PAB Pesquisa Agropecuária Brasileira

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Forestry/ Original Article

Eucalypt clone modelling in agrosilvopastoral systems

Adênio Louzeiro de Aguiar Júnior[1 ✉], Silvio Nolasco de Oliveira Neto[2], Carlos Pedro Boechat Soares[2], Marcelo Dias Müller[3], Amana Magalhães de Matos Obolari[2] and Leonardo Henrique Ferreira Calsavara[4]

[1]Serviço Brasileiro de Apoio às Micro e Pequenas Empresas, Avenida Washigton Luiz, nº 176, Gonzaga, CEP 11055-000 Santos, SP, Brazil. E-mail: adenio57@gmail.com

[2]Universidade Federal de Viçosa, Departamento de Engenharia Florestal, Avenida Peter Henry Rolfs, s/nº, Campus Universitário, CEP 36570-900 Viçosa, MG, Brazil. E-mail: snolasco@ufv.br, csoares@ufv.br, amanaobolari@gmail.com

[3]Embrapa Gado de Leite, Rua Eugênio do Nascimento, nº 610, Dom Bosco, CEP 36038-330 Juiz de Fora, MG, Brazil. E-mail: marcelo.muller@embrapa.br

[4]Empresa de Assistência Técnica e Extensão Rural do Estado de Minas Gerais, Rua Capitão Anselmo, Vila Mendes, nº 400, CEP 36330-000 Coronel Xavier Chaves, MG, Brazil. E-mail: leonardo.calsavara@emater.mg.gov.br

✉ Corresponding author

Received
May 04, 2021

Accepted
December 13, 2021

How to cite
AGUIAR JÚNIOR, A.L. de; OLIVEIRA NETO, S.N. de; SOARES, C.P.B.; MÜLLER, M.D.; OBOLARI, A.M. de M.; CALSAVARA, L.H.F. Eucalypt clone modelling in agrosilvopastoral systems. **Pesquisa Agropecuária Brasileira**, v.57, e02547, 2022. DOI: https://doi.org/10.1590/S1678-3921.pab2022.v57.02547.

Abstract – The objective of this work was to evaluate height-diameter, volumetric, and taper models to estimate the height, volume, and bole profile of trees of eucalypt clones (*Eucalyptus grandis* × *Eucalyptus urophylla*) in an agrosilvopastoral system. Data were collected from permanent plots in an eight year-old agrosilvopastoral system, composed by three eucalypt clones (VE01, VE06, and VE07), located in the municipality of Coronel Xavier Chaves, in the state of Minas Gerais, Brazil. Two height-diameter, three volumetric, and four taper models were fit to the data of each clone and compared to each other, in order to select the best-fitting one. The equations fitted well to the observed data, and those of the models of Campos, Schumacher-Hall, and Garay stood out as the best ones. In addition, Graybill's F-test showed that the height-diameter and volumetric equations must be fitted separately for each genetic material. The model of Garay was the best taper model to estimate the bole profiles of all clones using a single equation.

Index terms: crop-livestock-forest integration, genetic material, tree component, volume production.

Modelagem de clones de eucalipto em sistemas agrossilvipastoris

Resumo – O objetivo deste trabalho foi avaliar modelos hipsométricos, volumétricos e de afilamento para estimar a altura, o volume e o perfil do fuste de árvores de clones de eucalipto (*Eucalyptus grandis* × *Eucalyptus urophylla*), em sistema agrossilvipastoril. Foram coletados dados de parcelas permanentes em sistema agrossilvipastoril com oito anos de idade, composto por três clones de eucalipto (VE01, VE06 e VE07), localizado no município de Coronel Xavier Chaves, no estado de Minas Gerais, Brasil. Dois modelos hipsométricos, três volumétricos e quatro de afilamento foram ajustados aos dados de cada clone e comparados entre si para selecionar o mais bem ajustado. As equações se ajustaram bem aos dados observados, e aquelas dos modelos de Campos, Schumacher-Hall e Garay se destacaram como as melhores. Além disto, o teste F de Graybill mostrou que as equações hipsométricas e volumétricas devem ser ajustadas separadamente para cada material genético. O modelo de Garay foi o melhor modelo de afilamento para estimar perfis de fuste de todos os clones, com uma única equação.

