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Absorption of nutrients and chemical reconditioning of red latosol by cover plants cultivated in Amazon environment

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Abstract

Maintaining the balance of the system using cover crops is a promising alternative for the Amazon region. In this context, the present study aimed to evaluate the absorption of nutrients by cover crops and the reconditioning of soil chemical attributes after management with different cover crops. The experiment was conducted in the experimental area of the Federal Institute of Education, Science and Technology of Rondonia, Colorado do Oeste Campus, in the municipality of Colorado do Oeste, RO, Brazil. The experimental design used was completely randomized, arranged in a 7x4 factorial scheme, consisting of seven species of cover crops (*Crotalaria spectabilis*, *Crotalaria breviflora*, *Crotalaria ochroleuca*, *Mucuna aterrima*, *Mucuna pruriens*, *Dolichos lablab* and *Canavalia ensiformis*) and four sampling depths (0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm), with four replicates. The results concluded that the cultivation of *Crotalaria spectabilis*, *Crotalaria ochroleuca* and *Crotalaria breviflora* provided higher dry matter yield. The species *Dolichos lablab* stood out in the accumulation of nitrogen, phosphorus, calcium and sulfur in the leaves at full flowering. The contents of organic matter, total carbon, C/N ratio, N-total, P, K, Ca^{2+} and Mg^{2+} of the soil were higher at the depth of 0-10 cm with a decrease in subsurface layers. The species *Dolichos lablab* and *Mucuna pruriens* are efficient in terms of supplying organic matter, organic carbon, C/N ratio, N-total, phosphorus, calcium and Ca/Mg ratio of the soil, promoting a direct impact on the fertility of its surface layers up to 10 cm deep. Cultivation of *Crotalaria breviflora* and *Crotalaria spectabilis* caused variation in soil exchangeable bases, being directly correlated with the values of pH, SB and CEC.

Keywords: Fabaceae, Green Manure, Nutrient Cycling, Organic Matter, Organic Carbon, N-Total, Sustainable soil management.

Introduction

The dominant soils of the Amazon biome, notably the *Latossolos* (Oxisols), are of clayey texture in general, well-structured with high aggregate stability, despite being highly weathered, acidic and poor in nutrients that are essential to plants. Under anthropic conditions, inadequate management of these soils affects their organic matter content and structure, reducing nutrient availability and aggregation (Santos et al., 2011).

Among the available technologies to manage tropical soils, the cultivation of cover crops preceding maize or soybean stands out, as it can result in increased yield and maintenance of the system's balance because maize and soybean are the two main grain crops in terms of planted area in Rondônia (Conab, 2020).

Legumes stand out among the species used as cover crops in crop succession or rotation systems, especially due to the potential for biomass production and nitrogen addition. It is also important for carbon sequestration in the soil (Sisti et al., 2004), providing more favorable conditions for carbon stock in the upper layers andin its deeper layers, over the time of adoption. The inclusion of legumes as green manure provides the nitrogen preferably used by microorganisms that synthesize the most stable fractions of soil organic matter (SOM) (Santos et al., 2012). This plant material deposited in the soil becomes part of its matrix, constituting the SOM, showing a varied and complex nature. These effects may mean a form of agriculture with low greenhouse gas emissions, which contributes to mitigating the effects of climate change and promoting increased sustainability of agroecosystems (Basches et al., 2014; Mukherjee; Lal, 2015). Thus, cultivating cover crops is a management practice that can return to the soil, part of what has been lost over decades of conventional cultivation.

The success in the adoption of management systems that include cover crops in the Amazon biome depends on climatic conditions, since there is a significant influence on the acceleration of the decomposition of plant residues with consequent reduction in SOM accumulation. The concentrations of nitrogen and organic compounds such as lignin, hemicellulose and cellulose regulate residue decomposition rate and affect the dynamics of fractions and accumulation of SOM (Santos et al., 2012; Carvalho et al., 2015). In addition, the deposition of plant residues over the years favored the increase in humic acid concentration, which together with the high annual rainfall, concentrated in the warmer months. This intensifies the biodegradation of unstable SOM fractions, with faster transformation from fulvic acid to humic acid, mainly in cover plants with lower lignin content (Santos et al., 2012).

In the Northwest region of the Amazon, especially in the state of Rondônia, there is little substantiated information on the operation of this technology in the maintenance or construction of soil fertility, which becomes fundamental for the success of the different production systems and an effective strategy to promote better soil conditioning. Thus, research focused on deepening this knowledge will serve as a scientific basis for a new technological process aimed at agricultural production in the Amazon region, contributing to the development and consolidation of research in the state of Rondônia. Therefore, the present study aimed to evaluate the absorption of nutrients by cover crops and the reconditioning of soil chemical attributes after management with different cover crops.

Results and discussion

Dry matter production and chemical composition of the shoots of cover crops

There was a significant difference ($p \leq 0.05$) between cover crops for dry matter production and nutrient content (Figure 2 and Table 3).

The cultivation of *Crotalaria spectabilis* led to the best results for dry matter production (13.2 $t.ha^{-1}$), but this species did not differ statistically from *Crotalaria ochroleuca* (10.2 $t.ha^{-1}$) and *Crotalaria breviflora* (8.3 $t.ha^{-1}$) (Figure 2). Such increase in dry matter in the soil can promote significant improvements in its physical and chemical characteristics and maintenance and/or elevation of soil organic matter content, maintenance of soil temperature, and act as a physical barrier against infestation of invasive plants, besides favoring the development and yield of agricultural species in subsequent crops (Andrade Neto et al., 2008; Boer et al., 2008). On the other hand, the lowest dry matter yields were obtained by the species *Canavalia ensiformis* (4.7 $t.ha^{-1}$), *Dolichos lablab* (5.8 $t.ha^{-1}$) and *Mucuna aterrima* (5.2 $t.ha^{-1}$) (Figure 2), being below the minimum amount of dry matter deposited annually necessary for adequate soil cover in no-tillage system. The low initial rainfall observed for the region during plant establishment (first 30 days – November) was possibly related to the low dry matter production by these cover plants (Figure 1). These results partially corroborate those obtained by Pereira et al. (2017), who observed high dry matter production for *Crotalaria spectabilis* and *Canavalia ensiformis* and low dry matter production for *Mucuna aterrima*, which makes it possible to infer that the capacity for dry matter production is directly related to edaphoclimatic conditions, soil fertility and agricultural year.

