

Biomass accumulation, extraction and nutrient use efficiency by cover crops
Acúmulo de biomassa, extração e eficiência de uso de nutrientes por plantas de
cobertura

Acumulación de biomasa, extracción y eficiencia en el uso de nutrientes por las plantas
de cobertura

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Abstract

The high biomass production of certain cover crops species is due to their high absorption capacity and nutrients use efficiency. Its potential for biomass production it is important to obtain productive plants using nutritional information especially in environments with low nutrient apport. The objective was to evaluate the biomass accumulation, extraction and nutrient use efficiency by cover crops growing in a soil of low fertility. The treatments were arranged in four randomized blocks, composed of seven cover crops: sunn hemp, spectabilis, pigeon pea forage, pigeon pea arbore, lab lab, jack bean and mucuna. To evaluate dry mass accumulation, crop growth rate and leaf area index, six plants were used in different times: 30, 45, 60, 75, 90 and 105 days after sowing. The cover crops differed in vegetative cycle, dry mass accumulation, yield, extraction and nutrient use efficiency, with better performance presented by pigeon pea arbore. The cover crops are good recyclers of nutrients, particularly nitrogen, potassium and calcium and have potential for use in the cultivation systems in the Northeast of Brazil.

Keywords: Green manure; Nutrient cycling; Phytomass.

Resumo

Alta produção de biomassa de certas espécies de plantas de cobertura deve-se a sua alta capacidade de absorção e eficiência no uso de nutrientes. Seu potencial para produção de biomassa é importante para a obtenção de plantas produtivas utilizando informações nutricionais, especialmente em ambientes com restrição de nutrientes. O objetivo foi avaliar o acúmulo de biomassa, a extração e a eficiência no uso de nutrientes por plantas de cobertura em solo de baixa fertilidade. Os tratamentos foram dispostos em quatro blocos ao acaso, compostos por sete plantas de cobertura: crotalária juncea, crotalária spectabilis, guandu forrageiro, guandu arbóreo, labe labe, feijão de porco e mucuna preta. Para avaliar o acúmulo de massa seca, a taxa de crescimento da cultura e o índice de área foliar, foram utilizadas seis plantas em diferentes épocas: 30, 45, 60, 75, 90 e 105 dias após a semeadura. As plantas de cobertura diferiram quanto ao ciclo vegetativo, acúmulo de massa seca, rendimento, extração e eficiência de uso de nutrientes, com melhor desempenho apresentado pelo feijão guandu arbóreo. As plantas de cobertura são boas recicladoras de nutrientes, principalmente

nitrogênio, potássio e cálcio e têm potencial para uso nos sistemas de cultivo da região Nordeste do Brasil.

Palavras-chave: Adubação verde; Ciclagem de nutriente; Fitomassa.

Resumen

La alta producción de biomasa de ciertas especies de cultivos de cobertura se debe a su alta capacidad de absorción y eficiencia en el uso de nutrientes. Su potencial para la producción de biomasa es importante para obtener plantas productivas utilizando información nutricional especialmente en ambientes con restricción de nutrientes. El objetivo fue evaluar la acumulación de biomasa, la extracción y la eficiencia del uso de nutrientes por cultivos de cobertura que crecen en suelos de baja fertilidad. Los tratamientos se organizaron en cuatro bloques al azar, compuestos por siete cultivos de cobertura: cáñamo sunn, spectabilis, forraje de guandú, arbore de guandú, lab lab, frijol rojo y mucuna. Para evaluar la acumulación de masa seca, la tasa de crecimiento del cultivo y el índice de área foliar se utilizaron seis plantas en diferentes tiempos: 30, 45, 60, 75, 90 y 105 días después de la siembra. Los cultivos de cobertura difirieron en ciclo vegetativo, acumulación de masa seca, rendimiento, extracción y eficiencia en el uso de nutrientes, con mejor desempeño presentado por el arbore *de guandú*. Los cultivos de cobertura son buenos recicladores de nutrientes, particularmente nitrógeno, potasio y calcio y tienen potencial para su uso en los sistemas de cultivo en la región Nordeste de Brasil.

Palabras clave: Abono verde; Ciclo de nutriente; Fitomasa.

1. Introduction

The transformation of natural vegetation into intensive agriculture with monoculture, based on the high input of industrial fertilizers, was responsible for increasing food production. However, it generated consequences such as the decrease in organic matter and soil fertility, loss of soil through erosion, reduction on biodiversity, contamination of rivers, increase in greenhouse gases emission and changes in soil microbiome (Matson et al., 1997), putting at risk the sustainability of this system and compromising the support of ecosystem services (Finney et al., 2016). In addition, there is fallow in the off-season, which increases production costs and accelerates the process of soil degradation, with losses of organic matter and nutrients (Calegari et al., 2008; Muoni et al., 2020). In this way, alternatives that can decrease the soil movement and increase the cultivation intensity, diversity and the input of

residues into the system can improve soil quality and the resilience of agroecosystems (Ghimire et al., 2019; Beniaich et al., 2020).

The integration of legume cover crops or not in conservationist cultivation systems can improve quality by reducing soil degradation and increasing biological fixation and consequently the yield of rotating crops (Baligar & Fageria, 2007; Hallama et al., 2019). Legumes are more used due to their efficient biological fixation, increasing the supply of available N into the soil (Alvarenga et al., 1995; Nyawade et al., 2020). The main characteristics to be evaluated in a cover plant must be its precocity and potential for biomass production (Alvarenga et al., 2001; Ruis et al., 2019), which depends on genetic factors and edaphic and climatic conditions.

A positive relationship has been observed between the shoot biomass production of the cover crops and a decreasing on N leaching and increasing on N accumulation in the shoot plant (Finney et al., 2016), nutrient cycling (Borkert et al., 2003; Venkateswarlu et al., 2007; Pereira et al., 2017) and water infiltration in the soil (Muoni et al., 2020).

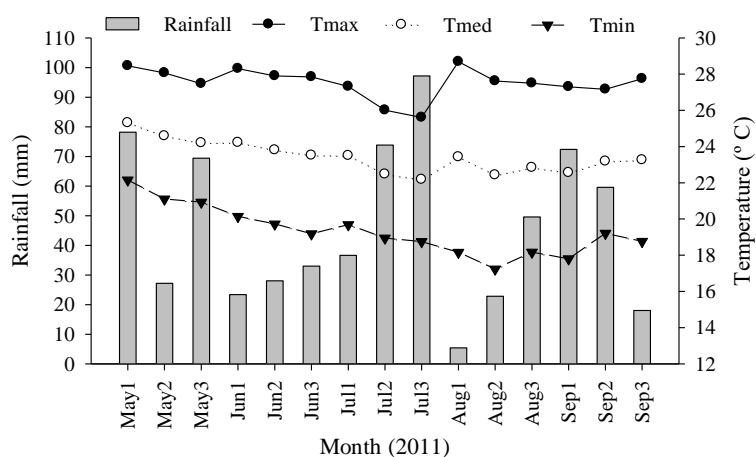
The use of suitable species favors better management in cropping systems (Teodoro et al., 2011). For this, the selection of species with greater nutritional efficiency favors the plant growth (Prado, 2008). Therefore, it is important to identify productive leguminous plants by using nutritional information, especially in environments with low nutrient apport, such as in the Northeast of Brazil. Thus, we hypothesize that the high biomass production of certain legume species is related to their high uptake capacity and nutrients use efficiency. Our objectives with study were evaluate the biomass accumulation, extraction and nutrients use efficiency from cover crops grown in low fertility Ultisol.

