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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], Octavio Campoe[5].

1 Cooperativa de Productividad Forestal, Departamento de Silvicultura, Fac. Ciencias Forestales, Universidad de Concepción, Concepción, Chile.

2 Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD), Pontificia Universidad Católica de Chile, Santiago, Chile.

3 Bioforest S.A., Km 15 S/N Camino a Coronel, Coronel, Concepción, Chile.

4 Forestal Mininco S.A., Avenida Alemania 751, Los Ángeles, Chile.

5 Departamento de Cîencias Florestais, Universidade Federal de Lavras, Lavras, MG 3037, Brazil.

* Correspondence: juvalverdeo@udec.cl; rafaelrubilar@udec.cl

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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 regiments (summer irrigated vs. no irrigated conditions). Diameter (DBH) and total height (H) measurements were considered in tree equations (Schumacher and Hall (1933), Honer (1967), and Clutter et al. (1983)). Then, the equation with the best fit considered: 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 little trend to underestimate total volume in trees with a DBH >18.3 cm. These results suggest that it is possible to use a generalized tree volume equation that would 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 the forest industry and management to develop future supply to industrial purposes, carbon sequestration [1, 2]. Usually, volume equations have been developed to estimate wood or biomass considering the diameter of the tree and the total or commercial height [3]. One of the key aspects that genetic improvement programs consider as a valuable individual tree trait is a cylindrical shape for robustness of volume estimates [4].

In the case of Eucalyptus plantations, having low bias equations is key for productive planning and the development of management measures to optimize production [5]; aspects such as water availability and/or genotypic are key in the consideration 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 volumetric models can be developed for clones or taxa, in which the effect of water availability to which individuals are exposed is considered. Therefore, the objective was to evaluate the effects of water availability and genotype and interaction 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); weather presented an average temperature of 13.8°C and precipitation of 1252 mm/yr; the soil was classified as dystric xeropsamments [7]. The site was planted in 2013 with a 2x3 m spacing and considering a split-plot design with three replicates, as the major factor was water availability (high- and low-irrigation); as the minor factor was genotype (*Eucalyptus globulus* (high-, EgH and low- yield, EgL), *E. nitens x globulus* (high-, EngH and low-yield, EngL), *E. camedulensis x globulus* (Ecg), *E. badjensis* (Eb), *E. nitens* (En) and *E. smithii* (Es)).

Per genotype treatment of the water regime x, five individual trees were selected and the DBH (diameter at 1.3m 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 determine the dry biomass, according to the methodology proposed by Valverde et al. [8]. Subsequently, three volume equations were fitted: Schumacher and Hall [9] (Eq. 1), Honer [10] (Eq. 2) and Clutter et al. [11] (Eq. 3). To evaluate the effects of the water regime and the genotype of the factor, dummy variables were used with the method proposed by Quiorez-Barraza et al. [12]. Finally, the selection of the best equations based on the adjusted coefficient of determination (Adj-R^2), RMSE, AIC and BIC. All analyzes were performed in R with a significance of 0.05.

$$V = \beta_0 DBH^{\beta_1} H^{\beta_2} \tag{1}$$

$$V = \frac{DBH^2}{\beta_0 + \frac{\beta_1}{H}} \tag{2}$$

$$V = \beta_0 + \beta_1 DBH^2 H + \beta_2 H + \beta_3 DBH^2 \tag{3}$$

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 as small size, with a DBH <14.8 cm and H< 14.2 m and a average total volume of 0.187 m^3 tree^{-1}; (ii) Eb, En, EngH, EgH and EngL were determined as bigger size, with DBH >16.2 cm and H>16.4 m and average total volume of 0.113 m^3 tree^{-1}.

The analyzes indicated that there is no significant effect of the genotype of the variables, irrigation regime, and interaction of the genotype x 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 RMSE. On the contrary, Clutter et al. presented the worst indicators and the worst volume estimation equation. Therefore, the best generalized volume equation (Eq. 4) can be used for any genotype x water regime in the study region; with the detail that the equation tends to underestimate the volume between 3 to 8% in individuals with a DBH > 25 cm.

$$V = 2.75x10^{-6}DBH^{1.71}H^{1.16} \quad (4)$$

Table 1. Statistical significance (p-value) of genotypes, irrigation, and their interaction on selected volume equations (ns not significant; ** significant at 0.01).

Equation	Variable analyzed		
	Genotype	Irrigation	Genotype x 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 do not show evidence that it affects the shape of the bolt. An aspect that Binkey et al. [15] showed by finding 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 selected according to the productivity and characteristics desired for the industry is implemented, the variability of bole in the shape of the stem is reduced, since it is desired to have the most homogeneous stems possible with a tendency to 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 the conditions for the study. Therefore, which implies an optimization in the management and modeling of Eucalyptus plantations.

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