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Comparing spacings of *Anadenanthera peregrina* (L.) Speg stand: response in biomass and carbon stock above and below ground

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ABSTRACT

Forests play a crucial role in the global carbon cycle. Among the factors that can affect carbon stocks in forest stands, planting spacing stands out. This study verified the effect of spacing on biomass and carbon stock in a stand of *Anadenanthera peregrina* (L.) Speg at 56 months of age. They were planted with 3 x 2 m, 3 x 3 m, 4 x 3 m, 4 x 4 m and 5 x 5 m spacings. The biomass of the above-ground compartments (stem, branches, leaves and bark) and root biomass was quantified, totalling 16.42 and 6.68 Mg ha^{-1}, respectively. The largest amount of biomass and carbon stock occurred in the denser spacings. Total biomass was twice as large at 3 x 2 m spacing compared to 5 x 5 m spacing. The root biomass represented 40.93% of the total biomass. The order of participation of the components in the total aboveground biomass was branches (44.99%), stem (40.77%), leaves (13.99%) and bark (4.90%). The denser spacings (3 x 2 m and 3 x 3 m) showed higher values of biomass and carbon stock than the wide spacings (4 x 3 m, 4 x 4 m and 5 x 5 m). There was no effect of planting spacing on carbon stock in necromass and soil.

Keywords: biomass, carbon sequestration, silviculture.

Comparando espaçamentos do povoamento de *Anadenanthera peregrina* (L.) Speg: resposta em biomassa e estoque de carbono acima e abaixo do solo

RESUMO

As florestas desempenham um importante papel no ciclo do carbono. Dentre os fatores que podem afetar os estoques de carbono nos povoamentos florestais, o espaçamento de plantio tem grande relevância. O objetivo foi verificar o efeito do espaçamento na biomassa e no estoque de carbono em um povoamento *de Anadenanthera peregrina* (L.) Speg aos 56 meses de idade. O povoamento foi implantado nos espaçamentos 3 x 2 m, 3 x 3 m, 4 x 3 m, 4 x 4 m e 5 x 5 m. Quantificou-se a biomassa dos compartimentos acima do solo (madeira, galhos, folhas e casca) e da raiz, totalizando 16,42 e 6,68 Mg ha^{-1}, respectivamente. A maior quantidade de biomassa e estoque de carbono ocorreu nos menores espaçamentos. A biomassa total foi duas vezes maior no espaçamento de 3 x 2 m em comparação com o espaçamento de 5 x 5 m. A biomassa abaixo do solo representou 40,93% da biomassa total. A ordem de participação dos componentes na biomassa aérea total foi galhos (44,99%), madeira (40,77%), folhas (13,99%) e casca (4,90%). Os espaçamentos mais densos (3 x 2 e 3 x 3 m) apresentaram maiores valores de biomassa e estoque de carbono do que os espaçamentos mais amplos (4 x 3 m, 4 x 4 m e 5 x 5 m). Não houve efeito do espaçamento de plantio sobre o estoque de carbono na necromassa e no solo.

Palavras-chave: Biomassa, sequestro de carbono, silvicultura.

1. INTRODUCTION

Brazil voluntarily responded to the call of the United Nations Climate Conference to reduce greenhouse gas emissions by 50% by 2030 and to neutralize carbon emissions by 2050 (ONU, 2021). This scenario will contribute to the recovery of degraded areas through the implantation of forest stands. In addition, projects that combine conservation with productivity will gain prominence, since the demand for food and forest products follows an accelerated pace and tends to grow for future generations (Gomez-Zavaglia *et al.*, 2020).

Agricultural, livestock and forestry activities can cause irreparable damage to the environment, including an increase in the rate of deforestation with the opening of new areas, greenhouse gas (GHG) emissions and the consequent global warming (Rajão *et al.*, 2020). Among the GHGs, CO_2 is the most important and its concentration increased from approximately 280 to 412 ppm between the years 1750 and 2021, mainly due to the use of fossil fuels and the change in land use (Dlugokencky and Tans, 2021). Given the increase in these concentrations, the potential of forests to store carbon in their biomass has gained prominence (Lipinski *et al.*, 2017; IPCC, 2021).

Forests provide ecosystem services, such as the global carbon cycle and maintenance of forest carbon, which is important to limit emissions to the atmosphere (Barreto-Garcia *et al.*, 2019). Increasing soil organic carbon can improve soil quality, acting as an indicator of sustainable use practices and contributing to climate change mitigation (Volkova *et al.*, 2015). Understanding the carbon balance, as well as its flow in the biomass compartments, is necessary to develop management techniques capable of recovering degraded areas and increasing soil fertility (Freitas *et al.*, 2018).

Among the factors that can affect carbon stock in forest stands, spacing is important, influencing canopy architecture, root distribution and directly affecting growth rate, reflecting the allocation of resources to different compartments of biomass (Rodrigues *et al.*, 2021). Trees in wider spacing compete less for resources and have higher individual biomass. On the other hand, trees in the denser spacing, although having smaller dimensions, produce more biomass per area, since they have a density of individuals with greater leaf area and photosynthesis rate (Forrester *et al.*, 2013).

