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Artigos

Biomass and carbon in *Schizolobium parahyba* var. *amazonicum* stands under different spacing

Biomassa e carbono em plantios de *Schizolobium parahyba* var. *amazonicum* sob diferentes espaçamentos

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ABSTRACT

Native species planted in areas previously occupied by degraded pasture can play an important role in biomass supply and atmospheric carbon sequestration. Evaluating the performance of native species in different planting spacings becomes important for forestry and the management of new species with economic potential. *Schizolobium parahyba* var. *amazonicum* is a non-traditional species in the southeastern region of Brazil and it was established in pasture areas to evaluate growth, biomass, and carbon stock. Five planting spacings (3 m x 2 m, 3 m x 3 m, 4 m x 3 m, 4 m x 4 m, and 5 m x 5 m, in monoculture) were tested in 9 experimental plots. The biomass of the shoot and root, as well as the carbon content, were obtained by the direct method. The biomass varied 31.4 and 52.9 kg tree^{-1} in the spacing 3 m x 2 m and 5 m x 5 m, respectively. The greater carbon stock was observed in the lower spacing (19.43 Mg ha^{-1}), 50% higher than in the larger spacing. The spacing did not influence the biomass and carbon stock in the roots per unit area. The performance of the species should be monitored at advanced ages given the different responses to planting spacing and competition between plants.

Keywords: Silviculture; Carbon stock; Tree legume

RESUMO

Espécies nativas plantadas em locais anteriormente ocupados por pastagem degradada podem desempenhar um papel importante no suprimento de biomassa e no sequestro de carbono atmosférico. Avaliar o desempenho das espécies nativas em diferentes espaçamentos de plantio se torna importante para a silvicultura e o manejo de novas espécies com potencial econômico. *Schizolobium parahyba* var. *amazonicum* é uma espécie não tradicional na região sudeste do Brasil, e foi estabelecida em área de pastagem com objetivo de avaliar o crescimento, a biomassa e o estoque de carbono. Foram testados cinco espaçamentos de plantio em monocultivo (3 m x 2 m, 3 m x 3 m, 4 m x 3 m, 4 m x 4 m e 5 m x 5 m) com 9 parcelas experimentais. A biomassa da parte aérea e radicular, bem como o teor de carbono foram obtidos por meio do método direto. A biomassa variou 31.4 and 52.9 kg árvore^{-1} nos espaçamentos 3 m x 2 m e 5 m x 5 m, repectivamente. O maior estoque de carbono foi observado no espaçamento mais adensado (19.43 Mg ha^{-1}), sendo 50% maior do que no espaçamento menos adensado. O espaçamento não influenciou a biomassa e o estoque de carbono nas raízes por unidade de área. O desempenho da espécie deveria ser monitorado em idades avançadas dado as diferentes respostas ao espaçamento de plantio e competição entre plantas.

Palavras-chave: Silvicultura; Estoque de carbono; Leguminosa arbórea

1 INTRODUCTION

Forests are essential to mitigate the effects of climate change, as they constitute large carbon deposits and have the capacity to continuously absorb carbon dioxide from the atmosphere (PENNE; AHRENDS; DEURER; BÖTTCHER, 2010). It is important to monitor the carbon stocks and sources in forests to understand the processes which affect their balance in order to verify the direction and magnitude of forest ecosystem reactions to global changes. This knowledge can also be incorporated into the forest management planning to assist climate change mitigation efforts (STINSON; KURZ; SMYTH; NEILSON; DYMOND; METSARANTA; BOISVENUE; RAMPLEY; LI; WHITE; BLAIN, 2011).

Planting spacing should be considered among the factors which affect the carbon stock, as well as changes in tree growth rates, wood quality, harvesting age, and forestry exploitation and management practices. That variable is also linked to ecological/silvicultural factors of paramount importance such as the decomposition of soil organic matter (BENOMAR; DESROCHERS; LAROCQUE, 2012).

Forest plantations in Brazil are commonly established in areas where previously existed pasture. Studies in planted forests with the objective of quantifying the biomass and soil carbon stock are easily found in the literature (KEITH; LINDENMAYER; BRENDAN; BLAIR; CARTER; MCBURNEY; OKADA; KONISHI-NAGANO, 2014). The specie *Schizolobium parahyba* var. *amazonicum*, popularly known as paricá, is a native tree species from the Amazon region which is little cultivated in Southeast Brazil. This specie is prominent in the Northern Region of Brazil and commonly planted in agroforestry systems (ROSÁRIO; BATISTA; PROVENZANO; LEMOS; SANTOS, 2014). The specie has rapid growth (30 m^3 ha^{-1} $year^{-1}$) (CORDEIRO; BARROS; LAMEIRA; GAZEL FILHO, 2015) and good performance in homogeneous formations and in consortia (CORDEIRO; BARROS; LAMEIRA; GAZEL FILHO, 2015). It is, therefore, recommended for commercial purposes, agroforestry systems and reforestation of degraded areas. Although there are several studies of *S. parahyba* var. *amazonicum* evaluating its aspects such as growth, wood yield, survival in natural conditions and in water deficit (CARVALHO, 2005), but there are no data in the literature on the carbon storage and biomass of this specie in southeast of Brazil.

