VOLUMETRIC PRODUCTION OF EUCALYPTUS SPP. CLONES UNDER DIFFERENT SPACING IN A SEVERE DROUGHT PERIOD IN THE SEMI-ARID REGION OF PERNAMBUCO, BRAZIL

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Resumo

Produção volumétrica de clones de Eucalyptus spp. Sob diferentes espaçamentos em período de seca severa no semiárido pernambucano. Após a implantação de experimentos com florestas de rápido crescimento se observou a adaptação de clones de *Eucalyptus* na Chapada do Araripe-PE. Esta região possui uma alta demanda por fontes energéticas alternativas devido ao Polo Gesseiro manter sua matriz energética basicamente da exploração da vegetação Caatinga. Sendo assim, como forma de aumentar os ganhos em produtividade volumétrica no plantio de clones de *Eucalyptus* spp. é importante entender quais níveis de espaçamentos proporcionam melhor competição entre os indivíduos. Desta forma, objetivou-se avaliar se a produtividade volumétrica de clones de *Eucalyptus* spp. é afetada por diferentes níveis de espaçamentos em povoamentos implantados em condições de seca severa na Chapada do Araripe-PE. O experimento foi desenvolvido na Estação Experimental do Instituto Agronômico de Pernambuco (IPA) no município de Araripina-PE. Foram dispostos três clones de *Eucalyptus* (C11, C39 e C41) com cinco níveis de espaçamentos (2 m x 1 m, 2 m x 2 m, 3 m x 2 m, 3 m x 3 m e 4 m x 2 m) em delineamento inteiramente aleatório com arranjo fatorial (3 x 5). A taxa de sobrevivência do experimento foi superior a 94%, mesmo em condições de estresse hídrico. A maior produtividade em volume foi obtida com o clone C39 no arranjo espacial 2 m x 1 m. O tipo de espaçamento influencia fortemente a produtividade. Mesmo a condição de seca severa regulando a produtividade, o clone C39 apresentou valores de IMA de 15,92 m^3 ha^{-1} ano^{-1}.

Palavras-chave: Polo Gesseiro do Araripe-PE, volume de madeira, incremento médio anual, idade técnica de corte.

Abstract

The adaptation of *Eucalyptus* clones in the Chapada of Araripe, PE, Brazil was observed after implementing experiments with fast-growing forests. This region has a high demand for alternative energy sources due to the Gypsum Pole, basically maintaining its energy matrix from the exploitation of Caatinga vegetation. Therefore, as a way to increase the gains in volumetric productivity in planting *Eucalyptus* spp. clones, it is important to understand which spacing levels provide the best competition between individuals. Thus, the objective of this study was to evaluate if the volumetric productivity of *Eucalyptus* spp. clones is affected by different spacing levels in stands implanted under severe weather conditions in Chapada of Araripe, PE, Brazil. The experiment was carried out at the Experimental Station of the Pernambuco Agronomic Institute (IPA) in the municipality of Araripina, PE, Brazil. Three *Eucalyptus* clones (C11, C39 and C41) with five spacing levels (2 m x 1 m, 2 m x 2 m, 3 m x 2 m, 3 m x 3 m and 4 m x 2 m) were arranged in a completely randomized design with factorial arrangement (3 x 5). The survival rate of the experiment was higher than 94%, even under conditions of water stress. The highest volume productivity was obtained with the C39 clone in the 2 m x 1 m spatial arrangement. The spatial arrangement strongly influences productivity. Even with the severe drought condition regulating productivity, the C39 clone showed MAI values of 15.92 m^3 ha^{-1} $year^{-1}$.

Keywords: Gypsum Pole of Araripe, PE, wood volume, mean annual increment, technical rotation age.

INTRODUCTION

Planted *Eucalyptus* forests are highly developed in the Southeast and Midwest regions. Together they hold more than 60% of the total planted area in Brazil. On the other hand, plantations in the Northeast region are basically concentrated in the state of Bahia, comprising only 11% of the total Brazilian area (IBÁ, 2019). The edaphoclimatic characteristics of the northeastern semi-arid region are a limiting factor for developing these forests. In recent years, several studies have been carried out with the aim of improving understanding of inserting the *Eucalyptus* genus in semi-arid regions with high water stress (DRUMOND *et al.*, 2003; SILVA *et al.*, 2013; GADELHA *et al.*, 2018).

The first studies conducted in the northeastern semi-arid region focused on identifying *Eucalyptus* species and/or clones that present adaptations to the edaphoclimatic factors characteristic of the region (DRUMOND *et al.*, 2003; ALVES *et al.*, 2007; SILVA *et al.*, 2013; FONTENELE *et al.*, 2018). In these, the planting viability for clones from the *Eucalyptus tereticornis* and *Eucalyptus urophylla* species was confirmed. Thus, new studies in the region are focused on silvicultural practices.

Determining the spatial arrangement of the population that provides greater volumetric yields is an important factor, as wood from planted forests in the region is mainly used as a local energy source (BARROS *et al*., 2010; SANTANA, 2016). In a study carried out in the Chapada do Araripe in the semi-arid region of Pernambuco, Drumond *et al.* (2012) tested five spacing levels (3 m x 2 m; 3 m x 2.5; 3 m x 3 m; 3 m x 3.5 m and 3 m x 4 m). The authors concluded that the 3 m x 2 m spacing presented a greater increase in volume compared to the other levels. Silva *et al*. (2013) recommended testing different spatial arrangements to assess the productive performance of *eucalyptus* forests in the semi-arid region. Little attention was paid to spacing with less area available for plant development. The spacing level in forest stands causes differences in diametric distribution, height and survival rate (CARON *et al*., 2015). The average and current volume increment rates, as well as the technical cutting age of the planting can also be affected in small rotation cycle cases. Smaller spacing levels can provide an increase in volume productivity for energy purposes.

