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Scientific Article

Effects of planting density on characteristics of sabiá wood

Efeitos da densidade de plantio sobre características da madeira de sabiá

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ABSTRACT - This study aimed to evaluate the biomass yield, volume, and basic density of *Mimosa caesalpiniifolia* Benth. wood in response to planting densities in 13-year-old trees. The research was conducted in Mossoró-RN using a randomized block design with three replications. Plants obtained from seeds collected from the natural vegetation of the Caatinga in Mossoró-RN were subjected to densities of 800 (5.0 m x 2.5 m), 1600 (2.5 m x 2.5 m), 2000 (2.0 m x 2.5 m), and 4000 (1.0 m x 2.5 m) plants ha^{-1}. The following characteristics were assessed: plant height, diameter at breast height, cross-sectional area, basal area, individual volume, stere volume, aboveground biomass, and basic wood density. The dendrometric variables showed a high correlation with planting density. For DBH and cross-sectional area, higher values were observed in the lowest planting densities. The highest values of basal area, volume (m³), stere volume, and dry biomass per hectare were found at the highest planting density. Biomass allocation showed the sequence stem>branches>leaves, regardless of the planting density evaluated. The higher densities resulted in a higher basic density of the wood. The higher planting densities proved advantageous 13 years after planting due to the higher production of dry biomass, volume (m³), and stere volume per hectare.

Keywords: Plant populations. Spacing. Wood density. Caatinga. Aboveground biomass.

RESUMO - Este estudo teve como objetivo avaliar o rendimento de biomassa, o volume e a densidade básica da madeira de *Mimosa caesalpiniifolia* Benth. em resposta às densidades de plantio, em árvores com 13 anos de idade. A pesquisa foi realizada em Mossoró-RN no delineamento de blocos ao acaso com três repetições. Plantas obtidas a partir de sementes coletadas da vegetação natural da Caatinga do referido município, foram submetidas às densidades de 800 (5,0 m x 2,5 m), 1600 (2,5 m x 2,5 m), 2000 (2,0 m x 2,5 m) e 4000 (1,0 m x 2,5 m) plantas ha^{-1}. Foram avaliadas as seguintes características: altura da planta, diâmetro à altura do peito, área transversal, área basal, volume individual, volume estéreo, biomassa da parte aérea e a densidade básica da madeira. As variáveis dendrométricas apresentaram alta correlação com a densidade de plantio. Para o DAP e área transversal foram observados maiores valores na densidade menos ampla. Em relação a área basal, volume (m³), volume estéreo e biomassa seca por hectare, foram observados maiores valores na densidade mais ampla. A alocação de biomassa apresentou a sequência fuste>ramos>folhas, independente da densidade de plantio avaliada. As densidades mais amplas proporcionaram maior valor de densidade básica da madeira. O maior adensamento mostrou-se vantajoso aos 13 anos após o plantio devido a maior produção de biomassa seca, volume (m³) e volume estéreo por hectare.

Palavras-chave: Populações de plantas. Espaçamento. Densidade da madeira. Caatinga. Biomassa aérea.

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INTRODUCTION

Mimosa caesalpiniifolia Benth. or Sabiá as it is popularly known, belonging to the Fabaceae family, is a species native to the Northeast region of Brazil, occurring from Maranhão to Pernambuco, with a small size and rapid growth (MENDES et al., 2013; BEZERRA et al., 2019). It has been widely used to replenish organic matter and recover degraded soils, and, according to Araújo and Paes (2018), it is one of the most promising species for commercial forest plantations in northeastern Brazil.

The use of forest plantations to minimize plant suppression in native forests has gained prominence. In this context, *Mimosa caesalpiniifolia* plays a significant role in the scientific scenario, as the wood produced in these plantations has a versatile role and can be used for various purposes, such as the production of stakes, posts, living fences, and supplying furnaces and boilers in sugar-energy plants, grain drying systems, and animal feed production industries (MELO et al., 2018).

Regarding wood production, planting density becomes a key decision from a silvicultural, technological, and economic point of view since it will affect growth, wood quality, and the age at which trees are cut, and thus production costs (MACHADO et al., 2019).

The planting of forest species can be directly affected by abiotic and biotic factors, which impact their growth and, consequently, their wood production. In this context, it is important to note that the quality and yield of a given site are natural and inherent to it but can be influenced by the management practices used, such as planting spacing (LAFETÁ et al., 2021).

Aboveground biomass production is used as a parameter to assess the wood production potential of a given species for energy purposes, and two methods can be used to quantify aboveground biomass in forests. The first is the direct method, which weighs all the aboveground tree components (stems, branches, and leaves) on a scale in the field, thus providing a real value. The second is the indirect method, which aims to use some variables that can be easily obtained in the field without the need to cut down the plant to obtain aboveground biomass using biomass expansion factors and allometric models, obtaining an estimate of aboveground biomass (VIRGENS et al., 2017).