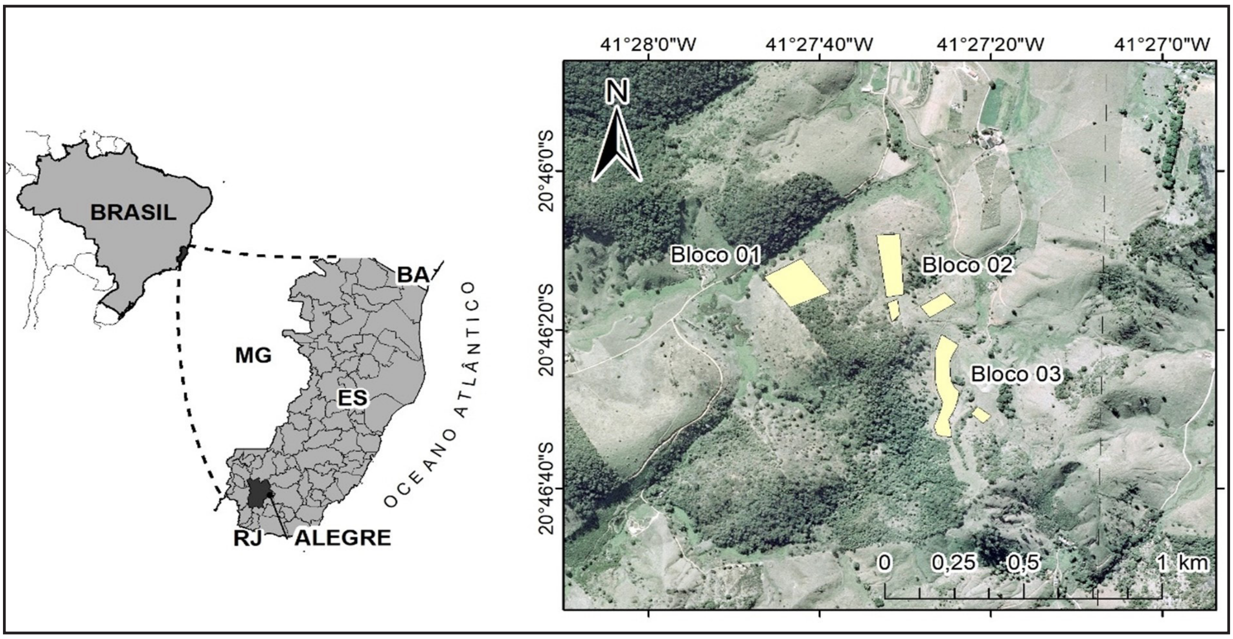
Quantifying the carbon stored in trees in different planting spacings is important to understand the mechanisms associated with CO_2 absorption from photosynthesis and its stock conservation in above and below ground (roots) biomass as a function of the competition between trees. Although yield estimates exist, little is known about the spacing effects on biomass allocation and root distribution in *S. parahyba* var. *amazonicum*. Therefore, this study aimed to quantify the biomass and carbon stock in *S. parahyba* var. *amazonicum* under different planting spacings in order to reduce the gap of studies of the cited specie.

2 MATERIAL AND METHODS

2.1 Study area

This study was conducted in the municipality of Alegre, Espírito Santo State, Brazil, at the coordinates 20° 46’ 26.09” S and 41° 27’ 26.21” W, in an area granted by the Federal Institute of Education Science and Technology of Espírito Santo, Alegre, ES (Figure 1).

Figure 1 – Location of the experiment with *S. parahyba* var. *amazonicum* stands, in Espírito Santo, Brazil.



Source: Authors (2019)

The regional climate is Aw with a dry winter and rainy summer, according to the Köppen classification (ALVARES; STAPE; SENTELHAS; GONÇALVES, 2013). The average precipitation in the analyzed period (2011 to 2016) was 1222 mm (rains concentrated in the rainy season from November to March), and the average temperature was 23.9°C. The area was previously used for extensive livestock, without any management and with dominance of *Urochloa* sp. species. The seedlings were produced and donated by the Vale Natural Reserve, Linhares, ES with seeds from selected trees located in Dom Eliseu - Pará, with high genetic diversity (SILVA JÚNIOR; SOUZA; PEREIRA; CALDEIRA; MIRANDA, 2017). Seedlings planting was carried out in June 2011 in seedling trays with dimensions of 0.30 m x 0.30 m x 0.30 m along with basic fertilization using 220 g per hole of NPK 06-30-06 and micronutrients (0.2 % B; 0.2 % Cu; and 0.2 % Zn).

2.2 Experimental design

The experiment consisted of completely randomized design with five treatments (spacing) and nine repetitions per treatments, totaling 45 experimental units. Through the forest inventory, growth and biomass were determined in the different spacings of *S. parahyba* var. *amazonicum*. The studied spacings was: T1, 3 m x 2 m; T2, 3 m x 3 m; T3, 3 m x 4 m; T4, 4 m x 4 m; T5, 5 m x 5 m. Each experimental unit was 30 meters per 50 meters (1500 m^2).

The total height (Ht) and the diameters at breast height (DBH) were evaluated at 56 months old (March 2015). We measured diameters at breast height and the total height of 30 trees selected sequentially in the central lines of each sample unit, totaling 270 trees in each spacing. Height and diameter models were adjusted to predict heights of other trees in the stand. With the best adjustments were selected based on the adjusted determination coefficient (R^2aj.) and the standard error of the percentage estimate (Syx) (Table 1).

