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Chemical attributes of the soil and agronomic characteristics of maize as a monocrop and intercropped with herbaceous and woody legumes in the savannah of Roraima, Brazil

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Several studies seek to identify management systems that promote an increase in soil quality. As such, the aim of this study was to evaluate the effect of combinations of herbaceous and woody legumes on the productivity of green maize and the chemical attributes of the soil. The research was developed over two crop years (2016 and 2017). The experimental design was of randomized complete blocks with three replications and subdivided plots, in a 2 × 5 factorial scheme, representing the presence and absence of an alley cropping system with gliricidia, and five intercrops of maize with legumes: Maize + jack bean planted at the same time; maize + pigeon pea planted at the same time; maize + velvet bean planted 15 days after the maize; maize + *Crotalaria juncea* planted at the same time; single maize crop. The alley system increases the total and commercial productivity of husked cobs in maize intercropped with velvet bean. Intercropping maize with legumes under an alley system helps to increase the levels of phosphorus and potassium in the soil. Irrespective of the type of intercrop, green manure with legumes increases the soil organic matter content of farmed land in Roraima.

Key words: Alleys, gliricídia, agroforestry system, green manure.

INTRODUCTION

Disordered use and occupation of the land has caused several environmental changes that are often irreversible. Magalhães et al. (2013) found that substituting the forest for another type of land use can lead to significant losses in organic matter and other soil nutrients, changing its dynamics, and consequently altering the input and output of nutrients in the system (Durigan et al., 2017).

To minimise the damaging effects of conventional farming on the environment, studies have been developed to evaluate management systems that maintain or

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improve soil quality (Salmi et al., 2009; Oliveira and Bueno, 2016; Xu et al., 2019). As such, agroecological farming is emerging as one way of relieving environmental problems, following the principle of a rational use of natural resources. The use of legumes can be an alternative for recovering and improving the soils of degraded areas, since legumes use their own vegetation to protect the soil, in addition to the large deposition of plant biomass on the ground that contributes to improve the chemical and biological attributes of the soil through incorporation (Nogueira et al., 2012; Abreu et al., 2016; Oliveira et al., 2016). Soil conditions can also be improved by the use of species of woody and herbaceous legumes that are capable of associating with atmospheric nitrogen-fixing bacteria and with mycorrhizal fungi (Habiyaremye et al., 2018). This technique is considered low cost and can give promising results (Nogueira et al., 2012).

Under an alley cropping system, annual plants are grown between rows of woody legumes that are periodically pruned and their branches deposited on the crop rows, thereby transferring nutrients from the trees to the agricultural crops. Decomposition of the branches of the legume species in the soil increases the organic matter content, the availability of nutrients, the cation exchange capacity and the production of organic acids (Moura et al., 2012; Santos et al., 2012; Aguiar et al., 2013). In this way, green fertilisation of the maize from the intercrop with legumes can promote increased productivity in the crop of commercial interest, and at the same time, the production of plant biomass in the species that make up the intercrop can improve the chemical attributes of the soil, with positive effects on crop development (Castro and Prezzoto, 2008; Fanish, 2017).

In view of the above, the aim of this study was to evaluate the effect of combinations of woody and herbaceous legumes on the productivity of green maize and on the chemical attributes of the soil.

MATERIALS AND METHODS

The work was carried out from April 2016 to November 2017, and consisted of an experiment under rainfed conditions, conducted in the experimental area of the Sector for Olericulture of the School of Agricultural Technology, on the Murupu campus of UFRR, 37 km from the town of Boa Vista in the state of Roraima, 07° 28' 14” S and 34° 48' 31” W.

According to the Köppen classification, the climate in the area is type Aw, characterised as tropical rainy, hot and humid, with a distinct dry period following alternating periods of wet and dry. The mean temperature is around 25°C, and the annual rainfall in the study area was around 1,600 mm, with irregular distribution over two distinct wet periods and the most rainfall between April and September. The mean annual relative humidity ranges from 70 to 80% (Alvarez et al., 2013).