2. Materials and Methods

2.1 Site description

The experiment was carried out in an area under fallow for about 10 years, located in the experimental area of the Federal University of Alagoas, Campus Arapiraca, Alagoas, Brazil (9°41'57" S, 36°41'10" W, 321 m a.s.l.). According the classification of Köppen, the climate of the region Northeast of Brazil is a tropical 'As' with winter rains (April-August) and summer drought (September-March) with average annual rainfall of 854 mm (Xavier & Dornellas, 2005); minimum and maximum temperature of 21.4 and 28.3 °C, respectively. Mean each ten days rainfall and air temperature during the experimental period were obtained (Figure 1).

Figure 1. Rainfall and air temperature every ten days during the growth period of cover crops (from May to September 2011).



Source: Authors.

The local soil is classified as Ultisol (Embrapa, 2018). Soil samples from 0-20 cm layer were collected for chemical analysis (Table 1).

Table 1. Chemical properties in 0-20 cm layer of the soil used in the experiment.

Property	Results
pH (H ₂ O)	5.7
Organic matter (g dm ⁻³)	15.0
P-Mehlich-1 (mg dm ⁻³)	13
K (cmol _c dm ⁻³)	0.2
Ca (cmol _c dm ⁻³)	1.4
Mg (cmol _c dm ⁻³)	1.4
Al (cmol _c dm ⁻³)	0.2
H+Al (cmol _c dm ⁻³)	4.0
Base sum (cmol _c dm ⁻³)	3.0
Capacity Exchange Cation (cmol _c dm ⁻³)	7.0
Fe (mg dm ⁻³)	44.5
Cu (mg dm ⁻³)	0.9
Zn (mg dm ⁻³)	2.4
Mn (mg dm ⁻³)	32.0

Source: Authors.

2.2 Experimental design and treatment

The experiment was arranged in a randomized block design with four replications. The treatments were composed by seven cover crops: *Crotalaria juncea* (sunn hemp), *Crotalaria spectabilis* (spectabilis), *Cajanus cajan* (L.) Millsp) (pigeon pea forage), *Cajanus cajan* (pigeon pea arbore), *Dolichos lablab* (lab lab), *Canavalia ensiformis* (jack bean) and *Mucuna aterrima* (mucuna). About 25-30, 30-35, 18-20, 18-20, 10-12, 4-5 and 3-4 seeds were used per meter to grow sunn hemp, spectabilis, pigeon pea forage, pigeon pea arbore, lab lab, jack bean and mucuna, respectively. Each plot consisted of 8 rows of 8 m long at 0.5 m spacing.

Soil conventional tillage was performed at 20 cm using disc harrows to incorporate residues of the locate vegetation. Weed control was performed manually using hoe.

2.3 Plant measurements

The vegetative phase or vegetative cycle was considered how the phenological stage in which 50% or more of the plants in each plot were with the flowers fully open. To determinate the days to flowering (DF) of cover crops species was counted the number of days from sowing to full flowering.

To evaluate growth, dry mass accumulation, crop growth rate and leaf area index as a function of time were determined. Six plants of each species were harvested at ground level to measure dry mass and leaf area. These evaluations were carried out over the time: 30, 45, 60, 75, 90 and 105 days after sowing (DAS).

The measurement of dry mass was performed after drying each sample in an air circulation oven at 60 °C until reaching constant mass. The leaf area was determined using a LICOR® LI 3100 AREA METER. Crop growth rates (CGR, kg ha⁻¹ day⁻¹) were defined using the formula:

$$CGR = \left(\frac{DM2 - DM1}{T2 - T1} \right) \quad (1)$$

where DM1 and DM2 represent the dry mass in Mg ha⁻¹ of two successive samples in their respective time T1 and T2.

The leaf area index (LAI, m² m⁻²) was obtained by the ratio of the total leaf area (TLA, m²) of the plants contained in 1 ha, divided by the corresponding soil area (SA) (10,000 m²):

$$LAI = \left(\frac{TLA}{SA} \right) \quad (2)$$

Yield was measured at the end cover crops flowering, in which the plant harvest was realized at the ground level, in 1 m² of area in the central area of each plot and placed to dry in oven at 60 °C. Then, the weigh was recorded. Subsequently, plant material was ground for nutrients analysis.

The determination of nutrients concentration in plant tissue followed the procedure described by Malavolta et al. (1997), in which N was determined by sulfuric digestion followed by distillation and titration by the Kjeldahl method; P, K, Ca, Mg and S were determined after nitric-perchloric digestion. Ca and Mg were read at atomic absorption spectrophotometry, K at flame emission spectrophotometry, S at turbidimetry and P at colorimetric phosphovanadomolybdate method.

The nutrients accumulated in above-ground mass was calculated by multiplying the dry mass by the concentration of the nutrient in the plant tissue. Nutrient use efficiency (NUE, kg kg⁻¹) was obtained according to Baligar et al. (2001):

$$NUE = \left(\frac{DM}{NE} \right) \times 1000 \quad (3)$$

where DM represent the dry mass in Mg ha⁻¹ and NE is the amount nutrient extracted by shoot in kg ha⁻¹.

2.4 Statistical analysis

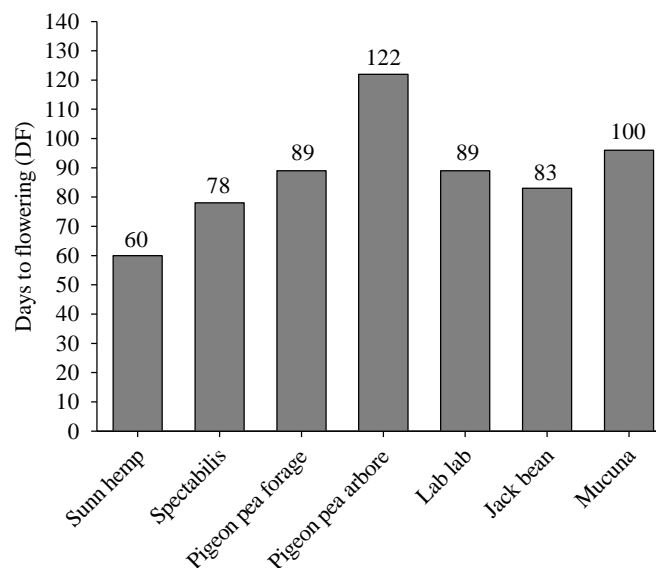
Data were submitted to analysis of variance by the F test ($p < 0.05$) and the means of the qualitative data were compared by Tukey test ($p < 0.05$). For quantitative data, regression analysis was performed. All statistical analyzes were performed using Statistical Analyses System (SAS, 2009).

3. Results and Discussion

3.1 Vegetative phase

Figure 2 shows the number of the days required for species to reach the phenological stage of full flowering. It is possible to observe that the vegetative cycle ranged from 60 days for sunn hemp to 122 for pigeon pea arbore. Spectabilis, jack bean, pigeon pea forage, lab lab, mucuna and pigeon pea arbore presented longest vegetative cycle compared to sunn hemp cycle. The vegetative cycle of the species obtained in this research were similar to those found by Cavalcante et al. (2012) that observed 65, 78, 92, 92, 100, 100 and 129 days for the species sunn hemp, spectabilis, pigeon pea forage, jack bean, lab lab, mucuna and pigeon pea arbore, respectively, grown in 2009 in the same area of our study. Similar results were reported by Carvalho et al. (2003) for these species to reach full flowering in the region of the Recôncavo Baiano, which presents a climatic condition more similar to those where the present research was carried out, with full flowering at 65, 85, 100 and 120 DAS for sunn hemp, spectabilis, pigeon pea arbore and mucuna, respectively.