Table 1 – Adjusted equations and their respective statistics for estimating the total height of *S. parahyba* var. *amazonicum* (n=270) at 56 months of age in Rive, Alegre, ES, Brazil

Spacing (m x m)	Equation	R^2aj. (%)	Syx (%)
3 x 2	Ht=1.907129+1.44394*DBH-0.030937*DBH^2	0.55	17.01
3 x 3	Ht=17.2935/(1+EXP((9.7931-DBH)/4.4074))	0.66	19.61
4 x 3	Ht=15.9735/(1+EXP((9.3846-DBH)/4.3516))	0.59	15.26
4 x 4	Ht=18.87/(1+EXP((11.3868-DBH)/4.0261))	0.69	20.47
5 x 5	Ht=17.6477/(1+EXP((9.8337-DBH)/4.93451))	0.56	21.38

Source: Authors (2019)

In where: R^2aj. = adjusted determination coefficient; Syx = residual standard error; Ht = total height (m); and DBH = diameter at 1.30 m from the ground.

A total of 45 trees were sampled to estimate the volume of trees with bark, with 9 individuals of average diameter ± one standard deviation in each spacing. The stem with bark volume was calculated using the Smalian method. The regression model described by Schumacher and Hall was used to estimate the volume of the other trees in the stand from the values of DBH, Ht and stem volume with bark of the 45 trees felled. The equation adjusted by this model was: V = 0.00007296 * DBH1.986 * Ht0.7784, in which: V = Volume (m^3); DBH = diameter at breast height (cm); and Ht = total height (m).

2.3 Aboveground and belowground biomass

At 56 months old, a total of 45 trees were felled to quantify the aboveground biomass in the following compartments: stem with bark, bark, branches and leaves (RIBEIRO; SOARES; FEHRMANN; JACOVINE; GADOW, 2015). Samples were taken from each compartment to obtain dry weight. Thus, subsamples were removed from portions in the lower, middle and upper third of the tree canopy to sample branches and leaves.

The root biomass was quantified in the approximate area of the canopy projection of 15 trees with a pneumatic backhoe, which resulted in excavated areas of 6 to 9 m^2) and approximately 1 m in depth. All the roots were removed from each tree and cleaned. After, the weighed in the field with a portable scale with a maximum capacity of 50 kg and precision of 0.1 g. The samples taken were composed of the root system containing roots with different diameters (> 1 mm) to obtain dry weight.

Aboveground biomass and root biomass were obtained by discounting sample moisture. The biomass of the aboveground tree components and that of the roots was estimated for the spacing (treatments) based on the individual values of the 45 trees felled. Six linear allometric models were tested in which DBH and total height were used as independent variables. The models were selected according to the Schlaegel coefficient of determination (R^2adj.) and residual standard error (Syx) (Table 2).

Table 2 – Adjusted equations to estimate biomass in the compartments of *S. parahyba* var. *amazonicum* at 56 months of age in Alegre, ES, Brazil

Compartment	Equation	R^2aj	Syx
Roots	Bio= -8.416673 + (0.218092.DBH^2) - 0.006885*(DBH^2.Ht)	0.87	1.99
Stem	Bio = -3.09641 + (0.16979.DBH^2) + 0.00505*(DBH2.Ht)	0.95	5.54
Bark	Bio = -5.78683 + (0.63483.DBH) + (0.15817.Ht)	0.92	0.70
Branches	Bio= -3.789381 - (0.901851.DBH) + (0.21063.DBH^2) - 0.005204(DBH^{2}Ht)	0.49	7.46
Leaves	Bio= 2.0114073 + (-0.3166008.DBH) + (0.0097108. DBH^2) + (0.0007603.(DBH^2*Ht)	0.72	0.90
Total*	Bio=-11.323296+(0.313999.DBH^2) + 0.001973.(DBH^2.Ht)	0.94	8.64

Source: Authors (2019)

In where: R^2aj. = adjusted determination coefficient; Syx = residual standard error; Bio = biomass; DBH = diameter at 1.30 m from the ground (cm) and Ht = total height of the tree (m). * Total aboveground biomass.

2.4 Carbon stock of above and belowground biomass

The carbon content of aboveground compartments (stem with bark, bark, branches, leaves) and roots were analyzed using a C-144 LECO analyzer (LECO, 2012). Thus, the carbon stock of the aboveground biomass compartments and root biomass were calculated by multiplying each aboveground biomass and root biomass compartment by the average carbon content obtained for each compartment.

The total aboveground carbon stock of the *S. parahyba* var. *amazonicum* species was calculated by adding all the carbon sets of the tree compartments available for each spacing. The total belowground carbon stock is comprised of the carbon stock of the roots. The carbon stock of the tree was the sum of the total aboveground carbon stock and the total root carbon stock.

2.5 Data analysis

The growth, biomass and carbon stock data were subjected to the homogeneity of variance and normality test using the Bartlett and Shapiro-Wilk tests, respectively, at the 5 % error probability level. After meeting the requirements, the data were analyzed using analysis of variance (ANOVA). The treatment means were compared using the Tukey test at a 5 % probability error level.

