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Chemical attributes of agricultural soil after the cultivation of cover crops

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Abstract

The use of cover crops is a strategy to maintain the productive capacity of agricultural soils. The increase of organic carbon content, nutrient cycling and, consequently, the increase in soil fertility are some of the greatest benefits. This study evaluated the chemical attributes of the soil after the use of cover crops species in the Cerrado region of Piaui. The experiment was carried out from January 2015 to July 2016. It was performed in a completely randomized block design with eleven treatments and four replicates. The treatments consisted of six species of Fabaceae, two of Poaceae, two-component intercrops and spontaneous vegetation (control). The soil chemical analyses were performed 14 months after the implantation of the cover crop species. The following soil horizons were evaluated: 0.0-0.10; 0.10-0.20 and 0.20-0.40 m. The values of phosphorus (P), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), aluminum (Al^{3+}), potential acidity (H + Al), soil organic carbon (OC), the saturation of bases (V%), saturation by aluminum (m%) and effective CEC were measured. Fifteen months after their establishment, cover crops positively influenced the levels of P, K and OC with no changes in the other chemical properties. The OC contents were higher with the use of *C. cajan* – cv. 'fava larga', brachiaria and *C. ochroleuca* + millet, mainly in the topsoil. *C. espectabilis*, spontaneous vegetation, *M. aterrima*, brachiaria and *C. ochroleuca* were the most efficient in K cycling.

Keywords: nutrient cycling; fertility; Fabaceae; nutrient; Poaceae; soil.

Introduction

The agricultural growth in the Cerrado of the Piaui state is a result of improved soil management, especially fertility, genetic, phytotechnologies and external demand for agricultural products. The soils of this region are acidic with low CEC and low retention of cations (Stefanoski et al., 2016). The CEC depends almost exclusively on organic matter (Six et al., 2002). Therefore, the current challenge is to search for management systems that promote acidity and fertility correction, soil quality and regional sustainable economic and environmental development.

Thus, efforts are mainly focused on (i) increasing the accumulation of cover on the surface to enable no-tillage system (NT); (ii) increasing organic matter content to improve soil structure. There is an increase in the microbiota and water retention in the soil due to the increased organic matter content, especially in periods of water deficit (Carvalho et al. 2011). As consequence, there is also an increase in nutrients cycling by cover crops species aiming at the reuse by subsequent crops.

Crop rotation and the use of cover crops are practices which aim at enabling no-tillage systems, increasing cover and yield crops and improving soil quality with lower environmental impact (Pacheco et al. 2013). The choice of cover plants depends on the potential of phytomass production and on the ability to absorb and accumulate nutrients (Pacheco et al., 2011).

In general, the Poaceae family presents a high C/N ratio and the decomposition rate is slow, increasing the permanence of cover on the soil surface (West and Wali, 2002; Silva et al., 2007; Raiesi and Kabiri, 2016, Vasu et al., 2016). As the amount of nutrients in the cover is not adequate (mainly N) for the decomposition process, there is a greater immobilization of nutrients which reduces the availability of some nutrients for the crops (Mangaravite et al., 2014, Anderson, 2017).

On the other hand, the Fabaceae family plays a fundamental role in nutrients cycling, especially of N. Besides, they present a faster rate of mineralization as a consequence of the low C/N ratio (Mangaravite et al., 2014). This aspect and the presence of some soluble compounds benefit its decomposition, mineralization and cycling of nutrients (Siqueira Neto et al., 2010). There is also the possibility of species consortium which results in a material with intermediate C/N ratio. Teixeira et al. (2010) observed that millet + *Canavalia ensiformis* consortium produced a greater amount of dry matter with low decomposition rate and showed a greater amount of dry matter on the soil surface in the end of the study.