Another parameter that is widely used to check the quality of plantation wood is basic density since it is possible to check several characteristics simultaneously, which vary with the species, between individuals of the same species, radially and longitudinally within the same individual, with age, spacing, and planting location (HSING; PAULA; PAULA, 2016).

Due to its multiple uses, commercial value, and adaptive capacity, *M. caesalpiniifolia* can be an excellent alternative for forest plantations in semi-arid regions. In this context, it is essential to understand the impact of different planting densities on the species to optimize the results.

Given the above and the lack of research into biomass production, volume, and basic density in forest plantations in the semi-arid region, this study aimed to assess how spacing affects the production of aboveground biomass, volume, and basic density of wood of *Mimosa caesalpiniifolia* trees 13-year-old.

MATERIAL AND METHODS

The study was conducted at the Rafael Fernandes Experimental Farm, belonging to the Federal University of the Semi-Arid Region (UFERSA), in Mossoró, in the state of Rio Grande do Norte (RN), at 5º03'48" S and 37º24'02" W, with an altitude of 84 m (Figure 1). According to the Koppen classification, the climate of the region is BSwh'-type, being dry and very hot, with two climatic seasons, a dry one defined from June to December and a rainy one from January to May. The average temperature is 27 °C, the relative humidity 71%, and the average annual rainfall is 567 mm (INMET, 2019). The soil in the experimental area is classified as Argissolo Vermelho-Amarelo according to the Brazilian Soil Classification System (EMBRAPA, 2018).

