ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Individual Tree Modeling Approach for Eucalyptus spp. Clones

[1]Fabrícia Conceição Menez Mota, [2]Josiane Silva Bruzinga, [3]Priscila Sales Rodrigues Aquino, [4]Reginaldo Sérgio Pereira, [5]Glória da Silva Almeida, [6]Renato Vinícius Oliveira Castro

[1]University of Brasilia, Department of Forestry, Graduate Program in Forestry Sciences, University Campus Darcy Ribeiro, Post Code 04357, CEP: 70919-970, Brasília – DF, Brazil.
[2]University of Brasilia, Department of Forestry, Graduate Program in Forestry Sciences, University Campus Darcy Ribeiro, Post Code 04357, CEP: 70919-970, Brasília – DF, Brazil.
[3]University of Brasilia, Department of Forestry, Graduate Program in Forestry Sciences, University Campus Darcy Ribeiro, Post Code 04357, CEP: 70919-970, Brasília – DF, Brazil.
[4]University of Brasilia, Department of Forestry, Graduate Program in Forestry Sciences, University Campus Darcy Ribeiro, Post Code 04357, CEP: 70919-970, Brasília – DF, Brazil.
[5]Federal University of Acre, Department of Forestry, University Campus of Floresta, Post Code 69910-900, Acre – AC, Brazil.
[6]Universidade Federal de São João del Rei, Campus of Sete Lagoas, Department of Agricultural Science, Post Code: 35.701-970, Sete Lagoas-MG, Brazil.

ARTICLE INFO

Article history:
Received 12 March 2015
Accepted 28 April 2015
Available online 5 May 2015

Keywords:
Individual-tree, Eucalyptus, competition indexes, growth models.

ABSTRACT

This study aimed to select competition index regardless the distance that better describe height and diameter growth for three *Eucalyptus* spp. clones and evaluate the individual-tree growth model fit for each clone and for all. It was used data from 23 permanent plots of clonal planting with the hybrids: *Eucalyptus camaldulensis*, *Eucalyptus grandis* × *Eucalyptus urophylla* and *Eucalyptus urophylla*, which have been monitored for three years and are located in Cristalina city, Goiás State, Brazil. For each tree, it was calculated five distance-independent competition indexes. These indexes were evaluated by means of simple correlation coefficient and Student's t test. In addition, we used the identity test to check the possibility of using a single equation to design variables. Solely basal area index was selected for individual-tree model fit. Moreover, it was not possible a single equation adjustment for the three studied clones.

© 2015 AENSI Publisher All rights reserved.

To Cite This Article: Fabrícia Conceição Menez Mota, Josiane Silva Bruzinga, Priscila Sales Rodrigues Aquino, Reginaldo Sérgio Pereira, Glória da Silva Almeida, Renato Vinícius Oliveira Castro., Individual Tree Modeling Approach for Eucalyptus spp. Clones. ***Aust. J. Basic & Appl. Sci.,*** *9(11): 553-558, 2015*

INTRODUCTION

The Brazilian forest plantations are an important economic activity with great impact; therefore, it is interesting for any plantation manager to quantify and forecast, reliably, the commercial forest stock (EISFELD, 2005). This prognosis can be obtained through the growth and yield models, which can be used to design other stand parameters, such as plant trunk diameter and height (FERRARI et al., 2005), variables of interest to forest management (IMAÑA-ENCINAS et al., 2005; SALLES, 2010).

These variables' design is attached to the modeling universe that aims to forecast plant growth due to a number of quantifiable variables within forest stand by linear or nonlinear regression analysis (ZEIDE, 1993; CASTRO, 2013). The prognosis of these variables and consequently growth is important for meeting the objectives of an organization and its own forest management (SCOLFORO, 1998).

The term "growth" is defined as the irreversible increase in one or more physical magnitudes (dimensions) of an individual in a given period of time (PRODAN et al., 1997), resulting from the interaction of two opposing positive and negative forces (ZEIDE, 1993). The positive component is the organism innate trend to exponential multiplication, which is associated with biotic potential, photosynthetic activity, nutrient absorption. The other component (negative) is the restriction of growth, namely outer (competition) and internal (feedback mechanism) (ZEIDE, 1993).