Figure 2. Days to flowering (DF) of cover crops species.



Source: Authors.

In experiments conducted in the Cerrados, Alvarenga et al. (1995) observed longer cycles with 111, 181, 159, 90 and 145 days for sunn hemp, pigeon pea arbore, lab lab, jack bean and mucuna, respectively to reach full flowering, while Teodoro et al. (2011) reported

88, 92, 119, 163, 97 and 156 days for sunn hemp, spectabilis, pigeon pea forage, lab lab, jack bean and mucuna, respectively in the same region. Sakala et al. (2003) also observed that sunn hemp was the legume species that took less time to reach the stage of full flowering, ranged from 64 to 85 days, in different locations in Malawi. The variation in the vegetative cycle is associated with genetic factors, soil quality, climatic factors such as precipitation, temperature, degree days and photoperiod, ability to uptake and use nutrients for each species and management conditions (Nascente et al., 2017; Sennhenn et al., 2017), and it is important to know the agronomic performance of the species from research in the different regions where they will be used.

Pigeon pea arbore and mucuna showed longer cycles, which may make the introduction of these species in cultivation systems with crop rotation and succession unfeasible, and may be crucial in areas cultivated with vegetables such as lettuce, coriander and chives, which have an average of 30 days for each crop cycle in the region. The use of these species would imply staying for a longer period of time in the cultivation area, which is often not interesting for the farmer due to the less optimization of the area (Teodoro et al., 2011).

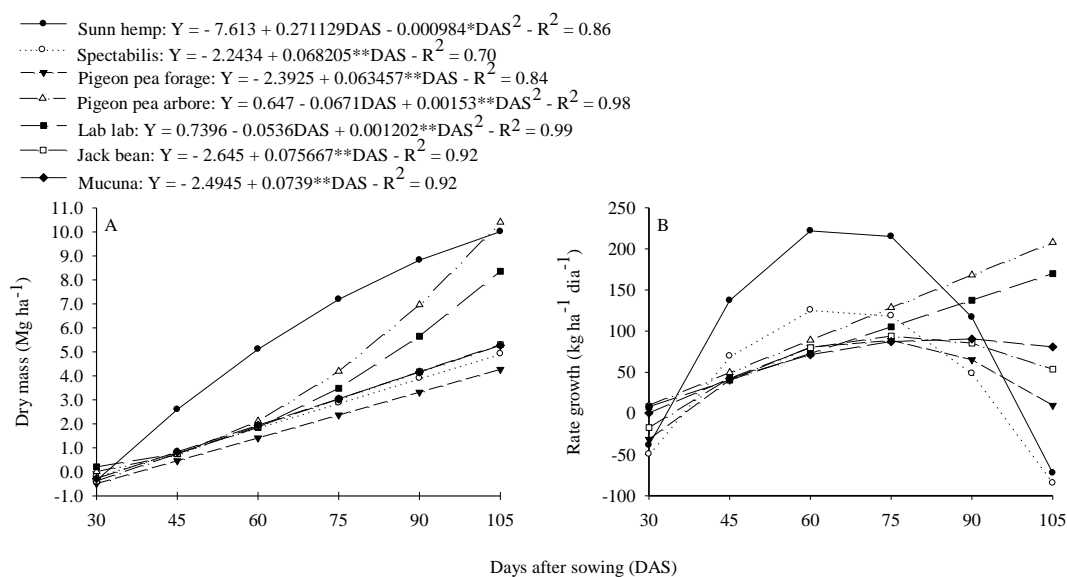
In this condition, the use of sunn hemp as green manure would be more advantageous in relation to the use of mucuna and pigeon pea arbore due to the DF of the latter having 40 and 62 days, respectively, more than sunn hemp, which would decrease by one to two cycles of cultivation of hardwoods for each rotation or succession of vegetable-cover crops in the region. The importance of using short-cycle species that produce satisfactory amounts of dry mass and N for use as cover crops in crop rotation systems has been highlighted (Alvarenga et al., 2001; Fageria, 2007), with emphasis on sunn hemp (Carvalho et al., 2003; Sakala et al., 2003; Teodoro et al., 2011; Cavalcante et al., 2012). The results for the DFs presented by the species assayed in this research allow farmers to choose the species that best suits the region's edaphoclimatic and management objectives and conditions.

3.2 Growth and dry mass accumulation

The accumulation of dry mass and the daily rates of accumulated mass by shoot cover crops as a function of time are shown in Figure 3. Shoot dry mass accumulation differed between the species of cover crops, adjusting to the linear regression model for pigeon pea forage, spectabilis, jack bean and mucuna and quadratic for sunn hemp, pigeon pea arbore and lab lab (Figure 3A). The species showed a similar response with low dry mass accumulation

up to 60 DAS, reaching from 1.4 to 2.1 Mg ha⁻¹, except for sunn hemp, which stood out from the others and produced 5.1 Mg ha⁻¹ in the same period. The pigeon pea forage was the plant species that had the lowest dry mass accumulation at the end of the evaluation period, 4.3 Mg ha⁻¹, followed by spectabilis with 4.9 Mg ha⁻¹, jack bean and mucuna, both with 5.3 Mg ha⁻¹, which is equivalent to 41, 47 and 50% of the mass of the pigeon pea arbore and 43, 49 and 53% of the mass accumulated by sunn hemp, respectively. Pigeon pea forage is a slow-growing legume with dry mass accumulation considered low during the first two months (Calvo et al., 2010).

Figure 3. Dry mass accumulation (A) and crop growth rate (B) of shoot cover crops species.



Source: Authors.

Sheldrake & Narayana (1979) observed that pigeon pea of early cycle (similar to pigeon pea forage) accumulated about half of the dry mass accumulated by pigeon pea species of intermediate cycle (closer to pigeon pea arbore), in a behavior similar to those observed for these species in the present study. Calvo et al. (2010) observed that the pigeon pea forage accumulated only 1.4 t ha⁻¹ at 60 DAS and reached 3.3 Mg ha⁻¹ at 90 DAS, which was similar to those values found in the present study.

The final accumulation of dry mass by pigeon pea arbore and sunn hemp were similar. However, at 60 DAS, sunn hemp accumulated 51% and pigeon pea arbore only 20% of the total dry mass produced. In the last 45 days (60 to 105 DAS), pigeon pea arbore accumulated 8.4 Mg ha⁻¹ of dry matter (80% of the total accumulated) and sunn hemp accumulated 4.9 Mg ha⁻¹ of dry mass (50% of the total accumulated). Pigeon pea arbore, which presents later

cycle, did not reach its maximum growth potential at 105 DAS (Sheldrake & Narayana, 1979; Alvarenga et al., 1995). The pigeon pea forage presents low growth rates (Figure 3B) and is a plant species of early cycle in relation to pigeon pea arbore (Figure 2). Thus, pigeon pea forage produces less biomass (Figure 3A and Table 2) grown single and can be shaded when in intercropping with grass with rapid initial growth due to competition, which is a disadvantage (Sheldrake & Narayana, 1979; Calvo et al., 2010).

Sunn hemp reached 8.8 t ha^{-1} at 90 DAS (Figure 3A) and 4.6 Mg ha^{-1} when it was harvested during flowering (Table 1) at 60 DAS (Figure 2). This addition of residue added to the soil can bring improvements in physical, chemical and biological properties, protection against erosion and increase in nutrient cycling (Beniaich et al., 2020). Jack bean would reach yield of 5.3 Mg ha^{-1} at 105 days, which corroborate the values reported (4.6 and 7.6 Mg ha^{-1}) by Padovan et al. (2011) at 112 and 117 DAS for the regions of Dourados and Itaquira, respectively, in Mato Grosso do Sul state.

