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Cover crops in coffee management in production

Manejo de plantas de cobertura em cafeeiros em produção

Cultivos de cobertura en el manejo del café en producción

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Kleso Silva Franco Júnior
ORCID: https://orcid.org/0000-0002-6807-8889
Centro Superior de Ensino e Pesquisa de Machado, Brasil
E-mail: kleso.jr.agro@gmail.com
Ligiane Aparecido Florentino
ORCID: https://orcid.org/0000-0002-6807-8889
Universidade José do Rosário Vellano, Brasil
E-mail: ligiane.florentino@unifenas.br
Ana Beatriz Carvalho Terra
ORCID: https://orcid.org/0000-0002-1912-0059
Universidade José do Rosário Vellano, Brasil
E-mail: beatriz.terra@hotmail.com
José Ricardo Mantovani
ORCID: https://orcid.org/0000-0002-9817-8143
Universidade José do Rosário Vellano, Brasil
E-mail: mantovanijr@yahoo.com
Adriano Bortolotti da Silva
ORCID: https://orcid.org/0000-0003-1316-8243
Universidade José do Rosário Vellano, Brasil
E-mail: mantovanijr@yahoo.com
Ademir Calegari
ORCID: https://orcid.org/0000-0001-8584-2132
Instituto Agronômico do Paraná, Brasil
E-mail: ademircalegari@bol.com.br
Márcio de Souza Dias
ORCID: https://orcid.org/0000-0001-8367-1341
Secretaria de Estado de Educação de Minas Gerais, Brasil
E-mail: marciodesouzadias2013@gmail.com
Ivan Franco Caixeta
ORCID: https://orcid.org/0000-0002-4117-5363
Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas, Brasil
E-mail: ivan.caixeta@ifsuldeminas.edu.br

Abstract
Cover crops between rows of coffee contributes to the promotion of a sustainable production. The objective of this work was to evaluate the improvement of the chemical and physical attributes of the soil and coffee production using cover crops between the coffee lines. This study was at Boa Esperança Farm, Serrania – MG. The experimental design consisted of randomized blocks, with 7 treatments and 4 replications: control, no cover plant, with traditional farm management (chemical and mechanical weed control); crotalaria (*Crotalária spectablis*); cuandu (*Cajanus cajan*); cowpea (*Vigna unguiculata* L. Walp.); mix of crotalaria + cuandu + cowpea; *Brachiaria brizanta* (*Urochloa brizantha*) and *Brachiaria ruziziense*s (*Urochloa ruziziense*s) as cover plants. The data were submitted to analysis of variance by the Scott-Knott test at 5% probability. Results confirm that cover crops promote cycling and nutrient accumulation in the soil, maintain a mild temperature and promoted better moisture maintenance. It also demonstrated that although the population dynamics of weeds have a positive result, only the use of cover crops is not enough for 100% weed control in the coffee crop. Besides, they have a contribution to the development and production of coffee and to reduce the phytonematoid population.
Keywords: Coffee growing; Fertility; Green manure; Sustainability.

Resumo
As culturas de cobertura nas entrelinhas de café contribuem para a promoção de uma produção sustentável. O objetivo deste trabalho foi avaliar a melhoria dos atributos químicos e físicos do solo e da produção cafeeira utilizando plantas de cobertura nas entrelinhas de café. Este estudo foi realizado na Fazenda Boa Esperança, Serrania – MG. O delineamento experimental foi de blocos casualizados, com 7 tratamentos e 4 repetições: testemunha, sem planta de cobertura, com manejo tradicional da fazenda (controle químico e mecânico de plantas daninhas); crotalaria (*Crotalária spectablis*); guandu (*Cajanus cajan*); feijão caupi (*Vigna unguiculata* L. Walp.); mistura de crotalaria +

guandu + geijão-de-corda; *Brachiaria brizanta* (*Urochloa brizantha*) e *Brachiaria ruzizienses* (*Urochloa ruzizienses*) como plantas de cobertura. Os dados foram submetidos à análise de variância pelo teste de Scott-Knott a 5% de probabilidade. Os resultados confirmam que as plantas de cobertura promovem a ciclagem e acúmulo de nutrientes no solo, mantêm uma temperatura amena e promovem melhor manutenção da umidade. Demonstrou também que embora a dinâmica populacional de plantas daninhas tenha um resultado positivo, apenas o uso de plantas de cobertura não é suficiente para 100% de controle de plantas daninhas na lavoura cafeeira. Além disso, contribuem para o desenvolvimento e produção do café e para a redução da população fitonematóide.
Palavras-chave: Cafeicultura; Fertilidade; Estrume verde; Sustentabilidade.

Resumen
Los cultivos de cobertura entre hileras de café contribuyen a la promoción de una producción sostenible. El objetivo de este trabajo fue evaluar el mejoramiento de los atributos químicos y físicos del suelo y la producción de café utilizando cultivos de cobertura entre líneas de café. Este estudio fue en la Hacienda Boa Esperança, Serrania – MG. El diseño experimental consistió en bloques al azar, con 7 tratamientos y 4 repeticiones: testigo, planta sin cobertura, con manejo tradicional de finca (control químico y mecánico de malezas); crotalaria (*Crotalária spectablis*); guandú (*Cajanus cajan*); caupí (*Vigna unguiculata* L. Walp.); mezcla de crotalaria + guandu + caupí; *Brachiaria brizanta* (*Urochloa brizantha*) y *Brachiaria ruzizienses* (*Urochloa ruzizienses*) como plantas de cobertura. Los datos fueron sometidos a análisis de varianza por la prueba de Scott-Knott al 5% de probabilidad. Los resultados confirman que los cultivos de cobertura promueven el ciclo y la acumulación de nutrientes en el suelo, mantienen una temperatura suave y promueven un mejor mantenimiento de la humedad. También demostró que si bien la dinámica poblacional de malezas tiene un resultado positivo, solo el uso de cultivos de cobertura no es suficiente para el control de malezas al 100% en el cultivo de café. Además, tienen un aporte al desarrollo y producción de café y a la reducción de la población fitonematoide.
Palabras clave: Cultivo de café; Fertilidad; Abono verde; Sustentabilidad.