The growth and yield models are classified as models applied to individual trees and stands (FERRARI et al., 2005). However, solely the models applied to individual trees, the Individual Tree Models (ITMs), can explain the negative growth component. These models use each tree individual as a basic modeling unit and estimate growth using in addition to the usual variables (age, yield capacity,

Corresponding Author: Fabrícia Conceição Menez Mota, University of Brasilia, Department of forestry, Graduate Program in Forestry Sciences, University Campus Darcy Ribeiro, Post Code 04357, CEP: 70919-970, Brasília – DF, Brazil.
Tel: +55 61 3107 5628; E-mail: fabriciacmm@yahoo.com.br,

mortality, diameter and height), the competition indexes (CLUTTER, 1983; HASENAUER, 2006; HÄRKÖNEN et al., 2010; CAMPOS and LEITE, 2013; CASTRO et al., 2013).

In the individual tree growth model, the competitive status of a tree is described by the use of distance independent or dependent competition measures (TONINI, 2007). Theoretically, independent indexes differ from dependent ones for using variables at stand level and initial dimensions of the target-tree, i.e. using non-spatial measures based on tree height distribution within a given area. On the other hand, in dependent indexes, the competitors are identified based on besides above-mentioned variables, they use data related to number, size, location of nearby trees or competitors with regard to target-tree (TOMÉ e BURKHART, 1989; WIMBERLY e BARE, 1996; RADTKE et al., 2003).

Therefore, the aim of this study was to evaluate individual tree modeling and check the possibility of single equation use to forecast tree diameter and height growth for *Eucalyptus* sp. clones.

MATERIAL AND METHODS

Study area:

The data used in this study come from continued surveys (from 2011 to 2013) in clonal plantations of eucalyptus hybrids such as *Eucalyptus camaldulensis*, *Eucalyptus grandis* × *Eucalyptus urophylla* (commercially known as GG100), and *Eucalyptus urophylla*, in a plant spacing of about 3.3 m x 1.8 m. The area is located at 16º 49' 21.5" S and 47º 36' 21.1" W, in Cristalina county – GO, Brazil. It lies in an average altitude of 1,180 m, and has average temperatures of 22 ºC and average rainfall of 1,700 mm. The local climate is humid tropical with savannah-like subtype with a defined period of drought during winter (May to September) and rainy and wet in summer (October to April) (SILVA et al. 2008). Local soil is classified as Cambisols (Inceptisols) and Gleisols (Entisols).

Data sampling:

It was measured 2,230 trees, which were 30, 42 and 54 months old and located over twenty-three 400-m² permanent plots (Table 1).

In each survey, it was taken measurements of DBH for all trees with more than 5-cm diameter at 1.3 m and total height of 10% trees within plots, which were measured by caliper and a "Haga" hypsometer, respectively, to set hypsometric equations. As a complement, the real height of felled trees was added up the data for hypsometric equation fit purpose, using on average 23 trees in per clone in each measurement.

Table 1: Diameter at breast height (DBH) at 1.3m above ground and total height (H) per clone and tree age: *Eucalyptus camaldulensis*, *Eucalyptus grandis* × *Eucalyptus urophylla* and *Eucalyptus urophylla*.

Age (months)	E. camaldulensis				E. grandis × E. urophylla				E. urophylla			
	Min.	$\bar{M}$	Max.	VC%	Min.	$\bar{M}$	Max.	VC%	Min.	$\bar{M}$	Max.	VC%
	DBH (cm)											
30	5.00	10.71	15.40	17.98	5.10	10.35	13.50	15.43	5.00	10.74	16.90	17.96
42	5.57	12.55	18.72	19.29	5.90	12.47	16.23	14.82	5.57	12.94	20.53	18.57
54	6.21	13.90	20.05	21.10	5.63	13.99	19.35	15.66	5.57	14.42	24.35	20.88
	H (m)											
30	4.910	9.58	10.230	9.02	4.22	13.49	17.85	18.57	5.760	7.61	15.42	13.76
42	6.92	15.30	18.09	13.71	9.88	19.35	22.91	10.99	8.72	19.15	24.08	9.81
54	13.35	17.83	22.64	11.47	11.59	23.71	28.33	10.17	11.03	22.86	25.99	13.24

Min: Minimum; $\bar{M}$: Average; Max: Maximum and; VC: Variation coefficient.

For the remaining trees, it was set up equations of single and double entry and the best fit selection was based on coefficient of determination $(R)^2$ values and estimate standard error in percentage (S_{xy}%), both calculated in original unity of the dependent variable, in meters (Table 2).

