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VOLUMETRIC EQUATIONS FOR *Calophyllum brasiliense* CAMBESS IN THE SOUTH FROM TOCANTINS

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Abstract: The objective of this work was to carry out the adjustment of mathematical models to estimate volume through data obtained from the cube of trees and forest inventories with continuous plots, to generate the equations that best represent the production of *Calophyllum brasiliense* of a company located in the municipality of Dueré in the southern region of the state of Tocantins. The database is composed of plantations with an initial spacing of 4.0 x 2.0 meters, implanted in 2009. The adjustment of the models was carried out by evaluating the adjusted coefficient of determination (R^2aj) and the standard error of estimate (Syx%), Coefficient of variation (CV%), in addition to the residual distribution graphs. The model that best fitted was the Meyer model (modified), with a value of $R^2aj = 0.97$; Syx% = 1.14 and CV% = 80. The average value for volume was 66.2778 m3/ha.
Keywords: Forest Plantations, Native Species, Forest Inventory, Guanandi, Meyer.

INTRODUCTION

Brazil is a country with potential for forestry production, either because of its available area, its soil and climate conditions and its technological development in the sector. In 2019, the total area of planted trees totaled 9.0 million hectares, representing an increase of 8.79 million hectares compared to 2018 (IBÁ, 2020). THE *Calophyllum brasiliensis* Cambess, popularly known as Guanandi is a species native to Brazil that, currently, has been sought after for commercial plantations in the southeastern and northern regions of the country due to its similarity to cedar and mahogany, both in beauty and in the possible uses of loggers (CIDRÃO, 2012).

Calophyllum brasiliensis. its characteristics are the wide and rounded crown, easily reaching 40 meters in height and the wide and rounded crown at 150 centimeters. It has a great advantage over other species, as there is no significant record of attack by pests or diseases, according to IPEF – Instituto de Pesquisas e Estudos Florestais (2011). According to Urzedo et al. (2013) Guanandi is an alternative to the species Tectona grandis L.f. and others, which are also commercially recommended. The commercial exploitation of Guanandi is recent, but it has good prospects for the future. Among the commercial uses of wood from Guanandi, Urzedo et al. (2013) mentioned shipbuilding, woodworking, carpentry, and others.

Production planning has to facilitate maximum use for the owner of the forest and, also, so that the forest has other multiple functions complementary to timber production. It is an important tool to generate information that will guide the planning and the rational and sustainable use of forest production, allowing quick, orderly and safe decision-making, mainly regarding the guidance of thinning and shallow cuts, harvesting and forest transport, planting planning and meeting market demands, optimizing the application of financial resources. For the valorization of forest plantations of native species to occur, it is extremely important to carry out studies with these, in order to obtain results that allow the quantification of the productive capacities of native species, as well as the best ways to conduct commercial plantations.

Height and diameter at breast height (DBH) are the two main parameters that are used to calculate the basal area and the volume that exists in a forest (VIEIRA et al., 2014). To generate accurate estimates of the volume of wood from forest stands, regression models are used. Given the above, the objective of this work is to adjust volumetric models to *Calophyllum brasiliense* Cambess in the southern region of Tocantins, testing the hypothesis that the *Calophyllum brasiliense* Cambess presents potential for commercial plantations in the state of Tocantins.

METHODOLOGY

With its registered office in the countryside, called Fazenda Reunidas, at Estrada Dueré à Capão do Côco, Km 25, in the Municipality of Dueré - Tocantins, CEP 77.485-000, represented in the form of its articles of association, according to the Private Agreement of "Partnership in Agricultural Exploration", dated 07/01/2007, duly registered under No. 118, pages 001 of book B-01 on 10/02/2007, and its amendments: 1st amendment registered under No. Av.01/118 pages 071 of book B-2 on 07/21/2009; 2nd amendment registered under No. Av.02/118 on pages 72-v of book B-2, on 04/27/2010; 3rd amendment registered under No. Av.03/R.118 pages 001/040 of book B-12, on 08/11/2014, and 4th amendment registered in book B 15, filed and scanned under No. 672, registered in the margin of Registry 118 AV.004, pages 120/129, on 02/26/2018, all duly registered in the registry of titles and documents of the Municipality of Dueré, State of Tocantins.