1. Introduction

Currently, there is a great concern regarding sustainable food production, considering both the necessity to increase agricultural production and the society's demand, based not only on the environment but also on the social and economic aspects (Asmus et al., 2014). There are several reports from the Intergovernmental Panel on Climate Change - IPCC (2007) that have been alerting to the prediction of global warming, especially the rise of earth temperature and changes in rainfall in tropical regions.

According to Venturin et al. (2103), regarding coffee planting, confirming the predictions about climate change, the exploration areas will be reduced, leading to large losses. Data from the UN report on climate change estimate that there will be a large reduction in coffee cultivation in major producing states in Brazil, such as Minas Gerais and São Paulo.

Camargo (2010) reported that rising global temperatures could reduce areas suitable for coffee cultivation up to 50% in the world over the next thirty years, highlighting that wild coffee, still existing in African forests, may disappear over the next seven decades, extinguishing genetic material essential to research and breeding that seeks better climate adaptation and quality, greater resistance to pests and diseases, and other favorable characteristics.

Looking for alternatives to minimize these negative impacts on national coffee production, researchers have been working with various methods and, among these, is the use of cover plants intercropped with coffee. Pacheco et al. (2011) stated that cover plants can protect soil from the action of rain and wind in the off-season of economically exploited crops. Generally, species belonging to the Fabaceae family are cultivated. Besides protecting the soil, they also have the capacity for biological nitrogen fixation. These species produce easily decomposed organic matter concerning grasses and are also great green manure.

According to Lima Filho et al. (2014), the use of cover crops as green manure aims to cultivate rotating plant species or intercrop with economically exploited crops. These plants can be incorporated into the soil or mowed and kept on the surface, improving the chemical, physical, and biological characteristics. On the other hand, according to Cavalcante et al.

(2012) and Pereira et al. (2017) cover crops integrated with existing cropping systems generally incurs extra costs, such as seed, agrochemicals, extra labor, and management skill.

Plants intercropped with coffee can contribute to the physical, chemical, and biological characteristics of the soil (Souza et al., 2013) increasing its biodiversity with a positive effect on reducing phytonematoids.

Kubo et al. (2013), explain that certain Brachiaria species such as *Tagetes patula*, contribute to the reduction of populations of some phytonematoid species such as *R. similis, Pratylenchus* spp., *M. incognita*, and *H. multicinctus*. If only *M. incognita* occurs in the area, an alternative is the cultivation of *Crotalaria spectabilis*, which has good control for this species.

Therefore, considering the concern with climate change that may negatively impact coffee growing and the search for practices that minimize these environmental impacts, the objective of this work was to evaluate the improvement of the chemical and physical attributes of the soil and coffee production using cover crops between the coffee lines.

2. Methodology

The experiment was carried out at Fazenda Boa Esperança, located in the city of Serrania, Southern Minas Gerais, from october / 2016 to december / 2018, with the geographical coordinates: Latitude: 21°36'18.29" S, Longitude: 46°07'46.29" O and altitude of 982 m.

The soil is characterized as Red Yellow Latosol and, according to granulometric analysis results, has an average texture with 28% clay, 43% sand, and 29% silt, that is, type 2 (Santos et al., 2018). the selected coffee plot is grown with Catuaí Vermelho IAC 144 (*Coffea arabica*), planted in 2011, spaced 3.5 m between rows and 0.7 m between plants, totaling 4.081 plants ha^{-1}.

The experimental design was randomized blocks, composed of 7 treatments and 4 replications: control, with traditional farm management and no cover plant (chemical and mechanical weed control); crotalaria (*Crotalária spectablis*); cuandu (*Cajanus cajan*); cowpea (*Vigna unguiculata* L. Walp.); mix of crotalaria + cuandu + cowpea; *Brachiaria brizantha* (*Urochloa brizantha*), and *Brachiaria ruzizienses* (*Urochloa ruzizienses*) as cover plants. Totaling 28 experimental plots. Each plot of the experiment consisted of 14 plants, being considered a useful plot the 10 central plants for evaluation.

The sowing was done with a manual *matraca* planter, with 3 rows between the coffee lines, 50 cm from the coffee canopy projection and spaced 50 cm. It was done in the first year in actober 2016 and managed until april 2017, when all the plants had already flowered, then it was mowed with an ecological brushcutter, directing the biomass to the projection of the coffee canopy. In october 2017, the cover plants were sown again and mowed in april 2018.

Planting densities of cover crops were 10kg.ha^{-1} for crotalaria (*Crotalaria spectablis*), cowpea (*Vigna unguiculata* L. Walp.), and *Brachiaria brizantha* (*Urochloa brizantha*); 20 kg.ha^{-1} for guandu (*Cajanus cajan*); mix of grotalaria (8 kg.ha^{-1}) + guandu (16 kg.ha^{-1}) + cowpea (6 kg.ha^{-1}) and 12kg / ha^{-1} for *Brachiaria ruzizienses* (*Urochloa ruzizienses*).