The large volume of *Eucalyptus* plantations are concentrated in the Southeast, Center-West and coast of Bahia (IBÁ, 2019), mainly because these regions present accumulated annual precipitation above 1,000 mm. However, Drummond *et al*. (2012) and Silva *et al*. (2013) have already shown the adaptation of eucalyptus clones in the semi-arid region of Pernambuco in a period with an average accumulated rainfall of 740 mm. However, due to the northeastern semi-arid region presenting severe drought cycles, it is necessary to investigate the development of clones of the genus under these conditions. Thus, the objective of this study was to evaluate whether the volumetric productivity of *Eucalyptus* spp. clones is affected by different spacing levels in stands implanted in the semi-arid region under severe drought conditions.

MATERIAL AND METHODS

Description of the experimental area and experiment planning

The experiment was installed in March 2010 in an area of 7.5 hectares at the Experimental Station of the Instituto Agronômico de Pernambuco (IPA) in the municipality of Araripina (coordinates 07° 29' 00”' S and 40° 36' 00” W, altitude of 816 meters), inserted in the semi-arid region of Pernambuco, Brazil (Figure 1).

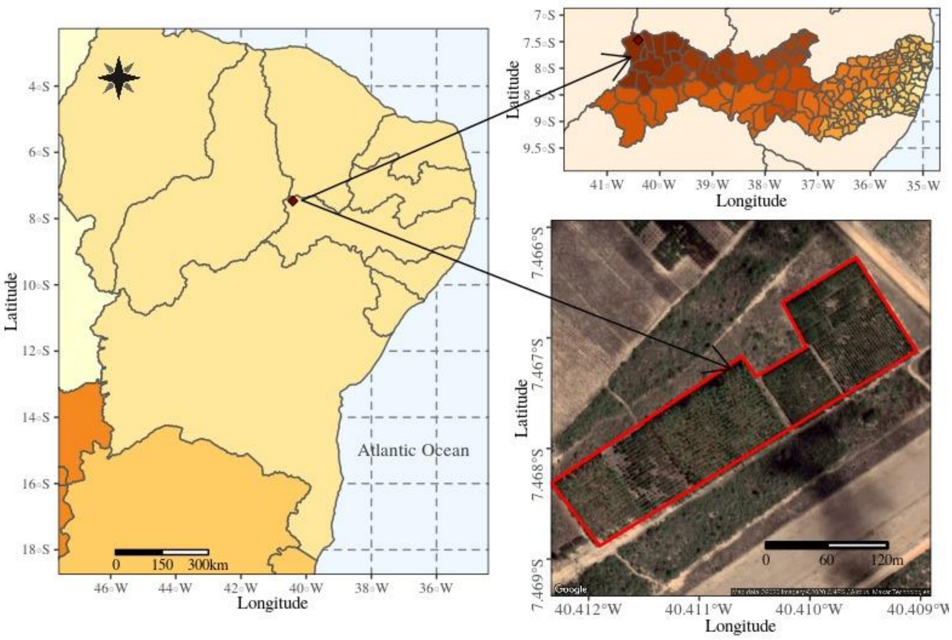

Figura 1. Mapa do Nordeste com destaque para a área experimental localizada no Instituto Agronômico de Pernambuco no município de Araripina-PE.

Figure 1. Northeast map with emphasis on the experimental area located at the Agronomic Institute of Pernambuco in the municipality of Araripina, PE, Brazil.

The climate in the region is BSh hot semi-arid according to the Köppen classification, characterized by lack of rainfall with quite irregular distribution. The average annual precipitation is 740 mm (Figure 2), and presents high evaporation rates and high average air temperature of approximately 25°C. The characteristic vegetation of this type of climate is xerophilic (Caatinga). The soil is LVAd1, Dystrophic Red-Yellow Latosols (SANTOS *et al.*, 2011).

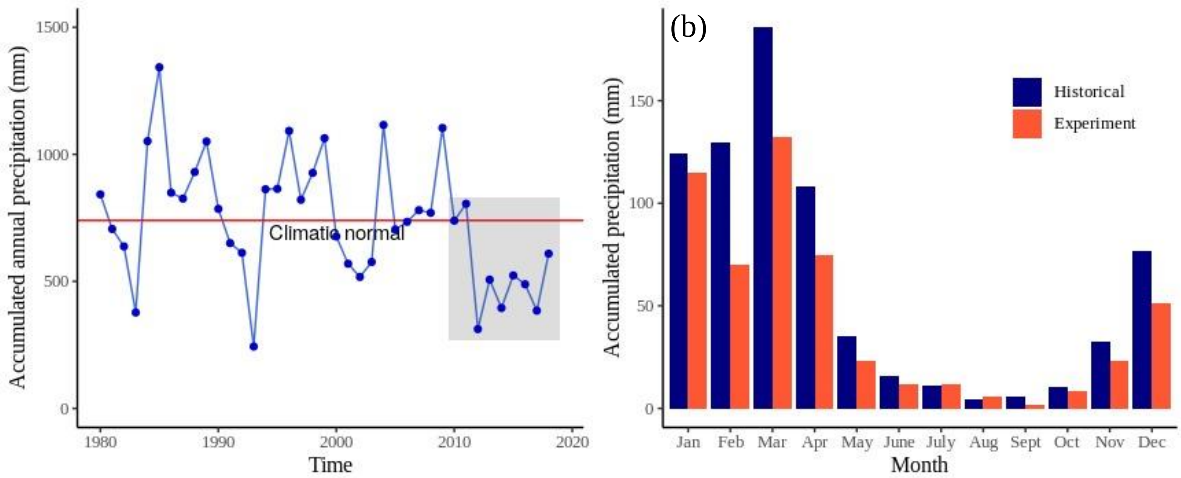

Figura 2. Precipitação anual acumulada (a) e precipitação média acumulada por mês (b), histórica e no período do experimento, para a área experimental.
Figure 2. (a) Accumulated annual precipitation and (b) average accumulated precipitation per month historically and in the experiment period for the experimental area.