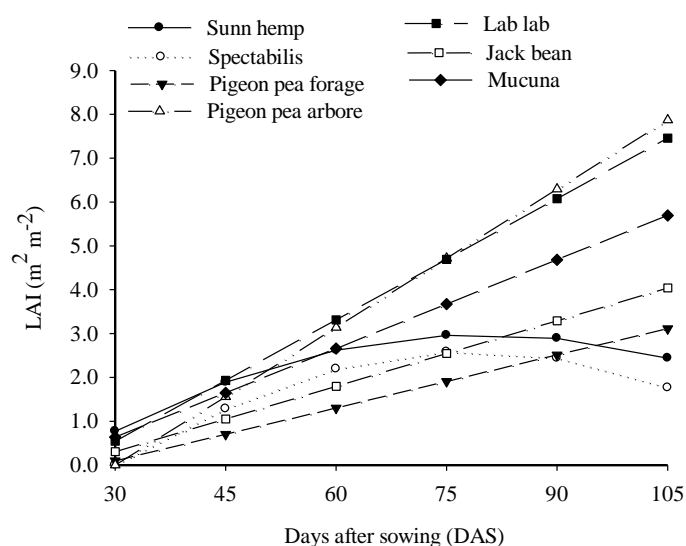
Growth rates were low up to 30 DAS for all species (Figure 3B). At 45 DAS, sunn hemp reached rates above $137 \text{ kg ha}^{-1} \text{ day}^{-1}$ of dry mass and reached maximum rates above $220 \text{ kg ha}^{-1} \text{ day}^{-1}$ at 60 DAS, beginning to decline slowly until 75 DAS and more pronounced until the end of the evaluated period, which can be attributed to senescence and leaf fall (Sakala et al., 2003; Carvalho et al., 2015). The species showed a growth rate higher than twice that of *spectabilis* and about three times the rates of other species in the 60 DAS period, which confirms its fast initial growth and mass accumulation in a shorter period of time (Sakala et al., 2003; Teodoro et al., 2011).

The growth rates of the species pigeon pea forage, jack bean and mucuna were similar each other until 75 DAS, when they reached maximum dry mass production rates. There was a decline from that time onwards, being more intense for pigeon pea forage, a species that had the lowest dry mass accumulation (Figure 3A) and yield at flowering, at the time of harvest (Table 2). Pigeon pea arbore and lab lab presented linear rates throughout the evaluated period, with constant and different rates in each evaluation period. The rates observed among 75 and 90 DAS was of $130 \text{ kg ha}^{-1} \text{ day}^{-1}$ for pigeon pea arbore and $105 \text{ kg ha}^{-1} \text{ day}^{-1}$ for lab lab, reaching rates above 200 and $170 \text{ kg ha}^{-1} \text{ day}^{-1}$ at the end of the evaluation period (90-105 DAS) for pigeon pea forage arbore and lab lab, respectively. Sheldrake & Narayana (1979) observed that the growth rates of early and intermediate cycle pigeons were low in the first two months, not exceeding $17 \text{ kg ha}^{-1} \text{ day}^{-1}$. The maximum rates occurred in the third month for the early cultivar, with about $70 \text{ kg ha}^{-1} \text{ day}^{-1}$ and in the fourth month for the intermediate cycle, with $171 \text{ kg ha}^{-1} \text{ day}^{-1}$, results compatible with those observed in this research.

Pigeon pea forage, jack bean and mucuna showed the lowest growth rates during the period evaluated, not exceeding $100 \text{ kg ha}^{-1} \text{ day}^{-1}$. There was a decline on growth rate from 75 DAS for pigeon pea forage and from 90 DAS for jack bean and mucuna. The greatest decline was observed for pigeon pea forage. The spectabilis growth rate curve was similar to those of sunn hemp but with lower values, reaching maximum rates above $125 \text{ kg ha}^{-1} \text{ day}^{-1}$ from 45 to 60 DAS, and then, slowly declining from 60 to 75 DAS and more strongly until the end of the evaluation period (Figure 3B).

Figure 4 shows the data about leaf area index (LAI). The LAI continuously increased for the species pigeon pea forage, pigeon pea arbore, lab lab, jack bean and mucuna. For sunn hemp and spectabilis, the LAI increased until 75 DAS when it reached a maximum LAI of 3 and $2.6 \text{ m}^2 \text{ m}^{-2}$, respectively.

Figure 4. Leaf area index (LAI) of cover crops species.



Source: Authors.

The LAI of the species reflected the growth rates and dry mass accumulation (Figure 3), biomass production (Table 2) and/or the sowing cycle until flowering (Figure 2). At 45 DAS only pigeon pea forage presented LAI below $1 \text{ m}^2 \text{ m}^{-2}$, and this plant species reached LAI above 3 at 105 DAS while pigeon pea arbore and lab lab reached at 60 DAS, mucuna at 75 and jack bean at 90 DAS.

High LAI values are not always able to maintain high levels of dry mass production due to self-shading, which reduces the photosynthetic rates (Nóbrega et al., 2001). This fact may have occurred for lab lab that presented increasing LAI at a constant rate of 1.4, reached a rate of 6.1 at 90 DAS (Figure 4) and produced only 3.4 Mg ha^{-1} of shoot dry mass at

flowering (Table 2), which occurred at 89 DAS (Figure 2). However, the fact that the lab lab cover can remain effective for the subsequent season should have a positive impact on the coverage and protection of the soil against run-off and erosion (Nyawade et al., 2020).

3.3 Yield, accumulation and nutrient use efficiency

The amounts of nutrients accumulated and the dry mass ratio produced per unit of accumulated nutrient in shoot cover crops (efficiency) at full flowering are shown in table 2. The shoot yield ranged from 3.4 Mg ha⁻¹ for pigeon pea forage and lab lab to 8.3 for pigeon pea arbore, which was significantly higher than the other species ($p < 0.05$). The percentage of dry mass of other species in relation pigeon pea arbore was 41% for pigeon pea forage and lab lab, 43% for spectabilis, 53% for jack bean, 55% for sunn hemp and 61% for mucuna. Mucuna produced 5.1 Mg ha⁻¹ and was greater to pigeon pea forage and lab lab ($p < 0.05$), and did not differ from sunn hemp, spectabilis and jack bean.

The dry mass production results of the present research are similar to those obtained by Cavalcante et al. (2012). These authors observed that pigeon pea arbore showed a yield of 8.7 Mg ha⁻¹, which was similar to pigeon pea forage (4.0) and mucuna (4.2) and was higher in 3.5 times for spectabilis, 2.9 for sunn hemp and jack bean and 2.7 times higher than the shoot mass of lab lab in an experiment conducted in the same area of the present study, in 2009. Alvarenga et al. (1995) also verified the superiority of the pigeon pea arbore over the other studied legumes. Carvalho et al. (2015) observed dry mass yields of 2.3, 3.5 and 3.9 Mg ha⁻¹ for the sunn hemp, pigeon pea forage and mucuna, respectively. These values are slightly below those observed in this research for the sunn hemp and mucuna as a result of sowing occurred at the end of the rainy season.

Mucuna has good potential for use as a cover crop for the research region, producing over 5 Mg ha⁻¹ in fallow area and reached 8.5 in build-up fertility area (Cavalcante et al., 2015). Among its main disadvantage is long vegetative cycle, reaching 100 days in the region. The higher shoot biomass produced by this species and its fast soil covering was responsible for the increase of water infiltration in the soil and the aggregation of soil particles (Muoni et al., 2020).

Table 2. Yield, accumulation and nutrient use efficiency by shoot cover crops species.