It was observed that, even with low dry matter production, the species *Canavalia ensiformis* and *Mucuna aterrima* were able to absorb and accumulate the highest nitrogen contents in their leaves at full flowering, about 25.28 g kg^{-1} and 24.34 g kg^{-1}, respectively, differing statically from the other cover crops. The lowest nitrogen contents were obtained by *Crotalaria spectabilis*, *Crotalaria breviflora and Crotalaria ochroleuca*, in an inverse relationship with dry matter production (Table 3). The results obtained are similar to those observed by Pereira et al. (2017), who studied nutrient cycling by different cover crops and found shoot N contents 29.50 g kg^{-1} in *Canavalia ensiformis* and 30.0 g kg^{-1} in *Mucuna aterrima*. Barros et al. (2013), Teodoro et al. (2011) and Padovan et al. (2011) indicate *Canavalia ensiformis* as an excellent cover species because it has high capacity for extracting nutrients from the soil and performing biological nitrogen fixation by the symbiotic association with bacteria of the genus *Rhizobium.* In addition, based on the results obtained, *Canavalia ensiformis* and *Mucuna aterrima* will contribute to high nutrient incorporation, promoted later by biomass decomposition.

The species *Dolichos lablab* stood out for the accumulation of nitrogen, phosphorus, calcium and sulfur in the leaves, with significantly higher contents than the other cover plants. This highlights its ability to accumulate N, P, Ca and S in the leaf tissues, with no close relationship with the supply of shoot dry matter (Table 3).

For potassium content, there was no significant difference between the cover plants. In areas with low potassium contents, it is important to use soil cover plants because of their capacity for cycling, accumulating and supplying this nutrient to the subsequent crop, which favors the agricultural systems (Teodoro et al., 2011).

Canavalia ensiformis had the highest calcium content (16.70 g kg^{-1}), corroborating the result found by Padovan et al. (2011) (being 17.25 g kg^{-1}). According to these authors, the phenological stage suitable for *Canavalia ensiformis* management is during the formation of the first pods, which corresponds to 90 days after emergence, because at this stage there is a significant accumulation of nutrients in the shoots after flowering, mainly nitrogen, potassium and calcium. The stage at which cover crops should be managed is important so that their use does not become harmful to the next crop, mainly due to the deposition of viable seeds and natural re-sowing in the subsequent crop Pereira et al. (2017). Calegari (1995) green manure as cover plant and noted that they should be mowed or desiccated at the flowering stage, as it enables satisfactory dry matter accumulation on soil surface. Nevertheless, according to Padovan et al. (2011 and 2014), cover plants (*Canavalia ensiformis* and *Crotalaria sp.*) intended for green manure should be managed at the beginning of the grain formation stage because it enhances the accumulation of dry matter and nutrients in the shoots. Besides, there is no risk of competition with the subsequent crop, due to the non-deposition of viable seeds of cover crops in the areas of cultivation. This information may explain the low contents of

N by the cover plants *Crotalaria spectabilis*, *Crotalaria breviflora* and *Crotalaria ochroleuca*.

Crotalaria spectabilis, *Crotalaria breviflora* and *Crotalaria ochroleuca* showed the highest contents of magnesium, which emphasizes the efficiency of Crotalaria species in cycling this nutrient (Table 3). These results confirm those reported by Pereira et al. (2017).

Soil chemical attributes and management with different cover plants

Regarding soil chemical attributes, the results showed significant effects ($p \leq 0.01$) of the double interaction between cover plants and sampling depth on SOM, organic carbon and N-total (Table 6), phosphorus, calcium, magnesium and Ca/Mg ratio (Table 7), pH, SB and CECpH7 (Table 8). The other results did not show significant effect of the interaction and presented independently for the different cover plants (Table 4 and 5) and different sampling depths (Figure 3 and 4).

At the different sampling depths, there was significant response ($p<0.01$) of SOM, total carbon, C/N ratio and N-total contents in the soil. The mean values of these variables at the 0-10 cm depth were higher and statistically different from those found at the other sampling depths. These data make it possible to infer that in this first period of evaluation of the no-tillage system in crop succession, there was a significant effect up to the depth of 10 cm. This includes the reduction in the soil contents of SOM, organic carbon, C/N ratio and N-total in subsurface layers (Figure 3A, 3B, 3C and 3D). In systems such with reduced soil activity and crop succession, the increase in SOM and total carbon contents in the most superficial soil layer is mainly associated with the increase in the supply of plant material to the soil due to the management of different cover crops (Figure 2). It also participate in improvement of soil physical quality and increase in soil organic matter humification, especially in the most surface soil layer (0-10 cm) (Figure 3A and 3B). Thus, it is important to point out that, as the soil structure is strengthened by the adoption of these management systems with little turning, the contents of SOM, organic carbon, C/N ratio and N-total will increase, enabling even the stabilization of organic matter in the long term, as reported by Conceição et al. (2013) and Lima et al. (2016). Thus, for the edaphoclimatic conditions under which the experiment was conducted, the accumulation of total organic carbon essentially depends on the stabilization of soil organic matter for subsequent effects in upper sampling layers. Lima et al. (2016) and Faccin et al. (2016) stated that reduced tillage systems are more efficient at accumulating carbon in the most superficial soil layer (0-30 cm and 0-5 cm, respectively), whereas that organic matter stabilization is important for maintaining the total organic carbon contents of the soil. Consequently, a large amount of carbon is accumulated in systems that are associated with large supplies of plant residues This corroborates the results by Salton et al. (2011), who studied carbon content and dynamics in soil in crop-livestock integration systems and found higher contents in the surface soil layers with reduction in subsurface. Ensinas et al. (2016) verified that the greater the addition and accumulation of plant residues on soil surface, the greater the organic carbon supply expected to occur in the surface layer. N-total contents in the soil decreases with the sampling depth, which was expected, because of the close relationship between the N contents in the soil and higher organic activity in surface, i.e., in the 0-10 cm layer (Figure 3D). In natural systems, the main routes of entry of N into soils are the decomposition and mineralization of organic matter (which varies according to the type of treatment), rainwater and washing water of living and dead biomass accumulated on the soil and from the vegetation (Smethus, 2000). Thus, the combination of dry matter yield with higher N contents resulted in higher N content in the soil (Figure 3D). Besides, the more accelerated decomposition of organic matter due to the low C/N ratio was observed in legume crops, since several studies show that these species accumulate more nutrients and release them faster during their decomposition.