The experiment was conducted on two strips of farmed land, under an agroforestry system of alley cropping planted in April 2013. The chemical attributes of the soil are shown in Table 1. After the results of the soil analysis, soil preparation began in May 2013 with liming, applying 2.0 t ha^{-1}, followed by a light harrowing to incorporate the existing vegetation. The gliricidia was planted using cuttings from the Experimental Unit of EMBRAPA Roraima in the District of Mucajaí. Alleys of gliricidia were planted at a spacing of 3.5 m between rows and 2.5 m between plants. After planting the cuttings, the seeds of the herbaceous legumes (crotalaria, pigeon pea, jack bean and velvet bean) were sown, following the distribution of the experimental design. Pruning management of the gliricidia plants began eight months after planting the cuttings, when the stems were over 1.5 m in height; any leaves and branches smaller than 1.5 cm in diameter were then spread over the ground.

After planting the alleys and sowing the legumes, the soil in the experimental area remained fallow until May 2015. Maize intercropped with herbaceous legumes (crotalaria, pigeon pea, jack bean and velvet bean) was then grown over two consecutive years. Activities for planting the system started with soil samples, collected from areas with and without gliricidia. Ten single samples were collected from each area at a depth of 0-20 cm to form one composite sample as illustrated in Table 2.

The experimental design was of randomised complete blocks, with three replications and subdivided plots, in a 2 × 5 factorial scheme, representing the presence and absence of an alley cropping system in the main plot, and five intercrops of maize with legumes in the subplots C1 = maize + jack bean planted at the same time; C2 = maize + pigeon pea planted at the same time; C3 = maize + velvet bean planted 15 days after the maize; C4 = maize + *Crotalaria juncea* planted at the same time; C5 = control (single maize crop), with three replications.

Before sowing the maize and legumes, the gliricidia plants in each area were pruned to a height of 2.0 m. The experiment began in May 2016 by planting the crops (creole maize and shrub-like legume species). The cover species and maize were sown manually in furrows, at a spacing of 0.70 × 0.25 m for both the intercropped maize and the single maize crop. Each subplot consisted of nine rows of 10 m, four rows of maize and five rows of legumes inserted between the rows of maize.

The seeds were distributed in the furrows: Four seeds per linear metre for the maize and three seeds per linear metre for the cover species such as velvet bean and jack bean; for the pigeon pea and *Crotalaria juncea*, 20 seeds were used per linear metre. After the plants had emerged, thinning was carried out to adjust the desired population per hectare.

Weeding and heaping were carried out during the experiment, in order to keep the area free of spontaneous plants and stimulate the development of secondary roots in the maize. It is important to point out that 17 days after planting the maize, the area with no gliricidia needed weeding, with four weedings carried out during each crop. In the area with gliricidia, three weedings were carried out during the first crop and two during the second, the first weeding taking place after 25 and 30 days respectively due to the incidence of spontaneous plants. To avoid competition for light, the gliricidia plants were again pruned 40 days after each planting. The pruned branches were deposited between the crop rows in the area with gliricidia. Every 15 days, preventive applications of neem extract (*Azadirachta indica*) were carried out to avoid the incidence of insect pests in the cultivated area. In order to help maize development, cover fertilisation was carried for with each crop, with 80 kg ha^{-1} N in two applications, 20 and 45 days after sowing the maize and legumes. Urea (45% N) was used as the source of N. It is important to note that only the agronomic characteristics of the maize from the 2017 harvest were determined; the maize grown in 2016 was harvested but its agronomic characteristics not verified, with all the straw produced remaining in the experimental area. Only the chemical characteristics of the soil were determined for both 2016 and 2017.

The green maize was harvested manually once the cobs were physiologically mature, when the grains presented a yellow, milky endosperm with a water content of 70% to 80%. At the time of harvesting, the height of the plants and of the first ear insertion

Table 1. Chemical attributes of the soil in the experimental area at a depth of 0 to 20 cm.

pH	P (mg dm^{-3})	K	Ca	Mg	Al	H+Al	CEC	SB	OM	V
		cmol$_c$ dm^{-3}							%	
4.8	4.6	0.06	0.5	0.2	0.23	2.0	5.0	0.75	0.7	27

pH in water = ratio1.0:2.5; P = Mehlich 1 extraction; CEC = cation exchange capacity; SB = sum of bases; OM = organic matter; V = base saturation.
Source: Laboratory: LABRAS, Minas Gerais, 2013.

Table 2. Chemical attributes of the soil in the experimental area at a depth of 0 to 20 cm on the land with and without alleys of gliricidia.

