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# Diameter Growth of *Melia azedarach* var. umbraculifera

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**Abstract**
The objective of this study was to model the diameter growth of *Melia azedarach* trees from the Campanha region in the state of Rio Grande do Sul, Brazil. Thirty-one (31) trees were randomly selected that showed no signs of pruning. Three increment cores were extracted per tree, the first 30 cm from the ground to determine age, and the other two, orthogonal, at 1.3 m (dbh) for growth analysis. Linear models with and without intercept were fitted to estimate diameters with bark (y) as a function of diameter without bark (x), using various transformations of the independent variables (x). In the modeling, the stepwise method was used for variable selection, with only those with the highest adjusted $R^2$ and significant F-value at 5% being kept in the models. Subsequently, multicollinearity was verified through the variance inflation factor (VIF), and only the most significant variables by the t-test and with VIF less than 10 were kept in the models. The selection of the best models was based on the Standard Error of the Estimate as a percentage (Syx%), Adjusted Coefficient of Determination (Adjusted $R^2$), and, in the case of diameter growth equations, the Akaike Information Criterion (AIC) was also used. The species exhibits moderate to rapid growth, reaching sufficient dimensions for the production of wood pieces, for example for carpentry and joinery. Among the models used to describe diameter growth, the Chapman-Richards model presented the best result, with statistics that allow its safe use under the conditions of this study.

**Keywords**
Mathematical Modeling — Growth and Yield Models — Forest Management — Southern Brazil.

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## 1. Introduction

Forestry plays an extremely important role from an economic, social and environmental point of view, not only in Brazil, but also in several countries where fast-growing exotic species have been introduced. The success of eucalyptus and pine species is due to their extreme adaptability, rapid growth and the possibility of using their wood for the most varied purposes (Ferreira & Silva, 2008). Regional forestry could enable the production of wood that would provide the noblest use of the resource, however, for this to be effective, information is needed about potential species, from the production of seedlings, silvicultural practices, growth and management, such as *Melia azedarach* (cinnamon), which occurs in different parts of the state of Rio Grande do Sul (Carvalho, 1998).

The umbrella cinnamon tree (*Melia azedarach* var. *umbraculifera* G.W.Knox) is a tree from the Meliaceae family, small to medium-sized, fast-growing, deciduous, and frost-resistant, originating from Southeast Asia (Waggy, 2009). It naturally occurs between latitudes 23º and 27º N, from low altitudes to over 2000 meters above sea level, showing satisfactory growth with annual rainfall ranging from 600 to 2000 mm in fertile, humid, well-drained soils. However, it tolerates almost all types of soil, except shallow, stony, and hydromorphic (Carvalho, 1998).

The species has been propagated in almost all tropical and subtropical regions of the planet, being used in southern Brazil as a shade tree for about a century, and it is present throughout the state, both in rural and urban areas. Reaching up to 60 cm in diameter and surpassing 20 meters in height, records document a remarkable growth of 10 meters in height and 20 centimeters in diameter in just 50 months (Waggy, 2009). Furthermore, promoting regrowth from stumps and roots is feasible. According

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to Dallagnol et al., (2011), besides timber production, in the current scenario of discussions about climate change, tree plantations that exhibit faster growth are noteworthy because these individuals have the potential to sequester more carbon dioxide from the environment in a shorter amount of time.

The wood of the species is easy to work with, provides a good finish, and drying processes are straightforward. It can be used in civil construction for ceilings, paneling, moldings, in furniture for decorative parts (handles, carvings), decorative furniture veneers, in the manufacture of sports equipment, toys, and packaging (IPT, 2017). According to studies in mixed plantations at different spacings, the wood has an average density of 0.46 to 0.49 $g.cm^{-3}$, and it is also considered suitable for charcoal production (Leles et al., 2014). It has a reddish-pink to brownish-orange color, with a rough texture and straight grain, indistinct taste and odor, durable, resistant to fungal and termite attacks (REMADE, 2022), but not durable in contact with soil and susceptible to termite attack when dry; under normal moisture conditions, it is durable and not attacked by wood-boring insects (Carvalho, 1998).

To propose the sustainable management of a forest species, studies on the development of key dendrometric variables such as diameter, height, and volume are required throughout the different ages of the production cycle. The age of a tree is utilized in assessments of site growth and productivity and in forest management planning, serving as a crucial tool in determining the present and future growth of forests and in management plan decisions. Age determination can be conducted through partial trunk analysis, enabling precise evaluation of tree age and detailed studies on corresponding diameter increments (Imanã-Encinas et al., 2005; Pretzsch, 2010). Partial trunk analysis involves extracting cylinders from the trunk at 1.3 meters above ground level using an increment borer (Imanã-Encinas et al., 2005), while age can be determined by cylinders extracted from the trunk base.