The study was carried out in 2020, in a plantation of Calophyllum brasiliense belonging to the JAMP company in the municipality of Dueré, 221 km from Palmas (TO). The plantation where the work was carried out has an area of 31.9 hectares, aged 12 years, and is located at an altitude of 225 meters above sea level, between the geographical coordinates Latitude: 11°20'46" South and Longitude: 49°16'6" West. The plantation is located in the cerrado biome, where the seasonal climate occurs with a hot winter and without any type of precipitation for 5 months, presenting savanna phytophysiognomy.

The data used in this work are based on a systematic forest inventory, obtained through permanent plots. The 31.9 ha of plantation were divided into units of fixed area, called plots of 800 m² each, with a spacing of 4x2 m. Nine plots were installed, out of a total of 398.75 possible plots, representing a sampling intensity of 2.25%. Outside measured 100 trees within the plot in a systematic distribution as shown in Figure 1.

According to NATURATINS, the minimum sampling level of 2% (two percent), which must be in relation to the explored area; with a 10% sampling error and a 95% confidence interval; this way it was calculated, for each field, using the formula:

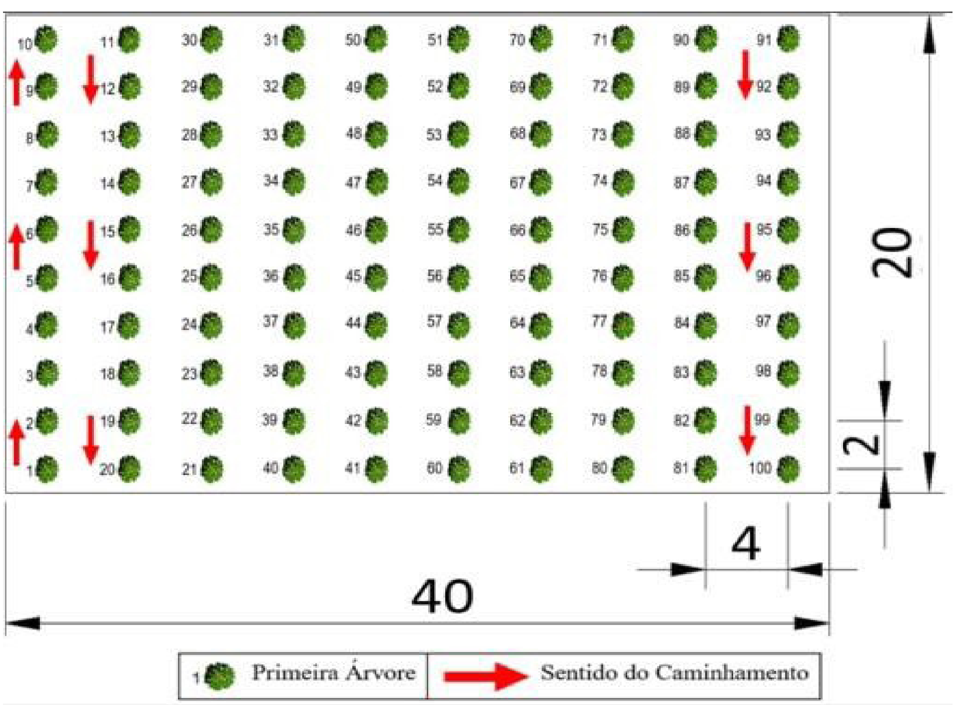
$$n = \frac{t^2\, CV^2}{E\%^2 + \frac{t^2\, CV^2}{N}}$$

Where: n = sample size; t = tabulated value of Student's t distribution, (n-1 gl); CV = coefficient of variation (value in %); E% = admissible sampling error; and N = total number of population units.

In order to determine the number of trees that must be rigorously cubed, it was necessary to establish a pilot sample, performing the cube in a small number of trees, in such a way that one has an idea of the variability of the volume present in the area.

The choice of sample trees felled contemplated trees with DBH ≥ 2 cm in order to consider individuals of all diameter classes found in the inventory. Following this precept, 16 trees were cubed to determine the rigorous volume using the Smalian methodology (FINGER, 1992).

$$v = v_0 + \sum_{i=1}^{n} v_i + v_c$$



Primeira árvore = first tree

Sentido do Caminhamento = Walking direction

Figure 1 - Plot sketch with direction of travel

Source: The authors

In which: v = volume, v_0 = stump volume, v_i = volume of transverse sections and v_c = cone volume.

