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Generalized Tree Volume Equations for Eucalyptus Genotypes under Contrasting Irrigation †

Juan Carlos Valverde [1,*], Rafael Rubilar [1,2,*], Alex Medina [3], Oscar Mardones [4], Verónica Emhart [3], Daniel Bozo [1], Yosselin Espinoza [1] and Otávio C. Campoe [5]

1 Cooperativa de Productividad Forestal, Departamento de Silvicultura, Faculty Ciencias Forestales, Universidad de Concepción, Concepción 4030555, Chile
2 Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD), Pontificia Universidad Católica de Chile, Santiago 7820436, Chile
3 Forestal Mininco S.A., Avenida Alemania 751, Los Ángeles 4440000, Chile
4 Bioforest S.A., Km 15 S/N Camino a Coronel, Concepción 4030000, Chile
5 Departamento de Cîencias Florestais, Universidade Federal de Lavras, Lavras 3037-202, Brazil
* Correspondence: juvalverdeo@udec.cl (J.C.V.); rafaelrubilar@udec.cl (R.R.)
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Abstract: Tree volume equations for Eucalyptus plantations are essential to estimate productivity, generalize equations that consider different genotypes and low-bias water regimes, and simplify plantation management. Our study evaluated the possibility of a generalized tree volume equation for eight Eucalyptus genotypes under contrasting irrigation regimens. We evaluated a seven-year-old plantation with eight *Eucalyptus* genotypes in two contrasting irrigation regimens (summer-irrigated vs. non-irrigated conditions). Diameter (DBH) and total height (H) measurements were considered in the tree equations (Schumacher and Hall (1933), Honer (1967), and Clutter et al. (1983)). The equation with the best fit considered the coefficient of determination, mean square error, and AIC and BIC parameters. The results showed that it is possible to use a generalized tree volume equation; the genotype, irrigation regime, and their interaction were not statistically significant for all equations. The best tree volume equation was Schumacher and Hall (1933), which showed the best fit and minor bias, with a small trend of underestimating the total volume in trees with a DBH >18.3 cm. These results suggest that it is possible to use a generalized tree volume equation to simplify plantation productivity projections while maintaining a good fit and low bias.

Keywords: model; water availability; allometric; tree improvement

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1. Introduction

Stem volume equations with high accuracy are essential for forest industry and management to ensure future supply for industrial purposes such as carbon sequestration [1,2]. Usually, volume equations are developed to estimate wood or biomass by considering the diameter of the tree and the total or commercial height [3]. One of the key aspects that genetic improvement programs consider to be a valuable individual tree trait is a cylindrical shape for the robustness of volume estimates [4].

In the case of Eucalyptus plantations, having low-bias equations is key for productive planning and for the development of management measures to optimize production [5]; aspects such as water availability and/or genotype are key considerations of generalized or specific models. Research has generally focused on improving productivity in specific sites, and volume modeling is specified, which limits the development of models that consider environmental conditions that infer the volume of the stem over time. For example, Assis et al. [6] generalized that volumetric models can be developed for clones or taxa, in which

the effects of water availability to which individuals are exposed to is considered. Therefore, the objective of the present research was to evaluate the effects of water availability and genotype and the interaction with water irrigation x genotype in *Eucalyptus* volume equations.

2. Materials and Methods

The plantation was located in Yumbel, Bio-Bio, Chile (37°8′0.01′′ S, 72°27′34.70′′ W); the weather presents an average temperature of 13.8 °C, and precipitation amounts to 1252 mm/yr; the soil was classified as dystric xeropsamments [7]. The site was planted in 2013 with a 2 × 3 m spacing and a split-plot design with three replicates, as the major factor was water availability (high- and low-irrigation); the minor factor was genotype (*Eucalyptus globulus* (high-yield, EgH; low-yield, EgL), *E. nitens x globulus* (high-yield, EngH; low-yield, EngL), *E. camedulensis x globulus* (Ecg), *E. badjensis* (Eb), *E. nitens* (En), and *E. smithii* (Es)).