The result of the variance analysis for soil chemical attributes showed an individual effect of sampling depth on phosphorus, potassium, calcium and magnesium contents in the soil, being clear that there were significant increments ($p<0.01$) in the contents of P, K, Ca and Mg in the 0-10 cm layer compared to the other sampling layers, but there was no significant difference between the subsurface sampling layers (Figure 4A, 4B, 4C and 4D). Among the mean values of P available in the soil at the sampling depth of 0-10 cm, the content was equal to 7.79 mg dm^{-3}, against 4.14 mg dm^{-3}, 3.80 mg dm^{-3} and 4.49 mg dm^{-3}, respectively, in the layers of 10-20 cm, 20-30 cm and 30-40 cm depth (Figure 4A). However, the mean values of K available in the soil in the 0-10 cm layer were 157.32 mg dm^{-3}, differing statistically from those found in the subsurface layers of 10-20 cm, 20-30 cm and 30-40 cm, which were equal to 63.40 mg dm^{-3}, 51.99 mg dm^{-3} and 45.81 mg dm^{-3}, respectively (Figure 4B). It is worth mentioning that the increments in P and K contents in the 0-10 cm layer under conditions of management with different cover plants were on the order of 94.75% and 92.02%, respectively, compared to the control based on the initial analysis of soil fertility before the experiment (Table 1). The accumulation of nutrients, such as P and K in the surface layer, results from their release in greater quantity due to the decomposition of plant residues and reduction in their fixation because of the lower contact of these elements with soil constituents (Sidiras and Pavan, 1985). However, these values are considered low and tend to decrease as the depth increases in the profile, which reflects their limited mobility in the soil. This is clearly observed in the experiment, in which there was a close and direct relationship of the contents of these nutrients in subsurface with the contents of SOM.

Regarding calcium and magnesium contents in the soil (Figure 4C and 4D), the values of exchangeable Ca^{2+} (31.77 mmol dm^{-3}) and exchangeable Mg^{2+} (18.66 mmol dm^{-3}) at the depth of 0-10 cm were higher than those found at depths of 10-20 cm, 20-30 cm and 30-40 cm, respectively. Although there is a significant difference, it is important to point out that these contents of Ca^{2+} and Mg^{2+} are considered high for crops, according to Raij et al. (1997). Silva et al. (2017) studied the effect of cover crops on the chemical quality of a *Latossolo distrófico* (Oxisol) under no-tillage and observed increments in P, K, Ca and Mg contents in the surface layers of the soil, with reductions in subsurface layers.

The species *Dolichos lablab* and *Mucuna pruriens* were statistically superior ($p \leq 0.01$) to the other cover plants regarding the supply of organic matter, organic carbon, C/N ratio, N-total, phosphorus and Ca/Mg ratio (Table 4). These results are related to the higher shoot dry matter production by *Mucuna pruriens* (Figure 2) and higher accumulation of nitrogen, phosphorus and calcium in the leaves by *Dolichos lablab* (Table 3), which favor the cycling of nutrients via decomposition. Thus, the increase in N and P contents are directly correlated with SOM contents in areas cultivated with *Mucuna pruriens* and *Dolichos lablab*. Studies demonstrate that the increase in SOM contributes to increasing P content in the soil (Canellas et al., 2003; Theodoro et al., 2003; Almeida et al., 2005; Cardoso et al., 2013) due to the return of P forms accumulated in plant biomass and greater complexation of Al and Fe ions in the soil solution (Azevedo et al., 2007).

Regarding Ca^{2+} and Mg^{2+}, the species *Mucuna pruriens*, *Crotalaria breviflora* and *Crotalaria spectabilis* were significantly efficient in increasing their contents in soil, not differing statistically from one another (Table 4). The significant increase was observed in pH of areas cultivated with *Crotalaria breviflora* and *Crotalaria spectabilis*, compared to the other cover plants. This insights the efficiency of these species in absorbing and accumulating Ca^{2+} and Mg^{2+} in their tissues, enabling the cycling of these nutrients, and consequently, reductions in Al content, potential acidity, saturation by Al^{3+}, and increase in the soil contents of basic cations (Ca^{2+} and Mg^{2+}), SB, CEC and %V (Table 5). In addition, the supply of organic material in the areas under cover crops contributes to the increase in pH and reduction in Al^{3+} contents. In a *Latossolo amarelo* (Oxisol) under no-tillage in the Cerrado of Maranhão, Bressan et al. (2013) also observed positive effects of soil cover on soil chemical attributes, especially pH, Al^{3+} contents, Al^{3+} saturation, and Ca^{2+} and Mg^{2+} contents.