Overseeding brachiaria (*Urochloa ruziziensis*) and millet (*Pennisetum glaucum*) into soybean and brachiaria intercropped with corn were the best options for the phytomass production, accumulation and nutrient release in agricultural systems in the Cerrado of Piaui (Pacheco et al., 2013). Brachiaria is efficient in soil protection and gradual release of nutrients to crops due to the greater accumulation of dry matter and nutrients and the slow decomposition rate (Leite et al., 2010). Similarly, Soratto et al. (2012) verified that millet produced a higher amount of phytomass and accumulation of some nutrients (N, P, K^+, Mg^{2+}, S and Si).

Therefore, it is necessary to use cover crop species to keep or increase the soil fertility in tropical regions, to maintain NT, to increase organic matter content and improve soil quality in the Cerrado. Thus, the study was developed aiming at evaluating the changes in the chemical attributes of the soil after the use of cover crops species.

Results and Discussion

Cover crops and organic matter interaction

There was an interaction between cover crop species and soil horizons only for the total organic carbon in the soil (TOC) (Table 3). A significant effect of the species was observed only for P and K. There was a significant effect in soil horizon for all the chemical attributes.

The amount of DM of the cover crops was higher than 6 mg ha^{-1} $year^{-1}$, except for the *C. espectabilis* + millet consortium, (Fig. 2). The highest amount of DM was obtained using *C. juncea*. Crops remains must cover at least 50% of the soil surface or maintain at least 6 t ha^{-1} of dry matter to achieve a good coverage rate (Alvarenga et al., 2001; Raiesi and Kabiri, 2016; Vasu et al. 2016). In this study, the amount of residues on the soil surface is close to or higher than this value.

The highest TOC values occurred in areas with cover crops, mainly in the 0-0.10 m horizon (Table 4). Among other factors, the increase in TOC is associated with the levels of plant residues on the soil surface. Regarding this, the control presented the lowest TOC content. A higher TOC concentration in the surface horizon is important for the soil quality in no-tillage systems, since different types of stresses related to the application of agrochemicals, fertilizers and rainfall affect this horizon more intensively (Tormena et al., 2004).

Nevertheless, in the 0.10 - 0.20 m horizon, higher values were observed in treatments of *C. espectabilis*, *C. cajan* - cv. 'fava larga', *M. aterrima*, millet and *C. espectabilis* + millet than in the other treatments. In the areas under cover plants, the increase in TOC levels in the areas under cover plants was not observed in deeper horizons (0.20-0.40 m), and this fact can be attributed to the short adoption period of this system and to the high decomposition rates caused by the high temperature and humidity conditions observed in the area of study.

Steiner et al. (2011), studying the influence of management systems and fertilization sources, verified that the rotation management system with cover plants did not modify the TOC content and the soil acidity components. As in the present study, this result was attributed to the short period between the system implantation and the evaluations. However, they concluded that NT systems with cover plants can increase organic carbon, calcium, magnesium and CEC of the soil as it stabilizes over time.

Soil phosphorus availability

Differences among species were observed for P levels in the soil. *C. espectabilis* was the species that contribute the most for P cycling (Table 5). However, the lowest concentrations of P in the soil occurred with brachiaria, C. ochroleuca, and M. aterima. Cardoso et al. (2013) observed that P content increased by 0.6 mg dm-3 in the soil when it was cultivated with *Canavalia ensiformis* and millet, 27 days after the cover crops cut (130 days after sowing), which corresponds to the beginning of phytomass decomposition. The increase in P was attributed to the ability of these plants to absorb P from sub-surface horizons and make it available to the surface. Among other characteristics, the potential of cover crop species to recycle nutrients depends on the potential for phytomass production and on the ability to absorb and accumulate nutrients.

Some crops optimize the increase of phosphate solubilizing microorganisms such as *Cajanus cajan* (Carneiro et al., 2004), favoring their accumulation in the soil. The absorption of P by the plants in deeper layers may result in accumulation of this element on the surface after the decomposition of its residues (Rheinheimer and Anghinoni, 2001), promoting greater difference in the P content available in the 0-0.5 m horizon under no-tillage system (Calegari et al., 2013).