Specie	Accumulation						
	Yield	N	P	K	Ca	Mg	S
	Mg ha ⁻¹	-----kg ha ⁻¹ -----					
Sunn hemp	4.6 bc*	84.1 bc	9.1 abc	61.2 abc	29.2 ab	10.2 bc	4.2 bc
spectabilis	3.6 bc	86.3 bc	8.4 bc	68.5 ab	30.5 ab	8.0 bcd	6.9 a
Pigeon pea forage	3.4 c	78.6 bc	6.6 cd	33.3 d	18.1 b	5.4 d	3.6 c
Pigeon pea arbore	8.3 a	133.9 a	12.4 a	79.5 a	32.6 a	13.2 a	6.8 a
Lab lab	3.4 c	59.3 c	5.1 d	35.7 cd	28.3 ab	6.7 d	5.0 abc
Jack bean	4.4 bc	113.6 ab	8.7 bc	47.2 bcd	39.8 a	10.9 ab	5.5 abc
Mucuna	5.1 b	109.9 ab	11.4 ab	63.2 ab	31.4 a	7.9 cd	5.6 ab
LDS 0.05	1.72	36.3	3.3	27.2	2.7	2.9	1.98
	Efficiency						
	-----kg kg ⁻¹ -----						
Sunn hemp		55.3 abc	508.0 b	76.5 ab	159.8 bc	452.5 c	1096 ab
spectabilis		42.0 d	435.3 b	53.0 b	119.8 c	465.0 bc	520.0 e
Pigeon pea forage		43.8 cd	525.5 b	103.0 a	190.0 b	626.3 ab	956.8 bc
Pigeon pea arbore		61.5 a	674.0 a	105.5 a	263.5 a	627.5 ab	1230.0 a
Lab lab		58.0 ab	672.5 a	95.3 a	121.3 c	516.5 abc	687.0 de
Jack bean		38.8 d	506.0 b	94.0 a	110.3 c	400.5 c	807.5 cd
Mucuna		47.8 bcd	449.3 b	83.8 ab	166.0 bc	657.3 a	938.3 bc
LSD 0.05		11.9	94.7	31.7	65.6	171.6	180.8

* Means followed by the same letters in column do not differ statistically by Tukey test ($p < 0.05$). LSD = Least significant difference. Source: Authors.

On the other hand, Fávero et al. (2000) reported yields of 7.6, 3.7, 6.6 and 5.1 Mg ha⁻¹ of dry mass for jack bean, lab lab, mucuna and pigeon pea, without fertilization in soils with better fertility than the present study. Soil fertility is determinant for cover crops produce dry mass. Koné et al. (2008) reported that the ability of cover crops to improve soil quality is achieved more quickly when carbon, total N and P contents are in proper amounts.

Proper soil fertility promotes higher biomass production, increases organic matter, microbial activity, soil nutrient cycling and improves the support of ecological services in ecosystems (Finney et al., 2016). However, when plants grow in conditions of low fertility such as long-term fallow area need to allocate more biomass to the roots to maintain the nutrient uptake capacity there is a decreasing on shoot dry mass production (Tian & Kang,

1998). The pigeon pea forage produced 3.3 Mg ha⁻¹ of dry mas when was harvested at 90 days after sowing in the final rainy season (Calvo et al., 2010). This yield is the same obtained in this research (Table 2) for the same period of time (Figure 2) under cultivation conditions. On the other hand, the species can produce over 5 t ha⁻¹ in areas with good soil fertility and proper climatic conditions (Fávero et al., 2000; Borkert et al., 2003; Cavalcante et al., 2015).

Calvo et al. (2010) reported that the pigeon pea forage has a low aptitude for the production of straw in the environment of Central Brazil, which corroborates the data obtained by this study and by Cavalcante et al. (2012) and Costa et al. (2019) in the Agreste region of Alagoas state under fallow conditions. The low yield observed for pigeon pea forage in relation to pigeon pea arbore can be explained by their physiology, relatively short vegetative cycle (Figure 2) and lower growth rates (Figure 3B). The fact that pigeon pea arbore flower at 122 days means that it took advantage of the days with more hours of photoperiod, allowing better water and soil nutrients exploration for longer time (Alvarenga et al., 1995), while pigeon pea forage flower earlier with lower temperatures (Figure 1) (Sheldrake & Narayana, 1979; Rowden et al., 1981).

Lab lab was one of the species that presented the lowest yield together with pigeon pea forage, 3.4 Mg ha⁻¹ (Table 2), confirming the low yield obtained in the same place of this experiment (1st year) by Cavalcante et al. (2012). This trend was also reported in the Southeast of Brazil, where lab lab produced no more than 3.8 Mg ha⁻¹ (Fávero et al., 2000; Bertin et al., 2005). This yield represents 50 to 60% of the yield recommended by Alvarenga et al. (2001) as the minimum amount of residue suitable for good soil coverage and protection against erosive agents.

The biomass and nutrients extracted can be made available for the next crop (Hallama et al., 2019). Studying cover plant species for six years in three locations Borkert et al. (2003) observed an average yield of 6.2 and 5.1 Mg ha⁻¹ for pigeon pea forage and mucuna, respectively. In 41% of the samples collected pigeon pea had a yield of up to 4 Mg ha⁻¹ and only in 5% of the samples had dry mass yield higher than 10. For mucuna, 45% of the samples had yield up to 5 Mg ha⁻¹. The average for N, P, K, Ca and Mg extraction was 30.1, 2.4, 14.2, 8.2 and 2.6 kg Mg⁻¹ for pigeon pea forage and 34.4, 3.4, 16.8, 11.8 and 2.9 kg Mg⁻¹ of dry mass for mucuna, respectively (Borkert et al., 2003). Although only pigeon pea arbore presented dry mass yield higher than that considered adequate by Alvarenga et al. (2001), the other species have potential to be used because the dry mass yield depends on several factors such as species, edaphoclimatic conditions and management (Venkateswarlu et al., 2007; Ruis et al., 2019). The production of a minimum dry mass of 3.4 Mg ha⁻¹, in fallow area, was

important because in soil with proper fertility yields up to 8.5 Mg ha⁻¹ were observed in the Agreste region of Alagoas state (Cavalcante et al., 2015). The incorporation of only 1.2 Mg ha⁻¹ over 10 years resulted in increase in the organic carbon of the soil, nutrients availability and in the yield of the main crop (Venkateswarlu et al., 2007).

There were significant differences for nutrients accumulation in the shoot of the cover crops ($p < 0.05$). The species accumulated amounts of N higher than 59 kg ha⁻¹ in a linear relation with dry mass production (Table 2). Pigeon pea arbore accumulated more N than lab lab, sunn hemp, spectabilis and pigeon pea forage and did not differ from jack bean and mucuna. Jack bean and mucuna accumulated more N than lab lab and presented similar N accumulation to sunn hemp, spectabilis and pigeon pea forage. The amounts of N accumulated are compatible with those found by Carvalho et al. (2015) in flowering cover crops, which observed accumulation of 91, 72 and 94 kg ha⁻¹ of N for sunn hemp, pigeon pea forage and mucuna, respectively.

The 133.9 kg ha⁻¹ of N accumulated by the pigeon pea arbore is 126% higher than the amount of N accumulated by lab lab (Table 2). These N apport represent from 132 to 298 kg ha⁻¹ of urea, which is higher than N fertilizer dose recommended for corn in the region. Alvarenga et al. (1995) observed that pigeon pea arbore accumulated more N, P and K than sunn hemp and crotalaria paulina, lab lab, jack bean, mucuna, cowpea and wild beans. Fávero et al. (2000) obtained accumulation of 206, 109, 196 and 137 kg ha⁻¹ of N for jack bean, lab lab, mucuna and pigeon pea, respectively, in cultivation without addition of fertilizers. Except for pigeon pea, these accumulations represent twice the accumulations obtained for the same species in this research, which should be attributed to the greater fertility of the soil where the research was developed (Koné et al., 2008).