Few studies expole native tree species, especially in the form of monospecific planting and its configuration in the field, with the evaluation of carbon and its dendrometric characteristics. The search for species that adapt to this production system is important, due to their potential for economic exploitation combined with environmental protection (Dallagnol *et al.*, 2011). *Anadenanthera peregrina (L.)* Speg belongs to a small neotropical genus from South America and is a species naturally adapted to different types of environments and with wide geographic distribution in Brazil. It presents moderate to fast growth and resistant heartwood, allowing several uses of wood (Lorenzi, 2000; Mota *et al.*, 2017). These characteristics make it a species with the potential to be used in monospecific planting for commercial purposes or intercropped with other tree species for the purpose of recovering degraded areas, in addition to being important in ecosystem services, through carbon sequestration.

This study investigated the effect of plant spacing on biomass production and above- and below-ground carbon stock in a stand of *Anadenanthera peregrina var peregrina* (L.) Speg. Therefore, our hypotheses were: biomass and carbon stock are influenced by planting spacing; and, carbon stock is higher in dense plantations.

2. MATERIAL AND METHODS

2.1. Characterization of the study area

The study was conducted at the Federal Institute of Education, Science and Technology of Espírito Santo – Ifes, in Alegre, ES, geographic coordinates 20º46'15.46" S and 41º27'13.04" W. The climate of the region, according to the Köppen classification, is of the Aw type, characterized by the occurrence of rainy summers and dry winters (Alvarez *et al.*, 2013). The average temperature and precipitation during the tree growth period were 23.9ºC and 1222 mm. The region is predominantly composed of mountainous relief, marked by the presence of mountain ranges, where the altitude in relation to sea level can vary from 90 to 280 m.

2.2. Implementation of the experiment

The experiment was carried out in an area previously used extensively for livestock and characterized with dominant pasture of *Urocloa* spp., without the application of fertilizers. The plantation was established in June 2011 with the species *Anadenanthera peregrina*. The seedlings were produced in the nursery of the Vale Natural Reserve, Sooretama, ES and had a height of around 0.50 m. The preparation of the area consisted of desiccating the pasture by applying glyphosate. Subsequently, seedlings were planted under 3 x 2 m, 3 x 3 m, 4 x 3 m, 4 x 4 m and 5 x 5 m spacings. Fertilization was carried out with the application of 220 g of NPK (02-30-06) and micronutrients (0.2% B, 0.2% Cu and 0.2% Zn) in side pits. Three sites were selected with different slopes in plots of 6.75 ha. The planting was done in three blocks and three repetitions of 1500 m^2, thus totaling 45 sampling units.

2.3. Dendrometric characterization of the stand

The forest inventory was carried out at 56 months of age. In each plot, the circumferences at 1.30 m in height were measured with a tape measure and later transformed into diameter at breast height (DBH). The measurement of the total height (Ht) was performed directly using a telescopic ruler with a maximum extension of 11 m. In total, 30 trees were measured in each sampling unit, totaling 270 in each treatment.

Hypsometric models were fitted for each planting spacing. The models that presented the best fits were selected through the adjusted coefficient of determination (R^2 ad.) and the residual standard error (Syx). The results of the best-fitted equations for estimating the height of trees are presented in Table 1.

Table 1. Adjusted equations and their respective statistics to estimate the height of *A. peregrina* trees, at 56 months of age, Alegre, ES.

Spacing (m)	Equation	R^2 ad. (%)	*Syx* (%)
3 x 2	$Ht = 2.02276 + 0.834053 \times DBH - 0.0274464 \times DBH^2$	54.17	13.62
3 x 3	$Ht = 8.3655 / (1 + EXP ((3.3654 - DBH) / 2.9517))$	60.35	12.74
4 x 3	$Ht = 8.6105 / (1 + EXP ((4.1175 - DBH) / 3.2164))$	71.89	12.95
4 x 4	$Ht = EXP (2.27778 - 3.3881 \times 1/DBH)$	64.45	13.36
5 x 5	$Ht = 1.908462 + 0.582306 \times DBH - 0.008698 \times DBH^2$	71.83	13.00

R^2 ad. = adjusted coefficient of determination; *Syx* = residual standard error; *Ht* = total height (m) e *DBH* = diameter at 1.30 m from the ground.

At 56 months, the volumes and total length of 45 trees were measured, nine trees in each spacing. The stem was subdivided into sections with a maximum length of 1.0 m, and the diameter of the stem with bark and the bark thickness at the beginning and end of each section were measured. The volume of the stem with bark was calculated using the regression model described by Spurr to estimate the volume of the other trees in the stand. The equation fitted by the model was: $Vol = 0.111107 + 0.00003327\ DBH^2 \times Ht$ (Table 2).

Table 2. Mean values of dendrometric variables in *A. peregrina* stand, at 56 months after planting, in Alegre, ES.