Table 2: Equations used to estimate height for each clone in each age: 30, 42 and 54 months. Wherein Clone I - *Eucalyptus camaldulensis*, Clone II - *Eucalyptus grandis* × *Eucalyptus urophylla* and Clone III - *Eucalyptus urophylla*.

Age (months)	Clone	Model	Equation	Precision measures	
				R^2	S_{yx}%
30	I	Naslund	h=-9.20187+(3.703925.dbh)+(-0.17650.dbh²)	0.87	9.15
30	II	Naslund	h=-7.76929+(2.62518.dbh)+(-0.05390.dbh²)	0.88	17.6
30	III	Naslund	h=10.15359+(-0.26005.dbh)+(0.04758.dbh²)	0.99	6.13
42	I	Naslund	h=-4.74972+(2.46646ap)+(-0.06657.dbh²)	0.96	7.91
42	II	Henriksen	h=-12.89195+(12.84410.ln dbh)	0.84	9.95
42	III	Naslund	h=0.32372+(2.34115.dbh)+(-0.06432.dbh²)	0.94	6.76
54	I	Naslund	h=11.32910+(0.21754.dbh)+(0.01728.dbh²)	0.79	9.84
54	II	Henriksen	h=-11.87349+(13.56987.ln dbh)	0.91	7.05
54	III	Naslund	h=-10.90391+(3.85287.dbh)+(-0.10060.dbh²)	0.96	5.26

We have therefore calculated, for each individual, five distance-independent competition indexes (IID), as described by Martins (2011):

$$IID_1 = \frac{d_i^2}{\overline{D}^2};\quad IID_2 = \frac{h_1}{\overline{H}};\quad IID_3 = \frac{d(d_i^2 \times h_1)}{\overline{D}^2 \times \overline{H}};$$

$$IID_4 = BAI = \frac{d_i^2}{q^2};$$

$$IID_5 = BAL = \sum_{i=1}^{n} \pi \ \frac{DAP^2}{4}$$

Where in: *d* is the diameter at 1.30 m above ground of the target-tree, in cm; $\overline{D}$ is the arithmetic mean of the diameter of the sample unit trees, in cm; h_1 is the total height of the target-tree, in m; $\overline{H}$ is the average height of sample unit trees, in m; *q* is the quadratic diameter of sample unit, in cm; BAI is the basal area index; and BAL sum of section area of trees higher than the target one.

Then, it was performed a correlation analysis between competition index and diameter and height individual growth, as suggested by Sánchez-González et al. (2006). Indexes with consistent and significant correlation with growth were selected to compose the group of independent variables used in growth models to forecast height (MARTIN; EK, 1984) and the diameter (ZHANG et al., 2004):

$H2 = f\ (IID, DBH_1, AB, I_1/I_2);\ DAP2 = f(IID, AB, I_1/I_2)$

Wherein: *H2* is the height at age 2; *IID* is the distance-independent competitive index; DBH_1 trunk diameter at 1.30 m above ground at age 1; *AB* is the basal area per hectare in m²; I_1 is the current age; I_2 is the future age and DBH_2 is the trunk diameter in future age.

The individual-tree modeling (ITM) for height and diameter growth forecast was performed for each clone and evaluated by graph of residues and statistical correlation coefficient (r), residual standard error (S_{xy}) (MURPHY; STERNITZKE , 1979) and bias (SIIPILEHTO, 2000), defined by:

$$r=\frac{\sum_{i=1}^{n}(Y_i-\overline{Y})\times(\hat{Y}_i-\overline{\hat{Y}})}{\sqrt{(\sum_{i=1}^{n}(Y_i-\overline{Y})^2).\left(\sum_{i=1}^{n}(\hat{Y}_i-\overline{\hat{Y}})^2\right)}}$$

$$S_{xy}=\sqrt{\frac{1}{n-p-1}\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2} \qquad bias=\frac{1}{n}\sum_{n-1}^{n}(Y_i-\hat{Y}_i)$$

Where in: *n* = number of observations; Y_i = values observed for the variables; $\hat{Y}_i$ = values estimated for the variables.

Subsequently, to test the contribution of competition index to explain plant growth in diameter and height, we evaluated the significance of the parameter associated with this variable through Student t test at 5% significance.