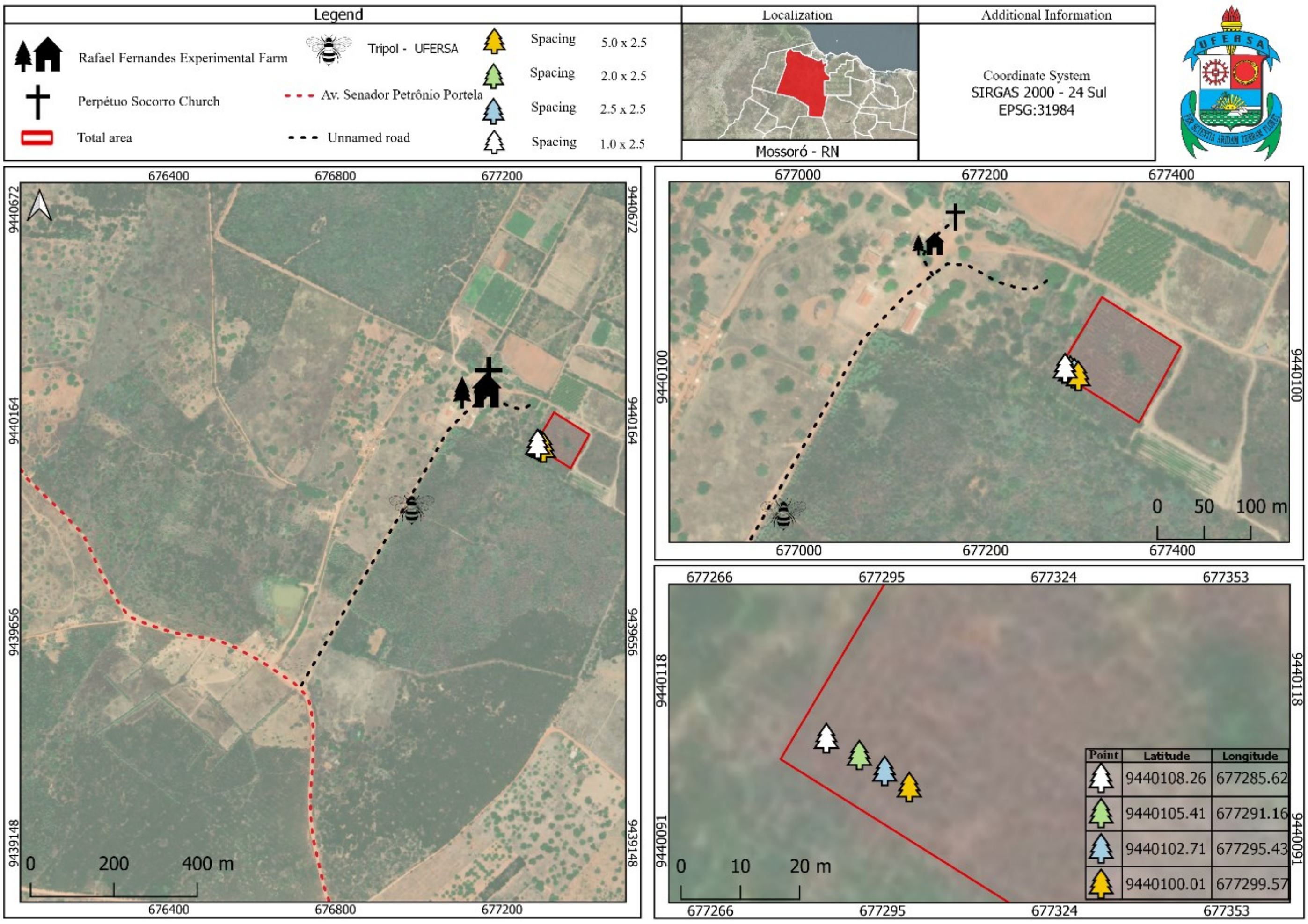

Figure 1. Experimental planting of *Mimosa caesalpiniifolia* at the Experimental Farm of the Federal University of the Semi-Arid Region (UFERSA), in Mossoró, RN, Brazil.

The seeds used for planting came from another experimental planting in Mossoró-RN and were sown in January 2008. The seeds were sown in black polyethylene bags, perforated in the lower third, 20 cm high, and 15 cm in diameter. The seeds were transplanted one month later into holes measuring 40 cm x 40 cm x 40 cm without fertilizer.

The experiment was evaluated 13 years after planting to check biomass production, volume, and basic density in developing *Mimosa caesalpiniifolia* at different levels of planting density. Four distances between plants in the planting line were analyzed, corresponding to the areas available for growth: 2.5, 5.0, 6.2, and 12.5 m² $tree^{-1}$ (Table 1). The experimental design was a randomized block design with a rainfed cultivation system.

Table 1. Useful area, planting spacing, and number of trees per hectare.

Spacing (m)	Useful area (m²)	Trees ha^{-1}
1.0 x 2.5	2.5	4000
2.0 x 2.5	5.0	2000
2.5 x 2.5	6.2	1600
5.0 x 2.5	12.5	800

Forest Inventory

The forest inventory was conducted 156 months after transplanting, based on all the trees in all the treatments evaluated. The diameter with bark at 1.30 cm (DBH, cm) and total height (HT, m) of all the individuals were measured using a tape measure and telescopic ruler, respectively. Due to the many different stems characteristic of the *Mimosa caesalpiniifolia* species, it was necessary to obtain the DBH using Equation 1 (SOARES; PAULA NETO; SOUZA, 2011).

$$D_{eq}=\sqrt{\sum_{i=1}^{n} DBH^2} \quad (1)$$

Where D_{eq} = equivalent diameter; DBH = diameter at breast height of each stem of the branched individual.

Rigorous scaling

Four trees were randomly selected from each treatment to obtain the precise volume. Rigorous scaling was then conducted using the Smalian method by sectioning the trees into logs (sections) approximately 1 m long. The volume of the bark of each log (section) was calculated as a function of the length and cross-sectional area of the ends (Equation 2), the volume of the stump was calculated using Equation 3, and the rigorous volume of each tree was obtained using Equation 4. To transform the volume obtained into stere volume (st), the stacking factor 3.14 proposed by FAO/IBAMA (1993) was used.

$$V_{ci}=\frac{(g_1+g_{i+1})}{2}*l_i \quad (2)$$

$$V_{c0}=g_0 * l_0 \quad (3)$$

$$V_{cr}=V_0+\sum_{i=0}^{n} V_i+V_c \quad (4)$$

Where V_{ci} = volume with bark of the intermediate sections (m³); g_1 and g_{i+1} = cross-sectional areas of the ends of the intermediate sections (m²); l_i = length of the intermediate sections (m); V_{c0} = volume with bark of the stump (m³); g_0 = cross-sectional area of the stump (m²); l_0 = length of the stump (m); V_{cr} = strict volume with bark of the tree (m³).

Biomass Quantification

After the rigorous scaling procedure, the felled trees were separated into stems, branches, and leaves. The fresh aboveground biomass of each tree was determined using a scale with a capacity of 100 kg and a precision of 50 g. Samples of stems, branches, and leaves were taken from the field, packed in paper bags, and taken to the laboratory to be weighed in saturated conditions on an analytical balance (± 0.01 g) and then dried in an air-force circulation oven (65 ºC ± 2 ºC) until they reached a constant mass, after which the dry mass was obtained. Based on the ratio between the fresh mass and dry mass of the samples, the biomass of each component was determined in kg $tree^{-1}$, using Equation 5 adapted from Soares, Paula Neto and Souza (2011):

$$B_s=\frac{(M_f*M_{sa})}{M_{fa}} \quad (5)$$

where: B_s = real dry aboveground biomass (kg); M_f = fresh aboveground biomass (kg); M_{sa} = dry aboveground biomass sample (kg); M_{fa} = fresh aboveground biomass sample (kg).

