

## **Dry matter accumulation and nutrient cycling by soil cover plants in an intensive corn silage production system**

**Acúmulo de matéria seca e ciclagem de nutrientes por plantas de cobertura de solo em sistema intensivo de produção de silagem de milho**

**Acumulación de materia seca y ciclo de nutrientes por plantas de cobertura del suelo en un sistema intensivo de producción de ensilaje de maíz**

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### **Abstract**

This study aimed to evaluate dry matter accumulation and nutrient cycling by soil cover plants in an intensive corn silage production system. At the beginning of October, a study consisting of five soil cover plants, plus a control treatment (fallow area vegetation) was installed. The following cover plants were used: brachiaria brizantha, brachiaria ruziziensis, crotalaria juncea, jack bean and velvet bean. At the beginning of February of the year following sowing, we evaluated dry matter and nutrient accumulation in plant shoots. There was a significant effect at 0.1% of the cover plants on dry matter and nutrient accumulation. The average values for dry matter accumulation in plant shoots were 19.88; 18.06; 16.38; 9.66; 8.96 and 4.26 t ha<sup>-1</sup> for brachiaria brizantha, crotalaria juncea, brachiaria ruziziensis, jack bean, velvet bean and fallow area vegetation, respectively. The highest nitrogen accumulation was observed in crotalaria juncea (343 kg ha<sup>-1</sup>), followed by jack bean (269 kg ha<sup>-1</sup>). For brachiaria brizantha and ruziziensis, N accumulation of 247 and 216 kg ha<sup>-1</sup> were found, respectively. Brachiaria brizantha had the highest accumulation of phosphorus and potassium, with average values of 39 and 362 kg ha<sup>-1</sup>. In the fallow area vegetation, the accumulations of N, P and K were 42; 9.0 and 62 kg ha<sup>-1</sup>, respectively.

**Keywords:** Feeding of ruminants; Production management; Direct seeding; Production systems.

### **Resumo**

No presente estudo foram avaliados o acúmulo de matéria seca e a ciclagem de nutrientes por plantas de cobertura de solo em sistema intensivo de produção de milho, destinado à ensilagem. No início de outubro, foi instalado o estudo constituído por cinco plantas de cobertura de solo, mais um tratamento testemunha (vegetação da área de pousio).

Foram utilizadas como plantas de cobertura de solo: braquiária brizantha, braquiária ruziziensis, crotalaria juncea, feijão de porco e mucuna-preta. No início de fevereiro do ano subsequente à semeadura, foram avaliados os acúmulos de matéria seca e de nutrientes na parte aérea das plantas. Houve efeito significativo a 0,1% para plantas de cobertura do solo sobre os acúmulos de matéria seca e de nutrientes. Os valores médios para os acúmulos de matéria seca na biomassa aérea das plantas foram 19,88;18,06; 16,38; 9,66; 8,96 e 4,26 t ha<sup>-1</sup>, respectivamente, para braquiária brizantha, crotalaria juncea, braquiária ruziziensis, feijão de porco, mucuna preta e vegetação da área de pousio. O maior acúmulo de nitrogênio foi observado na crotalaria juncea, 343 kg ha<sup>-1</sup>, seguido do feijão de porco, 269 kg ha<sup>-1</sup>. Para as braquiárias brizantha e ruziziensis foram constatados acúmulos de N de 247 e 216 kg ha<sup>-1</sup>, respectivamente. A braquiária brizantha foi a planta que mais acumulou fósforo e potássio, com valores médios de 39 e 362 kg ha<sup>-1</sup>. Nas plantas da área de pousio, os acúmulos de N, P e K foram, respectivamente, de 42; 9,0 e 62 kg ha<sup>-1</sup>.