Termos para indexação: integração lavoura-pecuária-floresta, material genético, componente arbóreo, produção volumétrica.

Introduction

According to Polidoro et al. (2021), the area occupied with integrated crop-livestock-forestry (ICLF) systems in Brazil will be around 22.27–29.32 Mha up to 2030. However, only 15% of this area incorporates trees associated with pastures and crops in agrosilvopastoral (AGF) systems. This is partially due to the knowledge gaps about productivity indexes and the models used to estimate wood yields related to ICLF systems, as highlighted by Salles et al. (2012), Müller et al. (2014), Abrantes et al. (2019), and Cerqueira et al. (2020). The studies developed for dendrometric modeling of the forest component in agroforestry systems have covered several models – including spatial arrangements, different species, and ages –, as well as a wide range of biomes, which leads to knowledge dispersion.

Müller et al. (2014), for example, fitted height, volume, and taper equations for *Eucalyptus grandis* W.Hill and *Acacia mangium* Willd. trees established in a ten-year-old mixed AGF system, at a planting density of 105 trees per hectare, in a mountainous area in a seasonal semideciduous forest environment. Fernandes et al. (2017) developed volumetric equations for two native species established in a silvopastoral system in the Amazon region. Silva et al. (2016) studied the use of regression and artificial neural networks for modeling the stem taper of an eucalypt clone in two spatial arrangements, also in a silvopastoral system. In a savanna region, the works that stand out are those on taper (Cerqueira et al., 2019a), volume (Lemos-Junior et al., 2016; Cerqueira et al., 2020), and height (Cerqueira et al., 2019b) modelling. However, these studies focused on the effect of spatial arrangements, disregarding that of genetic material.

Josephs et al. (2017) confirmed that genetic material affects the productive performance of eucalypt trees established in agroforestry systems, indicating the need to better investigate this effect on the allometry of these trees in order to obtain more accurate equations for each material, individually.

The objective of this work was to evaluate height-diameter, volumetric, and taper models to estimate the height, volume, and bole profiles of trees of eucalypt clones in an agrosilvopastoral system.

Materials and Methods

The study was conducted in a family dairy farm system, located in the municipality of Coronel Xavier Chaves, in the state of Minas Gerais, Brazil (21°00'44.75"S, 44°12'28.42"W). According to Köppen's classification, the climate of the region is of the Cwb type, with two well-defined seasons (humid summer and dry winter), an average annual temperature of 19.2°C, and an average annual precipitation of 1,413 mm, with an average of 623 mm, from October to April, and of 33 mm, from May to September. The experimental area consisted of 4.5 ha of an eight-year-old AGF system, on a gently wavy relief, with slopes of up to 10% and average altitude of 931 m.

The soil of the experimental area was classified as a Latossolo Vermelho-Amarelo distrófico (Santos et al., 2018), i.e., a Haplic Xanthic Ferralsol according to IUSS Working Group WRB (2015).

The system was implemented in November 2009, in an *Urochloa* ssp. pasture. The area was desiccated, and soil acidity was corrected through liming. Tree strips were established on contour lines, spaced 28 m between rows. Eucalypts trees from three clones of *Eucalyptus urophylla* S. T. Blake x *Eucalyptus grandis* W. Hill ex Maiden, commercially called VE01, VE06, and VE07 (Viveiro Esteio, São João del-Rei, MG, Brazil), were planted in double rows, spaced 3.0 m between rows and 2.0 m between trees within rows, resulting in a population density of 322 trees per hectare. Simultaneously, the area between the tree rows was cultivated with corn (*Zea mays* L.) seeded together with *Urochloa decumbens* (Stapf) R.D.Webster 'Basilisk'.

