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Management strategies of *Eremanthus erythropappus* (DC.) MacLeish under different initial spacing

Estratégias de manejo da candeia, *Eremanthus erythropappus* (DC.) MacLeish em diferentes espaçamentos

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ABSTRACT

Eremanthus erythropappus, commonly known as candeia, is an income-generating tree native to Brazil. This is due to the high durability of its wood and its essential oil containing the active component alpha bisabolol. Despite this economic potential, until the early 2000's no studies existed to explore the sustainable management in areas in which the species naturally occurs or for establishing commercial plantations. This study proposes new management strategies based on an individual tree model, and evaluates the growth behavior of candeia trees planted in different spacing. The experiment was installed in March 2002, in Carrancas municipality, Minas Gerais state, Brazil. The experimental area was divided into 4 blocks with 4 different spacings as treatments. The individual model used to propose the best management system uses development of crown area as a function of DBH. The results showed that candeia trees were sensitive to initial spacing variation. With increased initial spacing, candeia trees reached competition later, as demonstrated by crown area development. Thus, candeia trees planted at a wider spacing maintain a desirable growth rate without need for thinning for a longer time, compared to trees planted at narrower spacing. The fitted individual tree model presented in this study showed consistent results and flexibility, providing alternatives for different management strategies. The best growth response was obtained for planting densities greater than 3.75 m² per tree, which corresponds to a spacing of 1.5 x 2.5 m.

Index terms: Crown area; stand density; monomolecular model; individual tree model.

RESUMO

Eremanthus erythropappus, conhecida vulgarmente por candeia, é uma árvore nativa do Brasil, geradora de renda devido à elevada durabilidade apresentada por sua madeira e, também, pelo seu óleo produzido conter, como ingrediente majoritário, o alfa bisabolol. Apesar deste potencial econômico, até o início do ano 2000, a espécie não contemplava estudos sobre seu sistema de cultivo, tanto para o manejo sustentável em áreas de ocorrência natural quanto para o estabelecimento de plantios comerciais. Este estudo propõe estudar novas estratégias de manejo com base em modelo de árvore individual, e avaliar o crescimento da candeia em diferentes espaçamentos. O experimento teve início em março de 2002, no município de Carrancas, Minas Gerais, Brasil. A área experimental foi dividida em quatro blocos, com quatro diferentes espaçamentos como tratamentos. O modelo avaliado para definir o melhor sistema de manejo foi baseado na relação entre o desenvolvimento da área de copa e do DAP das árvores. Os resultados mostraram que a candeia foi sensível a variação no espaçamento inicial. Aumentando o espaçamento inicial, a competição entre as árvores de candeia ocorre mais tarde, ou seja, à medida que o espaçamento aumenta demora-se mais para que o plantio perca o ritmo desejado de crescimento. O modelo testado foi consistente e a técnica baseada na árvore individual apresentou flexibilidade, fornecendo alternativas para diferentes estratégias de manejo. As melhores respostas de crescimento foram obtidas para densidades iniciais de plantio a partir de 3,75 m² por planta, área que corresponde a um espaçamento de 1,5m x 2,5m.

Termos para indexação: Área de copa; densidade; modelo monomolecular; modelo de árvore individual.

INTRODUCTION

Eremanthus erythropappus (DC.) MacLeish, commonly known in Brazil as candeia, is an income-generating forest species. Its wood is predominantly used for fence posts due to its natural high durability and for extraction of essential oil that contains an active component alpha bisabolol (Scolforo et al., 2008; Silva et al., 2008). Alpha bisabolol is used in the manufacture of medicines and cosmetics such as lotions, tanners, sunscreens, prophylaxis care for sensitive skin, among other uses (Oliveira et al., 2009). Despite this economic potential, a consolidated management system for this species did not exist until the beginning of this century, neither for sustainable management in natural areas nor for plantations (Scolforo et al., 2012).

Studies were developed to investigate different management regimes for native candeia vegetation because there is a need to increase the understanding of candeia ecosystems to counteract its exploitative use in natural areas. The feasibility of this system has been demonstrated in studies by Scolforo et al. (2004) and Pérez et al. (2004), the pioneers in generating this information.

Experiments aimed at commercial cultivation of candeia as a pure or mixed plantations have also been performed since 2001 in different sites in the state of Minas Gerais (Scolforo et al., 2012). The monitoring of these experiments enabled studies of silviculture, forest nutrition, and forest management of *Eremanthus erythropappus* to be conducted.