**Palavras-chave:** Alimentação de ruminantes; Gerenciamento da produção; Semeadura direta; Sistemas de produção.

### Resumen

En el presente estudio se evaluó la acumulación de materia seca y el ciclo de nutrientes por plantas cubresuelos en un sistema intensivo de producción de maíz, destinado a ensilaje. A principios de octubre se instaló el estudio compuesto por cinco plantas cubresuelos más un tratamiento de control (barbecho vegetal). Como plantas de cobertura del suelo se utilizaron: brachiaria brizantha, brachiaria ruziziensis, crotalaria juncea, canavalia y frijol terciopelo. A principios de febrero del año siguiente a la siembra se evaluó la acumulación de materia seca y nutrientes en la parte aérea de las plantas. Hubo un efecto significativo al 0,1% para las plantas de cobertura del suelo sobre la materia seca y las acumulaciones de nutrientes. Los valores promedio para las acumulaciones de materia seca en la biomasa aérea de las plantas fueron 19.88;18.06; 16,38; 9,66; 8,96 y 4,26 t ha<sup>-1</sup>, respectivamente, para brachiaria brizantha, crotalaria juncea, brachiaria ruziziensis, canavalia, frijol terciopelo y barbecho. La mayor acumulación de nitrógeno se observó en el cáñamo sunn, 343 kg ha<sup>-1</sup>, seguido por la canavalia, 269 kg ha<sup>-1</sup>. Para brachiaria brizantha y ruziziensis se observaron acumulaciones de N de 247 y 216 kg ha<sup>-1</sup>, respectivamente. Brachiaria brizantha fue la planta que más fósforo y potasio acumuló, con valores promedio de 39 y 362 kg ha<sup>-1</sup>. En las plantas de barbecho, las acumulaciones de N, P y K fueron, respectivamente, 42; 9,0 y 62 kg ha<sup>-1</sup>.

**Palabras clave:** Alimentación de rumiantes; Manejo de la producción; Siembra directa; Sistemas de producción.

## 1. Introduction

Corn silage has been the most used forage for animal feed in dairy farms with medium to high animal productivity (Oliveira et al., 2017b). In recent decades several technologies have been developed by research centers, universities and private companies aiming to increase the yield of corn crops, reduce the cost of production, recycle waste from dairy production, improve silage quality and preserve the environment (Costa et al., 2014; Freitas et al., 2021 and Oliveira et al., 2021b).

In areas of intensive production of corn for silage, very little shoot plant material remains on the soil surface after the harvest of forage. In addition to the soil in these areas being unprotected, the intense traffic of machines also contributes to the degradation of the physical properties of the terrain, especially the sealing of the soil surface and the increase in soil density (Oliveira et al., 2017a; Oliveira et al., 2021b and Silva et al., 2021). In several crops intended for silage production, corn is sown without tilling and mulching with straw is one of the factors responsible for the success in direct seeding, especially in seedling emergence and in the early stages of corn development. Mulch regulates soil temperature, reduces erosion and soil sealing, increasing rainwater infiltration and water availability, thus facilitating the emergence of corn seedlings, resulting in more uniform crops with greater yield potential (Pittelkow et al., 2012; Oliveira et al., 2021b and Thomé et al., 2021).

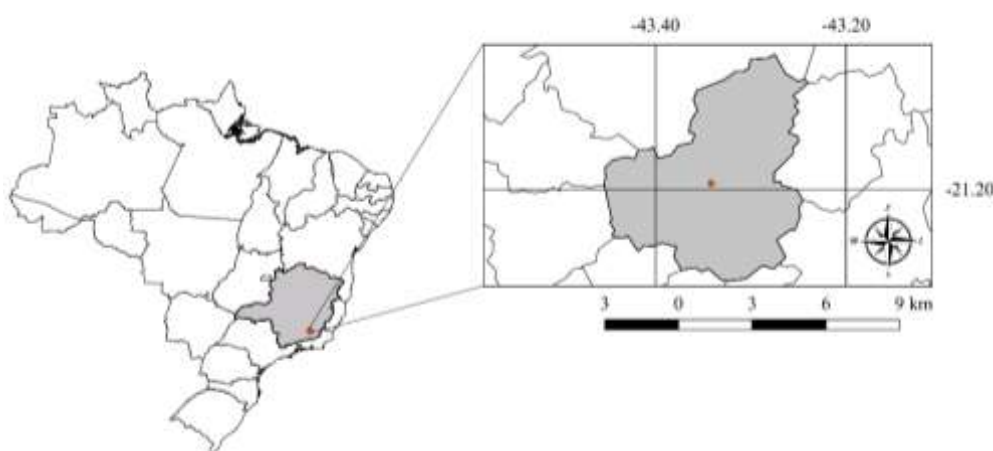
Numerous plants have been used for soil cover. Grasses stand out in terms of biomass yield and legumes because of biological nitrogen fixation from the atmosphere. Among the most common grasses used as mulch for soil cover are brachiaria, millet, Mombasa grass and forage sorghum. Among the most used legumes are crotalaria juncea, pigeon pea, jack bean, and velvet and black velvet beans (Haskel et al., 2020; Oliveira et al., 2021a; Oliveira et al., 2021b and Santos et al., 2021).