3 RESULTS

3.1 Growth of the *S. parahyba* var. *amazonicum* specie

The diameter at breast height (DBH) was 26.5 % greater in the 4 m x 4 m spacing in relation to the 3 m x 2 m spacing. However, the smallest spacing had a height increase of at least 16.5 % higher than the other treatments (Table 3). The density of individuals expected for each planting spacing is 1667 tree ha^{-1}, 1111 tree ha^{-1}, 833 tree ha^{-1}, 625 tree ha^{-1}, and 400 tree ha^{-1} for the 3 m x 2 m, 3 m x 3 m, 4 m x 3 m, 4 m x 4 m and 5 m x 5 m spacings, respectively. However, there was individual mortality of 35 %, 33 %, 34 %, 30 % and 28 % in plantations with 3 m x 2 m, 3 m x 3 m, 4 m x 3 m, 4 m x 4 m and 5 m x 5 m spacing, respectively. Due to the greater number of individuals planted per unit area in the smaller spacing, the basal area reaches 124.5 % greater in the 3 m x 2 m spacing in relation to the 5 m x 5 m spacing. The same trend is assessed for the variable population volume per unit area, which is up to 148.6 % higher in the 3 m x 2 m spacing.

Table 3 – Mean values of dendrometric variables in *S. parahyba* var. *amazonicum* 56 months after planting in Rive, Alegre, ES, Brazil

Spacing (m x m)	DBH (cm)		Ht (m)		V (m^3 ha^{-1})	
3 x 2	11.3	b	13.4	a	87.5	a
3 x 3	12.0	ab	10.4	b	55.5	b
4 x 3	13.4	ab	10.9	b	47.9	b
4 x 4	14.3	a	11.4	b	52.3	b
5 x 5	14.2	a	11.5	b	35.2	c
Mean	13.2		11.5		55.7	
CV (%)	30.1		9.63		17.7	

Source: Authors (2019)

In Where: DBH = diameter at 1.3 m above the ground; Ht = total height; V = volume of the stem with bark. Means followed by the same letter do not differ at the 5 % significance level by the Tukey test.

3.2 Aboveground and belowground biomass

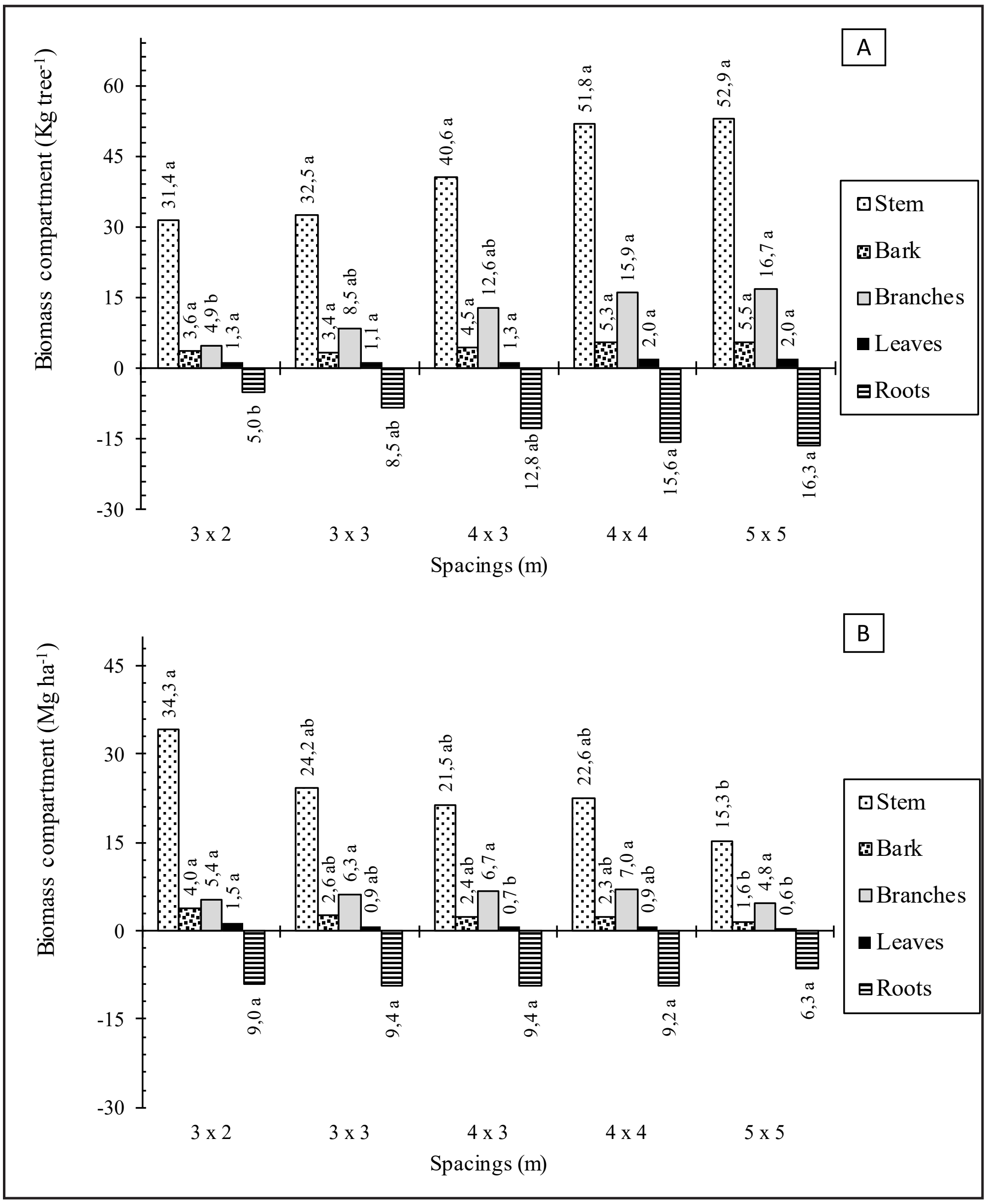
The individual biomass of the stem, bark, branches, leaves and roots compartments of the specie S. parahyba var. amazonicum was estimated and we verified statistical difference only for branches and roots. The averages of individual stem biomass ranged from 31.4 kg tree^{-1} in the 3 m x 2 m spacing to 52.9 kg trees^{-1} in the 5 m x 5 m spacing. The trees of *S. parahyba* var. *amazonicum* obtained an average bark biomass of 4.43 kg tree^{-1}. However, the biomass of branches had significant variation, being evaluated a minimum of 4.92 kg tree^{-1} in the 3 m x 2 m spacing and a maximum of 16.7 kg tree^{-1} in the 5 m x 5 m spacing. The specific characteristic of the canopy of the studied species was evidenced by the low variation of the leaf biomass, having evaluated an average of 1.54 kg tree^{-1} of leaves. The roots varied significantly. Variation greater than 11 kg tree^{-1} was evaluated when comparing the highest and lowest planting density. (Figure 2 A).