The levels of P available in the soil are ranged from appropriate (15.1 to 20.0 mg dm^{-3}) to high (> 20 mg dm^{-3}) for Cerrado soils (Sousa and Lobato, 2004). Some authors have verified that the effect of cover crops residues on the dynamics of P in NT systems occurs since the implantation, mainly in the 0-0.5 m horizon (West and Wali 2002, Varela et al., 2017). However, the greatest effects are observed in the long term.

Potassium, calcium and magnesium interaction in the soil

When compared to the analysis performed before the implantation of cover crops (Table 1), it was observed an increase in K^+ concentration in the soil for all treatments (Table 5). These results can be explained by the high cycling capacity of this element by the cover plants. Among the species tested, the highest levels of K^+ were verified in the treatment with *C. espectabilis* and the lowest with *C. juncea*. Cardoso et al. (2013) observed that K^+ content ranged from 47 to 76 mg dm^{-3}, with the highest value found in the control and in *Canavalia ensiformis* in the 0.25 m spacing. The other treatments presented a K^+ reduction and crotalaria showed the lowest content of this element, with values of 47 and 51 mg dm^{-3} in the 0.25 and 0.50 m spacing, respectively. This reduction is due to the nutritional requirement of the crop and to the nutrient immobilization in the phytomass. The K^+ recycled by the cover crops can be available to the next crop. For Cerrado soils, the ideal K^+ content is between 51 and 80 mg dm^{-3} (Sousa and Lobato, 2004).

The levels of Ca^{2+} in the soil after the cover crop were lower than those observed before the implantation of the experiment (Table 2). These values are close to the minimum limit of 1.5 $cmol_c$ dm^{-3} for Cerrado soils, as recommended by Sousa and Lobato (2004). It is possible that the levels of Ca^{2+} in the soil were not sufficient to supply the demand of cover plants and to maintain the levels of this element in the soil. Evaluating the effects of cover plants on chemical attributes of a dystrophic Red Latosol with 420 g kg^{-1} of clay in Goiás, there was also a decrease in the Ca^{2+} content over the years (Celik et al., 2012).

However, after the cultivation with cover crops, Mg^{2+} contents were very similar to the initial levels (Table 2), indicating that the amount of Mg^{2+} was enough to supply the plants and to maintain the nutrient levels in the soil. The minimum limit of Mg^{2+} is 0.5 $cmol_c$ dm^{-3}. Therefore, the

Table 1. Soil management history of the experimental area.

Uses	Management history
Native vegetation 1990	Area converted into an agricultural system in 1990, which was deforested and cultivated with cashew cultivation in a conventional tillage system with intensive soil rotation until 2010.
Pasture 2010	In 2010, cashew crop was removed and the area was revolved through plowing and leveling grid (conventional tillage system - CTS) with subsequent sowing of *Urochloa brizantha*. The area remained with this species until 2013.
Soybean cultivation 2013	Soybean monoculture since the end of 2013. Approximately 90 days before soybean sowing (Paragominas RR cultivar) in a conventional system, 2000 kg ha^{-1} of dolomitic limestone was incorporated into the soil. In the sowing, 173.4 kg ha^{-1} of K_2O (KCl), 50 kg ha^{-1} P_2O_5 (SFS), 22.5 kg ha^{-1} sulfur (Sulfogran 90®) and 0.45 kg ha^{-1} boron (Borogran®) were used.
No-tillage system (NT) 2015	NTS was implemented in 2015 with different cover plants for straw formation. In 2016, crops were introduced into the area in rotation systems (corn and soybean).