Therefore, the aim of this study was to evaluate dry matter accumulation and nutrient cycling by five soil cover plants and a control treatment (fallow area vegetation) in an intensive corn silage production system in the spring and summer.

## 2. Methodology

The study was conducted in a rural property which intensively uses forage to feed dairy cows. The property is in the city of Mercês (Latitude 21°11'39"S and Longitude 43°20'29"W), located in the Zona da Mata de Minas Gerais, Brazil (Figure 1). According to Köppen classification, the climate of the study area is tropical of altitude with rainfall in summer, and average annual temperature of 18 °C, with variations between 24 °C and 13.8 °C. The average annual rainfall is approximately 1,200 mm, with a water surplus from October to April. The relief varies from flat to gently undulating. The soil was classified as a medium-textured Dystrophic Red-Yellow Latosol.

**Figure 1** - Location of study area, city of Mercês, state of Minas Gerais.



Source: Authors.

In September, soil samples were collected in the 0-20 cm and from 20-40 cm layers to evaluate the need for lime and gypsum application. Due to the area use history, especially to previous applications of dolomitic limestone and gypsum, the soil had a base saturation of 63% at 0-20 cm and low aluminum saturation at 20-40 cm (Table 1), requiring no correction of soil acidity or gypsum application, according to the recommendation of Oliveira et al. (2007), Raij (2011) and Oliveira et al. (2021a).

At the beginning of October, the study was installed shortly after the first rainfall events. It consisted of five soil cover plants and a control treatment (fallow area vegetation). The following plants were used for soil cover: brachiaria brizantha, brachiaria ruziziensis, crotalaria juncea, jack bean and velvet bean. The experimental design was randomized blocks with five replications, and the plots consisted of five furrows of five meters long, spaced 0.50 meters apart.

**Table 1** - Chemical analysis of soil samples at 0-20 cm and 20-40 cm.

Layer	pH in H <sub>2</sub> O	P	K	In	Ca	Mg	Al <sup>3+</sup>	H+Al	BS	CEC (t)	CEC (T)	V	m
		. -- mg dm <sup>-3</sup> ---				. ----- cmolc dm <sup>-3</sup> -----				.-----%-----.			
0-20 cm	5.8	10.0	47	0.0	2.88	1.61	0.00	2.69	4.61	4.61	7.30	63.15	0.00
20-40cm	5.3	6.0	18	0.0	1.94	1.14	0.20	3.58	3.13	3.33	6.71	46.62	6.01

pH in H<sub>2</sub>O (Ratio 1:2.5). P, K, Mehlich extractant. Ca, Mg and Al: KCl extractant. H<sup>+</sup> + Al<sup>3+</sup>: Calcium Acetate extractant. Source: Authors.

The sowing densities were 15 kg of viable pure seeds per hectare for brachiaria, and 25, 100 and 70 kg ha<sup>-1</sup> for crotalaria juncea, jack bean and velvet bean, respectively. Green manure seeds were not inoculated as studies by Chada & De-Polli (1988), Barretto & Fernandes (2001), and Oliveira et al. (2011) in rural properties, sugar mills and research areas of federal universities showed that inoculation of legume seeds with nitrogen-fixing bacteria did not increase nitrogen intake in the soil-plant system.

Chemical control of leafcutter ants was necessary during the growth of soil cover plants. At the beginning of February of the following year, dry matter accumulation was evaluated in the shoots of the soil cover plants and fallow area vegetation. The plants were cut close to the soil surface, weighed and a subsample of each plot was put through forage chopper. Subsamples of these plants were dried in a forced ventilation oven at 65 °C to constant weight. These subsamples were passed in a stainless-steel mill and analyzed for nitrogen, phosphorus, potassium, calcium, magnesium and sulfur contents, following procedures described by Malavolta et al. (1997) and Silva & Queiroz (2002).