The production of total and compartment biomass by hectare varied significantly with the planting spacing. Except for the branches component, different planting spacings influence all aboveground biomass components (Figure 2 B).

The decreasing order of biomass production by area of *S. parahyba* var. *amazonicum* by planting spacing was 3 m x 2 m > 3 m x 3 m > 4 m x 4 m > 4 m x 3 m > 5 m x 5 m. The largest total biomass of 40.6 Mg ha^{-1} was observed in the 3 x 2 m spacing after 56 months of age, or 25 %, 31 %, 27 % and 51 % greater than the plantations carried out in the 3 m x 3 m, 4 m x 3 m, 4 m x 4 m and 5 m x 5 m spacings, respectively.

The mean root biomass values by individuals differed statistically in the analyzed planting spacings. The wider spacing generally promoted greater root biomass. However, there was no statistical difference in the biomass produced by area, indicating that the greater number of individuals in the denser spacing was not able to compensate for the greater individual growth of the trees planted in the wider spacing (Figure 2 B). The proportion of root biomass per area in relation to the leaves was 18 %, 24 %, 25 %, 24 % and 24 %, in the 3 m x 2 m, 3 m x 3 m, 4 m x 3 m, 4 m x 4 m and 5 m x 5 m spacings, respectively. Thus, *S. parahyba* var. *amazonicum* allocates an average of 23 % of the biomass in its roots.

Figure 2 – Above and below ground biomass components in kg tree^{-1} (A) and Mg ha^{-1} (B), in the different spacings of *S. parahyba* var. *amazonicum* at 56 months of age in Rive, Alegre, ES, Brazil



Source: Authors (2023)

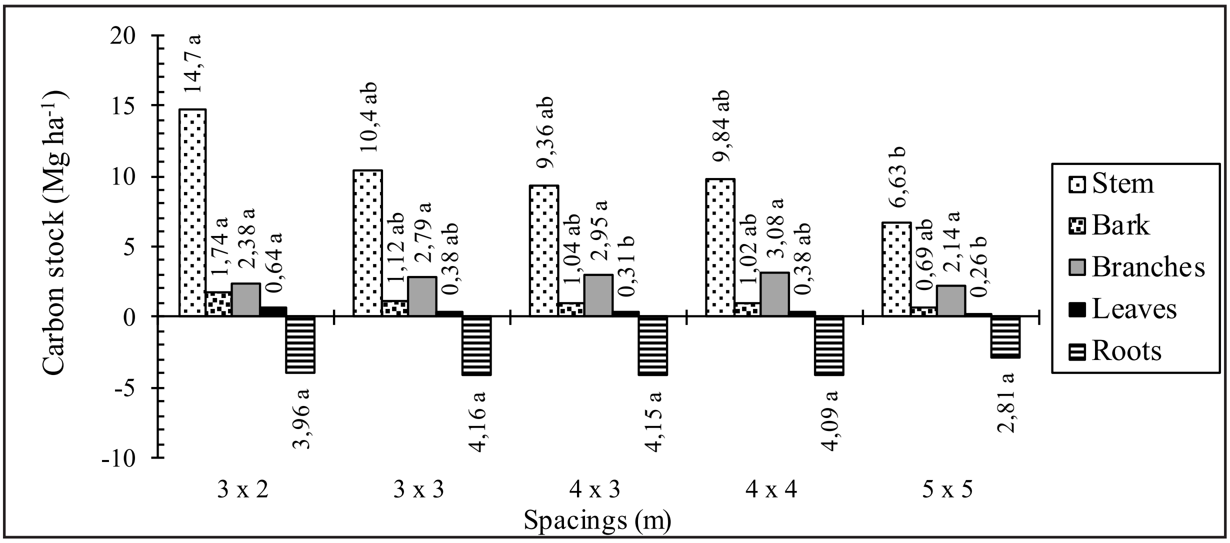
In where: Means followed by the same letter in the biomass component do not differ at the 5 % significance level by the Tukey test.