Dendrochronology is a crucial tool for enhancing the results of forest studies, as it contributes to understanding ecological processes and aids in decision-making regarding sustainable forest management. By analyzing the growth rings of tree species, it is possible to identify growth patterns and determine the annual growth rate of forests, especially tropical forests, which face challenges in obtaining accurate and reliable data on tree growth (Rosa et al. 2017).

The potential growth of a species can be obtained through the study of individual trees and allows for predicting how much a particular species can grow in a given location. Growth models can be used to plan the management of both pure and mixed stands (Pretzsch, 2010, Bettinger et al., 2016).

According to Hosokawa et al., (1998) the study of growth enables us to understand the forest production potential of a particular area and, consequently, to make decisions on various aspects, including biological and economic production.

Growth models support forest management by enabling the prediction of future yields and exploring silvicultural options. They provide an efficient way to prepare resource forecasts, facilitate the exploration of management options and silvicultural alternatives, as well as predict stand dynamics, assess probable outcomes, and determine intended and alternative harvesting limits, thus facilitating objective decision-making (Vanclay, 1994).

In order to provide data for regional silviculture, the objective of this study was to model the diameter growth of *Melia azedarach* var. *umbraculifera* trees in the Campanha Region, state of Rio Grande do Sul, through partial trunk analysis.

## 2. Material and Methods

The study was conducted in the municipality of São Gabriel (Figure 1), in the Campanha region, state of Rio Grande do Sul, where 31 trees of

the species *Melia azedarach* var. *umbraculifera* G.W.Knox (cinnamon) were randomly selected, without any signs of pruning.

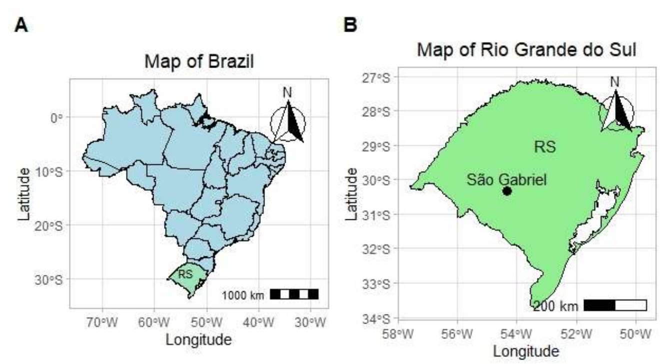


**Figure 1.** Location of São Gabriel municipality, RS.

For each selected tree, the following data were collected: circumference at 1.3 m above ground level (CBH), bark thickness (measured using a bark gauge from the outer surface to the cambium), total height (distance from the ground to the top of the canopy), crown height (distance from

**Table 1.** Mathematical models tested to assess the diameter growth of *Melia azedarach* in the Campanha region, RS.

| () | Author/ Type | Mathematical Model |
|---|---|---|
| 1 | Modeling by Stepwise with intercept | y = f (t and transformations) |
| 2 | Modeling by Stepwise without intercept | y = f (t and transformations) |
| 3 | Chapman-Richards | $y = \beta_0\ (1\text{-}e^{(-\beta_1 t)})^{\beta_2}$ |
| 4 | Strand | $y = (\frac{1}{\beta_0+\beta_1 t})^3$ |
| 5 | Hossfeld | $y = \frac{t^{\beta_2}}{(\beta_0+\beta_1 t^{\beta_2})}$ |
| 6 | Gemesi | $y = e^{\frac{1}{(\beta_0+\beta_1 t)}} - 1$ |
| 7 | Weibull | $y = \beta_0(1\text{-}e^{-\beta_1 t^{\beta_2}})$ |
| 8 | Bass | $y = \frac{\beta_0(1\text{-}\ e^{-\beta_1 t})}{(1+\beta_2 e^{-\beta_1 t})}$ |
| 9 | Gompertz | $y = \beta_0 e^{-\beta_1 e^{-\beta_2 t}}$ |

Where: $B_n$ = Coefficients of the models; y = diameter at breast height (cm); t = age (years).

the beginning to the end of the canopy), and stem height (distance from the ground to the beginning of the canopy - bifurcations below 1.3 m above ground level were considered two stems and bifurcations above 1.3 m were considered as one stem). All height measurements were taken using a Vertex IV hypsometer. Additionally, four crown radii were measured in the north-south and east-west directions.