Based on the values of the samples and chemical analysis, the accumulation of dry matter and nutrients in shoot biomass of the soil cover plants and spontaneous vegetation were calculated. The results of nutrient concentration in the shoots and dry matter and nutrient accumulation were submitted to analysis of variance and the means compared by the Scott-Knott test at 5% probability (Ferreira, 2011).

### 3. Results and Discussion

Firstly, we present and discuss the results of nutrient concentration in the shoots of the soil cover plants and fallow area vegetation.

#### 3.1 Nutrient concentration in the shoots of the cover plants and fallow area vegetation.

Table 2 shows the analysis of variance for nutrient concentration in the shoots of the cover plants and the vegetation of the fallow area. There was a significant effect of plants, at 0.1%, on the concentration of all the nutrients assessed in our study. The highest coefficients of variation were observed for nitrogen and magnesium concentrations. Several factors can influence the concentration of nitrogen, whose uptake and metabolism are strongly influenced by other elements, such as phosphorus and chlorine (Malavolta et al., 1997) and (Oliveira et al., 2021a). However, in addition to this factor, there was possibly high variability of organic matter or even nitrate contents in the area. Oliveira et al. (2018) evaluated the variability of soil fertility, nutritional status and yield of a sugarcane field managed homogeneously. In the phase of maximum growth of the sugarcane and at the time of its harvest, the authors performed visual evaluations of the uniformity of sugarcane, aiming to implement the study in the first regrowth cycle. At this time, ten georeferenced samples of the soil, leaf +3 and yield were taken in the center of the plot of about 5.0 hectares. For soil organic matter, the coefficient of variation was 31.93%, with values ranging from 8.0 to 28.0 g per dm<sup>3</sup> of soil, with an average of 19.8 g per dm<sup>-3</sup>.

**Table 1** - Mean squares of analysis of variance and coefficient of variation (CV) for concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) in the shoots of the soil cover plants and fallow area vegetation.

Source of Variation	GL	----- Mean Squares -----					
		N	P	K	Ca	Mg	S
		. ----- g kg <sup>-1</sup> ----- .					
<b>Plant</b>	5	295.74***	0.411***	24.74***	24.01***	0.439***	0,905***
<b>Block</b>	4	1.23	0.025	0.851	0.269	0.003	0,071
<b>Residue</b>	20	3.43	0.014	0.751	0.077	0.065	0,019
<b>Overall Average</b>		18,27	18.27	1.98	14.31	4.81	2.43
<b>CV (%)</b>		10,15	10.15	6.05	6.06	5.79	10.50

\*\*\* significant by the F test at 0.1% probability. Source: Authors.

Still regarding the evaluations carried out by Oliveira et al. (2018), large variations in soil fertility, nutritional status and yield were found even with the sugarcane regrowth being visually uniform and having been managed homogeneously. In this study, the variation of Mg content in the soil was also high: 34.95%, with minimum, average and maximum values of 0.80; 1.16 and 2.20 cmol<sub>c</sub> dm<sup>-3</sup>, respectively. According to Montezano et al. (2006), the spatial variability of some soil properties, expressed by the coefficient of variation, may be less than 10%, while for others, it exceeds 1,000%. Warrick and Nielsen (1980) classified variability into three levels: low (CV lower than 12%, average (12 to 52%), and high (above 52%).

Table 3 shows the average values of nitrogen, phosphorus, potassium, calcium, magnesium and sulfur concentrations in the shoots of the soil cover plants and fallow area vegetation. The highest nitrogen concentrations were found in legumes: jack bean and velvet bean, followed by crotalaria juncea, with values of 28.04; 26.77 and 19.12 g of N per kg of dry matter.

**Table 3** – Concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) in the shoots of the cover plants: brachiaria brizantha (B. briz.), brachiaria ruziziensis (B. ruziz.), crotalaria juncea (Crotalaria), jack bean (Jack bean), velvet bean (Velvet bean) and fallow area vegetation (Fallow).