The competing vegetation was removed to prepare the area, and furrows were subsequently opened in the ground with a depth of approximately 30 cm. Fertilization and acidity correction were performed based on the chemical analysis of the soil. A hydro-retaining polymer was used to improve water retention in the soil (GADELHA *et al.*, 2015).

Next, holes measuring 30 cm x 20 cm were opened to plant the seedlings. The experiment consisted of three clones (C11 - *Eucalyptus brassiana* clone, C39 - *Eucalyptus urophylla* clone, and C41 - *Eucalyptus urophylla* clone) distributed in five different spacings (2 m x 1 m, 2 m x 2 m, 3 m x 2 m, 3 m x 3 m and 4 m x 2 m), and four replications, arranged in a completely randomized design with a factorial arrangement (3 x 5). Each plot consisted of a total of 49 trees, and disregarding the border effect, 25 trees were used.

Data on diameter at breast height (DBH) and total height (Ht) were collected from September 2011 at 6-month intervals and the trees were felled in the field when the stand reached 8 years or 96 months of age. The Ht and the commercial height of the trunk were measured using a measuring tape (Hf, considering the trunk as the portion between the cut height (15 cm) to the height where the tree reaches a minimum diameter of three centimeters). Diameter measurements were taken using a sliding T bevel along the trunk at the following intervals: 0.30 m; 0.50m; 0.70m; 0.90m; 1.10 m; 1.30 m; 1.50 m; 1.70 m; 1.90m; and 2.30 m; measurements were obtained every one meter from these intervals.

Rigorous volumetric cubing and survival analysis

It was possible to determine the total wood volume per tree with the sectional diameter measurements. To do so, the Smalian formula was used (SILVA; NETO, 1979), given by:

$$V = \sum_{i=1}^{n} \frac{g_i + g_{i+1}}{2} \cdot l_i$$

In which: V is the volume of wood in m^3, g_i is the basimetric area at the beginning of section i in m^2, g_{i+1} represents the basimetric area at the end of section i in m^2, l_i is the length of section i, and n is the number of trunk sections.

The volume per hectare was obtained by multiplying the average volume of the plot, the number of trees in a hectare (according to the spacing) and the survival rate. We subsequently proceeded with the analysis of variance (ANOVA). If there were significant differences, Tukey's test of multiple comparisons was applied (when there were no significant differences for the interaction; in case of significance for the interaction, we proceeded with the unfolding calculation) at the 5% significance level.

Survival analysis was performed based on trees in the useful area of each plot at the age of 96 months. The survival percentage was calculated as the proportion of the number of living plants in relation to the total number of plants. Analysis of variance was used to verify differences in treatments. As differences were found by

ANOVA, the Scott-Knott test was used to compare the spacing and Tukey's test for the clones (in case there were no significant differences for the interaction), both at a 5% significance level.

Increment rates and technical cutting age

The age of maximum volumetric productivity or technical cutting age (TCA) is given by the age at which the mean annual increment (MAI) is equal to the current annual increment (CAI). The MAI was obtained through the expression: MAI = V_i/A, where A represents the age of the population.

The graphs that show the relationships between the mean and current increments were developed considering that the volumetric production can be expressed by the following Schumacher model:

$$V_i = e^{(\beta_0+\beta_1\frac{1}{I})} + \epsilon_i$$

In which: the Greek letters, β_0 and β_1 are model parameters and ϵ_i is the estimation error which follows a normal distribution. The model was fitted using the least squares method with the Gauss-Newton iterative algorithm. Thus, the CAI was obtained through the derivative of the model as a function of age A, as follows:

$$TCA = \frac{dV_i}{dA} = \frac{de^{(\beta_0+\beta_1\frac{1}{I})}}{dA} = \left(\frac{-\beta_1}{I^2}\right) \cdot e^{(\beta_0+\beta_1\frac{1}{I})}$$

Considering that the age at which MAI = CAI is the age of maximum productivity, the TCA was obtained through:

$$MAI = CAI \Rightarrow \frac{e^{(\beta_0+\beta_1\frac{1}{I})}}{A} = \left(\frac{-\beta_1}{I^2}\right) \cdot e^{(\beta_0+\beta_1\frac{1}{I})} \Rightarrow A = -\beta_1 \therefore TCA = -\beta_1$$

The Scott-Knott and Tukey tests were considered in developing the increment curves. As there was no significant differences for the spacing x clone interaction, the curves were developed in groups based on the differences of each factor.

The goodness-of-fit of the developed equations was evaluated using the corrected Schlaegel's fit index (IA_c), root mean square error (RMSE) and standard estimation error in percentage S_{xy}%, the residuals were submitted to the Shapiro-Wilk normality test (SW) and graphic analysis. All procedures for analysis of variance and calculation of post-tests, as well as the fitting of the models developed in this study were performed using the R software program (R Core Team, 2016).

RESULTS

Considering the survival rate for the clones and spacing effects at the age of 96 months, no significant differences were found through analysis of variance, and the interaction of these effects (clones x spacing) was not significant at the 5% significance level. Survival rates per treatment are shown in Figure 3. The C39, C11 and C41 clones showed the highest rates at 2 m x 1 m and 2 m x 2 m spacing.