As data obtained in cubagem foram calculated the individual volumes for each one of the trees-sample. The artificial shape factor was obtained by the ratio between the rigorous volume and the volume of the cylinder with a diameter of 1.3 m according to the expression (Finger, 1992):

$$f_{1,30} = \frac{\text{rigorous volume}}{\text{volume of the cylinder with diameter} d_{1,3}}$$

In which: $f_{1,30}$ = artificial form factor; $d_{1,3}$= diameter measured at 1.30 m from the total height of the tree

The given of these trees will serve as the basis for the adjustment of two volume models related to Table 1. For the selection of two mathematical models, the statistical parameters are considered as the adjusted coefficient of determination. (R^2_{aj}) and the standard error gives the estimate in percentage (Syx%) obtained in the following way, respectively:

$$R^2_{aj} = R^2 - \left[\frac{K-1}{N-K}\right].(1-R^2) \qquad Syx\% = \frac{Syx}{Ym} * 100$$

In which: R^2_{aj} = adjusted coefficient of determination; R^2 = coefficient of determination; K = number of coefficients of the equation; N = number of observations; Syx = Standard error of estimation in absolute terms; Syx% = Standard error of the percentage estimate, Ym = average estimated value;

To verify the accuracy of the adjusted equation and the existence of biased estimates, two residuals expressed by the equation were graphically analyzed:

$$E_i = \left(\frac{Y_i - \hat{Y}_i}{Y_i}\right).100$$

Inwhich: E_i = residue of the i-th observation; Yi = real value of the tree; Y^_i = estimated value of the tree

The givens of these trees will serve as the basis for or fit to two volume models related to Table 1. The volume models tested are selected from the existing literature on the topic.

RESULTS AND DISCUSSION

In Table 2 are presented the results for the adjustments of two eight models tested to estimate the individual volume for Calophyllum brasiliense Cambess. It can be

Nº	Function	Model
1	Hohenald-Krenn	$v = \beta_0+\beta_1.d+B_2.d^2$
2	Stoate	$v = \beta_0 + \beta_1. d^2 + \beta_2 . (d^2. h) +B_3. h$
3	Näslund	$v = \beta_0+\beta_1.d^2+\beta_2.(d^2.h)+\beta_3.(d.h^2)+\beta_4.h^2$
4	Meyer	$v =\beta_0+\beta_1.d+\beta_2.d^2+\beta_3.(d.h)+\beta_4.(d^2.h)$
5	Meyer (modified)	$v = \beta_0+\beta_1.d+\beta_2.d^2+\beta_3.(d.h)+\beta_4.(d^2.h)+\beta_5.h$
6	Spurr	$Inv = \beta_0+\beta_1.\ln(d^2.h)$
7	Schumacher-Hall	$In\ v =\beta_0+\beta_1.\ln d+\beta_2.In h$
8	I.B.W. Germany	$In\ v = \beta_0+\beta_1.\ln d+\beta_2. In^2 d+\beta_3.\ln h+\beta_4.In^2 h$

In which: v = individual volume em m3; h = total height (m) and d = diameter at height of the chest in cm; β_0, β_1, β_2, β_3, β_4 and β_5= regression coefficients.

Table 1 - Models of equations for determination of the individual volume in m3 of the commercial plantation of Calophyllum brasiliense Cambess in Dueré – TO

Source: The author (2021)

observed that the adjusted models presented satisfactory results, with high coefficients of determination (R^2aj), with the exception of the Hohenald-Krenn model, which presented an adjusted coefficient of determination less than 0.9.

Considering the values of R^2aj (0.97), Syx% (1.14), it was determined that the Meyer model (modified) is the best fit to estimate the volume for Calophyllum brasiliense at 156 months. Segundo Romaniuk (2015) based on precision fit statistics, or Meyer's model (modified) was chosen to estimate individual volumes for Pinus taeda L. in the Imbituva region, Paraná.

Coelho (2016) determined 74 months of age in a Calophyllum brasiliensis planting that the Schumacher-Hall model (R^2aj=0.99) was the best fit to estimate the volume. Coelho (2016) determined for the Meyer model (modified) the values for R^2aj as 0.99.