Cover plant	N	P	K	Ca	Mg	S
	. ----- g kg <sup>-1</sup> ----- .					
<b>Fallow</b>	10.04 a	2.11 c	14.62 c	3.88 b	2.17 a	1.61 c
<b>Velvet bean</b>	26.77 d	2.26 d	11.50 a	7.90 d	2.35 a	1.95 d
<b>Jack bean</b>	28.04 d	2.28 d	14.83 c	7.30 c	2.80 b	1.90 d
<b>B. Ruziz.</b>	13.22 b	1.60 a	12.97 b	3.19 a	2.24 a	1.21 b
<b>Crotalaria</b>	19.12 c	1.68 a	13.83 c	3.65 b	2.82 b	1.52 c
<b>B. Briz.</b>	12.42 b	1.94 b	18.11 d	2.96 a	2.22 a	0.83 a

Means followed by the same letter in the column do not differ from one another by the Scott-Knott test at 5% probability. Source: Authors.

Fernandes et al. (2014) reported N concentration values in shoot biomass of jack bean close to 28.0 g kg<sup>-1</sup>. Lima et al. (2010) found nitrogen concentrations of 29, 31, 37 and 16 g per kg of shoot dry matter for crotalaria juncea, velvet bean, jack bean and fallow area vegetation, respectively. According to Lima et al. (2010), the coefficient of variation for nitrogen contents in the shoot biomass was 8.6%, slightly lower than those obtained in this study (Table 3). Costa et al. (2014) reported nitrogen

concentrations of 11.2 and 13.0 g kg<sup>-1</sup> for brachiaria brizantha and ruziziensis, respectively, values which are close to those found in this study. The highest phosphorus concentrations were found in the biomass of velvet bean and jack bean, with values close to 2.3 g kg<sup>-1</sup>. Brachiaria brizantha showed the highest potassium concentrations, with average values of 18.11 g kg<sup>-1</sup>. Costa et al. (2014) also reported potassium concentration values of 13.0 g kg<sup>-1</sup> for brachiaria ruziziensis, which is practically the same concentration found in this study.

### 3.2 Accumulation of dry matter and nutrients in the shoots of soil cover plants

The chemical composition of the cover plants, especially nitrogen contents, carbon-to-nitrogen ratio (C:N ratio), lignin, cellulose, hemicellulose and polyphenol contents, associated with environmental factors such as temperature, humidity and aeration, are variables that interfere in the mineralization of plant material (Alovisi et al., 2021; Oliveira et al., 2021a). In situations where soil cover plants are intended to be a quick source of nutrients for the succeeding crop, faster mineralization is desirable. However, in most areas of direct seeding of corn, a longer time of permanence of straw on the soil is recommended. In this case, more important than nutrient concentration is the mass of recycled matter and nutrients or accumulation in plant shoots (Oliveira et al., 2021b; Silva et al., 2021 and Oliveira et al., 2022). Table 4 presents the analysis of variance for the accumulation of dry matter and nutrients in the shoots of the soil cover plants and fallow area vegetation.

**Table 4** - Mean squares of analysis of variance and coefficient of variation (CV) for the accumulation of dry matter (DM Acc.), nitrogen (N Acc.), phosphorus (P Acc.), potassium (K Acc.), calcium (Ca Acc.), magnesium (Mg Acc.) and sulfur (S Acc.) in the shoots of the soil cover plants and fallow area vegetation.

Source of Variation	----- Mean Squares -----						
	DM Acc.	N Acc.	P Acc.	K Acc.	Ca Acc.	Mg Acc.	S Acc.
	----- kg ha <sup>-1</sup> -----						
<b>Plant</b>	189,530***	50,051***	513***	59,973***	2,108***	1,207***	219***
<b>Block</b>	301.0	595.86	18.08	564.78	78.79	22.95	5.18
<b>Residue</b>	177.3	253.22	9.34	507.22	30.49	14.41	4.93
<b>Overall Average</b>	12.880	226.03	24.5	188.6	55.75	31.52	17.71
<b>C.V. (%)</b>	10.33	7.04	12.48	11.94	9.91	12.04	12.54

\*\*\*: significant by the F test at 0.1% probability. Source: Authors.

Similar to nutrient concentration, there was a significant effect of plants, at 0.1%, on the accumulation of dry matter and nutrients in plant shoots. Coefficients of variation above 10% were observed for the accumulation of dry matter, phosphorus, potassium, magnesium and sulfur. There is also a large accumulation of biomass and nutrient cycling considering the average values of dry matter and nutrients shown in Table 4. Table 5 shows the average values of dry matter and nutrient accumulation in each soil cover plant used in the study.