System of alley	pH H_2O	P	K	Ca	Mg	Al	H + Al	OM
		mg dm^{-3}	cmol$_c$ dm^{-3}					(dag kg^{-1})
With	5.7	15.9	0.10	1.0	0.4	0.06	1.5	1.1
Without	5.6	10.3	0.13	0.9	0.3	0.09	1.4	0.9

pH in water = ratio1.0:2.5; P = Mehlich 1 Extraction; OM = organic matter.
Source: Laboratory: LABRAS, Minas Gerais, 2013.

were determined using a metric tape in ten representative plants from each subplot; plant height was measured from ground level to the insertion point of the final leaf and the height of the first ear insertion was determined from ground level to the base of the ear. After harvesting, all the cobs from the working area of each subplot were husked and weighed on a balance for later estimation of productivity. After removing the husks, the length of the cobs was determined using a ruler graduated in millimetres. A 150 mm digital calliper was used to determine the diameter. The commercial productivity of the husked cobs was based on the commercial fresh weight of the cobs obtained in each subplot, with the results expressed in kg ha^{-1}. As per local market demand, a commercial cob was considered to have a length greater than 16 cm and a diameter greater than 4 cm, with no defects, such as a lack of seeds or damage caused by pests. At the same time, the total productivity of the husked cobs was determined from the total fresh weight of the cobs obtained in the working area of each subplot, with the results expressed in kg ha^{-1}.

For the chemical analysis of the soil in the experimental area, soil samples were collected at three stages of the experiment. The first collection was made before the experiment was set up in the areas with and without gliricidia. The second and third samples were taken two months after each maize harvest when four composite samples were collected each time, consisting of 10 single samples for each crop, as follows: Sample 1 = collected in the subplot of maize intercropped with legumes in the presence of gliricidia; sample 2 = collected in the subplots of single maize crop in the presence of gliricidia; sample 3 = collected in the subplots of maize intercropped with legumes in the absence of glyricidia; and sample 4 = collected in the subplots of single maize crop in the absence of gliricidia. After collection, the samples were air dried, sieved through a 2 mm mesh and sent to the LABRAS Laboratory for evaluation of the chemical characteristics of the soil in the experimental area. The analysis followed a methodology proposed by EMBRAPA (2011).

The pH was determined in water, measuring the effective concentration of H^+ ions in the soil solution by means of a combination electrode immersed in a soil suspension of water in the ratio of 1:2.5. To determine the phosphorus content, the Mehlich 1 extracting solution, also known as the double-acid or North Carolina solution, was used; the extracted phosphorus was determined spectroscopically by reading the colour intensity of the phosphomolybdic complex. Potassium was determined by extraction with dilute hydrochloric acid solution followed by flame spectrophotometry. Organic matter was determined by the colorimetric method, using sulphuric acid and sodium dichromate.

The data were submitted to analysis of variance and the mean values of the treatments compared by Scott-Knott test at 5% probability. The SISVAR statistical software (Ferreira, 2014) was used in analysing the data.

RESULTS AND DISCUSSION

According to the summaries of the analysis of variance, it was found that all the variables under evaluation relative to the agronomic aspects of the green maize showed significant interaction between the treatments being studied, except for plant height (PH) and ear insertion height (EIH) as described in Table 3.

Among the variables under evaluation in the maize crop, plant height and ear insertion height were only influenced by the intercrop of maize and legumes; from the results, it can be seen that the intercropped maize showed greater values for plant height as shown in Table 4. This behaviour may have occurred due to the greater N demand of the maize during the early stages of its development, since all the plant material from the previous crop had already decomposed, and its nutrients released into the soil, resulting in greater nutrient availability for the plants. The greatest heights for ear insertion were recorded in the treatments of maize intercropped with crotalaria and jack bean, and in the single maize crop as presented in Table 4.

Castro and Prezzoto (2008) evaluated the performance of maize in a green manure system, verified that the

Table 3. Summary of the analysis of variance by mean square, relative to plant height (PH), ear insertion height (EIH), cob length (CL), cob diameter (CD), total productivity (TP) and commercial cob productivity (CCP) in green maize produced under an alley system and intercropped with herbaceous legumes.