Individual tree models based on crown area is a method that can be used to determine adequate stand density management for plantations. For instance, Durlo and Denardi (1998), addressed management of *Cabralea canjerana* in native forests, evaluating living space required by individual trees and confirmed the importance of canopy variables in relation to diameter growth. Thus, there is a justification for studies that evaluate crown dimensions and its implications for forest management.

Nutto et al. (2006) reaffirmed the importance of these types of studies, emphasizing that this type of model enables prediction of different forest management strategy scenarios, enabling quantification of thinning severity to eliminate between tree competition and maximize growth.

The present study proposed management strategies based on the individual tree model and evaluated the behavior of *Eremanthus erythropappus* (DC.) MacLeish planted on different initial spacings.

MATERIAL AND METHODS

Experimental design and data collection

The experiment site is located at the coordinates 21º33'00"south and 44º42'43" west in the municipality of Carrancas, Minas Gerais, Brazil, which presents altitudes ranging from 896 to 1590 meters, and has a Cwa (highland tropical) climate with hot and humid summers, according to Köppen´s classification system. The mean monthly temperature is 19.4 ºC (minimum of 11.1 ºC in July and maximum of 27.8 ºC in January) and the mean annual rainfall is 1470 mm (minimum of 23.4 mm in July and maximum of 296 mm in January).

The soil of the experimental area is a Dystrophic Haplic Cambisol, with depths superior to 200 cm, texture in the 0-20 cm layer of 156, 386 and 459 g kg^{-1} of clay, silt, and sand, respectively. The experiment was installed in March of 2002, and the design used in this study was divided into four blocks, each of which contained four random plots. Each plot contained 112 plants, all of which were pruned. Pruning aimed to produce single-stem trees with potential use of either extraction of alpha-bisabolol or for the production of fence posts. Planting included a deep planting pit (0.50 m wide and 0.60 m depth).

The spacing treatments installed were: 1.5 x 1.5 m (2.25 m^2) (T01); 1.5 x 2.0 m (3.00 m^2) (T02); 1.5 x 2.5 m (3.75 m^2) (T03); and 1.5 x 3.0 m (4.50 m^2) (T04). An NPK fertilizer (4-14-08 + Zn 0.4%) was used in the pits (100 g/pit). The amount of fertilizer was defined in accordance with the soil fertility analysis in the experiment area. Scolforo et al. (2015) studied nutrient effect on candeia tree growth and concluded that this is the optimal fertilization application. Weed and ant control were carried out periodically. Ant control was done by applying 10g/nest of granular baits (main active ingredient is sulfluramide).

Tree circumference at breast height (CBH) was measured at 1.30 m from the ground for stems greater than 9 cm, and crown projection area (CA) was based on the sum of the areas within 8 fixed-angle radii. The first measurement was always performed on the north-facing radius. CBH and CA measurements were done when the experiment was 3.17, 4.17, 5.25 and 6.59 years old.

Crown area modeling based on tree diameter

The calculation of CA was made by the sum of the areas within the 8 triangles, formed by the 8 fixed-angle radii, measured in each evaluation (Figure 1).

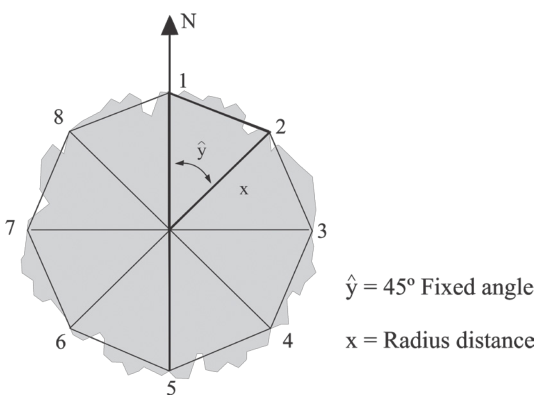

Figure 1: Measurement of CA based on the areas within 8 fixed-angle radii; the first measurement was always performed on the north-facing radius.

The CA of each tree was calculated using the following Equation 1:

$$CA = \frac{\left[(x_1 \times x_2)(\sin(y))\right] + \left[(x_2 \times x_3)(\sin(y))\right] + ... + \left[(x_8 \times x_1)(\sin(y))\right]}{2} \quad (1)$$

Where: CA is the crown area (m^2); x is the radii distance (m); y is the angle, which is always equal to 45º.

According to Assmann (1970), the standard value of canopy coverage that defines the time of thinning intervention to prevent tree crown overlap is 78% of the area value. Thus, plant competition for space starts when the sum of individual crown areas reaches 78% of the total area (or 7,800m² in 1 hectare).