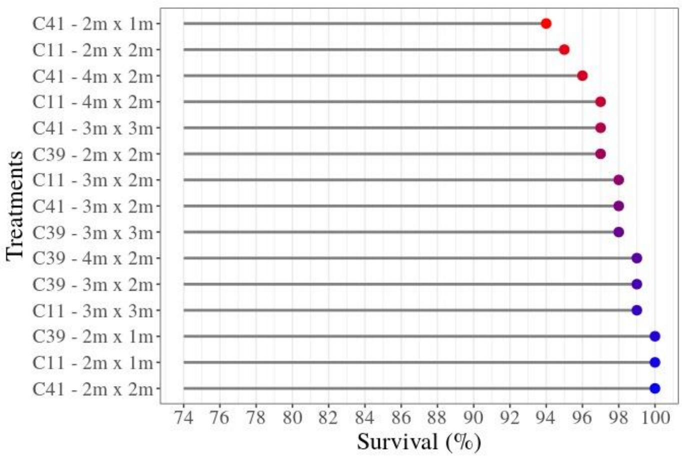

Figura 3. Taxa média da sobrevivência dos clones de *Eucalyptus* nos diferentes espaçamentos, cultivados no Polo Gesseiro do Araripe-PE.

Figure 3. Mean survival rate of *Eucalyptus* clones in different spacing, cultivated at the Gypsum Pole of Araripe, PE, Brazil.

Significant differences were found in analyzing the wood production for the clone and spacing factors, as the interaction between the factors was not significant. The effects of the factors are independent, meaning that the production of clones does not depend on the spacing level and vice versa. Thus, comparisons were made at the level of each factor. The 2 m x 1 m arrangement presented statistically higher mean values for volumetric production at the spacing level than the other spatial arrangements (Figure 4).

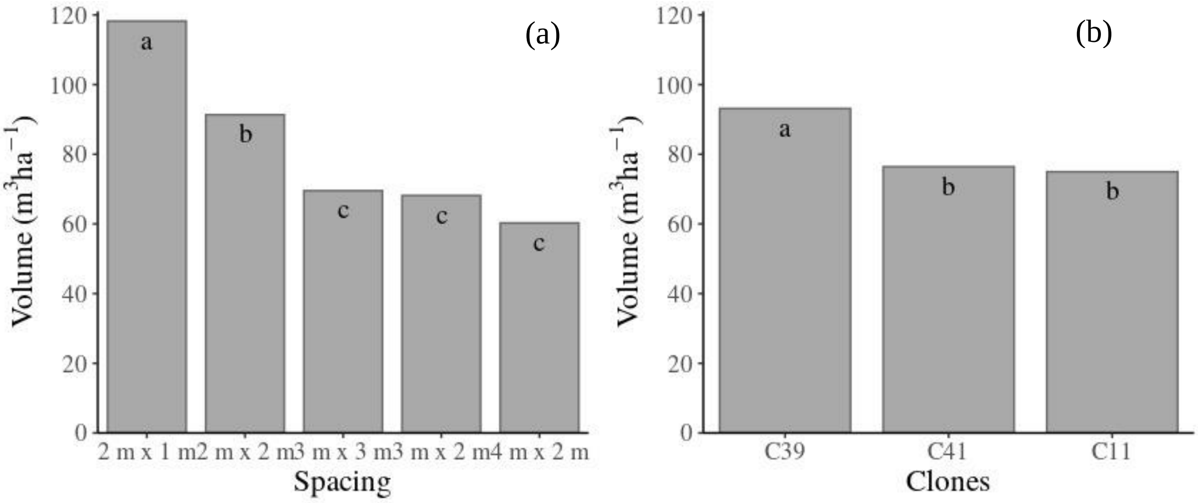

Figura 4. Produção volumétrica de *Eucalyptus* por fator espaçamento (a) e por clone (b), cultivados no Polo Gesseiro do Araripe-PE. *Médias seguidas pelas mesmas letras não diferem estatisticamente entre si ao nível de 5% de significância.

Figure 4. Volumetric production of *Eucalyptus* by (a) spacing factor and (b) by clone, cultivated at the Gypsum Pole of Araripe, PE, Brazil. *Means followed by the same letters do not differ statistically from each other at the 5% significance level.

The C39 clone was more productive for the wood production by clones. The mean volume for the clone factor is given in Figure 4. The overall MAI for the experiment was 9.5759 m^3 ha^{-1} yr^{-1}. The C39 clone at 2 m x 1 m spacing was the treatment with the highest MAI (15.92 m^3 ha^{-1} yr^{-1}), approximately three times higher than the least productive clone (C11) at 3 m x 2 m spacing with MAI of 5.84 m^3 ha^{-1} yr^{-1}.

It is necessary to determine the optimal harvest age or technical cutting age (TCA) for the forest stand to be more profitable. As shown in the methodology, the spacing and clones were grouped using the means test to estimate the TCA. Therefore, the C39 clone was renamed C1, and the C11 and C41 clones were renamed C2; the 2 m x 1 m spacing was given the nomenclature E1, the 2 m x 2 m spacing was renamed E2, and the other 3 m x 2 m, 3 m x 3 m and 4 m x 2 m spacings were denominated E3. Thus, the increment curves were developed for each new treatment, called Treatment: E1C1, E1C2, E2C1, E2C2, E3C1 and E3C2. The determined equations and the fitting statistics are presented in Table 1.

Tabela 1. Equações para estimativa do volume e definição da idade técnica de corte (ITC), por espaçamentos e clones, em experimento realizado no Polo Gesseiro do Araripe - PE.

Table 1. Equations for estimating the volume and defining the technical cutting age (TCA) by spacing and clones in an experiment at the Gypsum Pole of Araripe, PE, Brazil.