Spacing (m)	*N* (Tree ha^{-1})	*DBH* (cm)	*G* ($m^2\ ha^{-1}$)	*Ht* (m)	B_t (cm)	*SV* (m^3ha^{-1})
3 x 2	1373	6.57	5.17	6.18	0.21	16.36
3 x 3	844	7.14	4.00	6.28	0.22	12.86
4 x 3	609	7.28	3.06	6.01	0.23	9.67
4 x 4	459	7.42	2.55	5.86	0.26	7.52
5 x 5	383	8.97	2.79	6.33	0.32	9.03
Average	733	7.47	3.52	6.13	0.25	11.09

N = number of trees; *DBH* = diameter at 1.3 m above the ground; *G* = basal area; *Ht* = total height; B_t = bark thickness; *SV* = stem volume with bark.

2.4 Estimation of above, below ground and necromass biomass

The biomass of the aboveground compartments (stem, branches and leaves) was quantified. In this procedure, the trees were weighed individually, considering each compartment to obtain the wet weight in the field. Each compartment was sampled to determine the dry mass. For the leaves, subsamples were taken at the tip, middle and base of the branches located in the middle third of the crown. Sampling of branches was carried out by removing portions in the lower, middle and upper thirds of the tree canopy, containing branches with a diameter ≥ 1.0 cm. From each tree, two disks approximately 5.0 cm thick were removed in each position: base, DBH, 1/2 of the length of the stem and top of the stem for wood sampling. In the case of leaves, samples were taken at the base, middle and tip of the crown (Rondon, 2002; Dallagnol *et al.*, 2011).

Root biomass was determined in 15 trees, using an approximate canopy projection area of 4 to 6 m^2, with a pneumatic backhoe. After excavation, the roots were separated from the soil through a sieve with a mesh size of 1.0 x 1.0 cm. Subsequently, they were cleaned with a damp cloth and weighed on a portable scale to obtain the total wet weight in the field. A representative sample of the root system was taken from each tree, containing roots with different diameters, which were washed, then left to dry in the open air to remove excess water. Subsequently, the samples were dried in an oven with forced air circulation at 65°C in order to obtain constant weight and determine the dry mass. Root biomass, expressed in Mg ha^{-1}, up to 1.0 m depth was estimated using the mean values of three trees per spacing.

The necromass or fraction of dead biomass refers to the mass of fallen branches, leaves, and bark on the stand floor. This compartment was sampled during the dry period (56 months after planting), using microplots measuring 2.0 x 2.0 m and systematically allocated. All branches of the microplots were weighed with a portable scale, obtaining the wet weight in the field. For each experimental unit, a representative sample of branches, with different diameters, was collected to determine the dry weight in the laboratory. The necromass was expressed in Mg ha^{-1}, considering the arithmetic mean obtained for each spacing (15 plots with 27 replications each).

Biomass was adjusted as a function of DBH and Ht variables in the regression models. The selection of models considered the adjusted coefficient of determination (R^2 ad.) and the residual standard error (Syx) (Table 3).

Table 3. Adjusted equations to estimate total biomass and aboveground tree compartments for *A. peregrina* stand, at 56 months of age, in Alegre, ES.

Compartment	Tree/treat	Total	Fitted equation	R^2 ad. (%)	*Syx* (%)
Leaves	9	45	$Bio = 1.516948 + 0.003859\ (DBH^2Ht)$	46.96	47.70
Branches	9	45	$Bio = 0.676983 + 0.022195\ (DBH^2Ht)$	74.92	42.04
Bark	9	45	$Bio = 0.431142 + 0.001619\ (DBH^2Ht)$	82.52	23.85
Stem	9	45	$Bio = 1.308572 + 0.018539\ (DBH^2Ht)$	92.8	18.99
Roots	3	15	$Bio = -1.5018 + 0.16346\ (DBH \times Ht)$	0.48	46.10
Necromass	3	15	-	-	-
Total	42	210	$Bio = 3.561821 + 0.044706\ (DBH^2Ht)$	88.60	24.09

R^2 ad. = adjusted coefficient of determination; *Syx* = residual standard error; *Bio* = biomassa; *DBH* = diameter at 1.3 m above the ground; *Ht*= total height.

2.5. Carbon stock in biomass and soil

The carbon content in the aboveground biomass compartments (leaves, branches, bark, stem), roots and necromass were determined using the LECO equipment, Model C-144 (Leco, 2012). The carbon stock in the biomass was calculated by multiplying the average carbon content in each compartment by its respective biomass content, in kg ha^{-1}.

Soil sampling was carried out when the *A. peregrina* stand was 56 months old. In each of the 45 plots of the experiment, soil samples were collected at depths: 0-5; 5-10 and 10-20 cm at six different points, and a mixed sample of approximately 500 g of soil per depth was formed for chemical analysis. The collection points were distributed at different distances within an area equivalent to ¼ of the useful area of a reference plant. Each soil collection point had as reference a different tree within the plot, respecting two border lines.