**Table 5** - Accumulation of dry matter (DM Acc.), nitrogen (N Acc.), phosphorus (P Acc.), potassium (K Acc.), calcium (Ca Acc.), magnesium (Mg Acc.) and sulfur (S Acc.) in the shoots of the cover plants: brachiaria brizantha (B. briz.), brachiaria ruziziensis (B. ruziz.), crotalaria juncea (Crotalaria), jack bean (Jack bean), velvet bean (Velvet bean) and fallow area vegetation (Fallow).

Cover plant	DM Acc.	N Acc.	P Acc.	K Acc.	Ca Acc.	Mg Acc.	S Acc.
	t ha <sup>-1</sup>	.----- kg ha <sup>-1</sup> ----- .					
<b>Fallow</b>	4.26 a	42.4 a	9.0 a	61.6 a	16.4 a	9.2 a	6.8 a
<b>Velvet bean</b>	8.96 b	238.0 c	20.2 b	103.0 b	70.8 c	21.0 b	17.5 b
<b>Jack bean</b>	9.66 b	269.2 e	22.0 b	142.8 c	70.3 c	26.8 c	18.2 b
<b>B. Ruziz.</b>	16.38 c	216.0 b	26.4 c	212.2 d	52.2 b	36.6 d	19.8 b
<b>Crotalaria</b>	18.06 c	343.4 f	30.4 c	250.2 e	65.6 c	51.0 f	27.4 c
<b>B. Briz.</b>	19.98 d	247.2 d	39.0 d	362.0 f	59.2 b	44.6 e	16.6 b

Means followed by the same letter in the column do not differ from one another by Scott-Knott test at 5% probability. Source: Authors.

Based on the analysis of Table 5, there was great variation in shoot dry matter accumulation of the soil cover plants, ranging from 4.26 t ha<sup>-1</sup> in the fallow area vegetation (consisting mainly of brachiaria plantaginea with low plant density) to 19.98 t ha<sup>-1</sup> in the plots with brachiaria brizantha. Brachiaria ruziziensis and crotalaria juncea made up the group of plants with the second highest accumulation of dry matter. Oliveira et al. (2021b) found a large accumulation of dry matter in the shoots of brachiaria brizantha, reaching 20 t of dry matter per hectare 90 days after emergence (DAE). In addition, Oliveira et al. (2021b) found average values of shoot dry matter accumulation in brachiaria ranging from 0.22 to 0.25 t per hectare per day, for samplings carried out at 60, 70 and 90 DAE.

High rates of dry matter accumulation in the shoots of brachiaria brizantha and decumbens were reported by Santos et al. (2021). The evaluations were performed at 30, 45, 60, 90 and 105 DAE. In the first three evaluation periods, brachiaria decumbens accumulated a greater amount of dry matter than brachiaria brizantha in the stems + petioles as well as in shoot biomass of the whole plant. There was similarity between the brachiaria only for leaf dry matter accumulation in the evaluations performed at 45 and 60 DAE. Dry matter accumulation in plant shoots of brachiaria decumbens was 54, 25 and 22% higher than brachiaria brizantha at 30, 45 and 60 days, respectively. However, the average dry matter accumulation by brachiaria brizantha at 105 DAE was 22.74 t per hectare, which compared to 18.00 t of dry matter per hectare, surpassed the yield of brachiaria decumbens by 126.3%.

As previously mentioned, the growth rate and dry matter accumulation in the shoots of the cover plants are influenced by several factors, especially water and nutrient availability in the soil, temperature, luminosity, plant yield potential and evaluation period (Ernani et al., 2001; Meda, 2003; Haskel et al., 2020; Oliveira et al., 2021a). In this study, brachiaria brizantha surpassed brachiaria ruziziensis in dry matter accumulation, but there are reports in the literature of comparable dry matter accumulation by ruziziensis. One of these reports is that of Costa et al. (2014) who found average values of dry matter accumulation of 9.45 and 10.67 t ha<sup>-1</sup> for brachiaria ruziziensis and brachiaria brizantha, respectively.

