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Chemical attributes and microbial activity of soil cultivated with cassava under different cover crops

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ABSTRACT: Conservationist systems of crop management increases the amount of substrate, alters fertility and increases soil biological activity. The objective of this study was to evaluate the influence of soil management systems on the chemical attributes and microbial activity of soil under cassava crop. The experiment was set as completely randomized design in a factorial scheme of 2 x 3 x 2, being two systems of cultivation (minimum with only mown; minimum with mown and incorporation), three types of soil coverage (fallow; *Crotalaria juncea* L.; *Canavalia ensiformis* L.) and two soil depths (0-0.10 and 0.10-0.20 m), with four repetitions. The production of dry mass from cover crops, the soil chemical attributes and the soil microbial activity were evaluated. There were no differences between management systems, and the *C. juncea* cover crop presented superior dry mass production among the soil coverages. The concentrations of soil Ca and K were greater in the fallow coverage and *C. juncea* areas in the 0-0.10 m soil layer; however, these nutrients differ in the soil layer below (0.10-0.20 m). There were no differences for the basal respiration of soil microorganisms in both soil depths or among soil coverage, but the carbon from microbial biomass was superior in the most superficial soil layer where more substrate is available to soil microorganisms.

Key words: *Crotalaria juncea*, *Canavalia ensiformis*, *Manihot esculenta*, soil microbial biomass, plant residues

Atributos químicos e atividade microbiana do solo cultivado com mandioca sob diferentes coberturas vegetais

RESUMO: O aporte de resíduos vegetais no solo proporcionado pelos sistemas conservacionistas de manejo aumenta a quantidade de substrato, altera a fertilidade e aumenta a atividade biológica do solo. O objetivo deste estudo foi avaliar a influencia dos sistemas de manejo nos atributos químicos e na atividade microbiana do solo sob cultivo de mandioca. Com delineamento inteiramente casualizado, em esquema fatorial 2 x 3 x 2, foram avaliados dois sistemas de cultivo mínimo (somente roçado; roçado e incorporado), três tipos de cobertura (pousio; *Crotalaria juncea* L.; *Canavalia ensiformis* L.) e duas profundidades (0-0,10 e 0,10-0,20 m), com quatro repetições. Foram avaliados a produção de massa seca das coberturas, os atributos químicos e a atividade microbiana do solo. Não houve diferenças entre sistemas de cultivo mínimo e a *C. juncea* apresentou a maior produção de massa seca. Os teores de potássio e cálcio foram superiores nas áreas com resíduos de pousio e *C. juncea* na camada de 0-0,10 m; no entanto, estes nutrientes diferem na camada do solo abaixo 0,10-0,20 m. Não houve diferenças entre a respiração basal de microorganismo do solo em ambas as profundidades e coberturas, mas o carbono da biomassa microbiana foi superior na camada mais superficial, onde há mais substrato disponível para os microorganismos do solo.

Palavras-chave: *Crotalaria juncea*, *Canavalia ensiformis*, *Manihot esculenta*, biomassa microbiana do solo, resíduos vegetais

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Introduction

Cassava (*Manihot esculenta* Crantz) has been cultivated in all Brazilian regions, especially where the Cerrado biome (Savannah-like biome) predominates, since cassava is resistant to drought and produces well on low fertility acid soils. This cultivation is mainly done in a conventional way (stem seedling planting in furrows), however, this practice has intensified soil degradation, mineralization of organic matter (OM), soil compaction and low crop productivity along the years of cultivation (Fasinmirim & Reichert, 2011).

To alleviate the losses caused by tillage, the no-tillage system (NTS) and the minimum tillage (MT) are proposed as alternatives of conservationist management systems (Pequeno et al., 2007); however, Devide et al. (2017) underlined that NTS in the cassava cultivation has been questioned, since there is soil moving during the harvest, indicating that MT is more appropriated for cassava production.

For Otsubo et al. (2012), the association of MT and the green manure from crop residues offers more favorable conditions for cassava root growth and crop development, and maintain or increase the content of soil organic matter (SOM) improving soil fertility (Teixeira et al., 2012; Pacheco et al., 2017). According to García-Orenes et al. (2010), the addition of OM alters the physical, chemical and biological attributes of the soil and has been used as an indicator of soil quality, since it is sensitive to changes caused by the management system adopted (Lima et al., 2013).