The decomposition of the double interaction between cover plants and different sampling depths revealed that the species *Dolichos lablab* and *Mucuna pruriens* were statistically different ($p<0.01$) from the other cover crops regarding the contents of SOM, organic carbon and N-total at the different sampling depths (0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm). We also observed a reduction in SOM, organic carbon and N-total contents in subsurface (Table 6). In the 0-10 cm layer, the cultivation of *Dolichos lablab* and *Mucuna pruriens* resulted in the highest accumulations of organic matter, total carbon and N-total, while the lowest values were obtained by the species *Mucuna aterrima* (Table 6). The mean difference between *Dolichos lablab* and *Mucuna pruriens* plants in relation to organic matter supply at the different depths was in the order of 121% in the 0-10 cm layer, 205% in the 10-20 cm layer, 124% in the 20-30 cm layer and 72% in the 30-40 cm layer, when compared to *Mucuna aterrima* (lowest values obtained). For the total carbon and N-total contents, the values represent average increments of 12% and 112% in the 0-10 cm layer, 206% and 61% in the 10-20 cm layer, 121% and 71% in the 20-30 cm layer and 100% and 27% in the 30-40 cm layer, respectively. Accumulation of total carbon in the 0-10 cm layer, i.e. in the surface layer, results from the transformation of the shoots of the plants and their roots concentrated in the layer and that what is below 10 cm is derived from roots, root exudates and soluble organic carbon leached from the upper layers. The deeper tap root system of the cover legumes evaluated may have led to the accumulation of OC and N-total in the layers below 10 cm, but at percentages lower than in the surface layer of 0-10 cm. Bertiol (2014) observed that the increase in organic carbon and N-total in the soil was favored by the cultivation of legumes, especially *Mucuna pruriens*. Marques et al. (2012) quantified the concentrations of dissolved organic carbon (DOC) in soil of primary forest of the Amazon, at three topographic positions, and in areas of pasture, secondary succession and agroforestry system up to the depth of 2 m. They obtained the highest DOC contents in the surface layers in all studied environments, significantly differing from the other depths. The OC reservoir in soils reflects several biological (biodegradation/decomposition, biotransformation), chemical (adsorption, complexation, photodegradation) and physical (leaching and eluviation) processes that, in turn, are moderated by biotic and abiotic factors that include soil pH, OC and clay content, microbial activity, temperature and moisture (Bolan et al., 2011)

The cultivation of legume cover species led to variation in the contents of phosphorus, magnesium, calcium and Ca/Mg ratio at a depth of 0-10 cm, with reductions in upper sampling layers (Table 7). The cover crop *Dolichos lablab* caused significant variation compared to the other cover species in the P content available in the soil. As observed in Table 7 for pH, the values did not exceed 5.37 for *Dolichos lablab* and there was a reduction in subsurface, i.e., a higher level of acidity, which led to no statistical difference in P contents in layers below 10 cm (Table 6). The ideal pH for better availability of various nutrients, such as phosphorus, calcium and magnesium, varies between 5.5 and 6.5 for most crops, which justifies the reduction in the contents of these nutrients at depths greater than 10 cm. The available P contents in the soil, even under slightly more acidic pH conditions, as observed in the 0-10 cm layer, may be related to the fertilizer distribution depth at sowing.

The use of cover crops and other management practices aimed at maintaining or increasing SOM contents can favor the utilization of P by plants. The presence of straw and the higher OM content in the system of reduced soil tillage and in the system of crop succession provide a less oxidative environment, minimizing adsorption reactions and causing a direct impact on the fertility of the surface layer, up to 10 cm deep (Costa, 2000; Bertiol, 2014). Thus, plants are fundamental in the solubilization of P through the exudation of compounds in the rhizosphere, including organic acids that act on the dissolution of compounds and result in an increase in P-solution (Chien; Menon, 1995).

There was significant effect ($p<0.01$) of the cover crops *Dolichos lablab* and *Crotalaria spectabilis* on the exchangeable Ca^{2+} content in the soil at the depth of 0-10 cm, which is directly correlated with the values of SB and CEC (Table 8), not differing statistically from the species *Mucuna pruriens*, *Crotalaria breviflora* and *Crotalaria ochroleuca* at the same sampling depth and in subsurface (10-20 cm, 20-30 cm and 30-40 cm) (Table 7). While *Crotalaria spectabilis* stood out positively regarding the contents of exchangeable Mg^{2+} in the 0-10 cm layer, on the order of 25.97 mmol dm^{-3}, the species *Dolichos lablab* stood out in terms of Ca/Mg ratio in all sampled layers, with a reduction in Ca/Mg ratio in the surface layers and higher Ca/Mg ratio in subsurface layers, such as 20-30 cm and 30-40 cm (Table 7). In the 0-10 cm layer, the Ca^{2+} contents were relatively high, showing a reduction with the increase in the sampling depth (even though there was no statistical difference).

Table 1. Chemical attributes of the soil before installing the experiment at different depths.

Profundidade	N	SOM	OC	pH	P	K	Ca	Mg	H+Al	Al	SB	CEC	V	m
	mg dm^{-3}	g dm^{-3}		$CaCl_2$	mg dm^{-3}		------------------mmolc/dm^{-3}-----------------						------%------	
0-10	2553.5	11.4	6.62	4.9	4	81.9	29	8	30	1	40	70	57	2
10-20	2090.9	5.3	3.08	5.0	1	58.5	36	4	25	1	41	66	62	2
20-30	1848.3	4.2	2.44	5.3	1	42.9	37	3	20	0	40	60	67	1
30-40	1782.3	3.1	1.0	5.5	1	27.3	35	2	17	0	37	54	69	1

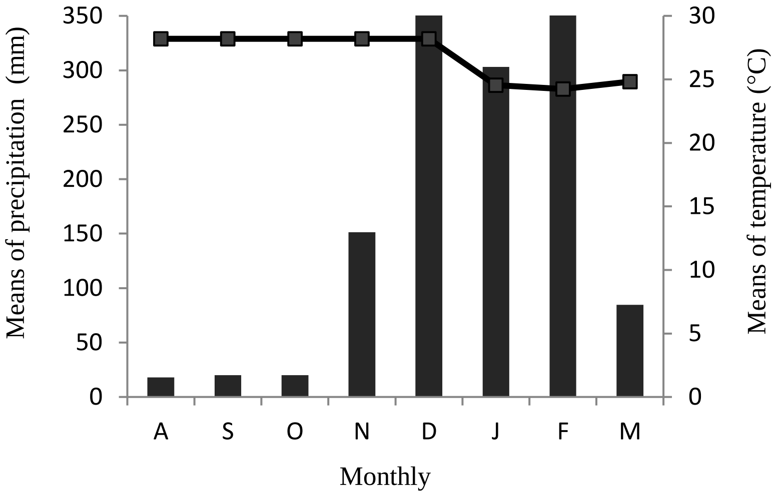

Figure 1. Monthly means of precipitation (mm) and temperature (°C), recorded in the weather station of the National Institute of Meteorology, from August of the 2019 the Marc of the 2020 agricultural year.