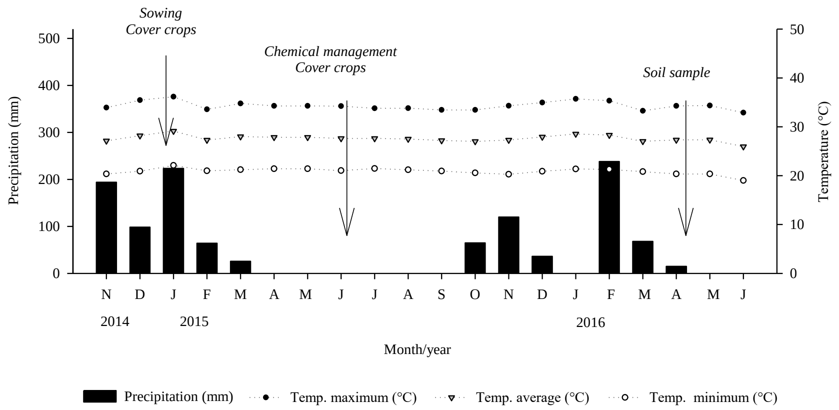

Fig 1. Precipitation and monthly temperature over the course of the experiment in the Brazilian Cerrado in the State of Piauí.

Table 2. Chemical and textural characterization of Oxisols before the implementation of the experiment in crop year 2014/15 in the Brazilian Cerrado of Piauí.

Depth	pH	P	K	OM	Ca	Mg	Al	CEC	V	Sand	Silt	Clay
(m)	H_2O	-- mg dm^{-3}--		g dm^{-3}	--- $cmol_c$ dm^{-3}---				%	---- g kg^{-1}---		
0.00 – 0.10	6.1	30.1	37.2	34.0	2.0	1.8	0.2	5.1	47	690	66	244
0.10 – 0.20	5.9	21.4	30.4	34.0	1.9	1.5	0.3	4.6	46	656	77	267
0.20 – 0.40	5.4	10.5	22.1	33.7	0.8	0.2	0.5	3.5	29	-	-	-

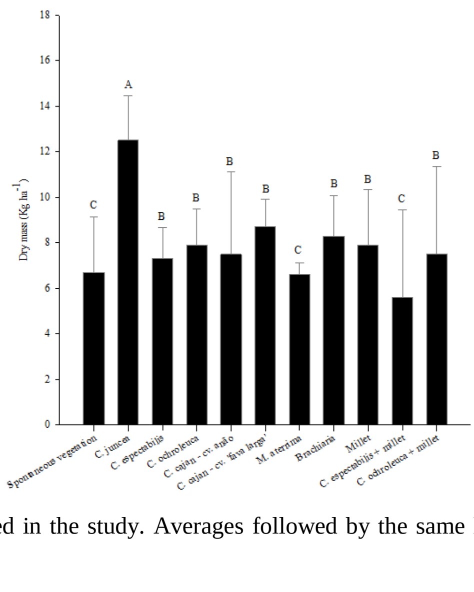

Fig 2. Dry mass of the cover crops used in the study. Averages followed by the same letter do not differ from each other, by the Scott-Knott test (P <0.05).

Table 3. Analysis of variance for soil chemical attributes evaluated.

FV	pH	TOC	P	K^{+}	Ca^{2+}	Mg^{2+}	Al^{3+}	Al +H	CEC	V	m
Block	0.005*	0.15^{ns}	0.63^{ns}	0.25^{ns}	0.10^{ns}	0.02*	0.46^{ns}	0.63^{ns}	0.42^{ns}	0.29^{ns}	0.13^{ns}
Treatment (T)	0.93^{ns}	<0.001*	0.0001*	0.0007*	0.45^{ns}	0.58^{ns}	0.73^{ns}	0.73^{ns}	0.22^{ns}	0.98^{ns}	0.76^{ns}
Layer(L)	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*	<0.001*
T*L	0.95^{ns}	0.01*	0.89^{ns}	0.93^{ns}	0.32^{ns}	0.95^{ns}	0.92^{ns}	0.84^{ns}	0.99^{ns}	0.88^{ns}	0.93^{ns}
CV(%)	7.6	6.9	55.2	26.9	34.4	35.7	103.5	28	13.5	28.4	108.3
MG	5.6	19.2	28	63.3	1.5	0.9	0.1	2.6	5.3	47.8	9.6

* Significant at the 5% probability level; ^{ns} not significant. FV: source of variation; Treatment (T): Effect of cover species; Layer (L): layer of soil evaluated; TOC: soil organic carbon; P: phosphorus; K^{+}: potassium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Al^{3+}: aluminum content; Al+H: potential acidity; CEC: cation exchange capacity; V: base saturation; m: aluminum saturation; CV: coefficient of variation; MG: general average.