The contribution of plant residues to soil dynamics is largely related to the essential substrate role responsible to maintain the diversity and increment the soil biological activity (Araújo Neto et al., 2014). This soil microbiological dynamics can be measured through the release of CO_2, which is the main indicator of the biological activity (Hungria et al., 2009).

After the implantation of a conservationist system soil management, a new condition of balance begins to be established due to changes in the chemical attributes and in the biological community (Alves et al., 2011), which need to be monitored, to establish a more reliable link between the soil uses and the sustainability of crop production. In this context, the objective of this study was to evaluate the influence of soil management systems on soil chemical and microbial activity after cover crop cultivation in a cassava plantation area.

Material and Methods

The experiment was conducted in Teresina, Piauí State, Brazil, at the geographical coordinates of 3° 5' S and 41° 46' W, with an altitude of 46.8 m, in the period between April 2014 and May 2015, in an experimental area of approximately 200 m^2. The climate of the region is characterized as dry subhumid, classified as C1dA'a', with annual mean temperature, precipitation and relative humidity of 27.9 °C, 1,003.5 mm and 75.5%, respectively.

The soil is classified as Oxisol, medium texture (Santos et al., 2013). The initial soil conditions of the experimental area in the topsoil (0-0.20 m) was: pH_{CaCl_2} 5.5; 76 mg dm^{-3} of P (resin); 2 $mmol_c$ dm^{-3} of K^+; 22 $mmol_c$ dm^{-3} of Ca^{2+}; 10 $mmol_c$ dm^{-3} of Mg^{2+}; 17 $mmol_c$ dm^{-3} of $H^+ + Al^{3+}$ and 19 g dm^{-3} of soil organic matter.

The experimental design was set as completely randomized, arranged in a factorial scheme of 2 x 3 x 2, being two systems of cultivation - minimum with only mown and minimum with mown and incorporation; three types of soil coverage - fallow, *Crotalaria juncea* L. and *Canavalia ensiformis* L.; and two soil depths (0-0.10 and 0.10-0.20 m), with four repetitions, totaling 24 experimental plots (n = 24) of 8 m^2 each.

The cover crops studied were used as green manure, and no fertilization was done at planting or topdressing in their cultivation after cassava harvest. The spontaneous vegetation (fallow) developed in experimental area was mainly composed by Poaceae species, from the existing seed bank in the soil or from natural dissemination.

The cover crops were cultivated in the period from April to July 2014, and when more than 50% of these plants had reached the maximum flowering, samples were taken in the central 1 m^2 of each plot, for evaluation of fresh mass. The dry mass was assessed after the samples dried in a forced air circulation oven at 65 °C for 72 h.

Soil samples were collected at 0-0.10 and 0.10-0.20 m depths for chemical analysis. Samples were taken inside the area surrounded by a metal template with 0.25 x 0.25 m. In part of each sample, the chemical analyses were performed to determine the levels of Al^{3+}, Ca^{2+} and Mg^{2+}, the potential acidity ($H^+ + Al^{3+}$), available P and exchangeable K^+, using the methodology proposed by Teixeira et al. (2017). The total organic carbon (TOC) was quantified by the oxidation of organic matter (Yeomans & Bremner, 1988), while the carbon of microbial biomass was determined by the method of irradiation/extraction in a microwave oven (Islam & Weil, 1998), with K_2SO_4 0.5 mol L^{-1} as the extractant.

Soil microbial biomass, as described by Anderson & Ingram (1993), was determined in the other part of the samples. Soil basal respiration was estimated according to the methodology proposed by Jenkinson & Powlson (1976), following Eq. 1.

$$SBR = \frac{\left[\left(V_b - V_a\right) M \ 6 \ 1000\right]}{\left(MDS \ T\right)} \tag{1}$$

where:

SBR - soil basal respiration (mg of CO_2 kg^{-1} soil h^{-1});
Vb - volume of hydrochloric acid in the titration solution of the control (mL);
Va - volume spent in the titration solution of the sample (mL);
M - molarity of hydrochloric acid;
MDS - mass of dry soil (g); and,
T - time of incubation of the sample.

The results were submitted to analysis of variance (F test), and the means of treatments were compared by the Tukey test at 0.05 probability using the software Statistical Analysis Systems (SAS) 9.0.