Furthermore, it was applied the identity test to group the clones and therefore enabling the use of a single equation to forecast the variables. For the identity test, it was developed Dummy variables (D_i) with binary values of 0 and 1 as described by Regazzi (2003), for each clone. For *Eucalyptus camaldulensis*, it was associated the D1 Dummy variable, being 1 when the tree belongs to the *Eucalyptus camaldulensis* species and zero when it does not. All the same, it was followed for the other clones, using D2 for *Eucalyptus grandis* × *Eucalyptus urophylla* and D3 for *Eucalyptus urophylla*.

The model identity test was used to check the equality hypothesis among a group of linear models using the F test, in which a complete and reduced model are defined, being the test applied on the reduction of the reduced model on the complete one (MAGALHÃES et al., 2004). Thus, the complete and reduced models adjusted for height and diameter variables were expressed by:

Complete model for height:

$H2 = \beta1.D1 + \beta2.D2 + \beta3.D3 + \beta4.D1.IID5 + \beta5.D2.IID5 + \beta6.D3.IID5 + \beta7.D1.DBH_1 + \beta8.D2.DBH_1 + \beta9.D3.DBH_1 + \beta10.D1.AB + \beta11.D2.AB + \beta12.D3.AB + \beta13.D1.\ I_1/I_2 + \beta14.D2.\ I_1/I_2 + \beta15.D3.\ I_1/I_2 + \varepsilon$

Reduced model for height:

$H2 = \beta0 + \beta1.IID5 + \beta2.DBH_1 + \beta3.AB + \beta4.\ I_1/I_2 + \varepsilon$

Complete model for DBH:

$DBH_2 = \beta1.D1 + \beta2.D2 + \beta3.D3 + \beta4.D1.IID5 + \beta5.D2.IID5 + \beta6.D3.IID5 + \beta7.D1.AB + \beta8.D2.AB + \beta9.D3.AB + \beta10.D1.AB + \beta11.D1.\ I_1/I_2 + \beta12.D2.\ I_1/I_2 + \beta13.D3.\ I_1/I_2 + \varepsilon$

Reduced model for DBH:

$DBH_2 = \beta0 + \beta1.IID5 + \beta2.AB + \beta3.\ I_1/I_2 + \varepsilon$

Wherein: *H2* is the height at age 2; DBH_2 is the diameter at a further age; DBH_1 is the diameter at a current age; $\beta1, \beta2, \beta3$ are model parameters; *D1, D2, D3* are "Dummy" variables for the evaluated clones; *IID5* is the competition index; *AB* is the basal area per hectare in m²; I_1 current age; I_2 future age.

The hypotheses tested at 5% significance were H_0 = the reduced model adjusted for all clones does not differ from complete model for each clone and H_1 = when H_0 is rejected. When H_0 is rejected, it was performed a paired combination of clones and a new model identity test to verify the possibility of using a single equation for pairs of clones was made through F test (REGAZZI, 2003).

RESULTS AND DISCUSSION

IID2 correlation with height growth was significant, however inconsistent. In contrast, IID1, IID3 and IID4 presented inconsistence only for *Eucalyptus grandis* × *Eucalyptus urophylla* clone; and just IID5 was significant and consistent for all clones. Nevertheless, for diametric growth all indexes had significant and consistent correlation (Table 3).

For above-mentioned consistence, it is expected that IID1, IID2, IID3 and IID4 indexes show positive correlation for diameter and height growth. Once the calculation of such indexes is based on the relationship between the target-tree size and the arithmetic mean of the trees of the sample unit. Then, according to the biological behavior, e.g. for smaller trees, the target-tree variable is likely to be lower than the average of this variable to the entire

population; fact that will generate a lower rate for smaller trees.

Table 3: Correlation between distance-independent competition indexes (IID) and height and diameter growth.

Indexes	Expected results	*Eucalyptus camaldulensis*	*Eucalyptus grandis* × *Eucalyptus urophylla*	*Eucalyptus urophylla*
	Diameter growth (cm)			
IID1	+	0.42*	-0.15*	0.29*
IID2	+	-0.14*	-0.20*	-0.04^{ns}
IID3	+	0.27*	-0.16*	0.19*
IID4	+	0.44*	-0.15*	0.25*
IID5	-	-0.59*	-0.14*	-0.53*
	Height growth (m)			
IID1	+	0.51*	0.25*	0.49*
IID2	+	0.26*	0.23*	0.21*
IID3	+	0.47*	0.24*	0.46*
IID4	+	0.48*	0.23*	0.46*
IID5	-	-0.59*	-0.37*	-0.55*

However, for the IID5, it is expected a negative correlation with the growth in height and diameter. Once this index is the sum of the cross-sectional area of trees larger than target-tree, so the index for larger trees will be smaller and larger to smaller trees.