Table 2. Species of cover crops (plot treatments), C/N ratio indicated in the literature and sowing density used.

Species	Family	C/N ratio	Sementes m²
Crotalaria ochroleuca	Fabaceae	25-29[2]	67
Crotalaria spectabilis	Fabaceae	10-16[1]	73
Crotalaria breviflora	Fabaceae	11-18	73
Mucuna aterrima	Fabaceae	12-21[1]	9
Mucuna pruriens	Fabaceae	12-21[1]	9
Dolichos lablab	Fabaceae	23-28[3]	10
Canavalia ensiformis	Fabaceae	10-16[1]	11

[1]Wutke et al. (2014); [2] Fischlerab et al. (1999); [3] Teodoro et al. (2011).

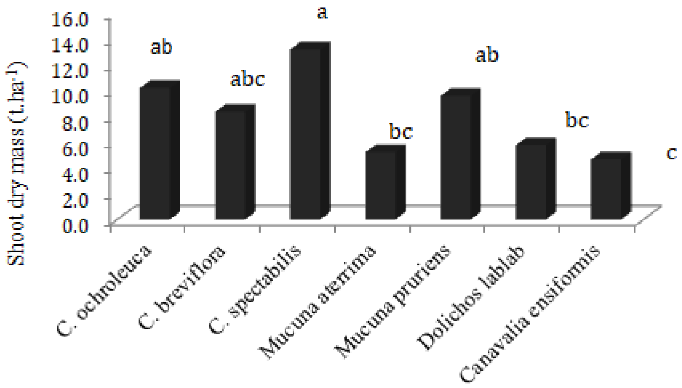

Figure 2. Production of shoot dry mass by different cover plants.

Table 3. Nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) content in the full flowering of different cover plants.

Cover plants	N	P	K	Ca	Mg	S
			(g kg^{-1})			
Canavalia ensiformis	25.28 a	1.87 b	13.94 a	16.70 a	1.91 bc	1.12 b
Dolichos lablab	21.28 abc	2.45 a	13.81 a	14.75 ab	1.82 d	1.78 a
Mucuna aterrima	24.34 ab	1.77 b	13.54 a	12.43 cd	1.78 d	1.15 b
Mucuna pruriens	23.00 ab	1.88 b	11.27 a	11.95 d	2.01 bc	1.23 b
C. ochroleuca	19.13 c	1.55 b	14.51 a	8.17 e	2.65 a	1.25 b
C. breviflora	19.32 c	1.54 b	13.42 a	13.25 bcd	2.38 ab	1.26 b
C. spectabilis	20.29 bc	1.68 b	14.51 a	14.55 abc	2.28 abc	1.44 ab
Mean	21.81	1.82	13.57	13.12	2.12	1.32
CV (%)	10.85	10.93	14.30	9.26	13.93	10.80

Means followed by the same letter in the column do not differ statistically by Tukey test at 5% probability level. CV (Coefficient of variation).

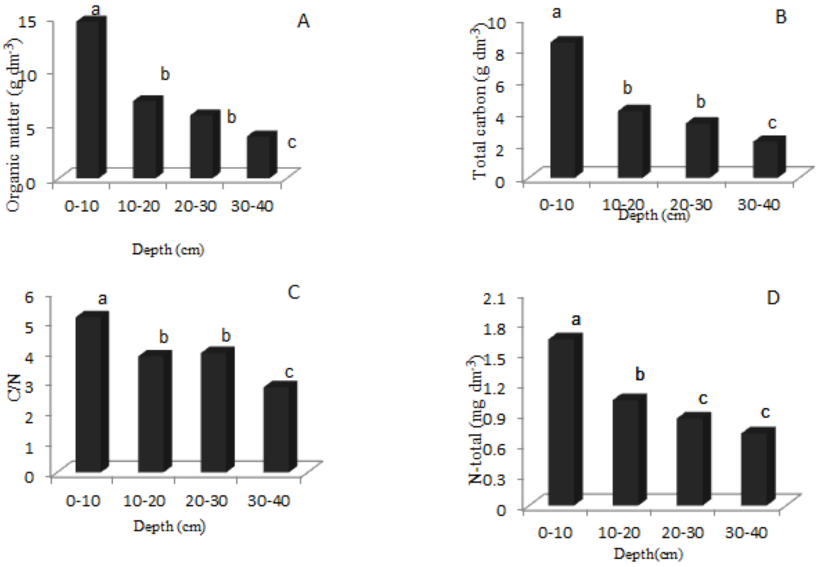

Figure 3. Mean levels of organic matter (A), total carbon (B), C/N (C) and N-total (D) of soil function of different sampling depths. Equal letters on bars do not differ statistically from each other by tukey test at 1% probability.

Table 4. Mean values of organic matter (SOM), organic carbon (OC), total N (N), C/N ratio (C/N), phosphorous (P), calcium (Ca), magnesium (Mg) and Ca/Mg ratio (Ca/Mg) in response to management with different cover plants.

Cover plants	SOM ($g\ dm^{-3}$)	OC ($g\ dm^{-3}$)	N ($g\ dm^{-3}$)	C/N
Canavalia ensiformis	6.49 cd	3.77 cd	0.99 cd	3.52 b
Dolichos lablab	11.49 a	6.68 a	1.47 a	3.91 ab
Mucuna aterrima	10.40 ab	6.04 ab	1.29 ab	4.50 a
Mucuna pruriens	4.74 d	2.75 d	0.74 e	3.53 ab
C. ochroleuca	6.77 cd	3.93 cd	0.91 cde	4.08 ab
C. breviflora	6.77 cd	3.93 cd	0.89 de	4.30 ab
C. spectabilis	8.50 bc	4.94 bc	1.14 bc	3.91 ab
CV (%)	26.33	26,33	18.15	19.25
Cover plants	P ($mg\ dm^{-3}$)	Ca ($mmol\ dm^{-3}$)	Mg ($mmol\ dm^{-3}$)	Ca/Mg
Canavalia ensiformis	5.02 b	20.33 de	10.74 c	2.57 b
Dolichos lablab	8.41 a	25.91 bcd	8.70 c	3.91 a
Mucuna aterrima	4.64 b	32.51 a	15.88 ab	2.06 bc
Mucuna pruriens	4.17 b	15.75 e	10.68 c	1.47 c
C. ochroleuca	3.54 b	25.41 cd	15.78 b	1.60 c
C. breviflora	4.65 b	31.44 ab	16.01 ab	1.97 bc
C. spectabilis	4.94 b	26.65 abc	19.02 a	1.39 c
CV (%)	35.86	18.28	18.10	33.52

Means followed by the same letter in the column do not differ statistically by Tukey test at 5% probability level. CV (Coefficient of variation).