3.3 Carbon in the trees and the plantation

The planting spacing did not influence the carbon content in the stem with bark, bark, leaf, branch or root compartments ($p > 0.05$). The average carbon content was 43.2 %; 43.9 %; 44.3 %; 44.4 %; and 44.2 % for the stem with bark, bark, branches, leaves and roots, respectively. Thus, the spacing affects the wood production volume and does not alter the carbon content in the different tree compartments.

Based on the carbon content and biomass production of each biomass component, the average carbon stock in planting *S. parahyba* var. *amazonicum* with the five different planting spacings was estimated at 56 months of age (Figure 3). It was found that the spacing had a significant effect on the carbon stock in the stem with bark, bark, leaf and total aboveground biomasses ($p < 0.05$). The largest carbon storage in the planting at 56 months of age was 19.43 Mg ha^{-1} using the 3 m x 2 m spacing, 50 % greater than in the planting with 5 m x 5 m spacing.

Figure 3 – Above and belowground carbon stock (Mg ha^{-1}) in the different biomass components and spacings of *S. parahyba* var. *amazonicum* stand, at 56 months of age in Rive, Alegre, ES, Brazil



Source: Authors (2023)

In Where: Means followed by the same letter do not differ at the 5% significance level by the Tukey test.

The spacing had no influence on the carbon stock of S. parahyba var. amazonicum roots. *S. parahyba* var. *amazonicum* trees allocate 17 %, 22 %, 23 %, 22 % and 22 % of the total carbon to the root system in the 3 m x 2 m, 3 m x 3 m, 4 m x 3 m, 4 m x 4 m and 5 m x 5 m spacings, respectively. The 56-months-old plants allocate an average of 3.84 Mg ha^{-1} of carbon in the roots.

4 DISCUSSION

4.1 Silvicultural evaluation

The trees showed the highest DBH in the widest spacing (Table 1). However, the reverse occurred for the height with the smallest spacing having the highest average heights. This trend was also observed by Lima, Inoue, Figueiredo Filho, Araujo and Machado, (2013), in which higher densities produced stems with smaller diameters in relation to the lower densities. It is inferred that there is an induction of growth in tree height in conditions of greater intraspecific competition in higher density sites of individuals due to competition for sunlight. Evaluating *S. parahyba* at 60 months in 5 x 2 m spacing in the Amazon, Sales, Oliveira Neto, Paiva, Leite, Siviero e Vieira (2021) found DBH ranging from 16 to 20 cm; total height of 15 and 21 m and withouth bark volume between 120 and 180 m^3 ha^{-1}.

There was a tendency for the basal area to increase with the smallest planting spacing. The basal area at 44 months of age was larger in the 3 m x 2 m and 3 x 3 m spacings, and smaller in the 4 m x 3 m, 4 m x 4 m and 5 m x 5 m spacings. The basal area values decrease progressively as the space increases. This is due to the number of trees per unit area which varied from 1091 tree ha^{-1} to 289 tree ha^{-1}. Even with smaller diameters, trees planted in smaller spacing accumulated a higher basal area than those planted in wider spacing. Higher basal area values were also found in the smallest spacing up to the age of eight years in studies carried out by Inoue, Filho e Lima (2011) in *Pinus taeda* stands.

The largest volumes of stands were obtained in plantations with smaller spacing. The difference in wood volume by area was 40.2 % between the lowest spacing of 3 m x 2 m and the highest of 5 m x 5 m. This result refers to the number of trees planted in each stand with different planting spacing. Similar results were found by Santos, Castro, Carneiro, Castro, Pimenta, Pinto e Marinho (2016) testing the effect of different spacing on the wood volume of *S. parahyba* var*. amazonicum*. The author found a volume of 204.8 m^3 ha^{-1} in the 3 m x 2 m spacing and 104.6 m^3 ha^{-1} in the 5 m x 5 m spacing at 48 months of age located between the municipalities of Dom Eliseu and Paragominas, PA, being about four times greater than the present study probably due to the different rainfall regime.

4.2 Biomass of trees and stands

The distribution of biomass in the different tree compartments followed the pattern observed in the literature: greater accumulation of biomass in the stem with bark, branches and finally in the leaves (VIRGENS; BARRETO-GARCIA; PAULA; CARVALHO; ARAGÃO; MONROE, 2016). Biomass per individual at 56 months was not significantly different between spacings, except for branch production (Figure 2). The production of branches per tree was lower in the 3 m x 2 m spacing and statistically higher in the 4 m x 4 m and 5 m x 5 m spacing. This fact may be a consequence of competition for growth resources, which intensifies with age and a smaller useful area per plant. Similar results were found for *Eucalyptus grandis* Hill ex Maiden x *E. urophylla* S. T. Blake (TRINDADE; LAFETÁ; AGUIAR; SILVA; FERRARO; PENIDO; VIERA, 2019).