The Annual Current Increment (ACI) is obtained by the difference between the diameter obtained in period n+1 and the diameter at the beginning of period n, expressed as:

$$ACI = D_{n+1} - D_n$$

Where:

$D_n$ = Diameter at the beginning of the period; and $D_{n+1}$ = Diameter at the end of the period.

The Mean Annual Increment (MAI) is obtained by the ratio of the diameter over the age, at a certain moment in the development of a stand, expressed as:

$$MAI = \frac{D_t}{t}$$

Where: Dt = diameter at age t; and t = age.

Three increment cores were extracted from each tree. The first core was collected 30 cm above ground level to determine tree age, while the other two were collected orthogonally at 1.3 m above ground level for growth analysis. The cores were mounted on wooden blocks, sanded, and subsequently measured for annual rings using the Lintab VI system. After measurement, the annual ring width patterns of the trees were compared to cross-date the rings.

The measurement results were corrected by excluding the thickness of the last growth ring, considering that the increment cores were not obtained during the vegetative rest period, resulting in an incomplete thickness of the last growth ring. Subsequently, the diameters measured without bark were corrected using the Lintab VI, proportionally to the diameters measured without bark in the standing trees without the increment of the last ring.

Subsequently, linear models were adjusted with and without intercept to estimate the diameters with bark (y) as a function of the diameters without bark (x), using the following transformations of the independent variables (x): x, $x^2$, $x^3$, $x^4$, $x^5$, $x^{(1/2)}$, $x^{(1/3)}$, $x^{(1/4)}$, $x^{(1/5)}$, 1/x, $1/x^2$, $1/x^3$, $1/x^4$, $1/x^5$, log(x), log($x^2$), log($x^3$), log($x^4$), log($x^5$), log(1/x), log($1/x^2$), log($1/x^3$), log($1/x^4$), log($1/x^5$). In the modeling process, the Stepwise method was employed for variable selection, retaining only the variables with the highest adjusted $R^2$ and with an F-value at the significance level of 5% in the models. Subsequently, multicollinearity was checked using the variance inflation factor (VIF), and only the most significant variables were retained in the models based on the t-test and with a VIF below 10.

After selecting the best model, the annual diameters with bark were estimated based on the diameters without bark using the resulting regression equation.

To describe the diametric growth, models (Table 1) extracted from Kiviste et al., (2002) were tested, all being differential, passing through the origin, with asymptotes and inflection points. Additionally, linear modeling was developed using the Stepwise method.

The selection of the best equations was based on the

Standard Error of the Estimate in percentage (Syx%), Adjusted Coefficient of Determination (Adjusted $R^2$), and, in the case of diameter growth equations, the Akaike Information Criterion (AIC) was also used. The AIC was con-

**Table 2.** Dendrometric characteristics of the 31 *Melia azedarach* trees studied in the Campanha Region, RS.

| Statistics | Dendrometric variables | | | | | | |
|---|---|---|---|---|---|---|---|
| | d | dwb | h | hs | hbc | CD | Id |
| Mean | 22.6 | 20.9 | 9.9 | 5.0 | 5.0 | 6.4 | 14.2 |
| CV | 29.0% | 28.6% | 20.9% | 40.9% | 50.7% | 34.9% | 43.4% |
| Minimum | 12.6 | 11.1 | 6.4 | 2.0 | 1.5 | 3.66 | 6 |
| Maximum | 34.9 | 31.3 | 13.8 | 10.2 | 12.2 | 15.91 | 25 |

presents the descriptive statistics of the characteristics of the 31 *Melia azedarach* trees used in the study. It can be observed that they range in age from 6 to 25 years, with diameters ranging from 12.6 cm to 34.9 cm and heights between 6.4 and 13.8 m.

sidered the most important in selecting these equations because they are nonlinear models, where the Adjusted $R^2$ is usually not used (Regazzi and Silva, 2010).

From the best-selected model,the diameter growth curve of the species and the Annual Current Increment (ACI) and Mean Annual Increment (MAI) curves were generated.According to Campos and Leite (2006), the intersection of the ACI and MAI curves indicates the technical cutting age, representing the appropriate moment for interventions in the forest, whether through clearcutting or thinning.