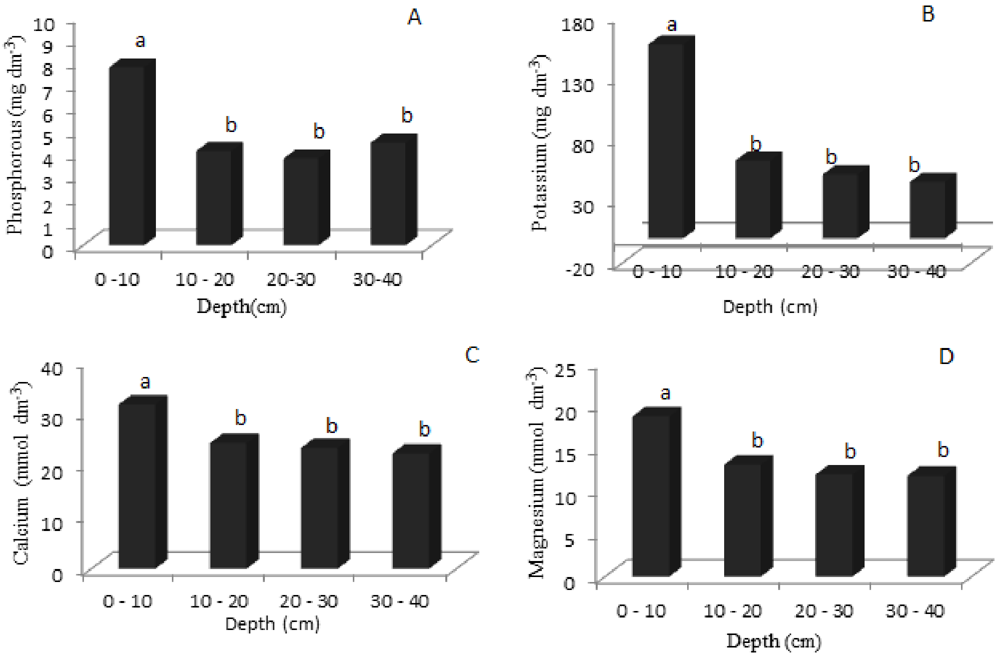

Figure 4. Mean levels of phosphorous (A), potassium (B), calcium (C) e magnesium (D) of soil function of different sampling depths. Equal letters on bars do not differ statistically from each other by tukey test at 1% probability.

Table 5. Mean values of pH, potential acidity (H+Al), sum of bases (SB), Cation Exchange capacity (CEC), base saturation (V%) and aluminum saturation (%m) in response to management with different cover plants.

Cover plants	pH	H+Al	SB ($mmol\ dm^{-3}$)	CEC ($mmol\ dm^{-3}$)	V%	%m
Canavalia ensiformis	4.41 c	30.11 a	32.79 c	62.91 abc	52,82 d	22,5 b
Dolichos lablab	4.67 b	21.92 b	36.80 bc	58.72 c	60,78 c	7,70 c
Mucuna aterrima	4.83 b	21.85 b	50.29 a	72.15 a	69,34 ab	4,90 c
Mucuna pruriens	4.29 c	32.27 a	28.56 c	60.84 bc	47,37 d	34,72 a
C. ochroleuca	4.81 b	20.18 bc	43.14 ab	63.33 abc	67,70 bc	4,45 c
C. breviflora	5.30 a	15.34 c	49.71 a	65.06 abc	76,21 a	1,78 c
C. spectabilis	5.32 a	21.43 bc	47.87 a	69.31 ab	67,87 bc	5,28 c
CV (%)	3.53	20.84	16.05	11.63	8,87	30,66

Means followed by the same letter in the column do not differ statistically by Tukey test at 5% probability.

Table 6. Unfolding of the significant interaction between cover plants and sampling depth for organic matter, organic carbon and N-total contents.

Cover plants	Organic matter (g dm^{-3})			
	0-10	10-20	20-30	30-40
Canavalia ensiformis	9.70 cA	6.53 bAB	6.53 bAB	3.20 bB
Dolichos lablab	21.57 aA	12.17 aB	7.13 aC	5.08 aC
Mucuna aterrima	16.79 abA	11.15 aB	7.99 aC	5.68 aC
Mucuna pruriens	8.67 cA	3.80 cB	3.37 cB	3.11 bB
C. ochroleuca	13..0 bcA	5.25 cB	5.08 bB	2.94 bB
C. breviflora	13.88 bcA	4.65 cB	4.99 bB	3.54 bB
C. spectabilis	17.64 abA	6.79 bB	5.85 bB	3.71 bB

Cover plants	Organic carbon (g dm^{-3})			
	0-10	10-20	20-30	30-40
Canavalia ensiformis	5.63 cA	3.80 bB	3.80 bB	1.86 bC
Dolichos lablab	12.54 aA	7.08 aB	4.14 aC	3.95 aC
Mucuna aterrima	9.76 abA	6.48 aB	4.64 aC	3.30 aC
Mucuna pruriens	5.04 cA	2.21 bB	1.96 bB	1.81 bB
C. ochroleuca	8.02 bA	3.05 bB	2.95 bB	1.71 bB
C. breviflora	8.07 bA	2.70 bB	2.90 bB	2.06 bB
C. spectabilis	8.26 bA	3.95 bB	3.40 bB	2.16 bB

Cover plants	N-total (g dm^{-3})			
	0-10	10-20	20-30	30-40
Canavalia ensiformis	1.07 cA	1.11 abA	1.04 aA	0.76 aB
Dolichos lablab	2.54 aA	1.60 aB	1.08 aC	0.68 aD
Mucuna aterrima	1.89 aA	1.58 aB	1.12 aC	0.90 aD
Mucuna pruriens	1.04 cA	0.66 bB	0.64 bB	0.62 aB
C. ochroleuca	1.67 bA	0.72 bB	0.66 bB	0.60 aB
C. breviflora	1.52 bA	0.69 bB	0.65 bB	0.70 aB
C. spectabilis	1.69 bA	1.13 abB	0.85 bB	0.71 aB

Lowercase letters separate the means within each column, and the uppercase separates the averages within the row. Equal letters do not differ from each other by the Tukey test at 1% probability.