A greater allocation of biomass in the stem becomes evident when comparing the individual biomass of the crown (composed of the leaf and branch components) with the individual biomass of the stem with bark, especially when evaluating the denser spacing where there is greater competition between individuals. The increasing allocation order of individual biomass relative to the stem with bark and total biomass was from the smallest to the largest spacing: 3 m x 2 m > 3 m x 3 m > 4 m x 3 m > 4 m x 4 m > 5 m x 5 m (84.35 %; 79.44 %, 76.69 %, 76.62 % and 76.28 %, respectively). These values are in accordance with the study conducted by Oliveira, Lima, Sanquetta and Corte (2018), because the stem biomass for the *Araucaria angustifolia* species (which also has monopodial growth) represented 80.31 % of the total biomass, while the crown biomass presented 19.69 %, indicating that most of the shoot biomass is located in the tree stem.

The literature proves the influence of spacing on biomass production by area in several forest species and in different sites (NASCIMENTO; LELES; OLIVEIRA NETO; MOREIRA; ALONSO, 2012). Rondon (2002) found that the largest spacings tested (4 m x 3 m and 4 m x 4 m) for *S. parahyba* var. *amazonicum* at 60 months of age provided the largest tree growth, while the lowest values for plant height and diameter and consequently for total biomass were found in the smallest spacings (1.5 m x 1.5 m, 2 m x 2 m, 3 m x 2 m and 4 m x 2 m). In addition, the author found total biomass production equal to 92.6 Mg ha^{-1} in the municipality of Sinop-MT, more than double that obtained in this study. The higher production found in Sinop-MT may be due to higher annual average temperatures and precipitation. Nascimento; Leles; Oliveira Neto; Moreira and Alonso (2012) also reported significant spacing effects on the growth of six different species, including *S. parahyba* var. *parahyba* at 22 months of age. The authors found that greater individual plant growth is generally observed in the wider spacing along with larger production per area in the smaller spacing, as in the present study.

Batista (2019) evaluated the biomass in stands of *S. parahyba* in Pará – Brazil. The method used was the biomass expansion factor. Stands at ages 42, 57 and 78 months had biomass of 34.5, 56.5 and 51.9 Mg ha^{-1}. Biomass production in our study was below the average found by Batista (2019), considering stands of the same age. This can be attributed, mainly, to climate conditions, since, in the region studied by the authors, the average annual precipitation is 83 % higher, 2200 mm. In addition, higher temperatures in the equatorial region contribute to increased biomass production.

Other recent studies also evaluated the biomass production in the species addressed in our research. In a 6-year-old stand implanted in the state of Rondônia, spaced 3 m x 3 m, Neves, Oliveira, Ataides, Santos, Pereira, Aquino, Sccoti, Tronco, Melo and Mascarenhas (2022) found a biomass production of 41.9 Mg ha^{-1}, with the participation of 72.2 , 7.3, 11.2 and 9.3 % for wood, bark, branches and leaves, respectively.

The choice of planting spacing is very important for maximizing biomass or carbon stock production, and for determining the forest production cycle. When data from *S. parahyba* var. *amazonicum* at 56 months of age were analyzed, the spacing effect on biomass production and carbon storage was significant. There was higher biomass and carbon production in the 3 m x 2 m spacing than the other tested treatments. However, more in-depth studies should be carried out in order to obtain data on the annual increment of the species to analyze the planting rotation in the south of Espírito Santo.

The biomass distribution patterns varied with the planting spacing, except for branches. The classification of the biomass production of the plantations by the components was stem > branches > bark > leaf. The production of the supporting components of the plant (stem and branches) was 25 times higher than that of the productive component (foliage). There was a change in the distribution pattern with increased spacing, for example that the foliage, bark and branches represented 4 %, 10 % and 13 % of the total biomass for planting in the densest spacing (3 m x 2 m) compared to 3 %, 8 % and 24 % for the widest (5 m x 5 m), respectively. A reduction in the stem proportion from the smallest to the largest spacing was also observed, which represented 84 %, 79 %, 77 %, 77 % and 76 % of the total biomass.

The increase in the root biomass proportion in the widest spacing may be associated with less competition between trees and for sustaining individuals with greater shoot size due to greater individual growth (Table 2). Furthermore, it should be noted that the literature shows that the biomass allocation proportion in the roots in forest stands tends to decrease with the advancing age of the stand, with a greater amount of biomass being allocated in the stem (FORSTER and MELO, 2007).

Published studies have identified the root/shoot ratio of both temperate (RANGER and GELHAYE, 2001) and tropical species (HASE and FOELSTER, 1983; KRAENZEL; CASTILLO; MOORE; POTVIN, 2003). This proportion generally and progressively decreases with age and ranges from 0.5 to 0.3 for young trees to 0.3 to 0.15 for old trees. As an example, in working with the Tectona grandis species, Hase and Foelster (1983) found a root ratio equal to 0.42 at 4 years of age and 0.20 at 9 years. Also working with the Tectona grandis species, Kraenzel, Castillo, Moore and Potvin, (2003) found 0.16 at 20 years of age. Similar trends were found by Laclau (2003) for *Pinus* sp. (0.24 at 10 years compared to 0.16 at 20 years). In addition, in a study with 44 species in nine heterogeneous reforestation areas in the Middle Valley of Paranapanema-SP, Forster and Melo (2007) evaluated that an average of 20 % of the tree's biomass is allocated in the roots. Furthermore, they found that 14.8 % of the biomass for *S. parahyba* var. *amazonicum* is allocated in the roots.