The amount of P accumulated ranged from 5.1 to 12.4 kg ha⁻¹ and was similarly to that observed for N. Pigeon pea arbore accumulated higher amounts of P than lab lab pigeon pea forage, spectabilis and jack bean and presented similar P accumulation to mucuna and sunn hemp. Mucuna accumulated more P than lab lab and pigeon pea forage. Lab lab accumulated the least amount of P, as well as pigeon pea forage. In general, the amount of P accumulated was lower than that observed by Cavalcante et al. (2012) that reported P accumulations ranged from 8.5 to 18.2 kg ha⁻¹, and in high fertility areas these accumulation ranged from 19 to 32 kg ha⁻¹ (Cavalcante et al., 2015), both in the Agreste region of Alagoas state. These differences are related to the lowest P concentration in the plant tissues and/or to the highest biomass in the case of high fertility area, since the content (kg ha⁻¹) is the result of multiplying the concentration by the dry mass produced.

The ability of cover crops mobilize P of lower lability and incorporate it in their shoot biomass has been reported. Possible mechanisms are associated to the root system, pH of the rhizosphere, release of organic acids and phosphatase activity (Wang & Lambers, 2020). However, Hallama et al. (2019) reported that the biomass produced by cover crops seems to be the main factor to increase the crop yield in succession by transferring the P from its residues and improving the potential for modification and interaction in the rhizosphere with phosphate-mobilizing microorganisms.

The K accumulated in the shoot of the plants ranged from 33 to 80 kg ha⁻¹ and the pigeon pea arbore accumulated the largest amount followed by spectabilis, mucuna and sunn hemp. Pigeon pea forage accumulated the lower amount of K and there was no difference in relation to lab lab and jack bean. The accumulation of cations like K by cover crops is very important, especially in sandy soils and in regions of high rainfall, where the element is subject to leaching (Abdollahi & Munkholm, 2014). Potassium accumulation can have positive effect in intercropping or rotation with cultures that presents high K uptake such as cassava, a culture of economic and social importance for the region (Teodoro et al., 2011).

The largest Ca accumulation was observed in jack bean (39.8 kg ha⁻¹). Jack bean, pigeon pea arbore and mucuna presented higher Ca accumulation than pigeon pea forage, but did not differ of spectabilis, sunn hemp and lab lab ($p < 0.05$). Pigeon pea arbore accumulated 13.2 kg ha⁻¹ of Mg, which was higher than the other species, except for jack bean. Pigeon pea forage and lab lab accumulated the lowest amounts of Mg, not differing of spectabilis and mucuna. The amounts of Ca and Mg accumulated were lower than those observed by Teodoro et al. (2011) for the same species in the Cerrado, which can be attributed to the liming effect and the high biomass.

For S, spectabilis and pigeon pea arbore accumulated 6.9 and 6.8 kg ha⁻¹, respectively. The amounts of S accumulated were lower than those obtained by Cavalcante et al. (2012) for the same species in the first year of cultivation in the same plots, except for sunn hemp, spectabilis and lab lab. When we compared our results with the same species in an area of built up fertility, the differences were even higher, with emphasis on spectabilis (38%), jack bean (132%) and mucuna (119%) (Cavalcante et al., 2015).

The amounts of macronutrients accumulated by pigeon pea arbore were about 2-fold time high as those of the species that accumulated the lower amounts. In general, the accumulation of nutrients presented relationship with dry mass production. Pigeon pea arbore, which was the species with the higher dry mass production, accumulated the higher amounts of macronutrients while pigeon pea forage and lab lab, which had the lower dry mass

production, accumulated the lower amounts of nutrients. This same trend was reported by Alvarenga et al. (1995) and Fageria et al. (2014). The order of nutrient accumulation in this research was $N > K > Ca > Mg > P > S$, which was similar to that found by Fageria et al. (2014) that reported nutrient accumulation in the order $N > Ca > Mg > P$ in all cover crops species (they did not evaluate K and S) and by Xavier et al. (2017) that described the order $N > K > Ca > Mg > P > S$.

Pigeon pea arbore stands out among the legumes assayed as the most promising in terms of dry mass production and nutrient cycling and is recommended for use as a cover crop for its tolerance to drought, high temperatures, pests and disease and for its high nutrient use efficiency in low fertility soils (Baligar & Fageria, 2007). Its extensive and deep root system allows access to water and nutrients, differently from species that have less deep root system (Sheldrake & Narayana, 1979; Alvarenga et al., 1995; Baligar & Fageria, 2007).

The use of soil cover crops for green manure in crop rotation systems has the ability to deposit expressive amounts of dry mass, which is important to protect the soil against erosive agents, maintain temperature, humidity and preserve soil biological diversity (Pereira et al., 2017). In addition, cycling and accumulation of nutrients in the shoot can reduce the use of inorganic fertilizers applied in the subsequent crop and contribute to the preservation of the agroecosystem (Calegari et al., 2008; Kumar et al., 2019).

The nutrient use efficiency, which indicates the dry mass produced per unit of nutrient accumulated in the shoot ranged with the species of cover crop for all nutrients (Table 2). For N, the pigeon pea arbore showed the higher efficiency, producing 61.5 kg of dry mass per kg of nutrient accumulated in the shoot, which was higher compared to other species, except lab lab and sunn hemp that produced over 55 kg of dry mass per kg of N accumulated. Pigeon pea arbore and lab lab showed the higher efficiency, with more than 670 kg of mass produced per kg of P accumulated in the shoot and differed from the other species ($p < 0.05$) that presented efficiencies ranging from 435 to 525 kg of mass per kg of P.

In relation to K, pigeon pea forage, pigeon pea arbore, lab lab and jack bean showed higher efficiency followed by mucuna and sunn hemp. Spectabilis had the lower efficiency, not differing from mucuna and sunn hemp. The efficiency for Ca was marked by pigeon pea arbore, with 263.5 kg of mass per kg of Ca in the shoot, which differed from all species ($p < 0.05$), followed by pigeon pea forage, which did not differ from sunn hemp and mucuna.

Mucuna was superior to jack bean, spectabilis and sunn hemp for Mg efficiency, with 657.3 kg of mass per kg of Mg (Table 2), not differing from pigeon pea arbore, pigeon pea forage and lab lab ($p < 0.05$). The higher amount of dry matter per kg of S in the shoot was

observed in pigeon pea arbore (1230 kg kg⁻¹) and sunn hemp (1096 kg of dry mass). Pigeon pea had an efficiency 2.4 times higher than *spectabilis*, which obtained 520 kg of dry mass per kg of S accumulated in the shoot (Table 2). The amounts of dry mass produced per kg of nutrient accumulated in the shoot of the cover crops were higher than those obtained by Fageria et al. (2014). These authors pointed out that the efficiency followed the order P > Mg > Ca > N, which was similar to the results observed in this research: S > P > Mg > Ca > K > N.

Nutrient use efficiency is particularly important for low availability nutrients such as P. Plant species that have greater P use efficiency are more productive when they grow in soil with limited nutrient supply (Baligar & Fageria, 2007), which may happen mainly for pigeon pea arbore due to its ability to solubilize and use phosphate bound to iron and aluminum (Ae et al., 1990). These forms of P are prevalent in weathered soils in tropical regions and efficient species could increase P use efficiency to make it available to the crop in succession (Hallama et al., 2019).