Another interesting study related to brachiaria ruziziensis is that of Oliveira et al. (2017a) who evaluated the production and chemical composition of brachiaria ruziziensis cultivated after silage of corn from the first crop, in place of another sowing of corn. The authors found the average shoot biomass accumulation of brachiaria ruziziensis was 11.84 t per hectare, with a coefficient of variation of 11.34%, even with the water and thermal restrictions of the second crop period. This

is because rainfall from February to June (growing season of *brachiaria ruziziensis*) was 282 mm, and the rainfall events of March and April equaled approximately 60% of the total. Thus, the results of Costa et al. (2014), Oliveira et al. (2021b) and Santos et al. (2021) support the need for local studies to evaluate the yield potential of soil cover plants.

*Juncea crotalaria* also stood out in terms of shoot dry matter accumulation, with an average of 18.06 t per hectare. When *crotalaria juncea* is sown in early spring, shoot dry matter accumulation ranges from 14 to 21 t per hectare (Mascarenhas et al., 1994; Lima et al., 2010; Teodoro et al., 2011 and Oliveira et al., 2021a). However, *crotalaria juncea* is highly sensitive to nyctoperiod (Haskel et al., 2020 and Oliveira et al., 2021a) and toxic soil aluminum, making it demanding in terms of soil fertility, and soil acidity should be corrected before cultivation (Ernani et al., 2001; Meda, 2003; Rast et al., 2010 and Oliveira et al., 2021a).

Oliveira et al. (2021a) compared the accumulation of dry matter and nutrients in *juncea crotalaria* cultivated in soils with medium fertility to those of low soil fertility. The average shoot dry matter accumulation of *juncea crotalaria* was 14.5 t per hectare in plots with medium soil fertility, while only 5.7 t per hectare in those with low fertility soil. Thus, in the soil of medium fertility, the accumulation of dry matter in the shoots of *crotalaria juncea* was equivalent to 254% of that found in the soil of low fertility. In soils of medium fertility, both the absence of exchangeable aluminum and the availability of phosphorus and basic cations contributed to the greater accumulation of dry matter in the shoots of *crotalaria juncea*, supporting the citations of Ernani et al. (2001) and Meda et al. (2003), which classified *crotalaria juncea* as one of the legumes most sensitive to exchangeable aluminum.

In the group of plants with the third highest shoot dry matter accumulation were the jack bean and velvet bean, with an average yield of 9.3 t per hectare, surpassing the vegetation of the fallow area by about 220%. In one of the studies cited by Oliveira et al. (2021a), yield potential of six green manures (*crotalaria juncea*, pigeon pea, jack bean, velvet bean, black velvet bean and spontaneous vegetation) was evaluated. *Crotalaria juncea* had higher accumulation of dry matter and nutrient cycling compared to the other green manures. In the average of the two years of study, *crotalaria juncea* accumulated about 15 t of dry matter per hectare in the shoots, statistically higher than the others. These results support the observations of Oliveira et al. (2021a), who reported higher biomass yield of *crotalaria juncea*, compared to other green manures. Pigeon pea had the second highest dry matter accumulation, on average 10.5 t ha<sup>-1</sup>. Jack bean and velvet bean accumulated close to 8 t ha<sup>-1</sup>, not differing from one another. For the vegetation of the fallow area, there was an average accumulation of dry matter close to 5 t per hectare.

In relation to nitrogen accumulation, jack bean had the second highest accumulation, being surpassed only by *crotalaria juncea*, which had an average accumulation of 350 kg per hectare, values close to those reported by Oliveira et al. (2021a). For *brachiaria ruziziensis*, velvet bean and *brachiaria brizantha*, nitrogen accumulations in shoot biomass ranged from 216 to 247 kg per hectare, surpassing the vegetation of the fallow area by about 200 kg per hectare (Table 5).

Nitrogen accumulation in the shoots of *brachiaria* is possibly largely cycling of soil nitrogen, perhaps even from deeper layers. However, for legumes, biological nitrogen fixation from the atmosphere is responsible for a large part of the nitrogen accumulated in the plant. Oliveira et al. (2021a) mentioned that for sowing carried out from early October to early November, nitrogen accumulation in the shoot biomass of *crotalaria juncea* oscillated around 300 kg ha<sup>-1</sup>, confirming the observations of Perin et al. (2004) and Duarte Júnior and Coelho (2008). Of the total nitrogen accumulated in the shoot biomass of *crotalaria*, about 60% to 70% originated from the symbiotic associations of legume roots with the atmospheric N<sub>2</sub>-fixing bacteria, resulting in the contribution of significant amounts of this nutrient to the soil-plant system (Perin et al., 2004), thus contributing to greater sustainability of the subsequent crop (Mascarenhas et al., 1994; Lima et al., 2010 and Haskel et al., 2020). For comparative purposes, ammonium sulfate, one of the most used nitrogen fertilizers is cited. In 100 kg of this fertilizer, there is 20 kg of N. So, to obtain 200 kg of N, we would need to use 1,000 kg of ammonium sulfate.