To make the mix, all seeds were mixed before sowing. All plots received the same treatments phytosanitary (fungicidal) and nutritional (350 kg.ha^{-1} of N, 75 kg.ha^{-1} of P_2O_5 and 350 kg.ha^{-1} of K_2O and B, Zn).

Before mowing, the phytosociological survey was also carried out in the plots, sampling the weeds through an area of 1,0 m^2, randomly released 3 times, according to recommendations of Partelli et al. (2010). The following phytosociological parameters were analyzed: Relative density, which indicates the participation of each species concerning the total number of plants present in the study area. Relative abundance or Relative Dominance (DoR) which expresses the percentage of the basal area of a given species (gi) concerning the basal area of all sampled species (G), the sum of the individual basal areas, both calculated per unit area.

The parameter importance Value Index (IVI) was also determined, which represents the index that characterizes the importance of each species in the community in horizontal analysis. To obtain this value, the results of the three parameters mentioned above are summed. These parameters, according to Pitelli (2000), are considered the most relevant in a phytosociological survey.

The cover plants were kept in the area from october 2016 to april 2017, at which time they were mowed and kept on the coffee line, repeating the same management from october 2017 to april 2018. In april, the survey of biomass production, according to the methodology of Cavalcante et al. (2012) was done, when it was evaluated in $1m^2$ the biomass production of the cover crops collected and analyzed the green mass and dry mass, after dehydrated in a forced air circulation oven at 70 °C. After drying, the material was subjected to analysis of nutrient levels in plant tissue in the plant drying laboratory of CESEP - Higher Education and Research Center – Machado / MG.

In october 2018 soil samples were taken from the 0 -10 cm and 10 - 20 cm layers to perform fertility analysis, soil moisture was determined using the gravimetric method, the most recommended, consisting of soil sampling and verification of weight, determining moisture through gravimetry, relating the water mass to the mass of solids of the samples, ie, it relates the volume of water contained in the sample to the volume of soil (EMBRAPA, 1997).

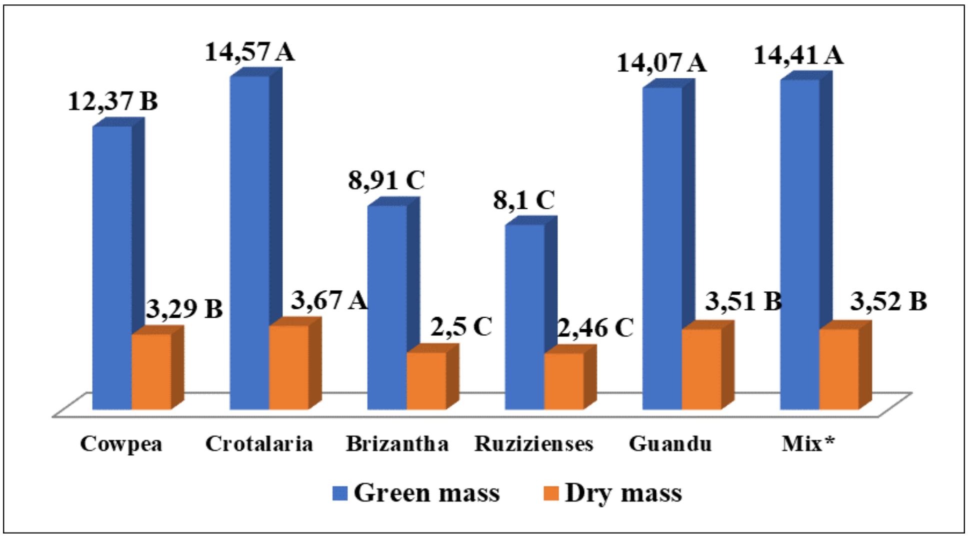
The soil temperature was followed with weekly measurements at 1 pm, during the research, using an infrared thermometer (EMBRAPA, 2011). To evaluate yield, 10 plants from each plot were harvested and, the coffee was measured, dried, and processed, and later classified and graded on sieves above 16 to determine the coffee percentages (BRASIL, 2003). For surveys on the nematode population, were collected soil and root samples under the coffee canopy at 25 cm depth, where a higher concentration of roots occurs, and after identifying the samples, they were sent to the nematology laboratory. This methodology is recommended to determine and quantify nematodes according to Salgado et al. (2011).

The results were submitted to analysis of variance and comparison of means made by the Scott-Knott test at 5% probability, both using the SISVAR® software (Ferreira, 2014).

3. Results and Discussion

Regarding the biomass of the cover plants (Figure 1), the behavior of the plants of the genus *Urochloa* had no statistical differences.

Figure 1 - Average weight of cover crops grown between rows of coffee in tons per hectare^{-1}**.** *MIX crotalária, guandu e cowpea). ** Means followed by equal letters do not differ significantly from each other by the Scott-Knott ao nível de 5 % de probabilidade. CV 21,34%.



Source: Authors

However, the area cultivated with crotalaria showed high values of dry and green matter, followed by mix and guandu, which were statistically equal. The achieved yields are lower than those reported in the literature, where we have green and dry mass yields of 20 to 30 (t. ha^{-1}) and 4 to 6 (t. ha^{-1}) for crotalaria, 20 to 55 (t. ha^{-1}) and 12 to 16 (t. ha^{-1}) for *Ruzizienses*, 12 to 45 (t. ha^{-1}) and 3 to 12 (t. ha^{-1}) to the guandu respectively (Calegari, 2016). Probably due to the influence of coffee plants, as Calegari (2016) reports these data in a single system. Melloni et al. (2013), found that intercropping led to a lower rate of weed biomass increment which, in this work, is represented by cover crops. Table 1 shows the nutrient extraction by plants grown in intercropping with coffee.