Corn was planted at a density of 55,120 plants per hectare (proportional to 65,000 plants per hectare, considering 15.2% of the space occupied by the tree rows). Corn and *U. decumbens* were fertilized with 32 kg N, 112 kg P_2O_5, and 64 kg ha^{-1} K_2O. Topdressing fertilization, using 350 kg ha^{-1} N (70 kg), P_2O_5 (17.5 kg), and K_2O (70 kg), was applied a month later.

For eucalypt trees, planting fertilization was performed with 0.15 kg N (9.0 g), P_2O_5 (45 g), and K_2O (9.0 g). Another two topdressing fertilizations of 0.10 kg N (20 g), P_2O_5 (5.0 g), and K_2O (20 g) per plant were carried out three months after the trees were planted.

After corn harvest, the pasture was available for grazing. Then, pastures were managed under a rotational stocking, with a defoliation interval of 24–28 days and pasture occupation of 3–5 days, depending on the period of the year.

Three plots of 594 m^2 each were established, with two lines of nine trees, 3.0 m between rows, and 2.0 m between trees within rows. The plots were 18 m long, with 15 m within each pasture strip, randomly distributed on each row.

Total tree height (Ht) and stem diameter outside bark at 1.3 m above the ground, i.e., diameter at breast height (DBH), were measured simultaneously for all trees inside the plots at 24, 30, 36, 42, 72, and 96 months after planting. Using a digital Vertex hypsometer, Ht was measured in 50% of the trees in each plot, totaling 81 trees distributed in eight diametric classes. DBH was measured using a measuring tape, and the diameters were distributed into 2.0 cm amplitude diameter classes.

Based on DBH and Ht data, the following height-diameter models of Curtis (1967) and Campos et al. (1984), respectively, were fitted and evaluated to estimate Ht for each clone:

$$\ln\left(Ht_i\right) = \beta_0 + \beta_1.\left(\frac{1}{DBH_i}\right) + \varepsilon_i$$

$$\ln\left(Ht_i\right) = \beta_0 + \beta_1.DBH_i + \beta_2.\ln\left(Hd_i\right) + \varepsilon_i$$

where Hd_i is the mean height of the dominant trees, defined as those with larger diameters, stems without defects, and crowns without damage; β_0, β_1, and β_2 are model parameters; ln is the Napierian logarithm; and ε is the random error.

Stem volume outside bark was determined for each clone using the Smalian formula (Soares et al., 2011). Three trees were selected per diametric class, and direct measurements of the diameters outside bark were taken at the absolute heights of 0.0, 0.3, 0.7, 1.0, and 1.3 m (DBH), totaling 12, 9, and 9 trees for clones Ve06, Ve07, and Ve01 respectively. A Wheeler pentaprism was used to measure the diameters along the stem above 1.3 m, at 1.0 m intervals up to a minimum diameter limit of 7.0 cm. Then, the following volumetric and taper models were adjusted for each clone (Campos & Leite, 2017): the volumetric models of Schumacher-Hall, Spurr, and Koperzky-Gehrhardt, respectively:

$$\ln\left(V_i\right) = \beta_0 + \beta_1.\ln\left(DBH_i\right) + \beta_2.Ln\left(Ht_i\right) + \varepsilon_i$$

$$\ln\left(V_i\right) = \beta_0 + \beta_1.\ln\left(DBH_i^2.Ht_i\right) + \varepsilon_i$$

$$\ln\left(V_i\right) = \beta_0 + \beta_1.DBH_i^2 + \varepsilon_i$$

and the taper models of Kozak, Garay, Demaerschalk, and Ormerod, respectively:

$$\left(\frac{d_i}{DBH_i}\right)^2 = \beta_0 + \beta_1\left(\frac{h_i}{Ht_i}\right) + \beta_2\left(\frac{h_i}{Ht_i}\right)^2 + \varepsilon_i$$

