant increases in the contents of the soil nutrients, soil organic matter, soil cation exchange capacity and soil base saturation. Soil fertility had improved from the first to the second year with growing cover crops;

The cover crops *Pennisetum glaucum*, *Brachiaria ruziziensis* and *B. brizantha* contributed more to increase soil fertility than fallow plots.

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