## 3. Results and Discussion

Table 2 presents the descriptive statistics of the characteristics of the 31 *Melia azedarach* trees used in the study. It can be observed that they range in age from 6 to 25 years, with diameters ranging from 12.6 cm to 34.9 cm and heights between 6.4 and 13.8 m.

The equations generated to estimate the diameter with bark as a function of the diameter without bark using the Stepwise method are presented in Table 3.

In both equations, the only significant independent variable retained in the models was the diameter without bark (dwb) without any transformation. The equation showed a non-significant intercept value, while the equation without intercept had a better fit ($R^2$ adj = 0.9972), with a similar standard error of estimation, leading to the choice of the equation without intercept as the best one. The adjusted equations for diameter growth that showed the lowest AIC values were 3 and 1 (Table S4), with similar adjusted determination coefficients ($R^2$aj) and coefficients of variation (CV%). The equation 3 adjusted with the Chapman-Richards model was chosen.

The estimates from the Chapman-Richards equation were overlaid on the observations in Figure 2, illustrating the fit of the regression line to the data. Using the equation, it was determined that the maximum current annual increment would reach 2.24 cm at 7 years of age, indicating the need for the first thinning. According to Assmann (1970), thinnings should be carried out as close as possible and up to the age of maximum current annual

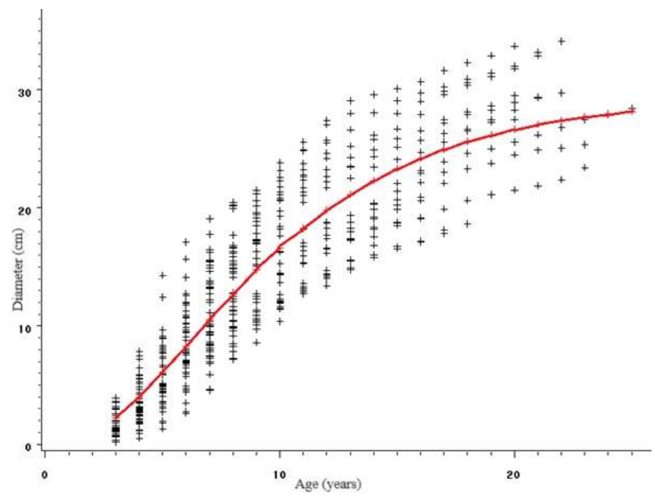


**Figure 2.** Regression line of the Chapman-Richards equation delineated over the observations of the diameter growth of 31 *Melia azedarach* trees in the Campanha Region, RS.

increment in diameter.

In Figure 3, the development of the diameter production curve, estimated by the Chapman-Richards model, and the curves of Annual Current Increment (ACI) and Mean Annual Increment (MAI) are observed. The crossing of these curves at the age of 12 years, as noted by Campos and Leite (2006), could be considered the rotation age of the forest or the

technical cutting age (TCA).

There is no information on the growth of this variety of chinaberry in the literature, so it was compared to two growth studies of *Pinus elliottii* conducted by Floriano (2004) in Piratini-RS and Floriano (2008) in Cachoeira do Sul and Encruzilhada do Sul. The diameter growth

of chinaberry in the Campanha Region falls between the growth of *Pinus elliottii* in the two studies, being greater than in Piratini and less than in the other two municipalities. There is no information available about the growth of this variety of cinnamon in the literature, so it was compared with two growth studies

**Table 3.** Adjusted equations to estimate the diameter with bark of *Melia azedarach* studied in the Campanha Region, RS.

| Equation | Type | x | B0 | B1 | R²aj | Syx (cm) | Syx% | VIF |
|---|---|---|---|---|---|---|---|---|
| 1 | MCI | dsc | 0.10778ns | 1.08304** | 0.9488 | 1.08 | 5.60 | 0; 1 |
| 2 | MSI | dsc | - | 1.08879** | 0.9972 | 1.05 | 5.46 | 1 |

Where MCI = Model with intercept; MSI = Model without intercept. x = Independent variable selected in the Stepwise procedure; dsc = Diameter without bark at 1.3 m from the ground (cm); B0, B1 = Coefficients of the equations; R²aj = Adjusted Determination Coefficient; Syx = Standard Error of Estimate (cm); Syx% = Standard error of estimate in percentage; VIF = Variance Inflation Factor; $^{ns}$= not significant at the 5% probability level; ** = significant at the 1% probability level.