Basic Density

After the biomass quantification procedure, cross-sections were made in the stems of the felled trees in the base-top direction using a chainsaw to obtain the disks. In this procedure, the following relative positions along the trunk were considered: 0%, 50%, and 100% of the total height of the tree.

The discs were then packed in paper bags to be taken to the laboratory. They were separated into pith, middle, and bark and then dried in an air-forced circulation oven (105 ºC ± 2 ºC) until they reached a constant mass, thus obtaining the dry mass.

The next step was to separate the discs by treatment and repetition and place them in water until they reached fiber saturation (humidity ≥ 28 %). The saturated volume data was then collected using the water displacement method (Equation 6), a xylometer with a metal rod, a beaker with water, and an analytical balance (± 0.01 g).

Subsequently, with the dry mass and saturated volume values of the disks, the basic density was calculated using Equation 7 (ABNT, 2003).

$$D=\frac{P}{V}\therefore V=\frac{P(g)}{D\left(\frac{g}{cm^3}\right)}\rightarrow V_s=cm^3 \quad (6)$$

Where: Dwate=1, and, V_s=P

$$D_b=\frac{M_d}{V_s} \quad (7)$$

Where: D = density; Dwater = density of water; W = weight; D_b = basic density; M_d = dry mass; V_s = saturated volume.

Statistical Analysis

The data analysis was conducted using the R 4.1.3 language (R CORE TEAM, 2023). The normal distribution (Shapiro-Wilk) and homogeneity (Bartlett) of data variances were evaluated. The F test was applied to assess the effect of planting densities on dendrometric parameters ($p<0.05$), and when significant, first-degree linear regression analysis was conducted. The linear correlation between the main dendrometric variables and planting density was assessed using the Pearson coefficient (r).

RESULTS AND DISCUSSION

The results found in the research (Table 2) evidenced a high positive Pearson correlation coefficient ($r> 0.80$) of basal area, volume and stere volume (st) per hectare, and fresh and dry biomass per hectare with the planting density (tree ha^{-1}). DBH, cross-sectional area, volume and stere volume (st), fresh and dry biomass, and basic density had a high negative linear correlation ($r< -0.80$) with planting density.

Table 2. Linear correlation between dendrometric variables and planting density in an experimental plantation of *Mimosa caesalpiniifolia* 13-year-old.

Variables	r	p-valor
DBH (cm) x Planting density (tree ha^{-1})	-0.98	0.02*
Cross-sectional area ($m^2.tree^{-1}$) x Planting density (tree ha^{-1})	-0.95	0.05*
Basal area ($m^2.ha^{-1}$) x Planting density (tree ha^{-1})	0.99	0.003**
Individual volume ($m^3.tree^{-1}$) x Planting density (tree ha^{-1})	-0.95	0.05*
Volume per hectare ($m^3.ha^{-1}$) x Planting density (tree ha^{-1})	0.98	0.02*
Stere volume ($st.tree^{-1}$) x Planting density (tree ha^{-1})	-0.95	0.05*
Stere volume per hectare ($st.ha^{-1}$) x Planting density (tree ha^{-1})	0.98	0.02*
Fresh biomass ($kg.tree^{-1}$) x Planting density (tree ha^{-1})	-0.96	0.04*
Fresh biomass per hectare ($t.ha^{-1}$) x Planting density (tree ha^{-1})	0.94	0.05*
Dry biomass ($kg.tree^{-1}$) x Planting density (tree ha^{-1})	-0.96	0.04*
Dry biomass per hectare ($t.ha^{-1}$) x Planting density (tree ha^{-1})	0.99	0.006**
Basic density ($g.cm^{-3}$) x Planting density (tree ha^{-1})	-0.97	0.03*

r = Pearson correlation coefficient. * = significant at 5% probability of error. ** = significant at 1% probability of error.

Pearson correlation coefficient explains the affinity of planting density with volume and stere volume (st) per hectare and fresh and dry biomass per hectare. This indicates the tendency for DBH, cross-sectional area, volume and stere volume (st), fresh and dry biomass, and basic density to decrease as planting density increases (WATZLAWICK; BENIN, 2020). The Pearson correlation coefficient (Table 2) results indicate that for *Mimosa caesalpiniifolia* 13-year-old, planting density directly influenced its diameter, cross-sectional area, basal area, volume, biomass, and basic density.

In the estimates of DBH and cross-sectional area (Figure 2), a negative relationship between average values was noted due to the decrease in planting density. Regression analysis indicated that DBH and cross-sectional area decreased as planting density increased. A positive relationship was observed for the basal area as planting density increased. The analysis showed that with increasing planting density, the basal area becomes larger.