Given this, it is visible that the Meyer model (modified) was also adjusted to better estimate the volume for Calophyllum brasiliensis at 74 months. Silva et al. (2019) similarly found the Schumacher-Hall model (ln(v)=-9.051+1.292*ln(d)+1.266*ln(h)); R^2aj=0.98) as the best estimate for Calophyllum brasiliense at 94 months of age in the southern region of Tocantins. This volumetric fit was chosen to fit the volumetric variance within the Clutter model.

A graphic analysis of residual dispersion (Figure 2), between the observed and estimated values, showed that the function V=-0.02714+0.0668*d-0.0038*d²-0.0062*(d*h) +0.0004*(d²*h)+0.0264*h (Meyer's model (modified)) showed adequate fit for the set of data between the equations tested, evidencing the selection of the model.

The descriptive statistics for volume (m^3), total height (m), basal area (m2) and DBH (cm) obtained are presented in Table 3. It is observed that the CV % presents a low variation for Ht variation (m) and of mean for the other variables according to the classification proposed by Warrick & Nielsen (1980), low for CV < 12%; mean of 12% < CV < 60% and high for CV > 60%. Being a greater variation for DBH justified by the greater amplitude of its data. The average value of the volume found was 66.2778 m^3/ha.

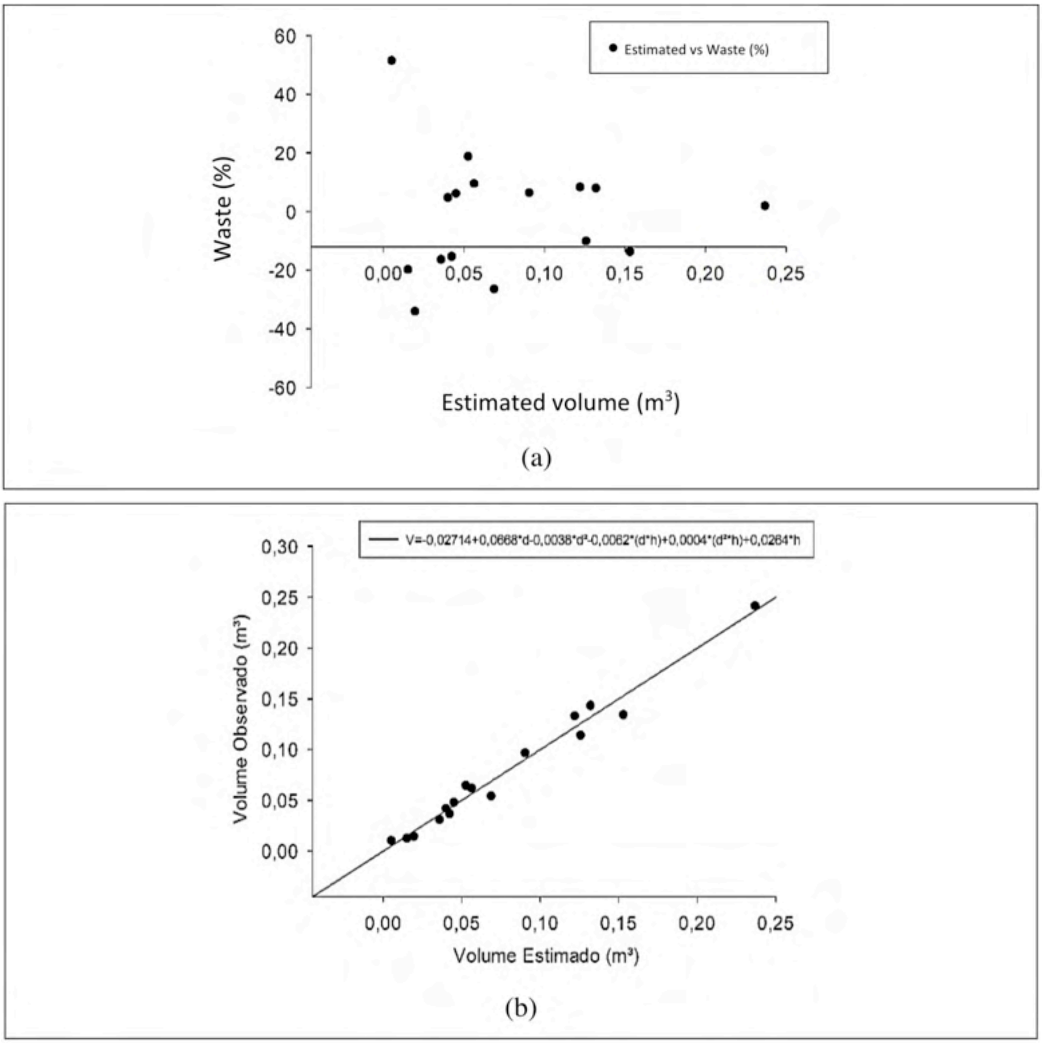
The plot with the highest volume was plot 4 with a value of 75.6250 m^3/ha and