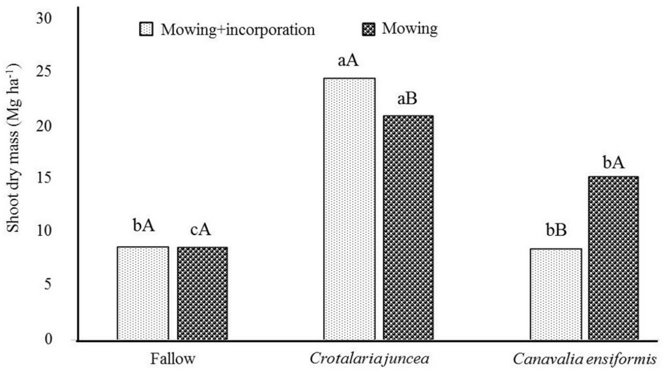
Results and Discussion

The shoot dry mass (DM) production of the soil coverages demonstrated that *C. juncea* presented the best performance in both systems, mowing and incorporation (24.5 Mg ha^{-1}) and only mowing activity (20.7 Mg ha^{-1}), being superior to the *C. ensiformis* DM (8.5 and 14.7 Mg ha^{-1}) and the fallow DM (8.7 and 8.5 Mg ha^{-1}) (Figure 1), highlighting the adequate growing of *C. juncea* under the edaphoclimatic conditions of the Brazilian Cerrado biome.

Some studies show that among the Fabaceae species, *C. juncea* is one of the cover crop that produce great dry biomass in quantity and quality, because presents greater fixation, accumulation and cycling of nitrogen, among other nutrients that are available in the soil after being managed (Pacheco et al., 2017).

The production of DM by the soil coverages studied are above the averages observed in other studies also conducted in the Brazilian Cerrado biome, ranging from 7 to 12 Mg ha^{-1} for *C. juncea* (Torres et al., 2017), 3.8 to 7.2 Mg ha^{-1} for *C. ensiformis* (Padovan et al., 2011; Torres et al., 2014) and from 2 to 7.2 Mg ha^{-1} for the fallow area (Crusciol & Soratto, 2009). The great biomass production observed in this study is probably due to the adequate water availability and temperature that occurred in the region during the study period.

In conservationist management systems, such as the no-tillage (NTS) and the minimum tillage (MT), the amount of plant residues deposited on soil surface over the years provides gradual increase in organic matter content in the 0 to 0.10 m soil layer, however, this increase is detectable only after six or seven years after the implantation of the system (Hickmann et al., 2012).



Means followed by the same lowercase letter (among soil coverages in the same management system) and uppercase letters (between management systems in the same soil coverage) do not differ by Tukey's test at $p \leq 0.05$

Figure 1. Shoot dry mass of soil coverages (Fallow, *Crotalaria juncea*, *Canavalia ensiformis*) in management systems (mowing+incorporation, mowing)

The soil chemical attributes were similar between management systems, differing among soil coverages in the 0-0.10 m soil layer, for pH, Ca and K, while the same did not occur in the 0.10-0.20 m soil layer. Significant differences occurred between pH, K, Ca and H+Al when compared between soil depths and covers evaluated (Table 1).

The greater contents of Ca and K in the superficial soil layer (0-0.10 m) can be justified by higher concentrations of these elements in the plant residues deposited on this layer. Meurer (2006) highlighted that K is one of the most required nutrients by the crop, therefore one of the most abundant in their tissues.

According to Vitti et al. (2006) the soil Ca is an essential nutrient in the formation and integrity of membranes and cell wall, and very important in the development of the roots; also, the authors highlighted the low Ca mobility in plant and high mobility in soil. The Ca concentration in the soil of this study was higher in soil pHs ranging between 5.75 and 5.99.

The mobility of nutrients is increased when plant residues deposited on soil surface are fragmented or incorporated, accelerating the process of organic matter decomposition, mineralization and nutrient cycling (Teixeira et al., 2012); however, this was not observed in this study, since there were no significant differences between the mowing area and the mowing + incorporation area, perhaps because the incorporation of plant residue has been done manually and superficially.

The soil pH in both depths presented similar values, with the exception of the area covered with *C. juncea*, which was low in the 0.10 to 0.20 m soil depth, however, the pH values remained within the soil pH range considered ideal for most crop cultivation. Since there was no mineral fertilizer or lime application in this study, the low soil pH may occur due to the higher extraction of nutrients (soil bases) from soil under *C. juncea*, which also produced a superior quantity of dry mass (Figure 1).