The DBH increased with the lower number of trees per hectare, where the density of 800 (tree ha^{-1}) gave the highest DBH value, with an average of 11.02 cm. This greater development may be related to less competition for space, light, water, and nutrients among plants at this lower density since, according to Venturin et al. (2014), the smaller the number of trees per hectare, the greater the diameter.

The cross-sectional area correlates the occupancy of each tree according to its diameter and is determined by the planting density adopted. For *Mimosa caesalpiniifolia*, the lower density resulted in a larger cross-sectional area, with an average of 0.010m², which was to be expected since the DBH also showed this trend.

The planting density influenced the basal area, with an average of 26.70 m² ha^{-1} in the highest planting density evaluated (Figure 2), demonstrating that although the DBH and cross-sectional area showed higher values in less dense spacings, they were not enough to compensate for the greater number of trees in the higher planting densities.

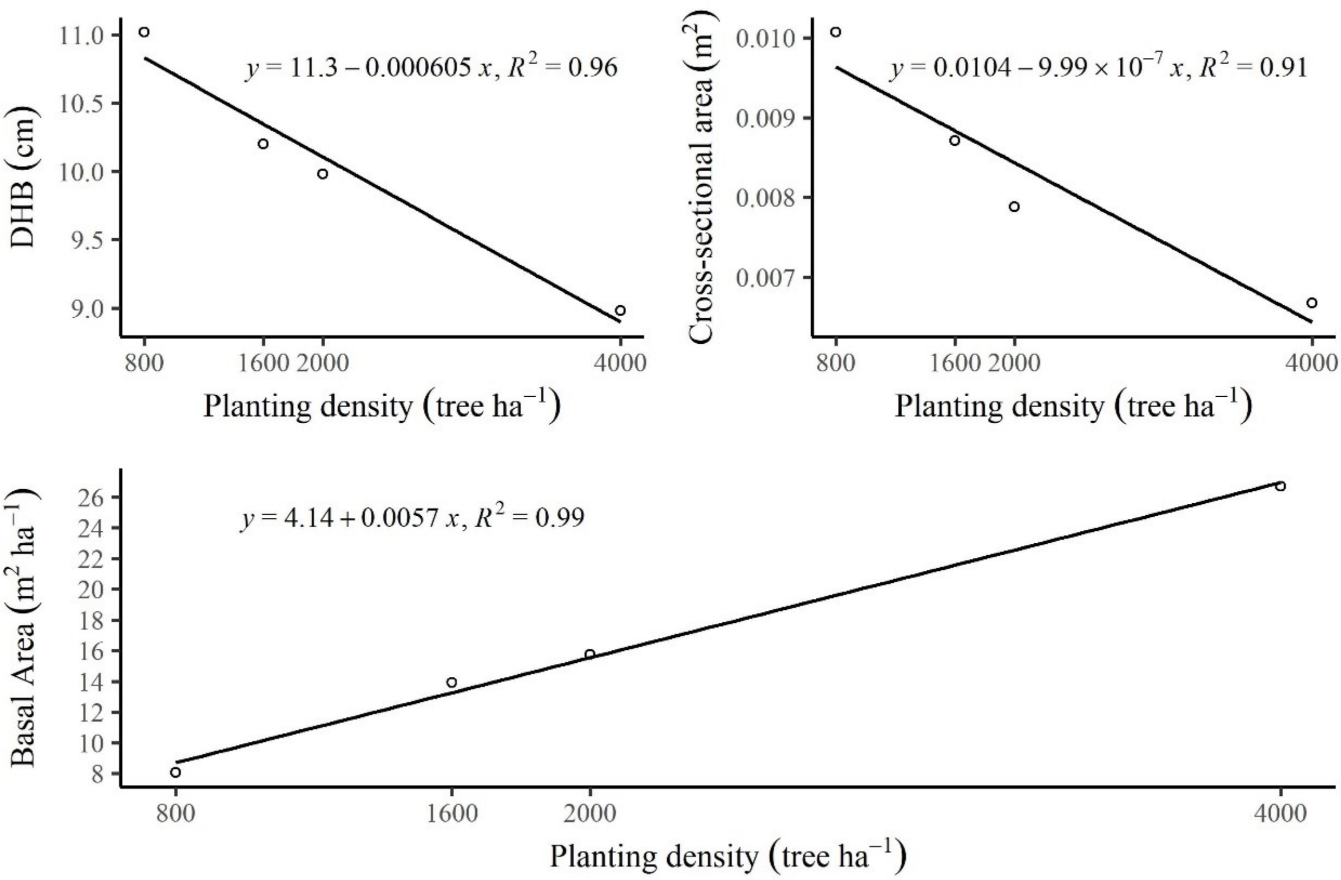

Figure 2. Diameter at breast height (DBH, cm), cross-sectional area (m²), and basal area (m² ha^{-1}) in an experimental plantation of *Mimosa caesalpiniifolia* 13-year-old according to the planting densities in Mossoró, RN, Brazil.