The analytical method of volumetric rings was used to estimate the soil bulk density (DS). For this, a simple sample was obtained at each depth, corresponding to the center of the quadrant formed by four trees from the stand, in each sampling unit (Embrapa, 2011). The metallic rings with known volume and weight were dried in an oven with forced air circulation, at a temperature of 105 ± 3ºC for 72 hours. After drying, they were placed in desiccators in order to be weighed on a precision analytical balance to obtain the dry mass. Soil bulk density was obtained from the ratio between the dry mass of the soil, in grams, and the total volume of the ring, in cm^3.

Soil carbon contents were determined by the total dry combustion method, using the LECO equipment, Model C-144, according to Embrapa (2011) and Sanquetta *et al.* (2014). Soil carbon stock, expressed in Mg ha^{-1}, was estimated by multiplying the soil mass at each depth by the carbon content. The carbon stock at the total depth sampled (0-20 cm) was obtained by summing the stocks of the individual depths.

2.6. Statistical analysis

Above and below ground biomass data, as well as carbon stock and soil data, were submitted to the Bartlett and Shapiro-Wilk test, in order to verify the homogeneity of variances and normality, respectively, at the 5% level. significance. Subsequently, with the positive assumptions, the data were analyzed by analysis of variance (ANOVA). The treatment means, when necessary, were compared using the Tukey test at a 5% significance level.

3. RESULTS AND DISCUSSION

3.1. Carbon content in the biomass compartments

The carbon contents were significantly different between the analyzed compartments ($p < 0.05$). Statistical analysis showed a significant difference between the stem, bark, branches and roots compartments in relation to the compartments formed by leaves and necromass (Figure 1). The general average of carbon content among the analyzed compartments was 44.19% (± 0.09).

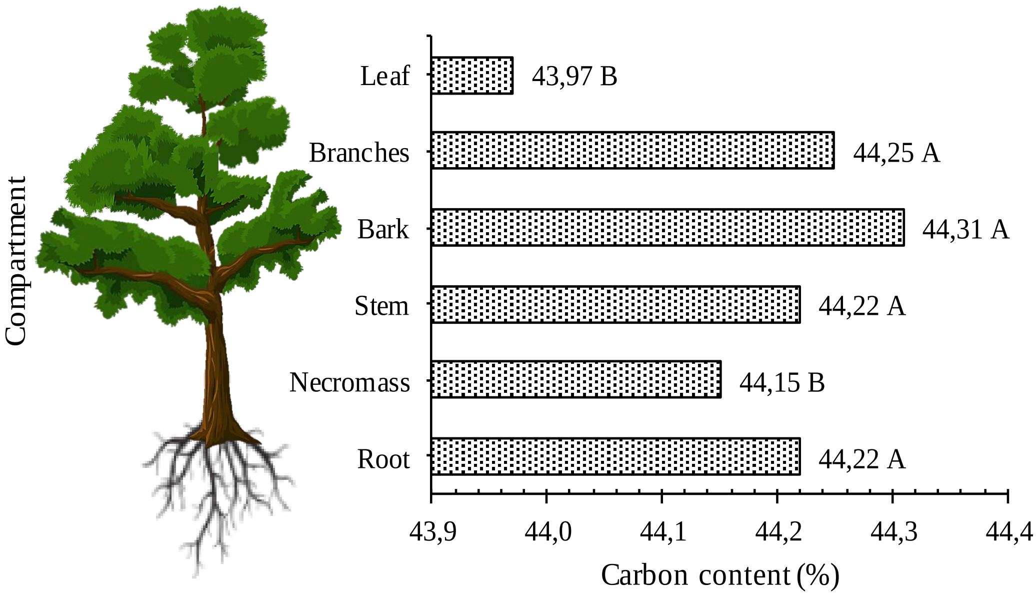


Figure 1. Mean carbon contents for the different biomass compartments in the *A. peregrina* stand, at 56 months of age, in Alegre, ES.

The average of carbon content in the analyzed compartments are lower than those suggested by the IPCC for estimating carbon stock in woody species (50% weight/weight of biomass). The conversion factor of 0.5 is widely used due to its practicality; however, it is always recommended to use specific carbon contents for each tree compartment in order to accurately calculate the carbon stock (Watzlawick *et al.*, 2014; Ribeiro *et al.*, 2015). Evaluating the stand of *Anadenanthera peregrina*, at 21 years of age in a restoration area, Silva *et al.* (2015) found carbon contents of 46.6% for the stem. These results reinforce the idea of not generalizing the average carbon content of 50%.

The low carbon content in the leaves may be related to the low amount of tannin when compared to the other compartments (Paes *et al.*, 2010). Studies show that the carbon content fixed in forest biomass varies according to the species and component analyzed (Dallagnol *et al.*, 2011; Behling *et al.*, 2014; Cubas *et al.*, 2016). Lisboa (2010) found carbon contents in the leaves of *Anadenanthera macrocarpa* (Benth.) Brenan ranging from 47.6 to 50.3%, planted under different spacings.

The values assigned to the necromass compartment may be related to the partial decomposition of this material, in which part of the carbon could have already been transferred to the soil and to the atmosphere, as it represents a transition stage of the carbon stock between living biomass and other sources (Russel *et al.*, 2015; Stutz *et al.*, 2017).