SV	DF	Mean square				TP	CCP
		PH	EIH	CL	CD		
Block	2	409.80[ns]	199.81[ns]	0.04[ns]	0.72[ns]	1310745.03[ns]	345721.28[ns]
Alley (A)	1	240.83[ns]	116.42[ns]	0.13[ns]	0.36[ns]	101920.06[ns]	80082.44[ns]
Residual a	2	227.26	25.28	1.84	0.28	2928510.94	1670733.7
Intercrop (I)	4	13116.33*	421.07*	10.90**	2.74*	13841889.37**	12043686.98**
A x I	4	1457.08[ns]	175.65[ns]	3.20**	11.43**	6096943.95*	12990620.51**
Residual b	16	412.-5	90.16	0.61	0.85	1311877.45	600025.36
Total	29	-	-	-	-	-	-
CV a (%)	-	4.57	3.37	8.68	1.33	23.1	27.14
CV b (%)	-	8.69	6.36	5.02	2.29	15.46	16.27

SV = Source of variation; DF = Degree of freedom; ns, *, ** = Not significant, significant at 5% and significant at 1% probability respectively by F-test; CVa = coefficient of variation of the main plot; CVb = coefficient of variation of the subplot.

Table 4. Mean values for plant height and height of the first ear insertion in cm, as a function of intercropping with crotalária juncea (CJ), pigeon pea (PP), jack bean (JB), velvet bean (VB) and single maize crop (SM).

Intercrop	Plant height	Height of ear insertion
Maize + CJ	241.33[a]	151.1[a]
Maize + PP	245.50[a]	145.8[b]
Maize + JB	253.00[a]	156.7[a]
Maize + VB	234.16[a]	136.8[b]
Single maize	193.50[b]	156.6[a]

Mean values followed by the same letter in the columns do not differ from each other by Scott-Knott test at 5% probability.

height of the plants was higher using the consortium with the pork bean, but the authors affirm that there is no difference between the height of the spikes among treatments without green manure, and intercropped with grass, pork beans, guandú beans and white mucuna. Gitti et al. (2012) also verified that the simultaneous intercropping of corn with *Crotalaria juncea* and *Crotalaria spectabilis* did not affect plant height, and it can be deduced that there was no competition for light between maize and legumes. In the present research, the results indicate the absence of interspecific competition and the benefits of legume intercrops for maize growth.

Under the alley system, the greatest cob diameter was recorded for maize intercropped with velvet bean (4.32 cm). There was no statistical difference between the other intercrops as shown in Table 5. When grown with no alleys, the maize cobs showed the greatest diameter for the intercrop with jack bean (4.26 cm). Castro et al. (2014), working with different cover crops and the P4285H hybrid maize cultivar in Araxá, Minas Gerais (MG), found higher values than found in this study, with the crotalaria affording an average diameter of 5.47 cm, greater than the control (5.12 cm) and equal to the other treatments.

Under the agroforestry system, the greatest cob length was seen in the intercrop of maize and jack bean, with an average length of 17.1 cm. In the area with no gliricidia, the greatest cob length was also seen in the intercrop of maize and jack bean, with a mean length of 18.5 cm as described in Table 5. This superiority of the jack bean compared to the other intercrops may be related to its growth habit, since the jack bean does not compete with the maize for light. These results agree with those of Santos et al. (2010), who recorded greater lengths for maize cobs when grown intercropped with jack bean. However, Torres et al. (2014) working with cover crops and nitrogen fertiliser in a crop of off-season maize, recorded no statistical difference for the length or diameter of the cobs. Growing maize under an alley cropping system, the total productivity of husked cobs showed no difference between the intercrops, while for commercial cob productivity, the treatments that provided the greatest weight were the intercrop with crotalaria (5,600.04 kg ha^{-1}) and with jack bean (5,299.42 kg ha^{-1}), there being no statistical difference between the two as shown in Table 6. However, the single maize crop without

Table 5. Mean values for diameter and length (cm) in maize, as a function of intercropping with *Crotalaria juncea* (CJ), pigeon pea (PP), jack bean (JB), velvet bean (VB) and in the single maize crop (SM), with and without alley cropping.