Table 4. Total organic carbon (TOC) levels after the use of cover crops in the evaluated layers.

Cover crops	TCO		
	0-0.10 m	0.10-0.20 m	0.20-0.40 m
		g kg $^{-1}$	
Spontaneous vegetation	20.9 Aa	18.9 Bb	16.0Bc
C. juncea	20.6 Aa	19.7Ba	17.0Bb
C. espectabilis	21.9 Aa	21.2Aa	16.5Bb
C. ochroleuca	21.2 Aa	19.9Ba	20.2Aa
C. cajan – cv. anão	21.0 Aa	18.1Bb	15.4Bc
C. cajan – cv. 'fava larga'	23.0 Aa	20.9Aa	17.0Bc
M. aterrima	21.7 Aa	21.0Aa	16.6Bb
Brachiaria	22.1 Aa	19.3Bb	16.3Bc
Millet	21.7 Aa	20.6Aa	16.4Bb
C. espectabilis + millet	21.0 Aa	21.5Aa	17.3Bb
C. ochroleuca + millet	22.2 Aa	19.3Bb	16.4Bc

Upper case letters compare species at the same depth and lower case letters compare depths for the same species by the Scott-Knott test (p<0.05).

levels observed in the treatments of the present study are considered high (Sousa and Lobato 2004).

Other soil chemical properties

The soil pH did not differ among species due to the acidity correction performed before the experiment (Table 5). The values observed for soil pH are appropriate for a good crop development (Sousa and Lobato, 2004).

There was a reduction in pH values after the implantation of cover species. This modification in the soil pH with vegetal residues is due to organic acids with carboxyl and hydroxyl phenolic groups, which have an important role in the acidity buffering and pH variation in acid soils (Costa et al., 2011). Different results were reported in other studies in which the soil pH was not modified by crotalaria, *Canavalia ensiformis* and millet (Almeida et al., 2008; Cardoso et al, 2013). Other studies show that the addition of organic residues may increase soil pH values (Silva et al., 2007; Silva et al., 2008; Celik et al., 2012).

The Al^{3+} levels were similar among the treatments (Table 5) probably due to the short implantation period. In general, no-tillage system can reduce Al^{3+} content and reduce Al^{3+} toxicity by adding dissolved organic carbon to the soil (Spera et al., 2014). Long-term studies show that the decomposition of plant residues contributes to the neutralization of H^{+} ions and organic complexation of Al $^{3+}$, increasing soil pH (Miyazawa et al., 1993; Bressan et al., 2013).

The low CEC values are due to the low amount of clay (240 g kg^{-1}) and the low levels of organic carbon. Even if there is an increase in TOC with the use of cover plants, the values are still considered low to promote changes in CEC. Thus, the continuous use of cover crops in the increase of organic matter is important since CEC is almost exclusively dependent on organic matter in highly weathered soils (Six et al., 2002).

After cover crops, soil base saturation (V%) ranged from 43 to 50%, characterizing as a dystrophic soil and, consequently, presenting medium to low CEC (Sousa and Lobato, 2004). The Al saturation (m%) ranged from 5.8 to 13% (Table 3). These values are considered low according to Souza and Lobato (2004).

The most efficient way to increase the input of these residues in agricultural systems is to introduce cover plants into the rotation system. It is important to emphasize the importance and necessity of the continuous use of cover plants because the amount of residues in the soil surface is a way to maintain the efficiency in NTS and the stabilization of the system is only obtained with time. After 15 months of

Table 5. Chemical attributes of a typic Dystrophic Yellow Latosol in different layers after the use of cover crops species in the municipality of Baixa Grande do Ribeiro - PI, 2016.