The average carbon content in the roots of *A. peregrina* trees at 56 months of age was equal to the stem, branches and bark. This result is especially interesting, given that sampling the roots is laborious (Freschet *et al.*, 2013). Thus, this equality in carbon contents, under similar conditions and age close to the population of this study, constitutes an alternative for estimating the carbon stock of this compartment with less cost and time.

3.2. Biomass and carbon stock

A significant spacing effect was observed for all above-ground biomass compartments (Figure 2). Total biomass was approximately twice as large at 3 x 2 m spacing compared to 5 x 5 m spacing. The lowest values for all components were found in the 4 x 4 m spacing, although they did not show statistical differences ($p<0.05$) for the 4 x 3 m and 5 x 5 m spacings.

Total above-ground biomass showed the greatest variation between spacings (Figure 2). This is explained by the number of trees and the variation in the biomass values of the stem and branches, which together represent 75% of the total dry mass. These components have coefficients of variation above 40%, classified as high. The leaves and bark have low values for the coefficient of variation (< 20%). This difference is due to the fact that the total biomass and its components were estimated using independent equations.

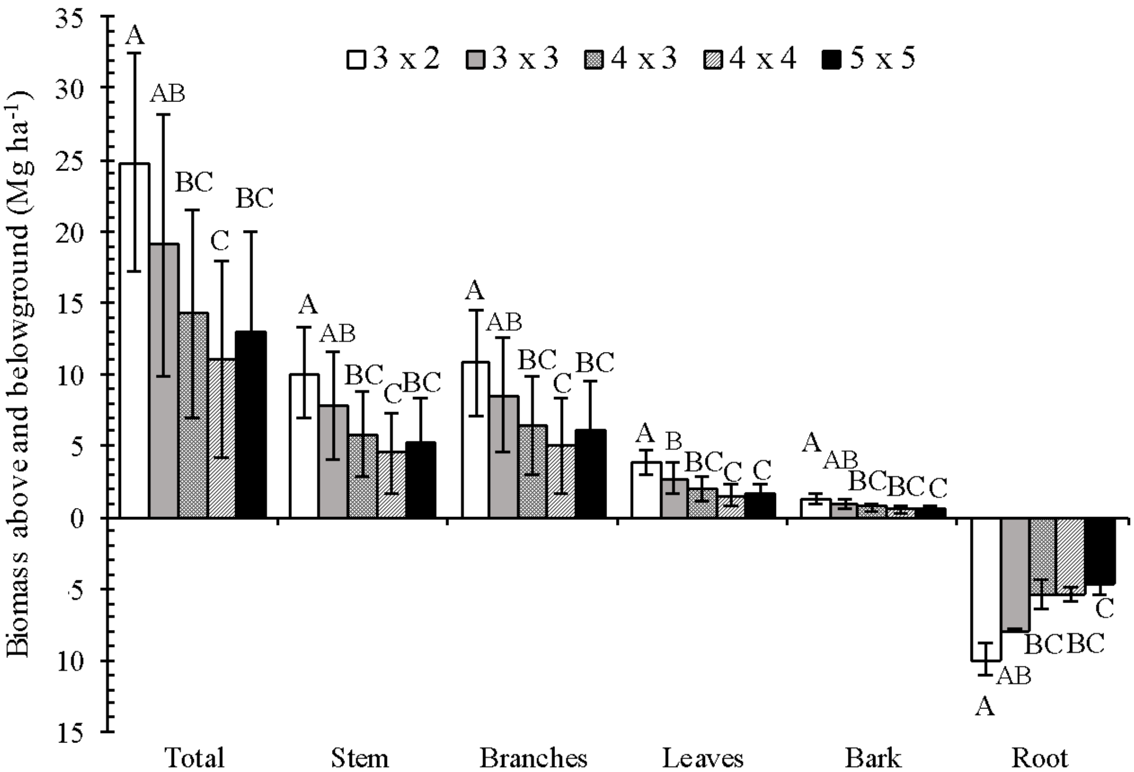
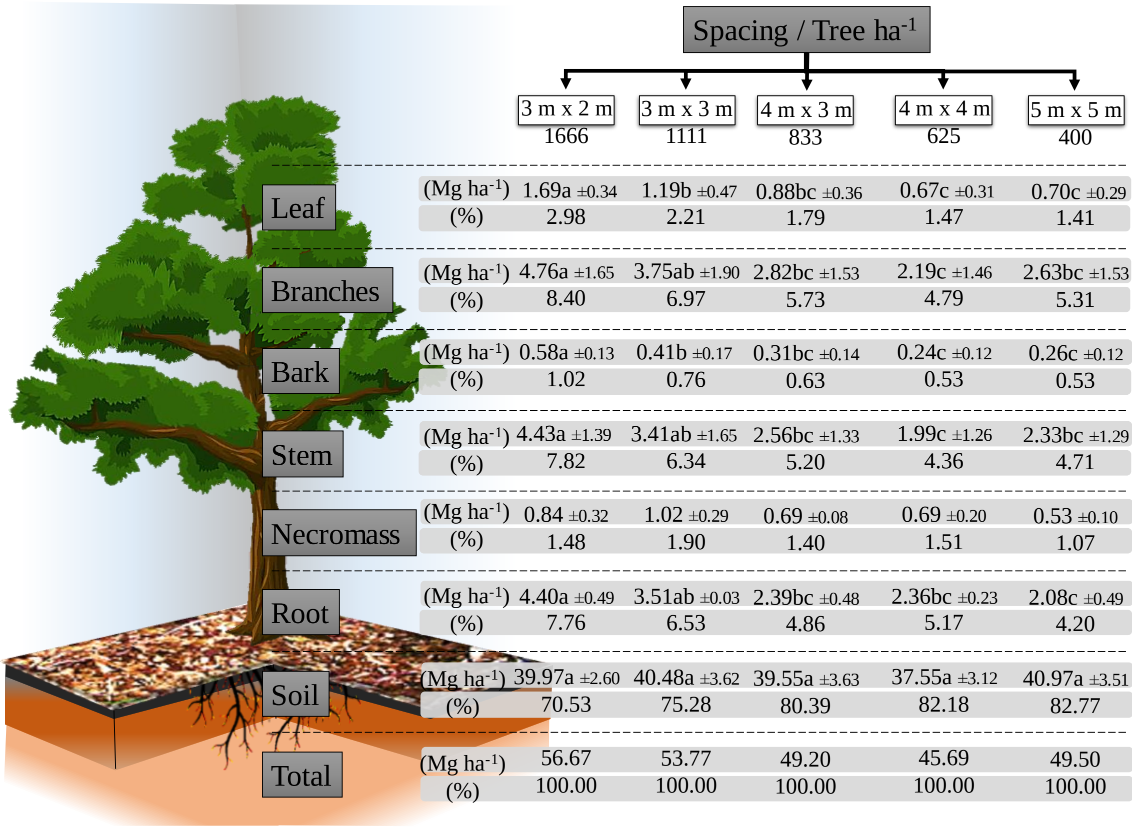