4.3 Carbon in trees and stands

Previous studies have shown that the carbon content varies between forest species. The average carbon content of the stem of 135 species of tropical trees ranged from 41.9 –51.6 % (THOMAS and MARTIN, 2012). Even in the case of a young population, the values found in the present study are within the range evaluated for trees of tropical climate.

Comparisons within the *S. parayba* var. *amazonicum* species are hampered by the small number of studies which have quantified the carbon content in different compartments of this species. Vidaurre, Vital, Oliveira, Oliveira, Moulin, Silva and Soranso (2018) only analyzed the carbon content for the stem of *S. parayba* var. *amazonicum* for stands at 5, 7, 9 and 11 years of age in 4 m x 4 m spacing and obtained higher averages than that found in this study (45.39 %, 45.33 %, 45.32 % and 45.65

%, respectively) in plantations located in Dom Elizeu, Pará, Brazil. The edaphoclimatic conditions and the age of the stand may have influenced the carbon content in the stem of the present study.

There was a significant difference ($p < 0.05$) for the total carbon stock only for the 5 m x 5 m spacing, with this being the treatment with the lowest carbon accumulation per unit area in the aboveground biomass of *S. parahyba* var. *amazonicum*. Based on the results of our study, trees in plantations with 3 m x 2 m planting spacing stock 19.49 Mg ha^{-1} at 56 months of age, with this value being similar to the *Eucalyptus urophylla* and *Acacia mangium* species (ZHANG; GUAN; SONG, 2012).

The higher carbon content in the leaves is an expected result due to the stomata density which allow CO_2 entry, with consequent performance of photosynthesis and carbon content in the leaf tissue (DALLAGNOL, MOGNON; SANQUETTA; CORTE, 2011). According to the authors, the normal fixation route between the compartments would be: foliage, branches, wood, root and bark. The carbon content distribution between the different spacings followed the order Leaf > Bark > Branches > roots > Stem with bark, similar to that found by Ribeiro, Soares, Fehrmann, Jacovine and Gadow (2015) for Eucalyptus in southeastern Brazil.

The carbon allocation to the tree roots found in the present study was similar to the values reported by previous studies. Oelbermann, Voroney, Kass and Schlonvoigt**,** (2005) found values of carbon allocated in the roots of *Erythrina poeppigiana* varying between 28 % at 4 years of age and 16 % at 10 years of age. The statistically equal averages of the carbon and biomass allocation in the roots between the spacings can be related to the age of the trees and that the planting is not yet in competition for nutrients. According to Oelbermann, Voroney, Kass and Schlonvoigt**,** (2005), the concept of nutrient exploration can explain the different rooting patterns among trees with a higher planting age (10 years) and a lower planting age (4 years). The authors found a greater carbon stock in the roots at a depth of 0 to 20 cm for 10-year-old trees due to the low level of soil nutrients at the time of tree establishment and higher nutrient content in this soil range.

4.4 Biomass and total carbon stock in the stand

The total carbon stock estimated in the *S. parahyba* var. *amazonicum* considering the total aboveground biomass and the root biomass was 49.78 Mg C ha^{-1}, and presented an annual carbon increase of approximately 3.8 Mg ha^{-1} year^{-1} up to 56 months of age. In the study by Neto, Jacovine, Torres, Oliveira Neto, Castro, Villanova and Ferreira (2017), an increase of 3.124 Mg C ha^{-1} year^{-1} was estimated for a silvopastoral system (eucalipto + brachiaria grass/cattle), smaller than that of the present study. Values close to this study were observed in two silvopastoral systems in the municipality of Alegrete, RS, in which Oliveira, Ribaski, Zanetti and Penteado Junior (2008) estimated a carbon increase of 3.40 Mg and 3.82 Mg ha^{-1} year^{-1} of carbon for a silvopastoral system with eucalyptus with a density of 500 and 1,000 trees per hectare, respectively.

The leaves stock the corresponding 73.35 % of the carbon present in the biomass. Thus, the roots have about 26.65 % of the carbon present in the trees of this species. Regarding the carbon stored in the shoot/root and similarly to the present study, Torres Jacovine, Soares, Oliveira Neto, Santos and Castro Neto (2013) found 84.10 % of the carbon contained in the shoot and 15.90 % in the roots of the species for a Seasonal Semi-deciduous Forest fragment. Paixão, Soares, Jacovine, Silva, Leite and Silva (2006) also found similar results to that of this study for a six-year-old *Eucalyptus* sp. plantation, with 67.06 % of the carbon being stored in the shoots of the trees and 20.68 % in the roots.

5 CONCLUSIONS

Greater spacing in a *Schizolobium parahyba* var. *amazonicum* stand promoted lower biomass per hectare, and indicates growth capacity with advancing maturity. This observation can only be made in the aboveground biomass, while the root system did not show variation and indicates absence of competition.

The highest biomass per tree in the 5 m x 5 m spacing, but not in the biomass per hectare, leads to the conclusion that the stand did not show the real potential of the species.

The different planting spacings did not influence the carbon content in all biomass compartments. Among the different compartments, the highest carbon content in the biomass was found in the bark, branch and leaf compartments, and the lowest carbon content was found in the stem of *S. parahyba* var. *amazonicum*.

Forest stands for furniture purposes can be considered as one of the main commercial activities that guarantee the accumulation and storage of carbon during and after tree growth, since industrialized wood promotes fixed carbon.

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