The average phosphorus accumulation in the shoot biomass ranged from 9.0 to 39.0 kg ha<sup>-1</sup>. *Brachiaria brizantha* had the highest, followed by *Crotalaria juncea* and *Brachiaria ruziziensis*. Compared to the vegetation of the fallow area, the inclusion of legumes or *Brachiaria* as soil cover plants resulted in increases of 220 to 430% in phosphorus cycling. High percentages of potassium cycling were also observed for *Brachiaria brizantha*, *Crotalaria juncea* and *Brachiaria ruziziensis* compared to the fallow area vegetation. According to Pittelkow et al. (2012) and Oliveira et al. (2021b), *Brachiaria* have shown to be plants with high capacity to cycle potassium. In a study conducted in soil with potassium content of 98 mg dm<sup>-3</sup>, Santos et al. (2021) found K accumulation by *Brachiaria decumbens* of 250 kg ha<sup>-1</sup> 60 days after emergence, reaching 630 kg ha<sup>-1</sup> at 105 DAE. In medium fertility soil, Oliveira et al. (2021b) found potassium accumulation in shoot biomass of *Brizantha* *Brachiaria* ranging from 385 to 468 kg ha<sup>-1</sup>, with an average value of 418 kg of potassium per hectare.

No plant stood out in isolation in terms of calcium, magnesium and sulfur accumulation. Jack bean and velvet bean accumulated calcium the most, with average values of 70 kg per hectare. For magnesium, there was emphasis on *Crotalaria juncea*, which was also the plant that accumulated sulfur the most. Compared to the vegetation of the fallow area, the *Brachiaria* and legumes increased nutrient cycling by at least 300% for calcium, 220% for magnesium and 240% for sulfur. In crops of the corn hybrid BM3066, Oliveira et al. (2017b) found average forage production of 59.5 t of natural matter, about 20 t of dry matter, per hectare. In these crops, the average accumulation of nitrogen, phosphorus, potassium, calcium, magnesium and sulfur were 245; 36; 195; 31; 25 and 24 kg ha<sup>-1</sup>, respectively. According to Oliveira et al. (2021b), unlike the other elements, potassium has a high release rate from straw or mulch. However, only in a situation of financial difficulty should the farmer deduct potassium recycled by the soil cover plants in fertilization, which emphasizes that return fertilization or fertilization based on the yield expectation has provided excellent financial and agronomic results in the production of corn for silage.

#### 4. Final Considerations

In the edaphoclimatic conditions in which this study was conducted, and based on results of a single agricultural year, *Brachiaria brizantha*, *Crotalaria juncea* and *Brachiaria ruziziensis* showed the highest accumulation of dry matter in plant shoots.

*Crotalaria juncea* had the highest accumulation of nitrogen, followed by jack bean, with values that exceeded 260 kg ha<sup>-1</sup>, though much of this nitrogen originates from the biological nitrogen fixation from the atmosphere.

*Brachiaria brizantha* accumulated the most phosphorus and potassium, with average values of 39 and 362 kg ha<sup>-1</sup>. The lowest values of nutrient accumulation were found in the plants of the fallow area.

In comparison to the fallow area vegetation, the *Brachiaria* and legumes increased nutrient cycling by at least 500% for nitrogen, 220% for phosphorus, 160% for potassium, 300% for calcium, 220% for magnesium and 240% for sulfur.

The soil cover plants with the highest potential for straw formation and nutrient cycling were *Brachiaria brizantha*, *Brachiaria ruziziensis* and *Crotalaria juncea*.

There is a need for long-term studies to quantify the effects of soil cover plants as an exclusive spring-summer crop in intensive corn silage production systems in the zona da Mata Mineira region.

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