The variation in nutrient use efficiency depends on genetic and physiological process, but it can be modified by the interaction of the plant with environmental variables. The variability in dry mass production and nutrient accumulation by species is associated with different growth habits, with the number of days to flowering and with the amount of shoot dry mass produced by the cover crops species, with the partition of N within the plant and with edaphic-climatic conditions (Fageria et al., 2014; Nascente et al., 2017). Finally, our study pointed out that the higher biomass production of pigeon pea arbore was associated with greater nutrients uptake or accumulation and also with greater macronutrients use efficiency. The results obtained allow to propose the cultivation of pigeon pea arbore as cover crop in conservation production systems in low fertility soils increasing the sustainability of these agroecosystems.

Further study must be focus on the behavior of cover crops grown in low fertility areas in long-term to assess improvements in soil quality and crop yield in succession.

4. Final Consideration

The vegetative cycle of cover crops ranged from two to four months. The short vegetative cycle of sunn hemp favors its insertion in intercropping or crop rotation in the cultivation systems of the Agreste region of Alagoas state, Brazil. Pigeon pea arbore showed the longest vegetative cycle and higher biomass production, accumulation and nutrients use

efficiency. The dry mass accumulation was up to 5.3 Mg ha⁻¹ for pigeon pea forage, spectabilis, jack bean and mucuna, 8.5 Mg ha⁻¹ for lab lab and 10 Mg ha⁻¹ for sunn hemp and pigeon pea arbore. Sunn hemp can accumulate more than 8 Mg ha⁻¹ of biomass if harvested at 90 days after sowing. The cover crops assayed are good recyclers of nutrients, particularly N, K and Ca, and have potential to be used in the cultivation systems of our region.

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References

- Abdollahi, L. & Munkholm, L. J. (2014). Tillage system and cover crop effects on soil quality: I. chemical, mechanical, and biological properties. *Soil Science Society of America Journal*, 78(1), 262-270. <https://doi.org/10.2136/sssaj2013.07.0301>.
- Ae, N., Arihara, J., Okada, K., Yoshihara, T. & Johansen, C. (1990). Phosphorus uptake by pigeon pea and its role in cropping systems of the Indian subcontinent. *Science*, 248(4954), 477-480. <https://doi.org/10.1126/science.248.4954.477>.
- Alvarenga, R. C., Cabezas, W. A. L., Cruz, J. C. & Santana, D. P. (2001). Plantas de cobertura de solo para sistema plantio direto. *Informe Agropecuário*, 22(208), 25-36.
- Alvarenga, R. C., Costa, L. M., Moura Filho, W. & Regazzi, A. J. (1995). Características de alguns adubos verdes de interesse para a conservação e recuperação de solos. *Pesquisa Agropecuária Brasileira*, 30(2), 175-185.
- Baligar, V. C. & Fageria, N. K. (2007). Agronomy and physiology of tropical cover crops. *Journal of Plant Nutrition*, 30(8), 1287-1339. <https://doi.org/10.1080/01904160701554997>.

Baligar, V. C., Fageria, N. K. & He, Z. L. (2001). Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis* 32(7-8), 921-950. <https://doi.org/10.1081/CSS-100104098>.

Beniaich, A., Silva, M. L. N, Guimarães, D. V., Bispo, D. F. A., Avanzi, J. C., Curi, N., Pio, R. & Dondeyne, S. (2020). Assessment of soil erosion in olive orchards (*Olea europaea* L.) under cover crops management systems in the tropical region of Brazil. *Revista Brasileira de Ciência do Solo*, 44, e0190088. <http://dx.doi.org/10.36783/18069657rbcS20190088>.

Bertin, E. G., Andrioli, I. & Centurion, J. F. (2005). Plantas de cobertura em pré-safra ao milho em plantio direto. *Acta Scientiarum Agronomy*, 27(3), 379-386.

Borkert, C. M., Gaudêncio, C. A., Pereira, J. E., Pereira, L. R. & Oliveira Junior, A. (2003). Nutrientes minerais na biomassa da parte aérea em culturas de cobertura de solo. *Pesquisa Agropecuária Brasileira*, 38(1), 143-153.

Calegari, A., Hargrove, W. L., Rheinheimer, D. S., Ralisch, R., Tessier, D., Tourdonnet, S & Guimarães, M. F. (2008). Impact of long-term no-tillage and cropping system management on soil organic carbon in an oxisol: a model for sustainability. *Agronomy Journal*, 100(6), 1013-1019. <https://doi.org/10.2134/agronj2007.0121>.

Calvo, C. L., Foloni, J. S. S. & Brancalião, S. R. (2010). Produtividade de fitomassa e relação C/N de monocultivos e consórcios de guandu-anão, milheto e sorgo em três épocas de corte. *Bragantia*, 69(1), 77-86.

Carvalho, A. M., Coser, T. R., Rein, T. A., Dantas, R. A., Silva, R. R. & Souza, K. W. (2015). Manejo de plantas de cobertura na floração e na maturação fisiológica e seu efeito na produtividade do milho. *Pesquisa Agropecuária Brasileira*, 50(7), 551-561. <https://doi.org/10.1590/S0100-204X2015000700005>.

Carvalho, S. R. L., Rezende, J. O., Fernandes, J. C. & Pereira, A. P. (2003). Cinética do crescimento de leguminosas e gramíneas com alto poder relativo de penetração de raízes em solo coeso dos tabuleiros costeiros do Recôncavo Baiano. *Magistra*, 15(2), 1-12.

Cavalcante, V. S., Barbosa, J. T. V., Costa, L. C., Santos, V. R. & Santos, M. J. N. (2015). Produção de adubos verdes e a utilização dos resíduos no cultivo da cebolinha. *Revista Brasileira de Agroecologia*, 10(1), 24-31.

Cavalcante, V. S., Santos, V. R., Santos Neto, A. L., Santos, M. A. L., Santos, C. G. & Costa, L. C. (2012). Biomassa e extração de nutrientes por plantas de cobertura. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 16(5), 521-528. <https://doi.org/10.1590/S1415-43662012000500008>.

Costa, L. C., Rocha, A. M. S., Silva, P. J. M., Martins, D. D., Santos, C. G. & Santos, V. R. (2019). Produção de biomassa por leguminosas em diferentes épocas de semeadura na região Agreste de Alagoas. *Revista Ambientale*, 11(1), 102-111. <https://doi.org/10.34032/ambientale.v11i1.226>.

Empresa Brasileira de Pesquisa Agropecuária. (2018). *Sistema Brasileiro de Classificação do Solo*. (5a ed.), Brasília: Embrapa.

Fageria, N. K. (2007). Green manuring in crop production. *Journal of Plant Nutrition*, 30(5), 691-719. <https://doi.org/10.1080/01904160701289529>.

Fageria, N. K., Baligar, V. C. & Li, Y. C. (2014). Nutrient uptake and use efficiency by tropical legume cover crops at varying pH of an Oxisol. *Journal of Plant Nutrition*, 37(2), 294-311. <https://doi.org/10.1080/01904167.2013.851695>.

Fávero, C., Jucksch, I., Costa, L. M., Alvarenga, R. C. & Neves, J. C. L. (2000). Crescimento e acúmulo de nutrientes por plantas espontâneas e por leguminosas utilizadas para adubação verde. *Revista Brasileira de Ciência do Solo*, 24(1), 171-177. <https://doi.org/10.1590/S0100-06832000000100019>.

Finney D. M., White C. M. & Kaye, J. P. (2016). Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. *Agronomy Journal*, 108(1), 39-52. <https://doi.org/10.2134/agronj15.0182>.