Thus, by having consistence and greater correlation, IID5 was chosen for the individual-tree modeling (ITM), both for diameter and height forecast. Sánchez-González et al. (2006) have also used it successfully at different kind of plant stands.

The values of the diameter growth correlation with IID5 varied between -0.37 and -0.59 for all clones (Table 3). Martins et al. (2011) and Davies; Pommerening (2008) found higher values, which were -0.63 and -0.75 for *Eucalyptus* sp. plantations sp. and *Picea sitchensis* (Bong.), respectively.

IID5 correlations (in modulus) for height and diameter were higher and near for *Eucalyptus camaldulensis* and *Eucalyptus urophylla*, which have differed greatly with *Eucalyptus grandis* × *Eucalyptus urophylla* that has presented the lowest value. This was expected, since the *Eucalyptus grandis* × *Eucalyptus urophylla* clone showed higher

growth in the period compared to others and therefore greater variation in growth parameters (diameter and height), generating a lower correlation with the index (Table 1).

Once chosen IID5, it was set ITM's for each clone and variable (diameter and height), being estimated parameters, significance and accuracy statistics presented in Table 4 and residue chart in Figure 1. In general, for both variables, adjustments showed good accuracy and high correlation among the estimated and observed values, being slightly "better" to estimate height growth. Regarding the clones, the statistical parameters were better for *Eucalyptus camaldulensis* in relation to diameter and for *Eucalyptus grandis* x *Eucalyptus urophylla* relative to plant height.

All of the ITM parameters for diameter forecast for all clones were significant by t-Student test at 5% significance, indicating the contribution of the used variables used including competition index in diameter forecast. However, for height variable forecast, the IID5 parameter, basal area and the relationship age 1/ age 2 were non-significant for *Eucalyptus camaldulensis* and *Eucalyptus urophylla*; *Eucalyptus camaldulensis*; and *Eucalyptus grandis* × *Eucalyptus urophylla*, respectively (Table 4). Contrarily, in view of the ease of obtaining these variables and their biological relationship with tree growth, it is recommended to maintain them in the equation. Martins et al. (2011) when assessing ITMs for Eucalyptus sp. found inferior values of estimate standard error (S_{xy}) for diameter and superior for height. This contributes to indicate ITM adjustment for height and diameter growth forecasts of eucalyptus clones.

Table 4: ITM's adjustment parameters for each clone and variable (diameter and height) with significance tested by t-Student test at 5% level; statistics of adjustment accuracy statistics, being *r* the correlation between observed and estimated values, Sxy the estimate standard error and Bias the accuracy estimate.

Clones [(1)]		Coefficients					Statistics of Accuracy		
	Index	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	$\hat{\beta}_4$	r	S_{xy}%	Bias
Diameter growth									
Clone 1	IID_5	45.1001	13.4624*	1.4428*	-66.2594*	-	0.95*	6.84	-3.6E-14
Clone 2	IID_5	22.9525	-7.0184*	0.6166*	-24.2138*	-	0.86*	8.38	1.49E-13
Clone 3	IID_5	15.7061	-9.7399*	0.5411*	-10.7821*	-	0.86*	10.42	3.16E-13
Height growth									
Clone 1	IID_5	-9.8395	1.4422 $^{n.s}$	1.0174*	-0.1953 $^{n.s}$	22.9060*	0.96*	4.03	3.30E-14
Clone 2	IID_5	-11.6421	0.8336*	1.3191*	-0.0394*	24.8260 $^{n.s}$	0.96*	3.83	-2.5E-14
Clone 3	IID_5	-20.9743	-0.0734 $^{n.s}$	1.0487*	-0.2151*	45.1685*	0.92*	5.94	-7.7E-13

[(1)]Clone 1, *Eucalyptus camaldulensis;* Clone 2, *Eucalyptus grandis* × *Eucalyptus urophylla*; Clone 3, *Eucalyptus urophylla*. Theoretical model used for growth equation adjustments of diameter and height parameter with IID_5 index (BAL): DBH2 = f (IID_5, basal area, and age1/age2) and Ht2 = f (IID_5, DBH1, basal area and age1/age2). In which ^{ns} means non-significant and * significant at 5%.