Treatment	Equations	IA_c	S_{xy}%	RMSE $m^3 \cdot ha^{-1}$.	SW (P-value)	TCA (years)
E1C1	$\hat{V} = e^{(5.4561 - 60.8717 \cdot \frac{1}{I})}$	0.9930	4.4447	3.3074	0.06	5.07
E1C2	$\hat{V} = e^{(5.1755 - 44.3153 \cdot \frac{1}{I})}$	0.9937	4.1529	8.8972	0.16	3.70
E2C1	$\hat{V} = e^{(4.9812 - 51.2919 \cdot \frac{1}{I})}$	0.9896	4.9216	2.6632	0.36	4.27
E2C2	$\hat{V} = e^{(4.9728 - 43.1735 \cdot \frac{1}{I})}$	0.9933	4.2151	7.1030	0.10	3.60
E3C1	$\hat{V} = e^{(4.9853 - 59.2509 \cdot \frac{1}{I})}$	0.9811	7.3396	3.4948	0.19	4.94
E3C2	$\hat{V} = e^{(4.5346 - 49.6020 \cdot \frac{1}{I})}$	0.9856	5.7971	2.0612	0.16	4.13

The test statistics were satisfactory considering the fitting conditions of the models, with high corrected Schlaegel adjustment index (IA_c) values and low standard estimate error (Sxy%), which demonstrates the good precision of the equations. All equations regarding the distribution of residuals showed deviations tending to normality, according to the Shapiro-Wilk test with 5% probability of error. The graphical analysis of the residuals for the equations obtained is given in Figure 5.

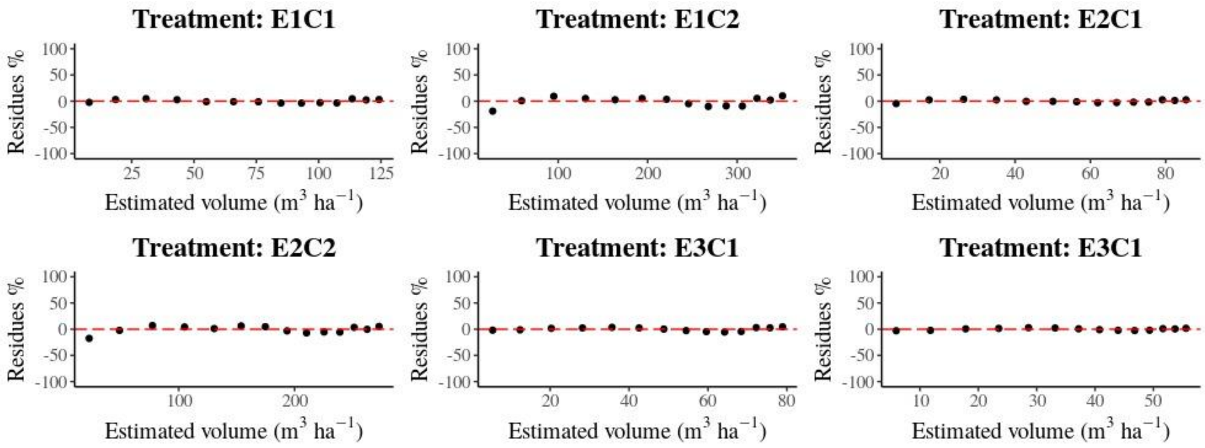

Figura 5. Produção volumétrica de *Eucalyptus* por fator espaçamento e por clone, cultivados no Polo Gesseiro do Araripe-PE.

Figure 5. Volumetric production of *Eucalyptus* by spacing factor and by clone, cultivated at the Gypsum Pole of Araripe, PE, Brazil.

The graphs with the mean annual increment (MAI) and current annual increment (CAI) curves, as well as the TCA results per treatment are shown in Figure 6.

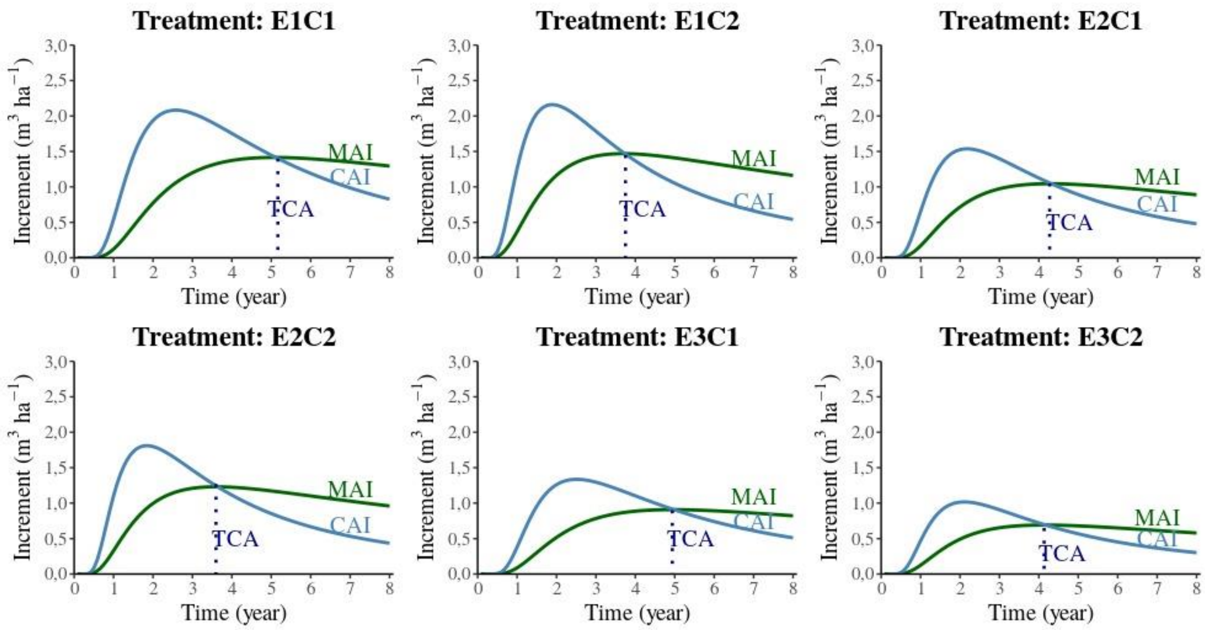

Figura 6. Curvas de incremento definidas para os clones de *Eucalyptus* em cinco espaçamentos, cultivados no Polo Gesseiro do Araripe-PE. Idade técnica de corte (ITC), definida pela interseção das curvas de incremento médio anual (IMA) e incremento corrente anual (ICA).