Alley		Crotalaria	Jack bean	Pigeon pea	Velvet bean	Single maize
Ear diameter (mm)	With	3.94Ab	4.09Ab	3.97Bb	4.32Aa	4.01Ab
	Without	3.94Bc	4.05Ab	4.26Aa	3.86Bc	4.11Ab
Ear length (cm)	With	15.7Ab	15.6Ab	17.1Ba	14.9Ab	14.8Bb
	Without	14.1Ac	16.2Ab	18.5Aa	13.6Ac	16.3Ab

Mean values followed by the same uppercase letter in the columns and lowercase letter on the rows do not differ by Skott-Knott test at 5% probability.

Table 6. Mean total productivity and commercial productivity of husked maize cobs (kg ha^{-1}), as a function of intercropping with *Crotalaria juncea*, pigeon pea, jack bean, velvet bean and in the single maize crop, with and without alley cropping.

Alley		Crotalaria	Pigeon pea	Jack bean	Velvet Bean	Single Maize
Total husked cob productivity (kg ha^{-1})	With	8.788.4Aa	8.098.0Aa	7.126.3Aa	7.353.6Aa	7.421.0Ba
	Without	6.221.8Ab	6.957.0Ab	8.607.0Aa	3.806.2Bc	9.259.6Aa
Commercial cob productivity (kg ha^{-1})	With	5.600.04Aa	4.285.37Ab	5.299.42Ba	4.062.00Ab	3.279.37Bb
	Without	4.357.91Ab	3.978.51Ab	7.412.44Aa	1.333.00Bc	8.013.58Aa

Mean values followed by the same uppercase letter in the columns and lowercase letter on the rows do not differ by Skott-Knott test at 5% probability.

Table 7. Mean values for pH, phosphorus (P) and potassium (K) in the 0-20 cm soil layer, in the first (2016) and second (2017) crop of maize intercropped with herbaceous legumes and alleys (M+L+A), of maize and alleys (M+A), of maize intercropped with herbaceous legumes (M+L) and of a single maize crop (SM).

Treatment	1st year (2016)			2nd year (2017)		
	pH	P	K	pH	P	K
		mg dm^{-3}			mg dm^{-3}	
M+L+A	5.6	9.4	25	5.6	15.9	36
M+A	5.1	6.6	21	5.7	9.4	33
M+L	5.3	10.5	23	5.7	14.7	40
M	5.8	7.1	23	6.4	16.5	42

Treatments: M+L+A = maize intercropped with legumes in alleys; M+A = single maize crop in alleys; M+L = maize intercropped with legumes with no alleys; and, M = single maize crop.

alleys favoured greater total (9,259.6 kg ha^{-1}) and commercial productivity (8,013.58 kg ha^{-1}) of husked cobs, showing no difference to the intercrop with jack bean. These results show that despite results close to those obtained for the single crop, there may have been competition between the legumes and the maize.

For Aguiar et al. (2010), the cultivation in a system of alleys and with green fertilization in soils of the pre-Amazon region contributes to increase crop production due to physical-chemical improvement of the soil. In the present research, the higher productivity in the cultivation of single maize may be related to plant population. The trend of the results was also verified by Madalon et al. (2016), testing different spacing in an intercrop of jack bean and maize, in which they found the intercrop influenced a reduction in maize productivity compared to maize conventionally fertilised with NPK. In relation to the chemical characteristics of the soil, each combination of legumes, maize and alleys contributed to increase soil fertility during both crops as shown in Table 7.

The pH of the soil before setting up the experiment was 4.8, 5.6 and 5.7 in the farmed area, the area with no gliricidia, and the area with gliricidia respectively as described in Tables 1 and 2. Each of the values obtained for pH after the first and second year of cultivation were therefore higher than in the farmed area as shown in Table 1; however, the area of single maize crop with no gliricidia showed a greater increase in pH, and was

Table 8. Soil organic matter (OM) in the 0-20 cm layer during the first (2016) and second (2017) years of maize intercropped with herbaceous legumes and alleys (M+L+ A), of maize and alleys (M+A), of maize intercropped with herbaceous legumes (M+L) and of a single maize crop (SM).