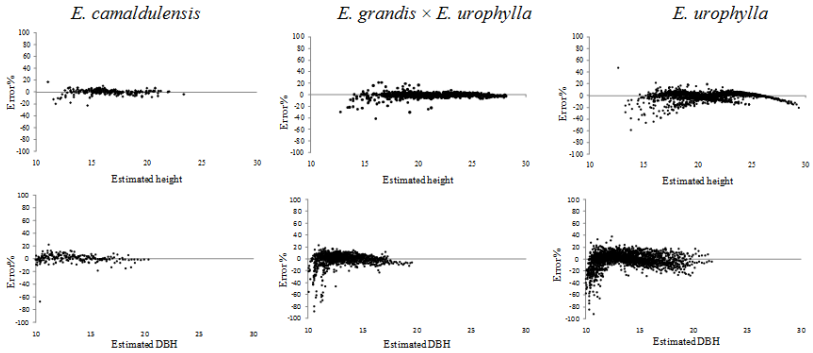

Fig. 1: Graph of residues in relation to estimate at individual-tree model (ITM) level of height and diameter for *Eucalyptus camaldulensis*, *Eucalyptus grandis* × *Eucalyptus urophylla* and *Eucalyptus urophylla* clones.

After adjustment and accuracy test, it was performed the model identity test. The F test to verify a single equation adjustment for the three clones was significant, what rejected the H_0 hypothesis. Therefore, it was not possible to fit a single equation both for diameter and height growth forecast for the three clones together (Table 5).

Then, it was proceeded a statistical breakdown of the paired combinations to verify the possibility of using a single equation for them. However, in these combinations for both height and diameter, the F test was significant, that is, it is recommended to use an equation for each clone even for diameter and height forecast.

Table 5: Variance analysis of the complete and reduced model for diameter and height growth of individual trees of the hybrids *Eucalyptus camaldulensis*, *Eucalyptus grandis* × *Eucalyptus urophylla* (GG100) and *Eucalyptus urophylla*

Model indentity test	V.S.	M.S.	F
DBH (all clones)	Reduction	132.4944	78.53064*
	Residue	1.687169	
Height (all clones)	Reduction	728.3341	607.535*
	Residue	1.198834	
	DBH Combinations		
Clone 1 and Clone2	Reduction	262.349	164.899*
	Residue	1.591	
Clone 1 and Clone 3	Reduction	21.492	24.810*
	Residue	0.866	
Clone 2 and Clone 3	Reduction	153.9314	87.62805*
	Residue	1.756646	
	Height Combinations		
Clone 1 and Clone 2	Reduction	1157.933	1817.06*
	Residue	0.637258	
Clone 1 and Clone 3	Reduction	1160.71	806.378*
	Residue	1.439411	
Clone 2 and Clone 3	Reduction	400.9075	318.775*
	Residue	1.25765	

[(1)]Clone 1: *Eucalyptus camaldulensis;* Clone 2: *Eucalyptus grandis* × *Eucalyptus urophylla* (GG100); Clone 3: *Eucalyptus urophylla.* V.S.: Variation Source; M.S.: Mean Square; F: F-test value. * Significant at 5% probability.

Conclusions:

The IID5 was the most appropriate index to describe the *Eucalyptus camaldulensis*, *Eucalyptus grandis* x *Eucalyptus urophylla* and *Eucalyptus urophylla* growth in diameter and height. ITM was needed to forecast accurately the height and diameter of the clones. Nevertheless, it was not possible to use an ITM single equation to predict diameter and height of the three clones.

ACKNOWLEDGEMENT

CNPq, GETAF company and Ramom Oline Rocha.

REFERENCES

Campos, J.C.C., H.G. Leite, 2013. Mensuração florestal: perguntas e respostas. 4ª ed. Viçosa-MG: UFV.

Castro, R.V.O., C.P.B. Soares, F.B. Martins, H.G. Leite, 2013. Crescimento e produção de

plantios comerciais de eucalipto estimados por duas categorias de modelos. Pesquisa Agropecuária Brasileira, 48(3): 287-295

Clutter, J.L., J.C. Fortson, L.V. Pienaar, G.H. Brister, R.L. Bailey, 1883. Timber management: A quantitative approach. New York: John Wiley & Sons.