The CA was fitted as a function of tree diameter using the equation proposed by Nutto (2001), who observed a precision gain in the equation's fit after adding a quadratic term to the Equation 2, when studying *Araucaria angustifolia*:

$$CA = (\beta_0 + \beta_1 DBH + \beta_2 DBH^2)^2 \quad (2)$$

Where: CA is the crown area (rather than the crown diameter used by Nutto (2001)); DBH is the measured diameter at 1.30 m from the ground, and β_i are the model parameters.

Since candeia is a tree species that naturally has several stems per individual, we considered total plant crown for each pit because it was not possible to separate the crown of each stem. Thus, when multiple stems per pit occurred, the equivalent diameter per plant was obtained. This measurement was obtained by the square root of the sum of squares of DBH from all measured stems in each plant.

We considered two hypotheses for the modeling part of this study. The first hypothesis assumed that DBH was linearly correlated with CA. The second hypothesis assumed the existence of a diametric increment-limiting factor related to planting density (initial spacing).

To accept the second hypothesis, DBH was fitted as a function of time. This was performed using each treatment as a categorical variable to check if significant differences exist in diameter growth with the different initial spacing.

To predict and test the hypothesis that groups (treatments with similar DBH growth) provide regressions that differ in level but not in form, the model used was as follows (Equation 3):

$$DBH = Treat + \beta_1 \times (1/t) \quad (3)$$

Where: $Treat$ is the categorical variable related to treatment; t is the age of the plantation in years; and β_i is the model parameter.

After validating the second hypothesis, DBH was fitted according to age (for each spacing criteria) using an organic monomolecular biological model (Equation 4):

$$DBH = \beta_0 \times (1 - \exp(\beta_1 \times t)) \quad (4)$$

Where: exp is the natural logarithmic base; t is the age of the plantation in years; β_i are model parameters.

RESULTS AND DISCUSSION

DBH growth groups

The fitted linear regression to predict DBH as a function of age using each treatment as a categorical variable showed that the initial spacing influenced DBH growth rate, identified by the statistical difference among treatments according to DBH growth (Table 1).

Table 1: Fitted linear regression, standard error (cm) for each parameter, statistical significance (p-value) of estimated parameters for model (3).

Parameter	Variable	Coefficient	Standard Error	p-value
β_0	Intercept	7.0625*	0.0653	0.00001
	T01	0.5420*	0.0490	0.00001
	T02	0.8501*	0.0501	0.00001
	T03	1.1255*	0.0486	0.00001
β_1	1/*t*	-11.3463*	0.2944	0.00001

* Significant at 5%; t: is the age of the plantation in years.

Modeling the development of CA based on tree DBH

CA based on tree diameter allows for identification of the ideal stand density over time, which is based on a predicted diameter per plant. Tree diameter must be modeled over time to implement this assumption, as shown in Table 2.

The fitted models presented Syx range from 1.1 to 1.4 cm (Table 2). These values are acceptable, since the data possess high variability.

Table 3 shows the equations resulting from fitting CA as a function of DBH, and their respective measurements for accuracy and coefficient of determination in each treatment.

The residual standard error, Syx (m^2) and Syx (%), indicate that there was marked variability among the data, which is acceptable for a species in which genetic improvement has not been conducted. The coefficients of determination (R^2) indicate the existence of correlation between CA and DBH. In this study, the R^2 between variables is acceptable, considering the high variability of the data (Figure 2). No trend in behavior of the residual values was observed in residual plots, showing a mean curve without a trend, which adequately reflects the behavior of CA as a function of DBH (Figure 2).

The parameters (intercept and slope) of each fitted equation for the different treatments suggest that candeia trees present differentiated growth behavior (Table 4), as confirmed in Table 1. Therefore, the second hypothesis, that the equations depicting relationships between CA and DBH represent stable and reliable behavior, is accepted.

The number of individuals per hectare in each treatment as a function of DBH, based on the variable CA (Table 3), allowed the calculation of the growth space required for a candeia tree to reach a certain size (predicted DBH). Table 4 shows the estimated DBH values and capacity (number of individuals per hectare) in each age without causing canopy overlap.

To avoid excessive crown overlap, the time to intervene with thinning is when canopy area per hectare approaches 78% (7,800 m^2 in 1 hectare). This approach prevents competition for space and the development of an irregular (non-circular) crown shape, which could compromise the plants' ability to increase in diameter. Values below 7,800 m^2 indicate that adjacent canopies have not yet overlapped, indicating that intra-tree competition has not occurred at that age.

Table 4 shows that the time to thin occurs sooner in closely spaced stands, since the high density of plants promotes earlier contact and increased competition between neighboring trees.