Figure 2. Above-ground and root biomass for *A. peregrina* stand, at 56 months of age, in Alegre, ES. Means followed by the same letter, in the biomass compartment, do not differ statistically from each other by the Tukey test, at a 5% significance level.

The order of volume of the components in the total above-ground biomass was: branches (44.99%), stem (40.77%), leaves (13.99%) and bark (4.90%). These results are different from those reported in the literature. Caldeira *et al.* (2015) found a percentage distribution of biomass production following the order of stem > bark > live branches > branches > dead branches in stands of *Araucaria angustifolia*. Nhaduco *et al.* (2021) also observed that *Pinus* spp. aged over seven years had estimated total biomass in the order of stem, branches, leaves and bark, corresponding to 50%, 14%, 10% and 10%, respectively. According to the authors, this variation is justified by the fact that the stand is in an intermediate stage of development, in which the participation of the canopy (branches and leaves) is greater than the stem biomass. In addition, stands of *Pinus* and *Eucalyptus* spp, have years of genetic improvement, which increases the production of stem wood compared to native species with no genetic improvement.

As shown in Figure 3, there is an inverse relationship in the carbon stock (%) between biomass and soil. As the spacing between plants increases, the contribution of total carbon in biomass decreases, while soil carbon increases. The contribution of carbon stored was 29.5, 24.7, 19.6, 17.8, 17.2% in the biomass and 70.5, 75.3, 80.4, 82.2, 82.8% in soil carbon, for the spacings 3 x 2 m, 3 x 3 m, 4 x 3 m, 4 x 4 m and 5 x 5 m, respectively.

Considering the contribution of each compartment, the aboveground carbon stock followed the same order found for biomass, being branches (44.88%), stem (40.78%) and leaves (14.29%). The highest values occur in the denser spacings tested, decreasing as the spacing was increased (Figure 3).



Compartment	Unit	Spacing / Tree ha^{-1}: 3 m x 2 m (1666)	3 m x 3 m (1111)	4 m x 3 m (833)	4 m x 4 m (625)	5 m x 5 m (400)
Leaf	(Mg ha^{-1})	1.69a ±0.34	1.19b ±0.47	0.88bc ±0.36	0.67c ±0.31	0.70c ±0.29
	(%)	2.98	2.21	1.79	1.47	1.41
Branches	(Mg ha^{-1})	4.76a ±1.65	3.75ab ±1.90	2.82bc ±1.53	2.19c ±1.46	2.63bc ±1.53
	(%)	8.40	6.97	5.73	4.79	5.31
Bark	(Mg ha^{-1})	0.58a ±0.13	0.41b ±0.17	0.31bc ±0.14	0.24c ±0.12	0.26c ±0.12
	(%)	1.02	0.76	0.63	0.53	0.53
Stem	(Mg ha^{-1})	4.43a ±1.39	3.41ab ±1.65	2.56bc ±1.33	1.99c ±1.26	2.33bc ±1.29
	(%)	7.82	6.34	5.20	4.36	4.71
Necromass	(Mg ha^{-1})	0.84 ±0.32	1.02 ±0.29	0.69 ±0.08	0.69 ±0.20	0.53 ±0.10
	(%)	1.48	1.90	1.40	1.51	1.07
Root	(Mg ha^{-1})	4.40a ±0.49	3.51ab ±0.03	2.39bc ±0.48	2.36bc ±0.23	2.08c ±0.49
	(%)	7.76	6.53	4.86	5.17	4.20
Soil	(Mg ha^{-1})	39.97a ±2.60	40.48a ±3.62	39.55a ±3.63	37.55a ±3.12	40.97a ±3.51
	(%)	70.53	75.28	80.39	82.18	82.77
Total	(Mg ha^{-1})	56.67	53.77	49.20	45.69	49.50
	(%)	100.00	100.00	100.00	100.00	100.00