Davies, O., A. Pommerening, 2008. The contribution of structural indices to the modeling of Sitka spruce (*Picea sitchensis*) and birch (*Betula* spp.) crowns. Forest Ecology and Management, 256: 68-77

Eisfeld, R.L., C.R. Sanquetta, J.E. Arce, A.A. Mello, 2005. Modelagem do Crescimento e da Produção de *Pinus Taeda* L. por meio do Processo de Difusão. Cerne, Lavras, 11(2): 167-177.

Ferrari, M.P., C.A.H.D. Ferreira, Roberto Trevisan, 2005. Prognose do Crescimento Volumétrico Individual de Árvores de Eucalyptus, em Povoamentos na Região Centro Sul. Bol. Pesquisa Florestal Colombo, 51: 5-16

Härkönen, S., A. Mäkinen, T. Tokola, J. Rasinmäki, J. Kalliovirta, 2010. Evaluation of forest growth simulators with permanent sample plot data from Finland. Forest Ecology and Management, Amsterdam, 259 (3): 573 – 582

Hasenauer, H., 2000. Princípios para a modelagem de ecossistemas florestais. Ciência e Ambiente, Santa Maria, 20(1): 53-69.

Imaña-Encinas, J., G.F. Silva, J.R.R. da; Pinto, 2005. Idade e crescimento das árvores. Brasília: UnB, Departamento de Engenharia Florestal, (série Comunicações Técnicas Florestais), 7(1): 31

Magalhães, S.R., R.D. Veiga, T. Sáfadi, M.A. Cirillo, M. Magini, 2004. Avaliação de Métodos para Comparação de Modelos de Regressão por Simulação de Dados. Semina, Londrina, 25(2): 117-122

Martins, F.B., 2011. Modelagem de crescimento em nível de árvore individual para plantios comerciais de eucalipto. Tese. Universidade Federal de Viçosa, Viçosa.

Martins, F.B., C.P.B. Soares, H.G. Leite, A.L. Souza, R.V.O. Castro, 2011. Índices de competição em árvores individuais de eucalipto. Pesquisa Agropecuária Brasileira, Brasília, 46(9): 1089-1098

Martin, G.L.E.K.A.R., 1984. A comparison of competition measures and growth models for predicting plantation red pine diameter and height growth. Forest Science, 30: 731-743

Murphy, P.A., H.S. Sternitzke, 1979. Growth and yield estimation for loblolly pine in the West Gulf. New Orleans: US Department of Agriculture. (Research paper, SO-154).

Prodan, M., R. Peters, F. Cox, P. Real, 1997. Mensura florestal. San Jose, CR: Instituto Interamericano de Cooperación para la Agricultura.

Regazzi, A.J., 2003. Teste para verificar a igualdade de parâmetros e a identidade de modelos de regressão não-linear. Revista Ceres, 50: 9-26

Radtke, P.J., J.A. Westfall, H.E. Burkhart, 2003. Conditioning a distance- dependent competition index to indicate the onset of inter-tree competition. Forest Ecology and Management, 175: 17-30

Salles, T.T., 2010. Modelagem de crescimento e produção de clones de eucalipto em um sistema agroflorestal.. 97 f. Dissertação – Universidade de Viçosa, Minas Gerais.

Sánchez-González, M., M. Río, I. del; Cañellas, G. Montero, 2006. Distance independent tree diameter growth model for cork oak stands. Forest Ecology and Management, 225: 262-270

Scolforo, J.R.S., 1998. Manejo Florestal. UFLA/FAEPE, 322.

Siipilehto, J., 2000. A comparison of two parameter prediction methods for stand structure in Finland. Silva Fennica, 34(4): 331-349.

Tomé, M., H.E. Burkhart, 1989. Distance-dependent competition measures for predicting growth of individual trees. Forest Science, 35: 816-831

Tonini, H., 2007. Índice de competição e o seu uso na modelagem do crescimento das árvores / por Hélio Tonini. Boa Vista: Embrapa Roraima. (Documentos/ Embrapa Roraima; 8).

Wimberly, M.C., B.B. Bare, 1996. Distance – dependent and distance-independent models of douglas - fir and western hemlocks basal area growth following silvicultural treatment. Forest Ecology and Management, (89): 1-11.

Zhang, L.J., C.H. Peng, Q.L. Dang, 2004. Individual-tree basal area growth models for jack pine and black spruce in Northern Ontario. The Forestry Chronicle, 80: 366-374.

Zeide, B., 1993. Analysis of growth equations. Forest Science, 39(3): 549 – 616