Table 7. Unfolding of the significant interaction between cover plants and sampling depth for phosphorus, magnesium, calcium and calcium/magnesium ratio.

Cover plants	Phosphorous (mg dm^{-3})			
	0-10	10-20	20-30	30-40
Canavalia ensiformis	7.28 bA	5.47aB	4.47 aBC	2.85 bC
Dolichos lablab	17.20 aA	6.59 aB	5.37 aB	5.59 aB
Mucuna aterrima	7.13 bA	3.76bB	3.23bB	3.43 bB
Mucuna pruriens	6.69 bA	2.88cB	3.14 bB	3.97 bB
C. ochroleuca	3.93 cA	2.86cA	3.43 bA	2.89 bA
C. breviflora	4.07 cA	4.44 bA	3.91 bA	2.92 bA
C. spectabilis	8.15 bA	3.89 bB	2.94 bB	2.79 bB

Cover plants	Magnesium (mmol dm^{-3})			
	0-10	10-20	20-30	30-40
Canavalia ensiformis	16.05 bA	11.17 bAB	8.52 cdB	7.22 bB
Dolichos lablab	19.63 bA	6.90 cB	4.36 dB	4.11 cB
Mucuna aterrima	18.68 bA	15.22 abA	13.90 bcA	15.74 aA
Mucuna pruriens	13.20 bA	9.54 bA	10.12 cdA	9.86 bA
C. ochroleuca	18.66 bA	15.26 abA	15.17 abA	14.01 aA
C. breviflora	18.66 bA	15.29 abA	14.47abA	15.62 aA
C. spectabilis	25.97 aA	17.86 aB	16.70 aB	15.56 aB

Cover plants	Calcium (mmol dm^{-3})			
	0-10	10-20	20-30	30-40
Canavalia ensiformis	24.30 bA	19.71 cA	18.44 cA	18.86 bA
Dolichos lablab	39.64 aA	21.09 bcB	21.34 bB	21.56 abB
Mucuna aterrima	33.45 abA	35.10 aA	31.96 aA	29.53 aA
Mucuna pruriens	19.58 cA	14.24 cA	14.20 cA	14.98 bA
C. ochroleuca	30.69 abA	24.98 bA	23.63 bA	22.36 abA
C. breviflora	35.59 abA	30.52 abA	31.52 aA	28.12 aA
C. spectabilis	39.16 aA	24.27 bcB	22.50 bB	20.69 abB

Cover plants	Ratio Ca Mg			
	0-10	10-20	20-30	30-40
Canavalia ensiformis	1.52 bB	2.00 bB	2.95 bAB	3.80 bA
Dolichos lablab	2.04 aB	3.11 aB	5.09 aA	5.40 aA
Mucuna aterrima	1.81bA	2.32 bA	2.23 bA	1.86 cA
Mucuna pruriens	1.47 bA	1.49 bA	1.40 bA	1.51 cA
C. ochroleuca	1.64 bA	1.62 bA	1.55 bA	1.60 cA
C. breviflora	1.90 bA	1.98 bA	2.18 bA	1.80 cA
C. spectabilis	1.53 bA	1.36 bA	1.34 bA	1.32 cA

Lowercase letters separate the means within each column, and the uppercase separates the averages within the row. Equal letters do not differ from each other by the Tukey test at 1% probability.

Table 8. Unfolding of the significant interaction between cover plants and sampling depth for pH, base saturation (SB) and cation exchange capacity (CEC).

	pH			
Cover plants	0-10	10-20	20-30	30-40
Canavalia ensiformis	4.41 bA	4.23 bA	4.33 bA	4.68 bA
Dolichos lablab	5.37 aA	4.42 bB	4.54 bB	4.63 bB
Mucuna aterrima	4.83 bA	4.84 bA	4.85 bA	4.80 bA
Mucuna pruriens	4.37 bA	4.24 bA	4.28 bA	4.27 bA
C. ochroleuca	5.04 aA	4.71 bA	4.70 bA	4.80 bA
C. breviflora	5.17 aA	5.23 aA	5.33 aA	5.27 aA
C. spectabilis	4.92 bA	4.60 bA	4.64 bA	4.73 bA
	SB (mmol dm^{-3})			
Cover plants	0-10	10-20	20-30	30-40
Canavalia ensiformis	43.49 bcA	32.48 cdB	28.19 bB	27.00 bB
Dolichos lablab	63.33 aA	29.75 dB	27.11 bB	27.00 bB
Mucuna aterrima	56.06 abA	51.85 aA	46.93 aA	46.32 aA
Mucuna pruriens	36.65 cA	25.66 dA	25.94 bA	26.00 bA
C. ochroleuca	52.98 abA	41.93 bcA	40.03 abA	37.63 abB
C. breviflora	59.12 abA	47.34 bA	47.31 aA	45.07 aA
C. spectabilis	69.77 aA	43.58 bB	40.67 abB	37.46 abB
	CEC (mmol dm^{-3})			
Cover plants	0-10	10-20	20-30	30-40
Canavalia ensiformis	70.85 bcA	69.77 aA	58.97bB	52.05 abB
Dolichos lablab	86.37 abA	56.51 aB	47.28 bB	44.72 bB
Mucuna aterrima	79.41 bcA	74.76 aA	66.66 aA	67.76 aA
Mucuna pruriens	65.36 cA	62.64 aA	57.26 bA	58.08 abA
C. ochroleuca	72.90 bcA	63.32 aA	60.34 abA	56.74 abA
C. breviflora	75.62 bcA	62.28 aA	62.57 abA	59.76 abA
C. spectabilis	92.69 aA	66.06 aB	61.41 abB	57.08 abB

Lowercase letters separate the means within each column, and the uppercase separates the averages within the row. Equal letters do not differ from each other by the Tukey test at 1% probability.