A positive relationship was observed for volume and stere volume per hectare (Figure 3A) as planting density increased, showing that this increase in planting density resulted in higher values for the parameters mentioned.

Concerning volume and stere volume per tree, a negative relationship was observed in the average values according to the decrease in planting density (Figure 3B), indicating that the volume and stere volume per tree will decrease as the density increases.

The highest volume and stere volume values were found in the lowest planting density (800 trees ha^{-1}), which suggests a greater influence of individual growth in volume in this densification. Plants in this planting density have a greater tendency to grow since it is a plantation with a lower number of trees (RODRIGUES et al., 2020).

Similar behavior to the basal area can be seen for volume and stere volume per hectare (Figure 3A), where the densest spacing showed the highest value. According to Soares et al. (2018), this is due to the greater competition for resources in denser spacings, which leads to greater development in less time, thus generating a need for production that is reached quickly, followed by a considerable decrease in production. The difference in volumetric production between a denser spacing and one with a lower density lies in the time it takes for the individuals to occupy the entire area, making the denser spacing ideal for shorter rotation plantings.

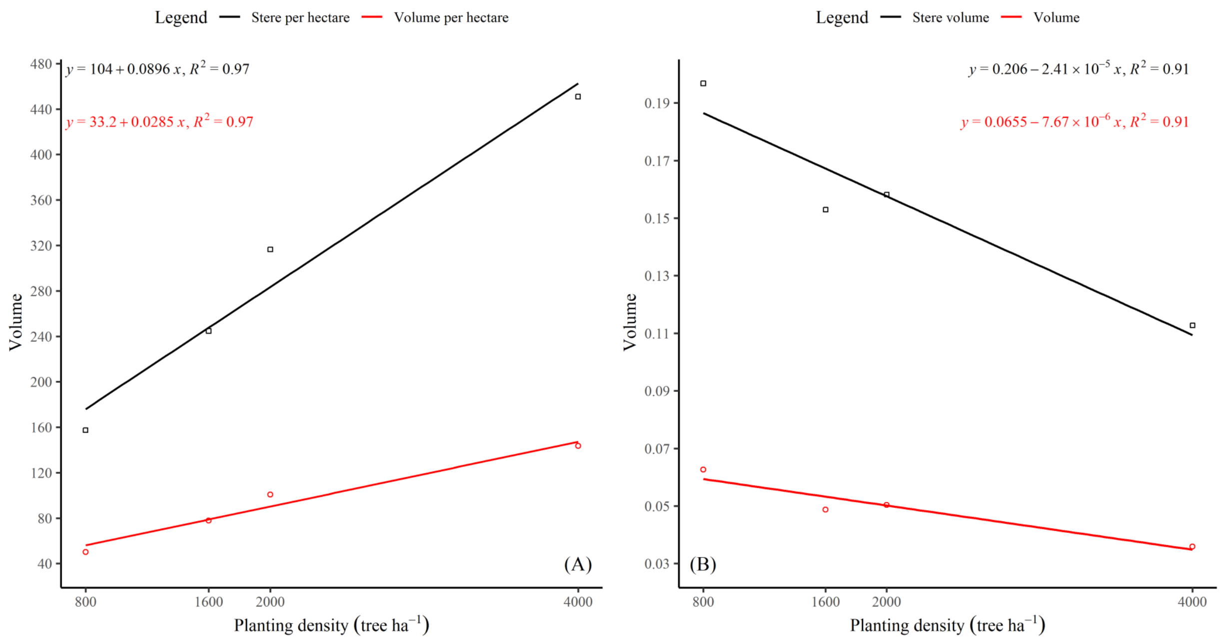

Figure 3. Volume (m³) and stere volume per hectare (A) and volume (m³) stere volume per tree (B) in an experimental plantation of *Mimosa caesalpiniifolia* 13-year-old according to the planting densities in Mossoró, RN, Brazil.

The different planting densities evaluated influenced the production of fresh and dry aboveground biomass and the stem, branch, and leaf components per hectare. It was noted that the highest density, corresponding to 4000 trees ha^{-1}, resulted in the highest biomass production, while the lowest density, 800 trees ha^{-1}, showed the lowest production (Figure 4A).

About fresh and dry aboveground biomass, as well as the components stem, branches, and leaves per tree, the average values varied according to the different planting densities, gradually increasing as the useful area per plant expanded, where the lowest planting density had the highest production (Figure 4B).