$$\frac{d_i}{DBH_i} = \beta_0\left[1 + \beta_1 \ln\left(1 - \beta_2 h_i^{\beta_3}.Ht_i^{-\beta_3}\right)\right] + \varepsilon_i$$

$$\left(\frac{d_i}{DBH_i}\right)^2 = 10^{2\beta_0}.DBH_i^{2\beta_1 - 2}.L_i^{2\beta_2}.Ht_i^{2\beta_3} + \varepsilon_i$$

$$\left(\frac{d_i}{DBH_i}\right)^2 = \left[\frac{h_i - Ht_i}{Ht_i - 1.30}\right]^{2\beta_1} + \varepsilon_i$$

where d_i is the diameter outside bark (cm) at a given height (m); DBH_i is the diameter outside bark at 1.3 m above the ground, i.e., diameter at breast height; h_i is the height (m) where a given diameter occurs outside bark (cm); Ht_i is total height (m); β_0, β_1, β_2, and β_3 are model parameters; and ε_i is the random error.

The adjustments of the height-diameter and volumetric models were performed using the method of ordinary least squares, based on the Gauss-Newton algorithm (Ribeiro et al., 2018; Abrantes et al., 2019). The best equation was selected based on the graphical analysis of the residues, the standard error of the estimates ($S_{y.x}$), and the adjusted coefficient of determination ($\bar{R}^2$) (Draper & Smith, 1998), obtained as follows:

$$S_{y.x} = \sqrt{\sum_{i=1}^{n} \frac{\left(y - \hat{y}\right)^2}{\left(n - p - 1\right)}}$$

$$\bar{R}^2 = \left[1 - \left(\frac{n-1}{n-p-1}\right).\left(1 - R^2\right)\right]$$

$$R^2 = 1 - \frac{\Sigma\left(y - \hat{y}\right)^2}{\Sigma\left(y - \bar{y}\right)^2}$$

where y is the observed value, ŷ is the corresponding estimated value, n is the number of observations, R^2 is the coefficient of determination, $\bar{R}^2$ is the adjusted coefficient of determination, and p is number of independent variables in the models.

The best taper model for each clone was selected through a comparative analysis of the following statistics: sum of the square of the residuals (SQRes), correlation coefficient between estimated and observed values ($r_{\hat{y}y}$), systematic error (bias), square root of the mean error (RQEM), and graphical representation of the stem profile and the estimated x observed values.

DOI: 10.1590/S1678-3921.pab2022.v57.02547

Specifically for the model of Kozak, the variance inflation factor (VIF) was used to assess multicollinearity, with values higher than 10 indicating collinearity (O'Brien, 2007), as follows:

$$VIF = \frac{1}{1 - R^2}$$

where VIF is the variance inflation factor; and R^2 is the coefficient of determination of the linear regression of the explanatory variables against the other predictors.

An identity test, as described by Graybill (1976), was carried out for the height-diameter, volumetric, and taper models, in order to evaluate the feasibility of a single equation to represent the behavior of the studied variables.

Results and Discussion

The Graybill F-test indicated that the height-diameter equations for each clone are statistically different (Table 1). This shows that using independent equations to estimate the total height of each clone can produce more accurate results.

Similar statistics were obtained for clones Ve01 and Ve06, specially for parameters $S_{y.x}$ and $\overline{R}^2$. However, a large difference was observed in $\overline{R}^2$ between the models of Campos (0.34) and Curtis (0.18) for clone Ve07. It should be noted that Ve07, unlike the other clones, did not show a significant adjustment for these parameters in both of these models. Ferreira et al. (2016) concluded that dendrometric characteristics are influenced by genetic material, regardless of plant spacing, when evaluating eucalypt clones established in two AGF systems.