Figure 6. Increment curves defined for the *Eucalyptus* clones in five spacings, cultivated at the Gypsum Pole of Araripe, PE, Brazil. Technical cutting age (TCA) is defined by the intersection of the curves of the mean annual increment (MAI) and current annual increment (CAI).

The maximum increment point between 1.5 and 2.5 years of age for the six treatments was recorded, with the C39 clone (C1) showing the highest maximum points. This period coincides with the interval in which the experiment received the greatest amount of precipitation. The TCA ranged from 3.6 to 5.06 years. The C39 clone (C1) had the highest TCA compared to the others. The lowest TCA was recorded for the E2C2 treatment, which corresponds to the C11 and C41 clones in the 2 m x 2 m spacing.

DISCUSSION

The different spatial arrangements of the population can lead to changes in the competition levels for resources and spaces. However, in this experiment, an increase in competition was not observed in denser spacings, which could decrease survival rates. In working with 9.4-year-old Eucalyptus clones in 3 m x 2 m, 6 m x 2 m, 6 m x 3 m and 6 m x 4 m spacing in the Northwest region of Minas Gerais, Magalhães *et al*. (2007) verified the existence of the increase in the survival rate in less dense spacing (6 m x 4 m). The authors highlighted the importance of the size of the available usable area for the development and growth of each plant. Low survival rates in higher density spacings can influence the final productivity of the stand (SILVA *et al*., 2016), being important to define the densities that provide the highest stand productivity.

According to Rodrigues *et al*. (2016), one of the factors that can increase the survival rate values, mainly in monospecific forests, is related to the species' adaptive power to the edaphoclimatic conditions of the studied region. The high survival rates found in this study corroborate this information, as the clones used in this experiment are those ones which presented the best productivity performance, considering a total of 15 clones tested in an experiment carried out from 2002 to 2009 in the same region, according to works performed by Silva *et al*. (2013) and Gadelha *et al.* (2018).

The volumetric production and the MAI of a forest stand are some of the variables of greatest interest in studies with energetic and high productivity forests. It can be seen that the volume production was higher for the denser spacings than the other spacings. In other words, there is possibly a positive relationship between population density and the increase in forest production. This same relationship was identified by Gadelha *et al*. (2018), working with the same experiment at the age of 42 months, as observed by Sereghetti *et al*. (2015) in an experiment with an *E. urophylla* x *E. grandis* clone under different spatial arrangements, and also evidenced by Silveira *et al*. (2014) and Moulin *et al*. (2017), who carried out research with *Eucalyptus* clones at different ages. Corroborating the results obtained by Gadelha *et al*. (2018) at 42 months of age, it is evident that the density/production relationship for this stand deployed in the semi-arid environment of Pernambuco remains even after the forest has stabilized. However, some authors have pointed out that this relationship can be changed, as forests with larger usable area tend to have a nutrient reserve greater than denser forests, especially when the stand is maintained for extended periods (OLIVEIRA *et al*., 2009).

The main factor affecting production per hectare is the greater number of individuals per planted area, as the individual volume is smaller in denser areas (DRUMOND *et al*., 2012, FERREIRA *et al*., 2016). However, it is necessary to emphasize that although dense plantations present a greater wood volume per hectare, they require higher costs due to the immobilization of capital and to fight diseases and pests when compared to stands with less dense spatial arrangements (FILHO *et al*., 2018). This entails losses in the economic viability of the planting.

Production at the clone level was below that found in other studies for the State. In an experiment carried out from 2002 to 2009 in the same region for a 7.5-year-old population, Silva *et al*. (2013) determined the production of 222.55 m^3. ha^{-1} for the same C39 clone. However, Fontenele *et al*. (2018) determined an average production of 72.99 m^3. ha^{-1} for the C39 clone under a coppice system started in 2009 and harvested in 2015. The spacing used in both cases was 3 m x 2 m. These differences in production were possibly caused by climatic factors, as the accumulated annual precipitation during the 2002 to 2009 period was mostly above the climatological normal (740 mm $year^{-1}$), whereas the average rainfall in the period from 2010 to 2018 was approximately 500 mm.$year^{-1}$, with six consecutive years of below-average rainfall, which configures a severe drought event.

As the MAI is the division of volume by a constant (A) referring to age, the differences between treatments are the same with respect to those obtained for volume. Silva *et al*. (2013) determined the MAI for the C39, C41 and C11 clones of 29.68, 22.85 and 15.65 $m^3.ha^{-1}.year^{-1}$, respectively, cultivated in the 3 m x 2 m spacing in an experiment carried out during a climatic period considered rainy for the region. Following the same scale of increments working in Chapada do Araripe, PE, Brazil, and also at a time considered rainy, Drummond *et al*. (2012) determined the MAI for the hybrid *E. brassiana* x *E. urophylla* and *E. grandis* x *E. camaldulensis* clones of 24.7 and 20.8 $m^3.ha^{-1}.year^{-1}$, respectively, in spatial arrangements of 3 m x 2 m, 3 m x 2.5 m, 3 m x 3 m, 3 m x 3.5 m and 3 m x 4 m. However, Fontenele *et al*. (2018) recorded low MAI values of 13.03; 10.30 and 4.74 $m^3.ha^{-1}.year^{-1}$ for the C39, C41 and C11 clones under coppicing at 3 m x 2 m spacing, cultivated in the same area during the dry season. Thus, extreme climatic conditions can severely affect the productivity of planted forests in the semi-arid region, considering that all experiments were carried out in a radius of 500 meters with the same silvicultural treatment conditions.