Cover crops	pH	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H + Al	CEC	V	m
		-----mg dm^{-3}----		----------------$cmol_c$ dm^{-3}-------------					%	
Spontaneous vegetation	5.7 ns	25.12 a	77.00 a	1.38 ns	0.84 ns	0.08 ns	2.67 ns	5.07 ns	47 ns	6 ns
C. juncea	5.5	39.35 a	56.56 b	1.55	0.85	0.13	2.53	5.07	48	8
C. espectabilis	5.7	44.67 a	78.09 a	1.85	1.11	0.15	2.59	5.73	52	10
C. ochroleuca	5.5	19.13 b	70.54 a	1.56	0.91	0.14	3.08	5.70	43	11
C. cajan – cv. anão	5.6	31.48 a	59.38 b	1.43	0.83	0.16	2.63	5.04	45	11
C. cajan – cv. 'fava larga'	5.6	26.71a	63.10 b	1.54	0.95	0.15	2.67	5.29	49	11
M. aterrima	5.6	41.67 b	75.72 a	1.50	0.94	0.15	2.77	5.38	46	11
Brachiaria	5.7	19.33 b	72.02 a	1.58	0.97	0.09	2.37	5.10	51	7
Millet	5.6	30.63 a	61.37 b	1.58	0.98	0.16	2.58	5.28	48	13
C. espectabilis + millet	5.7	32.88 a	63.78 b	1.73	0.99	0.10	2.4	5.24	51	8
C. ochroleuca + millet	5.5	26.63 a	59.44 b	1.67	1.07	0.10	2.66	5.53	49	6
Layer (m)										
0.00-0.10	5.9 a	36.44 a	79.89 a	2.31 a	1.35 a	0.01 c	2.12 c	6.02 a	65 a	0.3 b
0.10-0.20	5.7 b	23.23 b	70.30 b	1.68 b	0.99 b	0.08 b	2.71 b	5.60 b	51 b	4 b
0.20-0.40	5.1 c	21.78 b	45.86 c	0.64 c	0.30 c	0.30 a	3.00 a	4.24 c	27 c	24 a

pH in H_2O; phosphorus (P). potassium (K^+). calcium (Ca^{2+}) and magnesium (Mg^{2+}). aluminum (Al^{3+}). potential acidity (H+Al). cation exchange capacity (CEC effective). base saturation (V). aluminum saturation (m) . in the layers of 0.0-0.10. 0.10-0.20 e 0.20-0.40 m of depth. Mean followed by the same letter. lowercase in the column for each attribute and depth. do not differ from each other by the Scott-Knott test at 5% probability.

implantation, it was verified an improvement in the chemical quality of the soil, mainly in the superficial horizon. However, further study time is necessary to obtain increase and stability in TOC contents.

Materials and Methods

Study area

The experiment was performed at Fazenda Tropical, in the municipality of Baixa Grande do Ribeiro, PI, at 08°42'54.2" S and 45°01'41.4" W and 495 m of altitude. The climate of the region is hot and humid (Cwa) with annual average temperature of 26.6 ºC and annual average rainfall of 1,100 mm $year^{-1}$. February, March and April are the rainiest months and from July to November, the driest ones (Alvares et al., 2013). The soil is classified according to the Brazilian Soil Classification System as Dystrophic Yellow Latosol (similar to the Oxisol group in the U.S. Taxonomy) with medium texture, deep and well drained, in flat relief, cultivated with soybean.

Cerrado was the original cover crop of the area, with phytophysiognomy of Cerradão type (forest vegetation). The history of land use in the experimental area and the land use with the respective dates of implementation are shown in Table 1.

Experimental design

The experiment was implemented in January 2015. Before its installation, soil samples were collected in the 0.0-0.10, 0.10-0.20 and 0.20-0.40 m horizons for the determination of chemical composition and soil granulometry (Table 2).

The daily temperature and rainfall monitoring were performed with a pluviometer installed in the experimental area (Fig. 1).