Function	Model	R^2_{aj}	Syx%	CV%
Hohenald-Krenn	$V = 0,05-0,0119 * d + 0,001 * d^2$	0,82	2,67	74,27
Stoate	$V = 0,0423-0,0009 * d^2 + 0,0001 * (d^2h) - 0,0031 * h$	0,95	1,33	79,43
Näslund	$V = 0,0326-0,0009 * d^2 + 0,0001 * (d^2h) + 0,0000 * (dh^2) - 0,0002 * h^2$	0,95	1,37	79,47
Meyer	$V = -0,0819+0,0397 * d - 0,0029 * d^2 - 0,0024 * (dh) + 0,0003 * (d^2h)$	0,96	1,20	79,81
Meyer (modified)	$V = -0,02714+0,0668 * d - 0,0038 * d^2 - 0,0062 * (dh) + 0,0004 * (d^2h) + 0,0264 * h$	0,97	1,14	80,00
Spurr	$Lnv = -9,6251+0,9314 * In(d^2h)$	0,96	18,71	68,21
Schumacher-Hall	$Lnv = -10,1328+1,5806 * In(d) + 1,4523 * In(h)$	0,96	18,62	68,14
I.B.W. Germany	$Lnv = -1,4083+1,1955 * \ln(d) + 0,0898 * (\ln(d))^2 - 6,0525 * \ln(h) + 1,6729 * (\ln(h))^2$	0,97	16,85	75,71

Where: v=volume; d=diameter at chest height; h=total height; ln= natural logarithm; R^2aj = adjusted coefficient of determination; Syx% = standard error of the estimate; CV% = coefficient of variation in percentage; F = value of F; *= significance at 5%.

Table 2 - Mathematical models tested to discover the individual volume in m^3 of the commercial planting of Calophyllum brasiliense Cambess. 156 months of age in Dueré-TO

Source: The Authors (2021)



Volume Observado = Observed volume

Volume Estimado = Estimated volume

Figure 2 - Percentage distribution of the residuals of the Meyer model (modified) (a); Relation between observed volume and estimated volume (b).

Source: The Authors (2021)

Variable	Average	Standard mistake	Standard Deviation	Variation of the sample	Variation coefficient (%)	Curtosis	asymmetry	Break
DAP (cm)	12,02	0,08	2,35	5,53	19,56	0,94	-0,16	18,55
Ht (m)	11,06	0,03	1,06	1,12	9,58	0,48	-0,45	6,96
g (m^2)	0,0117	0,0001	0,0044	1,97E-05	37,59	3,1496	0,7542	0,0401
v (m^3)	0,1268	0,0021	0,0588	0,0034	46,35	5,7585	1,2468	0,5711

Where: DBH = diameter at breast height at 1.3 m. Ht = total height. g = basal area. v = volume.

Table 3 – Descriptive statistics for volume

Source: The Authors (2021)

the plot with the lowest volume was plot 1 with approximately 55.3750 m³/ha. Petit and Montagnini (2004), in their studies on the growth of pure and mixed plantations of tree species used without reforestation in rural areas of the humid region of Costa Rica, Central America, estimated the volume at 266.4 m³/ha of Calophyllum brasilian Cambess.

Through the Kolmogorov-Smirnov normality test with a significance level (α) of 5%, a value of $p > 0.15$ is obtained, concluding that the data present normality.

FINAL CONSIDERATIONS

Among the mathematical models selected to discover the total volume, or Meyer's model (modified) was the best fit.

The total volumes obtained in the plots will vary between 55,375 m³/ha to 75,625 m³/ha, presenting a general average of 66,2778 m³/ha.

The values for volume found are considered low when compared to other plantings of the species with the same nature. The normality test showed that the data posses equality at a level of 5% confidence, confirming the homogeneous growth of an equine planting.

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