Table 1 - Input of accumulated nutrients in dry mass cover crops cultivated between coffee lines (ha^{-1}).

Treatments	N	P	K	Ca	Mg	S	Zn	B	Mn	Cu
	Kg	**Kg**	**Kg**	**Kg**	**Kg**	**Kg**	**gr**	**gr**	**gr**	**gr**
Cowpea	86,8C	7,2C	43,4C	32,5C	9,2A	4,2B	78,5B	95,0B	403,6B	56,1A
Crotalaria	128,4A	11,3A	69,7B	44,7 A	9,5A	5,5A	110,1A	115,1A	496,3A	45,4A
Brizantha	30,0 D	6,5C	40,0C	22,2 D	7,2C	2,5AC	59,6B	38,4D	279,3C	19,6B
Ruzizienses	25,0 D	6,1C	34,4D	16,7 E	8,8B	3,2C	67,0B	20,6D	253,7C	20,9B
Guandu	101,7B	8,4B	66,6B	41,7 B	9,8A	5,2A	82,4A	67,8C	406,9B	49,5A
Mix *	127,0A	11,9A	73,9A	33,0C	7,3C	5,2A	88,2A	99,0B	418,5B	53,2A
CV (%)	22,45	13,77	12,66	18,53	8,33	5,33	16,58	20,71	18,65	8,17

* Mix (crotalaria, guandu and cowpea). ** Means followed by equal letters do not differ significantly by the Scott-Knott test at the 5% probability. Source: Authors.

Analyzing these results, as expected, *Fabaceae* accumulate higher N contents, especially crotalaria and the plant mix, with 128.45 and 127.07 kg per hectare respectively, while the *Poaceae* presented a lower efficiency. Pittelkow et al. (2012), obtained different results which Bachiaria showed a large accumulation of N.

Regarding P and K, there was a similar behavior among the plants, with emphasis again on crotalaria and the plant mix. According to Pereira et al. (2010), the use of cover plants increases the levels of organic matter, providing a lower phosphorus adsorption to the soil and, consequently, improving the absorption by plants mainly in the Cerrado biome.

For calcium, crotalaria and guandu showed better efficiency, therefore for magnesium, there was no statistical difference. For the sulfur element, Fabaceae also presented higher accumulation capacity with the plant mix.

Concerning micronutrients, the plants surveyed showed similar Zn, B, and Mn accumulation. For Copper, cowpea, guandu and plant mix accumulated higher contents, while *brizantha* and *ruzizienses* showed lower efficiency. Covering plants influenced, in several parameters, the behavior of spontaneous plants (Table 2). Although the phytosociological parameters are according to Pitelli (2000), this work focused on assessing Relative D. (Relative Density) or Relative Dominance (DoR). There was a reduction in the density of spontaneous plants (Table 2), especially in the treatments with crotalaria, cocktail, and *brizantha*, which showed better action in difficult-to-control plants, such as bougain and bitter including glyphosate resistance.

In the preliminary evaluation, 10 species of spontaneous plants were observed: brachiaria (*Urochloa* sp), trapoeraba (*Commelina* spp), picão preto (*Bidens pilosa*), buva (*Conyza bonariensis*), capim pé de galinha (*Eleusine indica*), gengibre (*Digitaria insularis*), guanxuma (*Sida* spp), poaia (*Richardia brasiliensis*), maria pretinha (*Solanum americanum*,) and picão branco (*Bidens pilosa*); being the *Bidens pilosa*, the Brizantha and the Eleusine indica the plants that stood out with the highest DoR. According to this parameter, Correia and Durigan (2010) noted that the incidence of spontaneous plants such as *Commelina* spp, *Eleusine indica*, *Bidens pilosa*, and *Conyza bonariensis* had the highest relative abundance indices, characterizing that the use of mowing and glyphosate contribute to the persistence of these herbs.

The results of the phytosociological survey on *Cajanus cajan* plots in the first and second year of project implementation demonstrate their influence on the behavior of spontaneous plants. In the first year, in the plots cultivated with guandu, among the spontaneous plants that presented relative density, we highlight the brizantha, *Commelina* spp, and the *Bidens pilosa*.

There is also a great allelopathic efficiency on the *Eleusine indica*, and *Solanum americanum* considering that there was a 100% suppression on these herbs. Different results were found by Ferreira (2011), who states that in the plots where the guandu bean (*Cajanus cajan*) was planted as green manure, six species found in greater quantity had a similar index. However, *Ageratum conyzoides* stood out with IVI close to 60, while the others stood at 50. Concerning *Solanum americanum*, its suppression probably occurred due to shading, corroborating with studies by Guimarães et al. (2014), who concluded that small seeds of pepper and other *Solanaceae* require light occurrence to break dormancy and consequently germination and development.

Table 2 also shows that there was a greater change in the population dynamics of weeds when grown with crotalaria compared to guandu. A large allelopathic effect is observed mainly on *Commelina* spp, *Conyza bonariensis*, *Eleusine indica*, and *Solanum americanum*, with 100% suppression in the two years of the experiment. It is observed that the other weeds showed prominence for *Eleusine indica* and *Sida* spp., corroborating with Monqueiro et al. (2009), who mentions that green manure may cause changes in the weed population due to allelopathic effects and competition for light, water, oxygen, and nutrients, leading to the suppression of some of them.