Figure 3. Carbon stock in different spacings and compartments in an *A. peregrina* stand, at 56 months of age. Means followed by the same letter, on the line, do not differ statistically by the Tukey test, at a 5% significance level.

The biomass and carbon stock of the roots followed the same trend of the aerial part of the stand. In general, the denser spacings (3 x 2 m and 3 x 3 m) presented the highest values for both variables. The 5 x 5 m spacing showed the lowest average, not differing statistically from the 4 x 3 m and 4 x 4 m (Figure 3).

Comparing the mean DBH values for the *A. peregrina* stand (Table 2), and the biomass stock, it is noted that these had an inverse relationship. As spacings increased, mean DBH values followed the same trend, while biomass decreased (Ferreira *et al.*, 2014; Stape *et al.*, 2010). Therefore, smaller trees predominate in the denser spacings, with individual biomass production being compensated by the density of individuals in the area, which favors the storage and capture of carbon from the atmosphere (Schneider *et al.*, 2015; Silva *et al.*, 2016).

There was a tendency towards a greater amount of biomass in the denser spacings (3 x 2 m and 3 x 3 m) in relation to the larger spacings. This behavior is corroborated by Eloy *et al.* (2015), Guerra *et al.* (2014), Moulin *et al.* (2015) and Forrester *et al.* (2013). However, the denser spacings increase competition between plants and can cause mortality and losses of stored carbon, so further studies are necessary.

The canopy represented a higher amount of biomass in relation to the stem. According to Ribeiro *et al.* (2015) and Figueredo *et al.* (2015), the stem usually represents the largest amount of biomass. The differences between the participation of the components may be related to the morphological structure of the species under study, age, as well as physiological aspects. Lorenzi (2000) mentions that *A. peregrina* is a species that presents a dense, open and sympodial canopy. In addition, up to 56 months of age, there was no significant natural or artificial fall of the branches, which highlights the need for direct light for its establishment (Nascimento *et al*., 2009; Tonini *et al.*, 2019).

It is also noted that the carbon stock in the canopy in relation to the stem can be attributed to the age of the trees. The stand is 56 months old and is not in a stage of maturity; therefore, the largest amount of carbon is stored in the canopy of the trees, in relation to the stem. *A. peregrina* is a pioneer species, needing light in its initial stage of development. However, an ecological strategy for this species is moderate growth, which makes the wood density high, with averages of 0.57 g cm^{-3} (Lorenzi 2014; Mori *et al.*, 2003). In general, this results in low growth rates and trunk hydraulic conductivity, in addition to higher survival rates when subjected to scarce resources (Reich, 2014; Mendes *et al.*, 2021).

Although there was no statistically significant difference between the spacings of the useful area above 12 m^2, the 4 x 4 m showed lower average values for carbon stock (total and fractions). This result can be attributed to the higher survival rate presented by 5 x 5 m spacings (95%) compared to 4 x 4 m (73%) (Tonini *et al.*, 2018; Eufrade Junior *et al.*, 2016; Ribeiro *et al.*, 2017).

The differences found between the spacings for biomass and carbon stock of the roots were mainly caused by the density of trees (Ratuchne *et al.*, 2016). In addition, the denser spacings reduce diameter growth and favor height and root system development due to competition for natural resources, such as light and nutrients in deeper layers (Stape *et al.*, 2010; Ferreira *et al.*, 2014).

The root biomass found in this study was lower than the values found by Ceconi *et al.* (2008) for *Acacia mearnsii* de Wild, whose characteristic is its rapid growth. These authors found values of 6.92 Mg ha^{-1} for root biomass at 48 months of age in up to 60 cm of soil depth. Almeida *et al.* (2010) reported that at a spacing of 2.2 x 3 m, in *Tectona grandis* Lf stand, the contribution of carbon stock by the roots was 4.70% of the total biomass at 66 months, representing about 15.15 Mg ha^{-1}.

3.3. Necromass

The carbon contents of the necromass also did not differ statistically, varying between 44.05 and 44.29%, with an average equal to 44.15% ($p > 0.05$) (Figure 2). The carbon stock of this compartment did not show statistically significant differences ($p > 0.05$) in the different spacings. The average for these variables were 0.76 Mg ha^{-1}, with an average coefficient of variation of approximately 36%.