The results in Table 4 show the need for a thinning intervention in each initial spacing to avoid excessive competition between trees. The age for thinning intervention increased as the initial spacing increased. The time for thinning in T01 (1.5 x 1.5 m spacing) occurred between the fifth and sixth year, while in T02 (1.5 x 2.0 m spacing) this moment occurred between the sixth and seventh year. The need for thinning for trees planted at wider spacing was between the twelfth and thirteenth year

Table 2: Fitted equations for prediction of DBH based on age of candeia trees planted according to different spacing criteria.

Treatment	Equation	Syx (cm)	Syx (%)
T01	DBH = 6.6983*(1-exp(-0.3099*t))	1.1	22.4
T02	DBH = 7.4040*(1-exp(-0.2825*t))	1.4	26.6
T03	DBH = 8.1816*(1-exp(-0.2544*t))	1.3	23.9
T04	DBH = 8.9049*(1-exp(-0.2171*t))	1.4	24.8

Treat.: Treatment; DBH: diameter at 1.30 m from the ground; exp: natural logarithmic base; t: age in years; Syx: standard residual error.

Table 3: Fitted equations for CA based on diameter of candeia trees planted according to different spacing criteria.

Treat.	Equation	Syx (m^2)	Syx (%)	R^2 (%)
T01	$CA = (1.2215 - 0.0525*DBH + 0.0131*DBH^2)^2$	0.6	33.5	29.1
T02	$CA = (1.0422 + 0.0371*DBH + 0.0068*DBH^2)^2$	0.7	31.2	45.0
T03	$CA = (1.2097 + 0.0003*DBH + 0.0081*DBH^2)^2$	0.8	34.0	29.2
T04	$CA = (1.2653 + 0.0027*DBH + 0.0082*DBH^2)^2$	0.9	35.5	29.4

Treat.: Treatment; CA: crown area per pit (m^2); DBH: diameter at 1.30 m from the ground; Syx: standard residual error.

in T03 (1.5 x 2.5 m spacing) and between the thirteenth and fourteenth year in T04 (1.5 x 3.0 m spacing).

Because candeia is a slow growing species, its economic rotation is estimated to be between 12 and 15 years (Silva et al., 2012). Thus, we recommend using an initial spacing greater than 3.75 m^2 per plant, avoiding the need for thinning, since thinning interventions were estimated to be needed only after 12 years for spacing equal to or greater than 3.75 m^2.

The assumption reported by Nutto (2001) and Nutto et al. (2006) in studies of other species was confirmed in this study, since CA was related to DBH. Thus, the higher the predicted DBH, the greater the individual CA and the smaller the plant density supported per hectare, and vice versa. A great part of the variation observed in candeia trees arises from the wild genetic material used in this study. It is expected that the relationship between CA, age, and DBH can improve in future candeia plantations with the advancement of technologies resulting from new nutritional, management, and genetic-improvement practices.

Although new experiments and analysis are necessary to consolidate the best management system for the species, the results of this study suggest that planting densities greater than 3.75 m² (1.5 x 2.5 m) are most favorable for commercial plantations. This enables the possibility for small landowners to use unproductive areas to grow candeia trees with an adequate growth rate and without need for thinning (rotation of 12 years). Since wider initial spacing provides a good growth rate for the trees, candeia wood at the end of the rotation may be used either for the extraction of alpha-bisabolol or for the production of fence posts.

Analysis of the models adopted in this study showed that the CA model based on DBH is flexible and provides management and analytical options for different treatments, in this case spacing. This model permits the identification of the time of thinning, along with the development of average diameter in each treatment. The model also allows quantification of the number of trees that can remain in the stand over the years to avoid a decreasing growth rate, as well as the time needed for the trees to reach a certain diameter.