The use of Cowpea in the 2 years of the research altered the population dynamics of spontaneous plants, especially brizantha and picão preto, with higher density, and total suppression of maria pretinha and the litter in the first year, also there was a reduction of brizantha (Table 2), but it was observed a high index analyzed for the black prick in the second year, besides the return of the suppressed herbs in the previous year.

Table 2 - Population dynamics of spontaneous weeds between coffee lines (density - plants/m^2).

	Braquiárias	***Trapoeraba***	***Buva***	***Amargoso***	***Pé de Galinha***	***Guanxuma***	***Poaia***	***Maria Pretinha***	***Mentrasto***	***Picão***
Implantation*	12,75	8,15	14,5	15,25	9,75	8,5	4,75	5,5	7,00	13,85
Control[1]	10,4	7,14	12,3	18,2	10,76	8,4	4,1	6,7	6,5	15,5
Control[2]	10,4	7,14	12,3	18,2	10,76	8,4	4,1	6,7	6,5	15,5
Crotalária[1]	21,2	0	0	19,3	0	16,2	13,5	0	12,6	17,2
Crotalária[2]	18,5	16,4	0	14,5	0	12,2	11,1	0	11,7	15,6
Guandu[1]	8,9	13,4	12,1	11,4	0	11,2	6,6	0	18	18,4
Guandu[2]	15,5	10,2	12,5	9,5	6,7	9,8	11	0	8	16,8
Cowpea[1]	20,6	8,5	6,9	11,2	6,6	11,2	8,8	0	0	26,2
Cowpea[2]	15,2	9,9	11,2	5,3	5,4	6,1	3,3	6,2	9,2	28,2
Mix[1]	21,1	15,4	11,5	0	10,9	0	0	0	11,2	29,9
Mix[2]	19,5	0	0	17,5	0	16,4	0	0	18,2	28,4
Brizantha[1]	19,4	10,2	11,2	0	7,4	18,8	0	6,6	8,9	17,5
Brizantha[2]	14,5	0	20,5	0	9,9	0	12,2	0	11,9	31
Ruzizienses[1]	11,2	14,4	5,2	4,4	8,7	6,9	5,8	12,8	4,6	26
Ruzizienses[2]	23,5	10,5	6,5	5,5	12,5	11,75	15	3	6,25	5,5

D. Relative (Relative Density). [1]first year of management with cover crops, [2] second year of management with cover crops. Crotalaria (*Crotalária spectabilis*), Guandu (*Cajanus cajan*), Cowpea (*Vigna ungulata*), Mix (Crotalaria, Guandu and Cowpea), Brizanta (*Urochloa brizantha*), Ruzizienses (*Urochloa ruzizienses*) * implementation (time of research installation). Source: Authors.

This return, although in small indices, possibly occurred due to the large accumulation of seed bank in the soil, and according to Machado et al. (2011), the genus to which *Brizantha* belongs presents a large production of biomass throughout the year, growing well even in soils with low fertility as being resistant to pests and diseases.

The results obtained by using *Brachiaria ruzizienses* as a cover plant and the population dynamics of weed plants indicate that there was an inverse change in the population dynamics of *brizantha* and *picão preto*, allowing a higher density from the first to the second year of research, the opposite being true for the black prick, which showed a significant decrease. *capim pé de galinha*, *guanxuma* and *poaia* have an increase in this index and the opposite for *maria pretinha*. These results obtained with the planting of *Brachiaria ruziziensis* probably occurred because this species had a slow initial growth, but Gimenes Jr et al. (2011), stated that this species stands out for its great competition capacity, promoting full soil cover, producing a satisfactory dry biomass and with significant weed suppression power, a fact not confirmed in this research.

Analyzing the influence of *brizantha*, it promoted a greater effect in the first year of cultivation on the total suppression of *poaia* and the bitter grass (*Digitaria insularis*). In the second year, the bitter grass was absent and all the *guanxuma* and *maria pretinha* were suppressed, although *poaia* reemerged. According to Borges et al. (2014), the cultivation of cover crops contributes to the reduction of spontaneous plants, changing the population dynamics and plant diversity, allowing a better management of species that present difficulties in their control.

The previous results show that when it is used a cover plant mix, it had better control in the population dynamics of weed. This is probably because cover plants have different allelopathic effects. Moreover, when mixed, spontaneous weeds compete with plants that develop and produce green and dry mass in a specific way, contributing to the control of a larger number of species. Table 3 shows the influence of cover crops on soil cycling and nutrient accumulation when compared to the control treatment.

Table 3 - Population dynamics of spontaneous weeds between coffee lines (density - plants/m^2).

	Braquiárias	*Trapoeraba*	*Buva*	*Amargoso*	*Pé de Galinha*	*Guanxuma*	*Poaia*	*Maria Pretinha*	*Mentrasto*	*Picão*
Implantation*	12,75	8,15	14,5	15,25	9,75	8,5	4,75	5,5	7,00	13,85
Control[1]	10,4	7,14	12,3	18,2	10,76	8,4	4,1	6,7	6,5	15,5
Control[2]	10,4	7,14	12,3	18,2	10,76	8,4	4,1	6,7	6,5	15,5
Crotalária[1]	21,2	0	0	19,3	0	16,2	13,5	0	12,6	17,2
Crotalária[2]	18,5	16,4	0	14,5	0	12,2	11,1	0	11,7	15,6
Guandu[1]	8,9	13,4	12,1	11,4	0	11,2	6,6	0	18	18,4
Guandu[2]	15,5	10,2	12,5	9,5	6,7	9,8	11	0	8	16,8
Cowpea[1]	20,6	8,5	6,9	11,2	6,6	11,2	8,8	0	0	26,2
Cowpea[2]	15,2	9,9	11,2	5,3	5,4	6,1	3,3	6,2	9,2	28,2
Mix[1]	21,1	15,4	11,5	0	10,9	0	0	0	11,2	29,9
Mix[2]	19,5	0	0	17,5	0	16,4	0	0	18,2	28,4
Brizantha[1]	19,4	10,2	11,2	0	7,4	18,8	0	6,6	8,9	17,5
Brizantha[2]	14,5	0	20,5	0	9,9	0	12,2	0	11,9	31
Ruzizienses[1]	11,2	14,4	5,2	4,4	8,7	6,9	5,8	12,8	4,6	26
Ruzizienses[2]	23,5	10,5	6,5	5,5	12,5	11,75	15	3	6,25	5,5