**Table 4.** Adjusted equations to estimate diameter growth with bark as a function of age for *Melia azedarach* in the Campanha Region, RS.

| Equation | x | 0 | 1 | 2 | AIC | R²aj | Syx (cm) | Syx (%) | VIF |
|---|---|---|---|---|---|---|---|---|---|
| Stepwise with intercept | 1/t; 1/t5 | -45.1425 | -3.39E-07 | 34.6580 | 2517.7 | 0.8205 | 3.6 | 26.2 | 0; 1.75; 1.75 |
| Stepwise without intercept | t; t5 | - | 1.5749 | -1.24E-06 | 2520.6 | 0.9435 | 3.9 | 27.9 | 1.85; 1.85 |
| Chapman-Richards | t | 29.3181 | 0.1705 | 2.8308 | 2515.6 | 0.8212 | 3.6 | 26.2 | - |
| Strand | t | 1.3252 | 0.2640 | - | 2528.1 | 0.8172 | 3.7 | 26.5 | - |
| Hosfeld | t | 3.6927 | -0.0947 | 0.0328 | 2518.6 | 0.8209 | 3.6 | 26.2 | - |
| Gemesi | t | 1.1786 | 0.2375 | - | 2563.9 | 0.8053 | 3.8 | 27.3 | - |
| Weibull | t | 27.8566 | 0.0137 | 1.8117 | 2523.8 | 0.8186 | 3.7 | 26.4 | - |
| Bass | t | 27.3504 | 0.2793 | 9.1285 | 2536.0 | 0.8147 | 3.7 | 26.6 | - |
| Gompertz | t | 27.8997 | 1.5279 | 0.2195 | 2523.8 | 0.8186 | 3.7 | 26.4 | - |

Where: x = independent variable(s) used in the models; t = age (years); B0, B1, B2 = Coefficients of the equations; R²aj = Adjusted Coefficient of Determination; Syx = Standard Error of Estimate (cm); Syx% = Standard Error of Estimates in percentage; AIC = Akaike Information Criterion; VIF = Variance Inflation Factor of the independent variables; t = time expressed by age in years; ( ) = significant at the 5% level of probability.

of *Pinus elliottii* conducted by Floriano (2004) in Piratini-RS and Floriano (2008) in Cachoeira do Sul and Encruzilhada do Sul. The diameter growth of chinaberry in the Campanha Region is situated between

the growth of *Pinus elliottii* in the two studies, being greater than in Piratini and less than in the other two municipalities. Based on the regression curve, considering a variation of 26.2%, it can

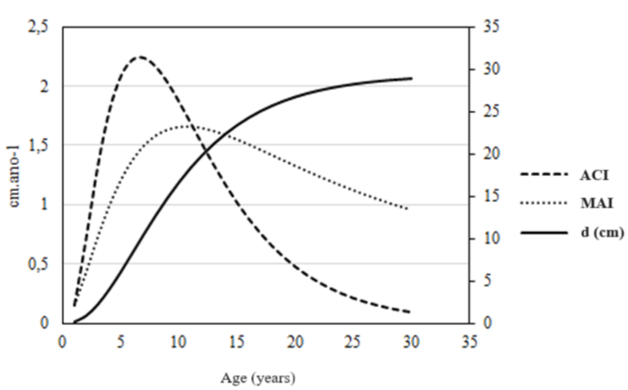


**Figure 3.** Regression line of the Chapman-Richards equation delineated over the observations of the diameter growth of 31 *Melia azedarach* trees in the Campanha Region, RS.

be inferred that the average trees would reach approximately 20 cm in diameter at the technical cutting age, while the thicker trees would reach about 30 cm at that age, a size sufficient for producing wood pieces for carpentry and construction. However, the species has potential for genetic improvement, and with appropriate silvicultural techniques, it is believed that its growth rate could be significantly increased.

Leles et al., (2014) working with cinnamon (*Melia azedarach* L.), considered it as one of the species with the highest growth and hardiness, which can thrive in competitive environments regardless of the spacing used. However, in pure stands, the same authors mention that cinnamon presents a different growth rate because plants of the same species (intraspecific competition) have the same requirements and growth pattern.

## 4. Conclusion

The specie *Melia azedarach var. umbraculifera G.W.Knox* exhibits moderate growth (in the study region) and reaches sufficient dimensions for the production of wood pieces for carpentry and joinery. It is important to note that studies on wood quality, in relation to tree age, have not been conducted. Among the equations tested to describe its diameter growth, the Chapman-Richards equation presented the best results, with statistics that allow its safe use under the conditions of this study.

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## Author Statements

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