Given the above, it is important to discuss the productivity of *Eucalyptus* clones in relation to native and exotic species from the Caatinga, which constitutes the predominant vegetation in the region. The comparison between the MAIs is a good starting point for this analysis. Working in the area of the Gesseiro do Araripe, PE, Brazil, Barros *et al*. (2010) installed plots with native and exotic species for comparison with *Eucalyptus* clones. This experiment was carried out from 2002 to 2008, configuring a 6.5-year-old population. The increments determined for the species Thrush (*Mimosa caesalpiniefolia*), Jurema (*Mimosa tenuiflora*), Angico (*Anadenanthera columbrina*), Ipê 1 (*Tabebuia* sp. 1) and Mesquite (*Prosopis juliflora*) were 8.04, 6.58, 5 .64, 1.28 and 0.24 $m^3.ha^{-1}.year^{-1}$, respectively. It is noteworthy that this experiment was conducted at a time with climatic conditions considered normal for the region, but even so the MAIs showed great variation. This indicates that species have different maximum increment points and some long cutting cycle periods. Considering that the MAI for the most productive clone in this experiment (C39 at 2 m x 1 m spacing) was 15.92 $m^3.ha^{-1}.year^{-1}$, which is twice as high as that found for Sabiá.

For a better understanding of the variation of the MAI in the Caatinga vegetation, it is necessary to present values for Forest Management Plans (FMP) conducted in this region. In working in different Caatinga areas in Rio Grande do Norte and Ceará with FMPs at different ages for the cutting cycle (cutting period ranging between 5 and 20 years), Riegelhaupt *et al*. (2010) found MAI values from 0.3 to 11 m^3 ha^{-1} $year^{-1}$. According to Meunier *et al*. (2018), it is unlikely that higher MAIs are obtained for the Caatinga vegetation in Pernambuco. The authors also warn that the FMPs in force in the State do not take into account growth estimates, adopting 15 years as the minimum age for the cutting cycle. Regarding this issue, Santana (2016) defined that 47 years is the minimum age for the clear-cutting cycle in a FMP area in the semi-arid region of Pernambuco with the purpose of wood for energy purposes.

Even under severe and atypical drought conditions in the semi-arid region, experiments with Eucalyptus clones conducted in Chapada do Araripe, PE, Brazil, show the possibility of cultivation, with volumetric yields above the average presented by native species.

CONCLUSIONS

- The tested clones are suitable for the semi-arid region, even in different spatial arrangements. These have a survival rate above 94%.
- The C39 clone is the most productive in volumetric terms.
- The spacing level factor most strongly affects productivity. The highest productivity for the three clones was obtained with the 2 m x 1 m spacing.
- The technical cutting age (TCA) is approximately 5 years for the most productive clone in the 2 m x 1 m spacing.
- Even under severe drought conditions regulating productivity, the C39 clone presented MAI values of 15.92 m^3. ha^{-1}. $year^{-1}$.

REFERENCES

ALVES, A. M. C.; SILVA, J. A. A.; FERREIRA, R. L. C.; BARRETO, L. P. Quantificação da produção de biomassa em clones de eucaliptos com 4, 5 anos, no Polo Gesseiro do Araripe-Pe. **Revista de Ciências Agrárias**, Amazonas, v. 48, n. 1, p. 161–174, jul/dez, 2007.

BARROS, B. C.; SILVA, J. A. A.; FERREIRA, R. L. C.; NEVES, A. C. M. Volumetria e sobrevivência de espécies nativas e exóticas no Polo Gesseiro do Araripe, PE. **Ciência Florestal**, Santa Maria, v. 20, n. 4, p. 641–647, out/dez, 2010.

CARON, B. O.; ELOY, E.; SOUZA, V. Q.; SCHMIDT, D.; BALBINOT, R.; BEHLING, A.; MONTEIRO, G. C. Quantificação da biomassa florestal em plantios de curta rotação com diferentes espaçamentos. **Comunicata Scientiae,** Bom Jesus, v. 6, n. 1, p. 106–112, jan/mar, 2015.

DRUMOND, M.; LIMA, P.; SANTOS, R. A. V. Comportamento de algumas espécies/procedências de *Eucalyptus* no município de Lagoa Grande-PE. **Brasil Florestal**, Brasil, n. 78, p. 75–80, Dezembro, 2003.

DRUMOND, M. A.; OLIVEIRA, V. R.; RIBASKI, J.; SANTOS, P. E. T.; TAVARES, J. A. Performance of two hybrid clones of *Eucalyptus* planted under five spacings in the Araripe plateau, Pernambuco, Brazil. **Acta Horticulturae**, n. 959, p. 167–171, 2012.

FERREIRA, A. D.; SERRA, A. P.; LAURA, V. A.; ORTIZ, A. C. B.; ARAÚJO, A. C. B.; PEDRINHO, D. R.; CARVALHO, A. M. Influence of spatial arrangements on silvicultural characteristics of three *Eucalyptus* clones at integrated crop-livestock-forest system. **African Journal of Agricultural Research,** v. 11, n. 19, p. 1734–1742, maio, 2016.