D. Relative (Relative Density). [1]first year of management with cover crops, [2] second year of management with cover crops. Crotalaria (*Crotalária spectabilis*), Guandu (*Cajanus cajan*), Cowpea (*Vigna ungulata*), Mix (Crotalaria, Guandu and Cowpea), Brizanta (*Urochloa brizantha*), Ruzizienses (*Urochloa ruzizienses*) * implementation (time of research installation). Source: Authors.

It is verified that statistical differences occurred for all analyzed parameters when compared with the control treatment. Regarding organic matter (OM), the cover plants mix presented higher accumulation capacity. The highlight for the mix is due to the diversity of plants accumulating a relatively high amount of biomass and, in the treatments with brachiaria, it occurs because the grasses usually have a higher C / N (Carbon / Nitrogen) ratio, providing a slower waste decomposition, and allowing better conditions for the accumulation of OM, besides stimulating the increment of soil microorganisms (Presotto et al., 2014).

Besides the many benefits promoted by increasing soil OM, it is interesting to note the economic aspect due to the lower demand for synthetic N. According to Maluf et al. (2015), decomposition of crop residues is directly proportional to the contents of N and water-soluble extracts, and the mineralized amount is directly proportional to their respective initial residue content.

For Phosphorus (P), compared to the control treatment, there are statistical differences, promoting an increase in absorption, although there was no significant difference between the different cover plant species analyzed, but the experiment demonstrates the great capacity of these plants to promote the cycling of this nutrient. These results corroborate the works of Casali et al. (2016), who stated that species of cover crops have a great capacity for absorption and accumulation of P, and that the release of P from waste directly depends on the amount of P existing in plant tissues, proving the great contribution of cover crops in promoting a more balanced agriculture.

Regarding potassium (K), statistical differences occurred, demonstrating that some cover plants have higher efficiency in the cycling of this nutrient. Brachiaria was the most efficient for this element, confirming research by Pacheco et al. (2013). Torres et al. (2008) also verified higher K accumulations by grasses, compared to legumes.

Concerning calcium (Ca), Crotalaria, *Brizantha*, and plant mix presented a higher capacity to accumulate this nutrient. Magnesium (Mg) had no statistical differences among the studied plants, but it is interesting to mention that for Mg, the accumulation maintained the ratio close to 1:3 compared to Ca. These results were different from those presented by the works of Pacheco et al. (2013), which although presenting good cycling of these elements, the relationship between Ca^{+2} and Mg^{+2} was narrowed to just over 1:1.

The increment in the sum of bases (SB) was proportional to the increase of the elements that make up this parameter. For soil cation exchange capacity (CTC), Ronquim (2010) states that the CTC of a soil, clay or humus represents the total amount of surface-retained cations of these materials that can be replaced or exchanged, and is obtained in tropical soils by the sum of the elements: Ca^{2+} + Mg^{2+} + K^{+} + H^{+} + Al^{3}, therefore, in this research it is verified the occurrence of statistical variation, except for Cowpea and *B. ruziziensis*, which were close to the control. The other cover plants showed an approximate efficiency in raising this parameter, considering the increment in the bases promoted by cover plants.

Considering base saturation (V%), which is the sum of exchangeable bases expressed as a percentage of cation exchange capacity, except for Cowpea there were statistical differences for the other cover crops, noting that Brizantha and the plant mix increased the value of V (%) to the ideal range of coffee demand, ie, raised it to more than 60%.

Analyzing Aluminum saturation (m%), only cowpea did not show efficiency in its decrease, being close to the control plot. Although these plants contributed to the decrease of m%, the same effect was not observed in the decline of hydrogen plus aluminum (H + Al), where only brachiaria and the plant mix reduced these soil contents. Table 4 shows the results obtained for the influence of cover crops on the 10 to 20 cm depth profile.

Table 4 - Results of soil analysis 1.

Treatments	**MO**	**P**	**K**	**Ca**	**Mg**	**SB**	**CTC**	**V**	**m**	**H + Al**
	%	mg dm^{-3}	mg dm^{-3}	cmolc dm^{-3}	cmolc dm^{-3}	cmolc dm^{-3}	cmolc dm^{-3}	%	%	cmolc dm^{-3}
Implantation***	2,54	6,48	94,3	2,42	0,68	3,33	10,3	32,6	34,67	6,96
Control	2,37C	11,70C	104,25B	2,52 C	0,62 B	3,41 D	7,59 B	45,13 C	7,29A	4,17 A
Cowpea	2,52C	16,45B	102,75B	2,86 B	1,10 A	4,22C	8,62 A	49,06 B	3,43B	4,40 A
Crotalária	3,10A	19,10A	117,75A	3,65 A	1,25 A	5,20 A	9,25 A	56,31 A	1,92B	4,05 A
Brizantha	3,00A	18,32A	114,25A	3,32 A	1,12 A	4,74 B	8,09 B	58,58 A	2,08B	3,35 B
Ruziziennses	2,77B	16,92B	104,00B	3,07 B	1,22 A	4,56 B	7,94 B	57,55 A	0,52B	3,37 B
Guandu	2,85B	17,72B	117.75A	3,27 A	1,05 A	4,62 B	9,16 A	50,57 B	2,12B	4,53 A
Mix*	3,17A	20,22A	126,50A	2,92 B	0,87 B	4,12 C	7,10 B	58,12 A	2,34B	2,97 B
CV (%)	6,21	8,34	10,65	6,45	9,72	4,49	6,30	8,23	16,66	12,88