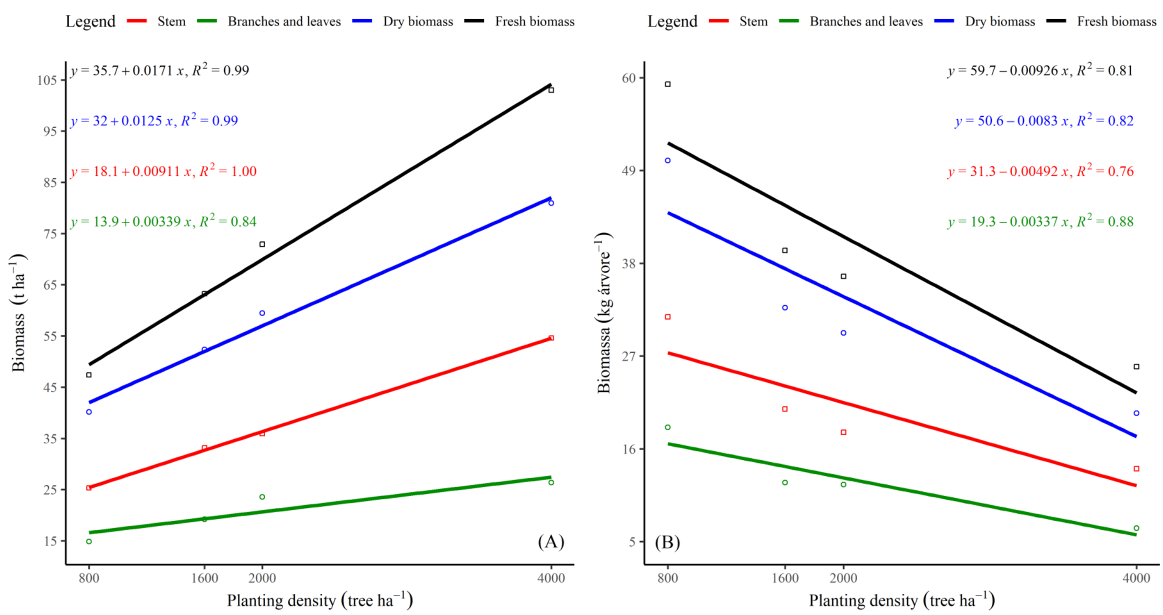

Figure 4. Production of fresh and dry aboveground biomass, stem biomass, and branch and leaf biomass per hectare (A) and per tree (B) in an experimental plantation of *Mimosa caesalpiniifolia* 13-year-old according to the planting densities in Mossoró, RN, Brazil.

According to Corrêa et al. (2020), the difference in biomass production per tree (Figure 4B) at the different densities evaluated is due to competition for light, water, and nutrients among the plants and the smaller leaf area of plants in the denser spacings. The choice of planting density depends on the purpose of the plantation. Lower planting densities are generally used for sawmilling and industrial purposes, while denser densities are used for energy purposes and with a short cutting cycle.

In this study, a direct relationship between biomass per hectare and planting density is observed as the highest values of dry and fresh biomass were obtained in the denser treatments (Figure 4A). According to Eloy et al. (2016), the number of individuals will affect biomass production, so denser densities tend to generate greater production. In the different densities, biomass production tends to stabilize over time. This stagnation occurs more quickly in the higher planting densities, while production takes longer to stabilize in the lower planting densities.

There was no influence of planting density on the percentage allocation of dry biomass accumulated in the stems, branches, and leaves (Figure 5).

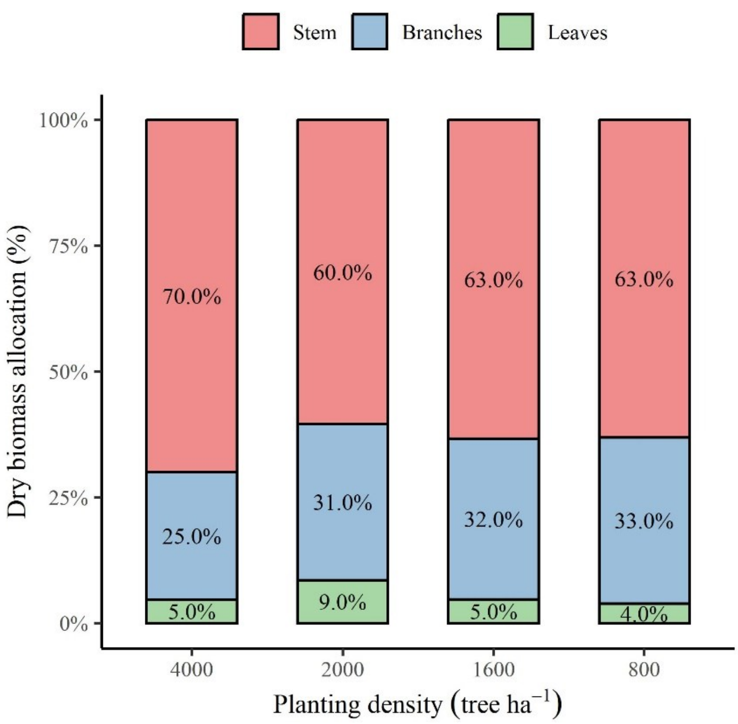

Figure 5. Dry biomass allocation among the stem, branch, and leaves in an experimental plantation of *Mimosa caesalpiniifolia* 13-year-old according to the planting densities in Mossoró, RN, Brazil.