The experiment was performed in a complete randomized block design, with four replicates, in plots of 12 m x 12.5 m. The treatments were composed of cover plants, with Fabaceae: *Crotalaria juncea* L. (*C. juncea*), *Crotalaria spectabilis* (*C. espectabilis*), *Crotalaria ochroleuca* (*C. ochroleuca*), *Cajanus cajan* (*C. cajan* - cv. anão), *Cajanus cajan* (*C. cajan* - cv. 'fava larga'), *Mucuna aterrima* (*M. aterrima*) and poaceae: *Braquiaria ruziziensis* (brachiaria) and *Pennisetum glaucum* (millet) and intercropping: 1) millet + *C. espectabilis* and 2) millet + *C. ochroleuca*, and the control composed of spontaneous vegetation (with predominance of the following species: *Borreria verticillata, Commelina nudiflora, Cenchrus echinatus, Eleusine indica* and *Senna obtusifolia*).

Cover crop treatments

The seeding of the cover crops species was carried out in early January 2015, with seed incorporation and leveling grid action. The quantities of seeds were: brachiaria: 3.5 kg ha^{-1}; *C. juncea*: 30 kg ha^{-1}; *C. espectabilis*: 15 kg ha^{-1}; *C. cajan* – cv. anão: 45 kg ha^{-1}; millet: 35 kg ha^{-1}; M. aterrima: 60 kg ha^{-1}; *C. cajan* – cv. fava larga: 60 kg ha^{-1}; *C. ochroleuca*: 10 kg ha^{-1}; intercrops *C. espectabilis* + millet: 9.0 + 5.0 kg ha^{-1} and millet + *C. ochroleuca*: 4 + 8 kg ha^{-1}.

To facilitate the sowing of the succession crop and to avoid the formation of a seed bank, all the plants were desiccated at 183 days after sowing (DAS) using two commercial formulations based on potassium glyphosate at 2.0 L ha^{-1}. Then, herbicide based on flumioxazin® was applied at a dose of 0.1 L ha^{-1}.

Before desiccation, the shoot part of cover plants was sampled to determine dry mass (DM). Biomass was cut to the ground, 0.5 m^2 in each plot, then dried in oven at 65°C until reaching a constant mass.

The sowing of the early-cycle Monsoy 8644 soybean was carried out on January 23rd, 2016, with precision pneumatic seed drills for NTS (John Deere model 2130) with seven rows spaced at 0.45 m, with a population of 289 thousand plants ha^{-1}, which corresponds to 13 plants per linear meter. Soybean crops were not fertilized at planting.

The soil sampling was performed 15 months after the sowing of cover species, with soybean cultivation at the beginning of pod formation (R3). The following soil horizons were sampled: 0.0-0.10; 0.10-0.20 and 0.20-0.40 m, with three simple samples to form one compost per plot. Samples were air dried, then sieved in a 2 mm sieve. The soil pH in water, macronutrients (Ca^{2+}, Mg^{2+}, P e K^+), fertilization parameters (Al^{3+}, H+Al, SB, T, V, CEC, m) and total soil organic carbon were determined according to methodology described by Silva et al. (2009).

The results of the studied variables were submitted to the normality test and analysis of variance by the F test. When significant, the means were compared by the Scott-Knott test ($p < 0.05$), using the statistical program SISVAR® version 5.6 (Ferreira, 2011).

Conclusion

There was an increase in the concentrations of phosphorus, potassium, and total organic carbon in the soil fifteen months after the use of cover crops. There were no changes in the concentrations of the other chemical attributes.

The highest levels of organic carbon occurred under cultivation of *C. cajan* – cv. 'Fava larga', brachiaria and *C. ochroleuca* + millet consortium, mainly in the 0.00-0.10 m horizon. The potassium concentration has undergone more changes due to the use of cover crops. *C. espectabilis*, the spontaneous vegetation, *M. aterrima*, brachiaria and *C. ochroleuca* were the most efficient in cycling this element.

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