FILHO, J. I. P.; BIALI, L. J.; SCHNEIDER, P. R.; FARIAS, J. A. Avaliação econômica de projetos de florestamento com *Eucalyptus grandis* hill ex maiden implantado sob diferentes espaçamentos. **Ciência Florestal,** Santa Maria, v. 28, n. 1, p. 240–248, 2018.

FONTENELE, N. M.; SILVA, J. A. A.; FERREIRA, R. L. C.; BERGER, R.; GADELHA, F. H.; GUERA, M. O. G. Volumetric and economic evaluation of *Eucalyptus* spp. clones in high forest, coppice and native vegetation systems at the Gypsum Pole of Araripe-PE. **Scientia Forestalis**, Piracicaba, v. 46, n. 117, p. 77–86, março, 2018.

GADELHA, F. H. L.; SILVA, J. A. A.; FERREIRA, R. L. C. Viabilidade econômica do cultivo de clones de *Eucalyptus* em função do espaçamento e do sistema silvicultural, em Araripina-PE. **Anais da Academia Pernambucana de Ciência Agronômica**, Recife, v. 15, n. 2, p. 105–123, 2018.

GADELHA, F. H. L. SILVA, J. A. A.; FERREIRA, R. L. C.; CUNHA, R.; TAVARES; J. A. Produtividade de clones de eucaliptos em diferentes sistemas de manejo para fins energéticos. **Pesquisa Florestal Brasileira**, Colombo, v. 35, n. 83, p. 263–270, jul/set, 2015.

IBÁ. **Indústria brasileira de árvores**. São Paulo, 2019. 80 p.

MAGALHÃES, W. M.; MACEDO, R. L. G.; VENTURIN, N.; HIGASHIKAWA, E. M.; JUNIOR, M. Y. Desempenho silvicultural de clones e espécies/procedências de *Eucalyptus* na região noroeste de Minas Gerais. **Cerne**, Lavras, v. 13, n. 4, out/dez, 2007.

MEUNIER, I. M. J.; FERREIRA, R. L. C.; SILVA, J. A. A. O licenciamento de Planos de Manejo Florestal da Caatinga assegura sua sustentabilidade? **Pesquisa Florestal Brasileira**, Colombo, v. 38, p. 1–7, 2018.

MOULIN, J. C.; ARANTES, M. D. C.; OLIVEIRA, J. G. L.; CAMPINHOS, E.; GOMES, F.; VIDAURRE, G. B. Efeito do espaçamento, idade e irrigação no volume e densidade básica do eucalipto. **Floresta e Ambiente**, Rio de Janeiro, v. 24, p. 1–10, 2017.

OLIVEIRA, T. K. *et al*. Desempenho silvicultural e produtivo de eucalipto sob diferentes arranjos espaciais em sistema agrossilvipastoril. **Pesquisa Florestal Brasileira**, Colombo, n. 60, p. 01–09, 2009.

R Core Team. R: **A Language and Environment for Statistical Computing.** Vienna, Austria, 2016. Disponível em: <https://www.R-project.org/> Acesso em: 01 de fev. de 2019.

RIEGELHAUPT, E.; PAREYN, F. G. C.; BACALINI, P. O manejo florestal na caatinga: resultados da experimentação. In: GARIGLIO, M. A. *et al*. (Ed.). **Uso sustentável e conservação dos recursos florestais da Caatinga.** Brasília, DF: Ministério do Meio Ambiente, Serviço Florestal Brasileiro, 2010. p. 256–275.

RODRIGUES, M.; JIMÉNEZ, A.; RIVA, J. l. Analysis of recent spatial–temporal evolution of human driving factors of wildfires in Spain. **Natural Hazards, Springer**, Springer, v. 84, n. 3, p. 2049–2070, dezembro, 2016.

SANTANA, O. A. Minimum age for clear-cutting native species with energetic potential in the Brazilian semi-arid region. **Canadian Journal of Forest Research**, Ottawa, v. 47, n. 3, p. 411–417, 2016.

SANTOS, H. *et al*. **O novo mapa de solos do Brasil: legenda atualizada.** Embrapa Solos-Documentos, Rio de janeiro: Embrapa Solos, p. 67, 2011.

SEREGHETTI, G. C. LANÇAS, K. P.; SARTORI, M. S.; REZENDE, M. A.; SOLER, R. R. Efeito do espaçamento no crescimento e na densidade básica da madeira de *Eucalyptus urophylla* x *Eucalyptus grandis* em florestas de ciclo curto. **Energia na Agricultura**, Botucatu, v. 30, n. 3, p. 257–262, jul/set, 2015.

SILVA, J. A. A.; ROCHA, K. D.; FERREIRA, R. L. C., TAVARES, J. A. Produtividade volumétrica de clones de *Eucalyptus* spp. no Polo Gesseiro do Araripe, Pernambuco. **Anais da Academia Pernambucana de Ciência Agronômica**, Recife, v. 10, p. 240–260, 2013.

SILVA, J. A. A.; NETO, F. P. **Princípios básicos de dendrometria**. Recife: Imprensa Universitária da UFRPE, 1979. 198 p.

SILVEIRA, E. R.; REINER, D. A.; SMANIOTTO, J. R. Efeito do espaçamento de plantio na produção de madeira e serapilheira de *Eucalyptus dunni* na região sudoeste do Paraná. **Revista Técnico-Científica**, Curitiba, v. 1, n. 2, p. 1–9, setembro, 2014.

SILVA, R. S.; VENDRUSCOLO, D. G. S.; ROCHA, J. R. M.; CHAVES, A. G. S.; SOUZA, H. S.; MOTTA, A. S. Desempenho silvicultural de *Tectona grandis* L. f. em diferentes espaçamentos em Cáceres, MT. **Floresta e Ambiente**, Rio de Janeiro, v. 23, n. 3, p. 397–405, 2016.