Ghimire, R., Ghimire, B., Mesbah, A. O., Sainju, U. M. & Idowu, O. J. (2019). Soil health response of cover crops in winter wheat–fallow system. *Agronomy Journal*, 111(4), 2108-2115. <https://doi.org/10.2134/agronj2018.08.0492>.

Hallama, M., Pekrun, C., Lambers, H. & Kandeler, E. (2019). Hidden miners - the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems. *Plant and Soil*, 434(1-2), 7-45. <https://doi.org/10.1007/s11104-018-3810-7>.

Koné, A. W., Jérôme, E. T., Angui, P. K. T., Bernhard-Reversat, F., Loranger-Merciris, G., Brunet, D. & Brédoumi, S. T. K. (2008). Is soil quality improvement by legume cover crops a function of the initial soil chemical characteristics? *Nutrient Cycling in Agroecosystems*, 82(1), 89-105. <https://doi.org/10.1007/s10705-008-9172-4>.

Kumar, T. K., Rana, D. S. & Nain, L. (2019). Legume residue and N management for improving productivity and N economy and soil fertility in wheat (*Triticum aestivum*)-based cropping systems. *National Academy Science Letters*, 42(4), 297-307. <https://doi.org/10.1007/s40009-018-0744-9>.

Malavolta, E.; Vitti, G. C. & Oliveira, S. A. (1997). *Avaliação do estado nutricional de plantas: princípios e aplicações*. Piracicaba-SP: Potafos.

Matson, P. A., Parton, W. J., Power, A. G. & Swift, M. J. (1997). Agricultural intensification and ecosystem properties. *Science*, 277(5325), 504-509. <https://doi.org/10.1126/science.277.5325.504>.

Muoni, T., Koomson, E., Öborn, I., Marohn, C., Watson, C. A., Bergkvist, G., Barne, A., Cadisch, G. & Duncan, A. (2020). Reducing soil erosion in smallholder farming systems in east Africa through the introduction of different crop types. *Experimental Agriculture*, 56(2), 183-195. <https://doi.org/10.1017/S0014479719000280>.

Nascente, A. S., Dambiro, J. & Constantino, C. (2017). Effects of grain-producing cover crops on rice grain yield in Cabo Delgado, Mozambique. *Revista Ceres*, 64(6), 607-615. <https://doi.org/10.1590/0034-737x201764060007>.

Nóbrega, J. Q., Rao, T. V. R., Beltrão, N. E. M. & Fideles Filho, J. (2001). Análise de crescimento do feijoeiro submetido a quatro níveis de umidade do solo. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 5(3), 437-443. <https://doi.org/10.1590/S1415-43662001000300012>.

Nyawade, S. O., Karanja, N. N., Gachene, C. K. K., Gitari, H. I., Schulte-Geldermann, E. & Parker, M. (2020). Optimizing soil nitrogen balance in a potato cropping system through legume intercropping. *Nutrient Cycling in Agroecosystems*, 117(1), 43-59. <https://doi.org/10.1007/s10705-020-10054-0>.

Padovan, M. P., Motta, I. S., Carneiro, L. F., Moitinho, M. R. & Fernandes, S. S. L. (2011). Acúmulo de fitomassa e nutrientes e estágio mais adequado de manejo do feijão de porco para fins de adubação verde. *Revista Brasileira de Agroecologia*, 6(3), 182-190.

Pereira, A. P., Schoffel, A., Koefender, J., Camera, J. N., Golle, D. P. & Horn, R. C. (2017). Ciclagem de nutrientes por plantas de cobertura de verão. *Revista de Ciências Agrárias*, 40(4), 799-807. <http://dx.doi.org/10.19084/RCA17065>.

Prado, R. M. (2008). *Nutrição de plantas*. São Paulo: Editora Unesp.

Rowden, R., Gardiner, D., Whiteman, P. C. & Wallis, E. S. (1981). Effects of planting density on growth, light interception and yield of a photoperiod insensitive pigeon pea (*Cajanus cajan*). *Field Crops Research*, 4, 201-213. [https://doi.org/10.1016/0378-4290\(81\)90072-1](https://doi.org/10.1016/0378-4290(81)90072-1).

Ruis, S. J., Blanco-Canqui, H., Creech, C. F., Koehler-Cole, K., Elmore, R. W. & Francis, C. A. (2019). Cover crop biomass production in temperate agroecozones. *Agronomy journal*, 111(4), 1535-1551. <https://doi.org/10.2134/agronj2018.08.0535>.

Sakala, W. D., Kumwenda, J. D. T. & Saka, A. R. (2003). The potential of green manures to increase soil fertility and maize yields in Malawi. *Biological Agriculture & Horticulture*, 21(2), 121-130. <https://doi.org/10.1080/01448765.2003.9755257>.

SAS Institute incorporation. (2009). *The SAS system for Windows*, versão 9.2.

Sennhenn, A., Odhiambo, J. J. O., Maass, B. L. & Whitbread, A. M. (2017). Considering effects of temperature and photoperiod on growth and development of *Lablab purpureus* (L.) sweet in the search of short-season accessions for smallholder farming systems. *Experimental Agriculture*, 53(3), 375-395. <https://doi.org/10.1017/S0014479716000429>.

Sheldrake, A. R. & Narayana, A. (1979). Growth, development and nutrient uptake in pigeonpeas (*Cajanus cajan*). *The Journal of Agricultural Science*, 92(3), 513-526. <https://doi.org/10.1017/S0021859600053752>.

Teodoro, R. B., Oliveira, F. L., Silva, D. M. N., Fávero, C. & Quaresma, M. A. L. (2011). Aspectos agronômicos de leguminosas para adubação verde no cerrado do alto Vale do Jequitinhonha. *Revista Brasileira de Ciência do Solo*, 35(2), 635-643. <https://doi.org/10.1590/S0100-06832011000200032>.

Tian, G. & Kang, B. T. (1998). Effects of soil fertility and fertilizer application on biomass and chemical compositions of leguminous cover crops. *Nutrient Cycling in Agroecosystems*, 51(3), 231-238. <https://doi.org/10.1023/A:1009785905386>.

Venkateswarlu, B., Srinivasarao, C. H., Ramesh, G., Venkateswarlu, S. & Katyal, J. C. (2007). Effects of long-term legume cover crop incorporation on soil organic carbon, microbial biomass, nutrient build-up and grain yields of sorghum/sunflower under rain-fed conditions. *Soil Use and Management*, 23(1), 100-107. <https://doi.org/10.1111/j.1475-2743.2006.00068.x>.

Wang, Y. & Lambers, H. (2020). Root-released organic anions in response to low phosphorus availability: recent progress, challenges and future perspectives. *Plant and Soil*, 447(1-2), 135-156. <https://doi.org/10.1007/s11104-019-03972-8>.

Xavier, F. A. S., Oliveira, J. I. A. & Silva, M.R. (2017). Decomposition and nutrient release dynamics of shoot phytomass of cover crops in the Recôncavo Baiano. *Revista Brasileira de Ciência do Solo*, 41, e0160103. <https://doi.org/10.1590/18069657rbc20160103>.

Xavier, R. A. & Dornellas, P. C. (2005). Análise do comportamento das chuvas no município de Arapiraca, região Agreste de Alagoas. *Geografia*, 14(2), 49-64.

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Leonardo Correia Costa – 10%

Antonio Márcio Souza Rocha – 10%

Cícero Gomes dos Santos – 10%

Márcio Aurélio Lins dos Santos – 10%

Flávio Henrique Silveira Rabêlo – 10%

Renato de Mello Prado – 10%