0-20 cm in coffee cultivated with cover crops * Mix (Crotalária, Guandu e Cowpea). ** Means followed by equal letters do not differ significantly by the Scott-Knott test at the 5% probability. ***Implantation (time of research installation). Source: Authors.

There is a potential for cycling and nutrient accumulation presented by the cultivation of cover plants intercropped with coffee, in the layer of 10 to 20 cm deep (Table 4). Crotalaria, brizantha and plant mix showed higher efficiency in the accumulation of organic matter to the soil, corroborating with Andrade et al. (2009). Salton and Tomazi (2014) also cited that "one of the main benefits of grass for soil is the accumulation of organic matter in-depth".

Concerning Phosphorus, significant differences were observed, especially crotalaria, brizantha and plant mix with higher efficiency in nutrient cycling. Cowpea, *Brachiaria ruzizienses* and Guandu also presented better results than control, confirming works by Salton and Tomazi (2014), who mentioned that brachiaria developed throughout the year, constantly renewing its roots, allowing the incorporation of biomass from its plants roots, contributing to the improvement of chemical conditions and increasing the efficiency of plant to use phosphate, and also Ragassi et al. (2013), who stated that the brachiaria is rich in associations with soil microorganisms, such as mycorrhizal fungi that increase phosphorus absorption.

The cowpea and *Brachiaria ruzizienses* showed no significant difference with the control treatment in potassium mobilization, and the crotalaria, brizantha, guandu, and plant mix presented a small difference, but superior to the control. For Ca and Mg changes in proportions occur, sometimes narrowing and sometimes widening this relation, unlike the results found in the 0 to 10 cm deep layer. Crotalaria, brizantha and guandu were more significant concerning Ca for Mg.

The results for the parameter sum of bases (SB) presented statistical differences mainly due to the cycling of the elements Ca, Mg, and K, that compose this parameter. Crotalaria presented higher efficiency, followed by brachiaria, guandu, Cowpea, and plant mix.

Adding the H^{+} + Al^{+3} to the SB, which gives the CTC result, there are statistical differences, highlighting the cowpea, crotalaria and guandu with the best efficiency for this attribute. Even at this depth layer, the base saturation (V%) had an increase, although not reaching 60%. Crotalaria, *B. brizantha*, *Brachiaria ruziziensis*, and the mix reached V% of 56.31, 58.58, 57.55, and 58.12, respectively.

Aluminum saturation was reduced for all treatments, with efficiency equal to all cultivated species. The mix of cover crops and brachiaria were more efficient in reducing H + Al in the 10 to 20 cm layer.

The use of cover crops presents statistical differences regarding soil moisture conservation (Table 5).

Table 5 **-** Average of soil moisture and temperature.

Treatment	Soil moisture (%)	Temperature (°C)
Control	19,50 C	30,85 A
Cowpea	25,81 A	26,70 B
Crotalária	24,75 B	26,42 B
Brizantha	26,75 A	26,05 B
Ruzizienses	26,43 A	26,00 B
Guandu	23,81 B	26,42 B
Mix*	26,81 A	25,70 B
CV (%)	3,55	5,68

*Mix (Crotalária, Guandu e Cowpea). **Means followed by equal letters do not differ significantly by the Scott-Knott test at the 5% probability. Source: Authors.

Crotalaria and guandu presented lower efficiency than brachiarias, cowpea, and plant mix. Regarding the Poaceae family, Carvalho et al. (2013), reported that its fast-initial development is one of the most important factors, as they rapidly cover the soil and reduce or even prevent spontaneous plant germination. They also have good drought tolerance and high biomass production.

The results corroborate with Rivero Herrada et al. (2017), who mention that the use of cover crops promotes an increase in water infiltration and, consequently, the preservation of soil moisture by minimizing the impact caused by raindrops and thus providing less influence on soil structure.

In the second column of Table 5, we observe the influence of cover crop cultivation between coffee lines on soil temperature. The statistical difference is verified proving that all the cover crops surveyed contribute equally, promoting a milder temperature in the rhizospheric region of the crop. According to Cortez et al. (2015), the ideal temperature for plants to absorb water should not exceed 32 °C, considering that, in Brazil, due to climate and uncovered soil, the temperature can reach up to 74 °C.

The authors also note that soils fully exposed to the sun favor low humidity, increasing the risk of compaction. High temperatures, associated with compaction, do not allow the proliferation of beneficial microorganisms and the absorption of water by plants, forming crusts on the soil surface, mainly clay, as the area of this research. Also, they reduce the infiltration of rainwater, leaving the root system of the plants in a shallow depth, not tolerating drought periods, negatively reflecting the development and productivity of crops.

Several studies have shown the contribution of cover crops to improve soil physical attributes, considering that Table 6 shows the results obtained concerning internode growth and coffee yield.

Table 6 - Average growth of internodes in plagiotropic branches and average productivity (2 years).