This effect may be associated with the superficial application of limestone. In all treatments, the contents of Ca^{2+} and Mg^{2+} (RAIJ et al., 1996) were high up to at least 10 cm deep. Such behavior was not observed in upper sampling layers, i.e., there was no statistical difference between the other sampling layers.

Materials and methods

Characterization of the experimental área

The experiment was conducted from August 2019 to March 2020, in the experimental area of the Federal Institute of Education, Science and Technology of Rondônia, Colorado do Oeste Campus, in the municipality of Colorado do Oeste, RO, Brazil, at the geographic coordinates 13° 06’ S and 60° 29’ W, with an average altitude of 407 meters. According to Köppen’s classification, the climate is Awa, tropical hot and humid with two well-defined seasons. Mean temperature and rainfall data during the experiment were obtained from the database of the National Institute of Meteorology (Figure 1). Chemical characterization of the soil was performed in the layers of 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm, with samples collected before the installation of the experiment, and the data are presented in Table 1. The particle-size analysis at the depth of 0-10 cm showed 343 g dm^{-3} of clay, 479 g dm^{-3} of sand and 178 g dm^{-3} of silt. Soil correction was performed thirty days prior to sowing, based on the results of soil analysis in the 0-10 cm layer, using the dose of 1230 kg ha^{-1} of dolomitic limestone (RNV 97%) in order to increase base saturation to 65%.

Experimental design

The experimental design was completely randomized, arranged in a factorial scheme 7x4, consisting of seven species of cover crops cultivated prior to the maize crop (*Crotalaria spectabilis*, *Crotalaria breviflora*, *Crotalaria ochroleuca*, *Mucuna aterrima*, *Mucuna pruriens*, *Dolichos lablab* and *Canavalia ensiformis*) and four sampling depths (0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm), with four replicates.

Soil preparation and planting

Primary soil tillage included plowing and harrowing (disc harrow) up to 15 cm deep, while secondary tillage includes the breaking of clods and leveling of the experimental area. Basal fertilization was carried out broadcast, with subsequent incorporation, applying 400 kg ha^{-1} of the formulation 0-20-20 to provide 120 kg ha^{-1} of P_2O_5 and 80 kg ha^{-1} of K_2O, respectively.

The planting furrows were mechanically opened at depths between 5 and 7 cm, according to the established spacing. Sowing was performed manually. The different amounts of seeds adopted were based on recommendations (Table 2). Seed inoculation was not performed in any of the legume cover plants. Each experimental unit was composed of 8 rows with length of 4 meters, spaced by 0.45 m between rows and 0.20 m between plants. The six central rows were considered as usable plot, disregarding 0.5 m on each end of the plot.

At fifteen and thirty days after emergence of the cover crops, plants were sprayed with insecticide containing the active ingredients (a.i.) Imidacloprid 100 g/L and Beta-cyfluthrin 12.5 g/L, chemical groups Neonicotinoid (Imidacloprid) and Pyrethroid (Beta-cyfluthrin), with recommendation of 750-1000 mL/ha for the control of *Lagria villosa*, *Diabrotica speciosa*, *Cerotoma arcuata* and *Edessa meditabunda*.

Desiccation and determination of dry mass production

At full flowering, the cover crops, except *Canavalia ensiformis* (collected at the beginning of grain filling), were desiccated with the herbicide glyphosate (1.920 g a.i. ha^{-1}) and then managed with manual mower at 0.05 m height from the soil surface, aiming at the standardization of the area. However, before desiccation, dry matter yield and macronutrient contents were evaluated in the shoots of the different cover crops. For dry matter determination, a square (0.50 m x 0.50 m) was used to demarcate the area of the plot, in which the sample was collected (close to the soil). It weighed to determine the fresh mass, dried in a forced air circulation oven at 65 ºC until reaching constant weight, and weighed to determine the dry matter. Subsequently, the samples were ground in a Wiley-type mill and subjected to sulfuric digestion and nitric-perchloric digestion, using the methodology described in Embrapa (2009) to determine leaf contents of macronutrients.

Determination of soil chemical atributes

In order to determine soil chemical attributes, soil samples were collected at depths of 0-10, 10-20, 20-30 and 30-40 cm after 30 days of decomposition of the cover crops. The soil samples were air dried, passed through a 2-mm-mesh sieve, homogenized and subjected to evaluations of pH values and contents of available P, exchangeable K^+, Ca^{2+} and Mg^{2+}, Al, H+Al, SB, CEC and %V, using the methodology described in Embrapa (2009). Organic matter and organic carbon stocks were determined by the methodology proposed by Cambardella and Elliot (1992), and soil N-total was determined by the Kjeldahl method, according to Tedesco et al. (1995).

Statistical analysis

The data were subjected to the normality test (Shapiro-Wilk) and analysis of variance, and the effects of the cover plants on nutrient absorption were evaluated by Tukey test at 5% probability level, while the effects between cover plants and sampling depth were evaluated by Tukey test at 1% probability level using the statistical program Sisvar.

Conclusions

Cultivation of *Crotalaria spectabilis*, *Crotalaria ochroleuca* and *Crotalaria breviflora* provided higher dry matter yield.

The species *Dolichos lablab* stood out in the accumulation of nitrogen, phosphorus, calcium and sulfur in the leaves at full flowering. The contents of organic matter, total carbon, C/N ratio, N-total, P, K, Ca^{2+} and Mg^{2+} of the soil were higher at the depth of 0-10 cm, with reduction in subsurface layers.

The species *Dolichos lablab* and *Mucuna pruriens* are efficient in terms of the supply of organic matter, organic carbon, C/N ratio, N-total, phosphorus, calcium and Ca/Mg ratio of the soil, causing a direct impact on the fertility of the surface layers, up to 10 cm deep.

Cultivation of *Crotalaria breviflora* and *Crotalaria spectabilis* caused variation in the contents of soil exchangeable bases, with direct correlation with the values of pH, SB and CEC.

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