Leite et al. (2010) observed in no-tillage systems superior values of soil pH, ranging from 5.54 to 6.09 in the 0-0.05 and 0.05-0.10 m soil layers for different cover crops, respectively. The authors attributed these results to the greater accumulation of exchangeable bases on the soil surface due to liming and the application of fertilizers. Pedrotti et al. (2015) observed soil pH superior (6.73) in the 0 to 0.05 m soil layer in the conventional system (tillage system) when compared to the minimum tillage system (pH 6.23). The authors attributed these results to the high soil organic carbon concentration of the experimental

Table 1. Soil chemical attributes in areas under different soil coverages and soil depths in cassava plantation area

Soil coverage	pH_{CaCl_2}	P (mg dm^{-3})	K^+	Ca^{2+}	Mg^{2+}	$H^+ + Al^{3+}$
			(cmol$_c$ dm^{-3})			
0-0.10 m						
Fallow	5.75 bA	1.20 aA	1.30 bA	4.10 aA	1.10 aA	3.66 aA
C. juncea	5.99 aA	1.24 aA	1.69 aA	3.84 aA	0.89 aA	3.69 aA
C. ensiformis	5.96 aA	1.13 aA	1.25 bA	3.32 bA	0.72 aA	3.36 aB
0.10-0.20 m						
Fallow	5.85 aA	1.03 aA	0.90 aB	2.72 aB	0.95 aA	3.69 aA
C. juncea	5.76 aB	1.26 aA	1.07 aB	2.77 aB	0.97 aA	3.49 aA
C. ensiformis	5.85 aA	1.11 aA	0.97 aA	3.24 aA	1.06 aA	3.92 aA
CV (%)	3.77	19.55	31.18	20.96	51.33	14.05

Means followed by the same letter do not differ by Tukey's test at $p \leq 0.05$, lowercase letters in column compare soil coverages at the same soil depth and uppercase letters in column compare soil depth at the same soil coverage; CV - Coefficient of variation area, which contributed to increase the sources of potential acidity of the soil in the superficial soil layer, reducing the pH in the system of minimum tillage.

The higher values of Ca and K found in the fallow areas and where *C. juncea* was cultivated, in the superficial soil layer, are justified by the great concentration of these elements in the plant residues and by the great soil mobility of these nutrients, as highlighted by Meurer (2006) and Vitti et al. (2006).

The shoot dry mass production, decomposition, accumulation and cycling of nutrients in fallow areas and areas cultivated with *C. juncea* or *C. ensiformis*, demonstrated that the largest accumulation and nutrient cycling occurred as follow: K > N > Ca > Mg > P > S (Padovan et al., 2011; Torres et al., 2014; Pacheco et al., 2017), which differs with the results observed in this study for K and Ca in the superficial soil layer, even with only one crop cycle studied. In a similar study, Favarato et al. (2015) observed that the conventional system of cultivation provided lower sum of bases due to the low content of K, Ca and Mg in the soil layer, in comparison to the no-tillage system that favors the organic matter accumulation and nutrient cycling.

Regarding the soil organic matter, no differences were observed between the management systems ($p \leq 0.05$), however, the content of OM in the area cultivated with *C. juncea* was significantly higher ($p \leq 0.05$) in 0-0.10 m soil layer when compared to the other soil coverages, which is justified by the great dry biomass production (Figure 1). However, in the 0.10 to 0.20 m soil layer the means of the soil coverages did not differ (Table 2).

The content of OM was greater in the 0.10-0.20 m soil layer than in the superficial layer (0-0.10 m), in all the soil coverages, demonstrating that plant residues accumulated on soil surface is still not influencing the contents of OM on the subsurface layer (0.10-0.20 m), and that the values found are from the OM that already existed plus the remnants of the root systems of the cultivated plants. These variations observed in the OM content prove that it is a sensitive indicator of changes, which can be used to evaluate different soil management systems (Rosa et al., 2011).

The evaluation of different soil management systems in an area of conventional cultivation of bean, pasture or in a forest (native) demonstrated that the area cultivated with bean resulted in low levels of OM (Pereira & Thomaz, 2015). This result was probably a consequence of the continuous soil revolving caused by conventional tillage, which contributes to the mineralization of the OM.