In the aboveground biomass allocation, more than 60% of the dry biomass corresponds to the stem with bark. All the planting densities evaluated had the following biomass accumulation order: stem > branches > leaves. Considering the sum of the stem and branches, at a density of 800 trees ha^{-1}, 96% of the biomass can be used for energy, 95% for 4000 and 2000 trees ha^{-1}, and 91% for 1600 trees ha^{-1}.

For the basic density of the wood, the analysis showed a negative relationship between the average values observed (Figure 6), indicating that as the planting density increases, the basic density of the wood of the *Mimosa caesalpiniifolia* plants will decrease.

According to Fortaleza et al. (2019), woods are classified as low density, those with a basic density below 0.50 g cm^{-3}, medium or moderately hard those with a density between 0.50 g cm^{-3} and 0.70 g cm^{-3}, and those classified as heavy density or hard those above 0.70 g cm^{-3}. Considering this classification, we can see that for all the densities evaluated, *Mimosa caesalpiniifolia* wood is considered heavy or hard.

Wood density is an important indicator for charcoal production since wood with higher densities tends to result in denser charcoal, consequently allowing for a higher gravimetric production per unit in a kiln (MOULIN et al., 2017a). Therefore, the greater the basic density, the greater the biomass stored per cubic meter (m^3) (SANTOS et al., 2016).

According to Moulin et al. (2017b), a high planting density results in greater competition for nutrients, water, and light, resulting in a lower basic density of the wood, corroborating the results found in this study. However, for energy purposes, a short cutting cycle and greater volume per area are essential for continuous production that meets local demand (SILVEIRA, REINER, SMANIOTTO, 2014).

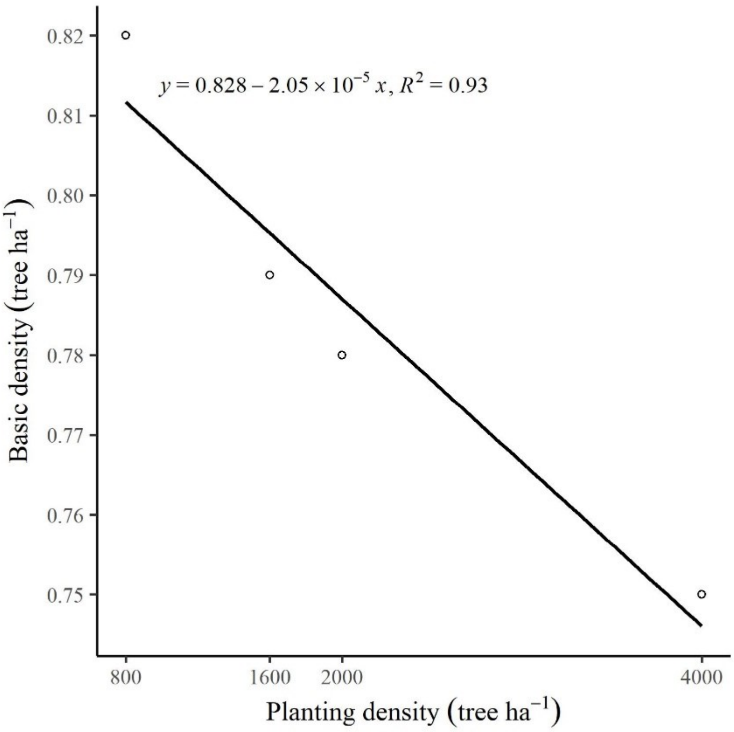

Figure 6. Basic density (g cm^{-3}) of wood in an experimental plantation of Mimosa caesalpiniifolia 13-year-old according to the planting densities in Mossoró, RN, Brazil.

CONCLUSIONS

Diameter at breast height, basal area, volume, aboveground biomass, and basic density were correlated and dependent on planting density. The highest planting densities resulted in the highest basic density of the wood, while the lowest planting densities resulted in the lowest basic densities. The biomass allocation showed the sequence stem>branches>leaves at 13 years of development, regardless of the planting density evaluated. The higher planting density proved advantageous 13 years after planting due to the higher production of dry biomass, volume (m³), and stere volume per hectare.

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