The biomass compartment analyzed for the determination of carbon contents refers to the same organ of the tree (branches); therefore, close values of carbon stock between the spacings were expected. Possibly, the variation in the stock of necromass and carbon may be responding to other factors not analyzed in this study, such as the amount of radiation that reaches the forest floor (Gora *et al.*, 2014), rate of residues decomposition (Zaninovich *et al.*, 2016) and age of the stand (Russel *et al.*, 2015).

Studies show that dense plantations can present greater amounts of necromass compared to larger spacings, justified by the smaller area available for growth and light restriction in the under forest (Schneider *et al.*, 2015; Trindade *et al.*, 2019). However, in the present study this did not occur, and it may be associated with the ecological characteristics of the species and the seasonal data collection. *A. peregrina* is a deciduous species, characterized by an increase in leaffall and twigs under water deficit conditions (Lorenzi, 2014). In addition, necromass sampling was performed only in the dry season, with the branches sampled with a diameter of less than 5.0 cm. The collection season may have influenced the amount of necromass in the stand, masking the effect of competition (Trumbore *et al.*, 2015).

3.4. Soil carbon stock

Soil carbon stock did not differ statistically between the spacings and depths analyzed (0-5, 5-10, 10-20 and 0 - 20 cm), according to the F test (p> 0.05) (Figure 4). The average for carbon stock in the 0-20 cm depth of the soil was 39.52 Mg ha^{-1}. Considering the same sampling depth, the values are within the range of soil organic carbon cited in the literature for most studies, considering a wide range of locations, types and ages of vegetation (Denardin *et al.*, 2014; Baldotto *et al.*, 2015).

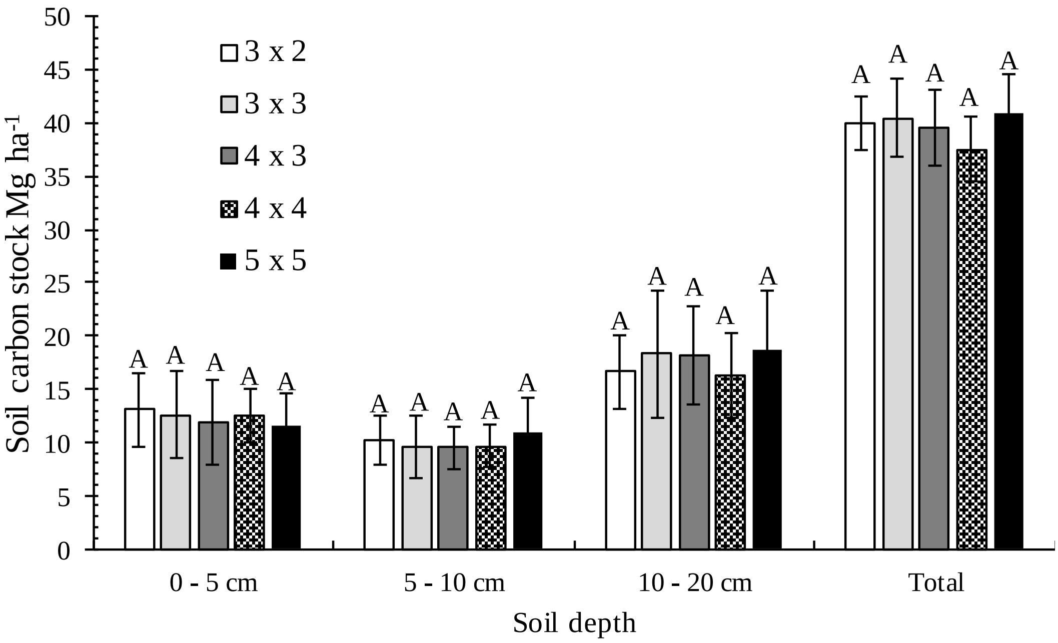


Figure 4. Soil carbon stock (Mg ha^{-1}) of *A. peregrina* stand, at different spacings, in Alegre, ES. *In the soil depth*, means followed by the same letter do not differ statistically from each other by the Tukey test at a 5% significance level.

The similarity of carbon stock in the layer up to 20 cm is due to the higher concentration of roots, especially fine roots, which promote the entry of carbon through the release of exudates and their decomposition in the root cycling process. Furthermore, this result is related to the greater contribution of organic residues, including senescence of branches and leaves in the surface layers of the soil (Salton *et al.*, 2011).

The stability of the carbon stock in relation to the spacings is mainly justified by the continuous addition of aboveground biomass produced by *A. peregrina*. However, this factor is regulated by the amount of litterfall produced and microbial action. Soil carbon levels are stable; however, they can change when exposed to specific situations, such as environmental climatic conditions and physiological characteristics of the species (Freitas *et al.*, 2018).

4. CONCLUSIONS

The denser spacings (3 x 2 m and 3 x 3 m) showed higher values of biomass and carbon stock than the wide spacings (4 x 3 m, 4 x 4 m and 5 x 5 m) for the stand at 56 months of age after planting. Plant spacing had no effect on carbon stock in necromass and soil.

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