Table 2. Biological attributes in areas under soil coverages and soil depths in cassava plantation area

Soil coverage	OM ($t\ ha^{-1}$)	SBR ($mg\ C\text{-}CO_2\ kg^{-1}\ soil\ h^{-1}$)	CMBNI	CMBI
			($mg\ g^{-1}\ CO_2$ of soil)	
		0-0.10 m		
Fallow	16.80 Bb	15.70 Aa	25.90 Aa	25.90 Aa
C. juncea	23.26 Ba	15.99 Aa	26.11 Aa	26.11 Aa
C. ensiformis	18.56 Bb	16.30 Aa	25.80 Aa	25.80 Aa
CV%	12.17	5.81	2.67	5.45
		0.10-0.20 m		
Fallow	27.27 Aa	15.69 Aa	15.56 Ba	26.70 Aa
C. juncea	26.26 Aa	16.15 Aa	16.15 Ba	25.56 Aa
C. ensiformis	26.37 Aa	15.60 Aa	15.60 Ba	25.60 Aa
CV%	8.19	4.62	2.67	4.41

Means followed by the same letter do not differ by Tukey's test ($p \leq 0.05$), lowercase letters in column compare soil coverages at the same soil depth and uppercase letters in column compare soil depth for the same soil coverage. SBR - Soil basal respiration; CMBNI - Carbon from microbial biomass not irradiated; CMBI - Carbon from microbial biomass irradiated; OM - Soil organic matter; CV - Coefficient of variation

The biological attributes observed [soil basal respiration (SBR), carbon from microbial biomass not irradiated (CMBNI) and carbon from microbial biomass irradiated (CMBI)] were similar among the soil coverages at the same soil depth, however, when comparing between soil depths, the value of carbon from microbial biomass not irradiated was significantly superior in the most superficial soil layer (0-0.10 m) (Table 2).

The soil basal respiration (SBR) reflects the microbiological activity in soil, which is assessed through the quantification of CO_2 released from microbial metabolism, without differences between soil coverages for this variable in this study, that can be justified by the recent introduction of cover crops in the area, indicating that the soil is still establishing to a new condition of equilibrium in its microbiological community; when the systems become more stable, the soil basal respiration tends to decrease (Alves et al., 2011). When certain microbial biomass (MB) becomes more efficient, less carbon is lost as CO_2 by SBR, with a significant fraction of the carbon incorporated by the MB (Insam & Domsch, 1988).

The CMBNI increase observed in the superficial soil layer (0-0.10 m) in all the soil coverages is associated with the plant residue deposition on soil surface, however, even with the great production of the *C. juncea* cover crop there were no significant differences for SBR, CMBNI and CMBI among the soil coverages evaluated, indicating that the biomass produced by the soil coverages were sufficient to increase the biological activity in the same proportion.

According to Hungria et al. (2009), the inflow of OM in the soil, even in smaller quantities than those observed in this study are sufficient to provide a source of energy required for microbial growth. Araújo Neto et al. (2014) highlight that land covered with spontaneous vegetation (fallow) presented higher microbial biomass when compared to cultivated areas with a single plant species because great plant diversity provides great regularity of plant residues deposition, even in stressful conditions of temperature and humidity as those found in Cerrado.

According to García-Orenes et al. (2010), the soil basal respiration and carbon from microbial biomass in areas of conventional cultivation are lower than in areas under no-tillage and minimum tillage; this condition was justified by the low intake of OM and the application of agrochemicals that negatively affects the soil microbial community.

Conclusions

1. No differences were observed between management systems (minimum with only mown, minimum with mown and incorporation for fallow management system), with the greatest shoot dry mass observed in the area cultivated with *Crotalaria juncea*.

2. The concentrations of Ca and K are superior in the fallow area and area cultivated with *Crotalaria juncea*, at the 0-0.10 m soil layer.

3. The soil organic matter content was superior in the area cultivated with *Crotalaria juncea*, at 0-0.10 m. Between the soil layers, the soil organic matter concentration was greater in the 0.10-0.20 m soil layer.

4. No differences were observed between soil basal respiration in both soil depths and all soil coverages. The carbon from microbial biomass not irradiated is high in the most superficial layer.

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