Treatment	N° internodes	Bags ha^{-1}
Control	20,75 B	32,50 B
Cowpea	25,50 A	37,46 A
Crotalária	25,50 A	38,19 A
Brizantha	25,75 A	37,70 A
Ruzizienses	25,75 A	37,23 A
Guandu	24,50 A	38,16 A
Mix**	26,50 A	38,30 A
CV (%)	4,07	4,89

Source: Authors.

All plants used promoted a statistically equal increase in the number of internodes of the productive branches of coffee. These results agree with Siqueira et al. (2009), who observed a greater growth in the height and diameter of the canopy (increase of internodes in coffee) compared to the control treatment that was grown in a single system. This shows that most plants used as cover crops besides protecting the soil, recycling, and accumulating nutrients, contribute to the development of coffee.

The same is observed in the second column of Table 6 regarding coffee yield, showing that all plants contributed to an increase in the number of bags produced per hectare. This is understandable considering that the increment in the number of internodes in the plagiotropic branches is responsible for a higher number of beans per branch and consequently a higher coffee yield per plant and per hectare. Carvalho et al. (2010), observed that coffee intercropped with lablab for 60 days showed better productivity influenced by the intercropping compared to the control. It was also verified that the accumulated production during four years of research presented statistical differences when there was the use of Fabaceae. Table 7 presents the results obtained on the influence of the plant mix on nematode population.

Table 7 - Nematode analysis results at end of Survey.

Treatments	***Meloidogyne* spp**	***Rotilenthus* spp**	***Helicotilentus* spp**
Implantation*	23,00	18,00	27,0
Control	14,50 A	18,50 A	28,50 A
Guandu	5,00 B	9,25 B	20,00 B
Crotalária	1,75 E	7,00 B	5,00 D
Cowpea	11,50 B	17,00 A	20,00 B
Mix**	3,50 D	5,50 C	6,00 D
Brizantha	7,25C	15,75 A	13,25 C
Ruzizienses	10,50B	16,50 A	23,00 A

* Composite samples of each plot at the time of research implementation. ** Mix Crotalaria, Guandu, Cowpea). *** Means followed by the same letter do not differ significantly by the Scott-Knott Test at the 5% probability. Source: Authors.

Although there are no national parameters to analyze the level of phytononematoid infestation in coffee growing, apparently there is no high population occurrence, according to the data presented in Table 7. From an infestation of 22, 15 and 17 nematodes for every 100 grams of soil/root of the species *Meloigodyne* spp, *Rotilenthus* spp, and *Helicotilencus* spp respectively, it was concluded that it did not show statistical efficiency in reducing the population of any of the 3 species surveyed, whereas in the final result the analysis showed a slight variation. This low efficiency of cowpea in relation to phytonematoids has already been explained in previous studies, in which Gardiano et al. (2012) state that cowpea proves to be a good host of nematodes, mainly *Rotilenthus* spp, being also considered as a susceptibility standard in a study by the same authors in 2014.

Brizantha showed a reduction of *Meloigodyne* spp and *Helicotilencus* spp, decreasing from 21 to 7, and from 25 to 13 nematodes to 100 grams of soil/roots, respectively. This result confirms a reference by Ragassi et al. (2013), who mention that this brachiaria decreases the population of nematodes of the genus *Meloidogyne*, for not being host to this soil pest and for presenting the ability to synthesize substances highly harmful to population increase. *Brachiaria ruziziensis* showed similar results to brizantha.

Crotalaria and the plant mix were the cover crops that showed the greatest effectiveness, drastically decreasing all phytonematoid species present in the soil. The authors Pacheco et al. (2015), working with *Crotalária juncea* (L.), stated that for being a plant with a great capacity to reduce phytomatoid infestations and considered an antagonist species to these microorganisms, it causes its death when they invade the root system.

Rosa et al. (2013) observed that the use of *Crotalária spectabilis* in an area infested with *Meloidogyne* nematodes inhibited their reproduction up to zero. Ritzinger and Francelli (2006), evaluating the nematicidal efficiency of chemical, biological and the use of *Crotalaria juncea*, alone and in combination, found no statistical differences, confirming the great potential of this species belonging to Fabaceae to control this significant pest of several cultures. Therefore, analyzing the plant mix and the results obtained with the other cover crops, it appears that the use of the plant mix has the same characteristics in the containment and control of nematodes.

Leal et al. (2012), Debiasi et al. (2016) and Giraldeli et al. (2017) stated that Crotalaria is a good option for nematode control, as it reduces by up to 80% the incidence of nematodes in areas where the legume is well-formed. Besides providing a significant improvement in the content of organic matter, expanding the biological activity of the soil, they also present the ability to synthesize allelopathic substances and a large number of proteins such as peroxidases, cysteine proteases and inhibitors of cysteine proteases, which contribute to the reduction of phytonematodes (Leal et al., 2012; Debiasi et al., 2016 and Giraldeli et al., 2017).

Therefore, the use of cover crops in coffee plantations is a sustainable practice that seeks a production of coffee combined with environmental conservation and can be adopted by small, medium and large farmers, leading to a positive response to the requests of the scientific community and for Brazilian and worldwide society.

4. Conclusion

The results confirm that cover crops promote cycling and nutrient accumulation in the soil, maintain a mild temperature and promote better moisture maintenance. They also demonstrated that, although it has a positive effect on weed population dynamics, the use of cover crops alone is not enough for effective control of weeds in the coffee crop. Besides, cover crops contribute to the development and production of coffee and assist in reducing the phytonematoid population.

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