Treatment	1st year (2016)	2nd year (2017)
	OM (dag kg^{-1})	
M+L+A	1.3	1.8
M+A	1.1	1.0
M+L	1.2	1.1
M	1.2	1.1

Treatments: M+L+A = maize intercropped with legumes in alleys; M+A = single maize crop in alleys; M+L = maize intercropped with legumes with no alleys; and, M = single maize crop.

higher than verified before planting. Furthermore, it can be seen that in the areas of intercropping (M+L+A) there was a small reduction in pH during the first (2016) and second (2017) year of cultivation, compared to values prior to the first year as presented in Table 2. As such, it was found that green manure with herbaceous and woody legumes were not enough to increase soil pH, but kept the acidity under control.

Aguiar et al. (2013) also saw higher values for pH under an alley cropping system. However, Barreto et al. (2010), testing areas under a system of alleys with gliricidia, single maize and secondary forest, at sampling depths of 0-5, 5-10, 10-20 and 20-40 cm, did not find any differences between the areas under evaluation. The phosphorus content of the soil increased under each treatment at the end of two years cultivation as presented in Table 7 in relation to the initial soil analysis before planting the maize as described in Table 2; however, during the first year there was a reduction in P levels under almost all treatments, except for the area of maize intercropped with legumes with no alleys (M+L). The levels of this element at the end of the first year of cultivation were 9.4, 6.6, 10.5 and 7.1 mg dm^{-3}, and 15.9, 9.4, 14, and 16.5 mg dm^{-3} at the end of the second year, under the M+L+A, M+A, M+L and M treatments respectively as shown in Table 2. The results show that the intercrop of maize with herbaceous legumes has a positive influence on P levels in the soil, and results in a greater capacity for releasing phosphorus adsorbed from the soil. The values for P obtained at the end of the second year were reflected in the productive performance of the maize, increasing productivity in areas of single maize and in areas with alleys of gliricidia, and although the greatest increase in P was seen in areas with no alleys, in the intercropped area with alleys (M+L+A), P remained at the same value seen at the beginning of the first year of cultivation, even with the nutrient exported for maize production and assimilated by the legumes. According to Aguiar et al. (2013), no-tillage under alley cropping increases the phosphorus content of the soil. It should also be emphasised that the levels of phosphorus influenced cob productivity. As such, Silva et al. (2014) point out that the levels of nitrogen and phosphorus in the soil are essential for increasing maize productivity.

For the potassium content, as seen with the phosphorus content, there was a reduction in the levels of the nutrient during the first year of cultivation; this could have occurred due to the lack of K fertilisation, and a part of what was in the soil being assimilated by the maize and legumes. Despite the reduction in K levels in the area with alleys, the reduction was less than in the open area, which can be explained by assimilation of this nutrient in the biomass of the gliricidia. Santos et al. (2010) found that the K concentration in plots fertilised with gliricidia biomass was greater during the first year of maize cultivation than found in the control without any fertilisation, explaining the accumulation of this nutrient in the biomass of the legume. During the second year of cultivation, K levels were higher in relation to the first year of cultivation, possibly influenced by decomposition of the plant biomass increasing the levels of the element in the soil. Agreeing with this result, Santos et al. (2010) found no difference in potassium content during the second year of cultivation between the treatments under study.

When considering the initial organic matter content of the soil (0.7 dag kg^{-1}, as presented in Table 1), it can be seen that the greatest accumulation during two years of cultivation was under the M+L+A treatment as shown in Table 8. This is probably due to the greater contribution of plant residue at the soil surface as illustrated in Table 8. However, irrespective of treatment, the organic matter content of the soil recorded at the end of the first and second years of cultivation was greater than the value seen before setting up the experiment as seen in Table 1. Similar results were seen by Loss et al. (2010), who found that OM is affected by the type of management in the area, where a greater amount of straw on the surface of the soil promotes increases in the levels of OM. In this sense, the results demonstrate the importance of the system of cultivation in alleys and of the green manure in the construction of soil fertility in the northern region of Brazil, especially in the savannah areas of Roraima. Moreover, the results express the importance of the use of agroecological practices in the maize cultivation system.

Conclusion

Intercropping maize with jack bean increases the diameter and length of the maize cobs in areas with and without alley cropping. The alley system increases the total and commercial productivity of husked cobs in maize intercropped with velvet bean. Intercropping maize with legumes under an alley system helps to increase the levels of phosphorus and potassium in the soil. Irrespective of the type of intercrop, green manure with legumes increases the soil organic matter content of agricultural land in Roraima.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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