Per the genotype treatments of the water regime x, five individual trees were selected, and the DBH (diameter at 1.3 m above-ground) was measured before harvesting; then, the total height (H) was measured (diameter > 2 cm) and the entire stem was weighed, while three samples were taken to estimate the moisture content and to determine the dry biomass according to the methodology proposed by Valverde et al. [8]. Subsequently, three volume equations were fitted: Schumacher and Hall [9] (Equation (1)), Honer [10] (Equation (2)), and Clutter et al. [11] (Equation (3)). To evaluate the effects of the water regime and the genotype of the factor, dummy variables were used according to the method proposed by Quiorez-Barraza et al. [12]. Finally, the best equations were selected based on the adjusted coefficient of determination (Adj-R^2), RMSE, AIC, and BIC. All analyses were performed in R with a significance level of 0.05.

$$V = \beta_0 DBH^{\beta_1} H^{\beta_2} \quad (1)$$

$$V = \frac{DBH^2}{\beta_0 + \frac{\beta_1}{H}} \quad (2)$$

$$V = \beta_0 + \beta_1 DBH^2 H + \beta_2 H + \beta_3 DBH^2 \quad (3)$$

3. Results and Discussion

The genotypes did not show significant differences between water availability conditions; therefore, two dasometric groups were obtained: (i) Es, Ecg, and Ecg were considered to be small in size, with a DBH < 14.8 cm, H < 14.2 m, and an average total volume of 0.187 m^3 $tree^{-1}$; (ii) Eb, En, EngH, EgH, and EngL were determined to be bigger in size, with DBH > 16.2 cm, H > 16.4 m, and average total volume of 0.113 m^3 $tree^{-1}$.

The analyses indicated that there is no significant effect of the genotype on the variables, irrigation regime, and interaction of the genotype × irrigation regime in the tree volume equations analyzed (Table 1). When determining the equation of best fit (Table 2), Schumacher and Hall showed the best statistical indicators (highest Adj-R^2 and lower RMSE, MAD, AIC, and BIC), followed by the Honer equation, which differed by showing higher statistical criteria, especially for RMSE. On the contrary, Clutter et al. presented the worst indicators and the worst volume estimation equation. Therefore, the best generalized volume equation (Equation (4)) can be used for any genotype × water regime in the study region; however, the equation tends to underestimate the volume between 3 and 8% in individuals with a DBH > 25 cm.

$$V = 2.75 \times 10^{-6} DBH^{1.71} H^{1.16} \quad (4)$$

Table 1. Statistical significance (*p*-value) of genotypes, irrigation, and their interaction on selected volume equations (ns, not significant).

Equation	Variable Analyzed		
	Genotype	Irrigation	Genotype × Irrigation
Schumacher and Hall	0.203 ^{ns}	0.413 ^{ns}	0.100 ^{ns}
Honer	0.382 ^{ns}	0.402 ^{ns}	0.334 ^{ns}
Clutter et al.	0.221 ^{ns}	0.100 ^{ns}	0.239 ^{ns}

Table 2. Statistical values for selecting generalized volume equations for Eucalyptus.

Equation	Adj-R^2	RMSE	AIC	BIC	Ranking
Schumacher and Hall	0.98	0.02	132.78	138.90	1
Honer	0.87	2.01	149.33	142.26	2
Clutter et al.	0.73	3.11	150.47	168.17	3

Scolforo et al. [13] and Gomat et al. [14] highlighted that the irrigation regimen can directly infer the growth of the tree, but they did not show evidence that it affects the shape of the stem. An aspect that Binkey et al. [15] showed was that variations in temperature and rainfall directly affect water use and productivity but not the stem profile in Eucalyptus genotypes. In the case of genotype, when clonal material is selected according to the productivity and characteristics desired for the industry, the variability in the bole in the shape of the stem is reduced since it is desired to have the most homogeneous stems possible that have a tendency towards a cylindrical shape. This is due to the optimization of the use of bole [16]. Therefore, the contribution of this variable is not significant in practice and can be omitted from the equations [13].

4. Conclusions

The effects of the irrigation regimen, genotype, and their interaction were not found in any of the volume equations used. In this way, it is possible to use general equations that consider all of the conditions for the study. Therefore, this implies optimization in the management and modeling of Eucalyptus plantations.

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