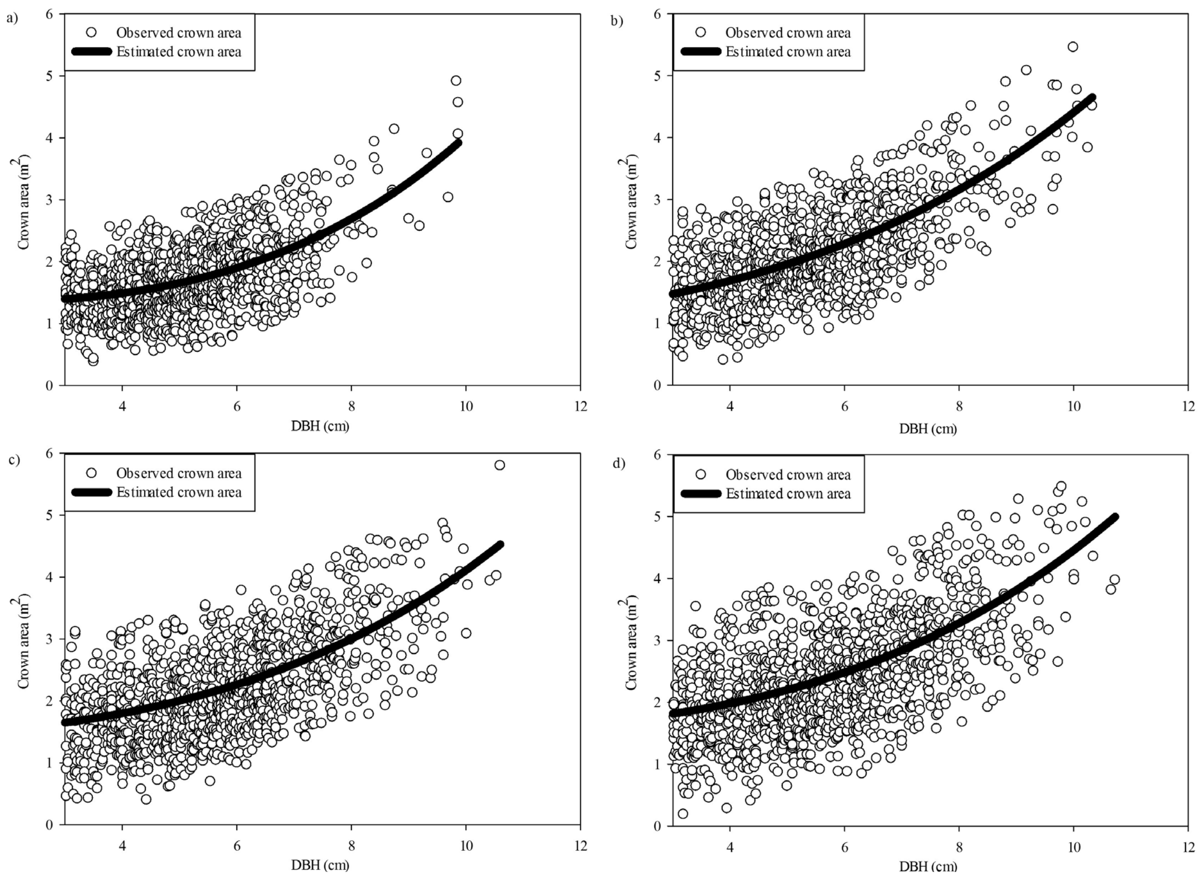

Figure 2: Crown area prediction as a function of DBH for: a - T01; b - T02; c - T03; d - T04.

Table 4: Maximum number of individuals per hectare (N/ha), with predicted DBH at different ages (years), estimated with the CA model (canopy coverage factor = 0.78).

Age	T01 (4444 N/ha)		T02 (3333 N/ha)		T03 (2667 N/ha)		T04 (2222 N/ha)	
	DBH	N/ha	DBH	N/ha	DBH	N/ha	DBH	N/ha
1	1.78	4444	1.82	3333	1.84	2667	1.74	2222
2	3.09	4444	3.20	3333	3.26	2667	3.14	2222
3	4.05	4444	4.23	3333	4.37	2667	4.26	2222
4	4.76	4444	5.01	3333	5.22	2667	5.17	2222
5	5.28	4444	5.60	3333	5.89	2667	5.90	2222
6	5.65	4320	6.04	3333	6.40	2667	6.48	2222
7	5.93	4148	6.38	3212	6.80	2667	6.96	2222
8	6.14	4020	6.63	3084	7.11	2667	7.34	2222
9	6.29	3927	6.82	2991	7.35	2667	7.64	2222
10	6.40	3858	6.96	2922	7.54	2667	7.89	2222
11	6.48	3808	7.07	2871	7.68	2667	8.09	2222
12	6.54	3771	7.15	2833	7.80	2667	8.25	2222
13	6.58	3744	7.22	2805	7.88	2643	8.38	2222
14	6.61	3724	7.26	2784	7.95	2617	8.48	2215
15	6.63	3710	7.30	2768	8.00	2596	8.56	2188

DBH: diameter at 1.30 m from the ground.

CONCLUSIONS

Average diameter growth for candeia trees is significantly different between different initial spacings. The need for early thinning in trees planted with close spacing was observed based on crown area and resulted in different management alternatives for each planting density.

Modeling the development of crown area in plantations based on tree diameter showed consistent results. The technique based on relating crown area and tree diameter is flexible, since it provides management and analytical alternatives for different initial spacing.

The best growth response was obtained for planting densities greater than 3.75m² per plant, since densities greater than this showed tree competition only after 12 years of age, which is the estimated rotation age.

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