$\overline{R}^2$ ranged from 0.18 to 0.65 for those two models. For Ht and DBH, variability was low due to the small sample sizes and similar tree sizes (Table 2), so the equations did not fit well to the observed data. Moreover, the obtained estimates are lower than the ones reported in recent studies carried out specifically for AGF systems (Müller et al., 2014; Cerqueira et al., 2019b; Santos et al., 2019; Abrantes et al., 2019).

The graphical analysis of the residues (Figure 1) showed no strong tendencies of under- or overestimation of the data for both equations used in the estimation of heights and homogeneous dispersions, varying +/- 30% for clones Ve01 and Ve07 and +/- 20% for Ve06. This behavior is typical of equations that present a low coefficient of determination (Campos & Leite, 2017).

The coefficients of the fitted stem volume equations for all clones were statistically different by the Graybill F-test, indicating that the genetic materials significantly influence volume estimation. Consequently, a specific equation was selected for each clone (Table 3).

Table 1. Parameters and statistics of the height-diameter models applied to eucalyptus (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones in an agrosilvopastoral system(1).

Height-diameter model	Clone	Parameter	Estimate	Standard error	p-value	$S_{y.x}$	$\overline{R}^2$
Campos et al. (1984)	Ve01	β0	3.3247	1.1136	<0.05	4.1533	0.4347
		β1	0.0360	0.0139	<0.05		
		β2	-0.3041	0.3350	0.3729		
	Ve06	β0	0.2348	1.1363	0.8379	3.1878	0.6506
		β1	0.0250	0.0070	<0.05		
		β2	0.7320	0.3298	<0.05		
	Ve07	β0	2.3481	0.7063	<0.05	3.3555	0.3456
		β1	-0.0141	0.0122	0.2593		
		β2	0.3854	0.2100	0.0794		
Curtis (1967)	Ve01	β0	4.0492	0.3265	<0.05	4.0166	0.4746
		β1	-20.2934	7.5276	<0.05		
	Ve06	β0	4.1183	0.1839	<0.05	3.3602	0.6033
		β1	-17.0066	4.4090	<0.05		
	Ve07	β0	3.0106	0.2851	<0.05	3.4559	0.1883
		β1	5.9046	6.2856	0.3569		

(1)$S_{y.x}$, standard error of the estimates; and $\overline{R}^2$, adjusted coefficient of determination.

DOI: 10.1590/S1678-3921.pab2022.v57.02547

The stem volume equations fitted well to the observed data for the three assessed clones, with values of $\overline{R}^2$ ranging from 0.82 to 0.97 and of $S_{y.x}$ from 0.0415 to 0.1835. The models that showed the best adjustments to describe tree volume were those of: Schumacher-Hall for Ve01, Spurr for Ve06, and Koperzky-Gehrhardt for Ve07.

However, the graphical analysis (Figure 2) indicates that the equations generated by the Schumacher-Hall model provide a slightly better distribution of the residues than those generated by the models of Spurr and Kopetzky-Gerhardt. Based on these criteria, the best equation to estimate the volume outside bark of the three studied clones was selected.

The Schumacher-Hall and Spurr models are widely recognized and used in forestry literature (Campos & Leite, 2017). Some studies have already proven their effectiveness in AGW systems for: *E. grandis* and *A. mangium* trees in a mixed AGF system (Müller et al., 2014), an eucalypt clone in an AGF system (Lemos-

Table 2. Descriptive data statistics for three eucalyptus (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones in an agrosilvopastoral system[(1)].

Clone	Total tree height (Ht)					DBH				
	Minimum	Mean	Maximum	SD	CV (%)	Minimum	Mean	Maximum	SD	CV (%)
VE01	14.50	24.31	31.40	4.41	18.16	22.92	23.43	28.97	2.52	10.75
VE06	21.00	30.68	36.70	4.17	13.60	20.05	24.51	30.88	3.05	12.45
VE07	19.30	26.73	34.00	3.44	12.88	24.51	22.32	26.26	2.08	9.34

[(1)]DBH, diameter at breast height; SD, standard deviation; and CV, coefficient of variation.

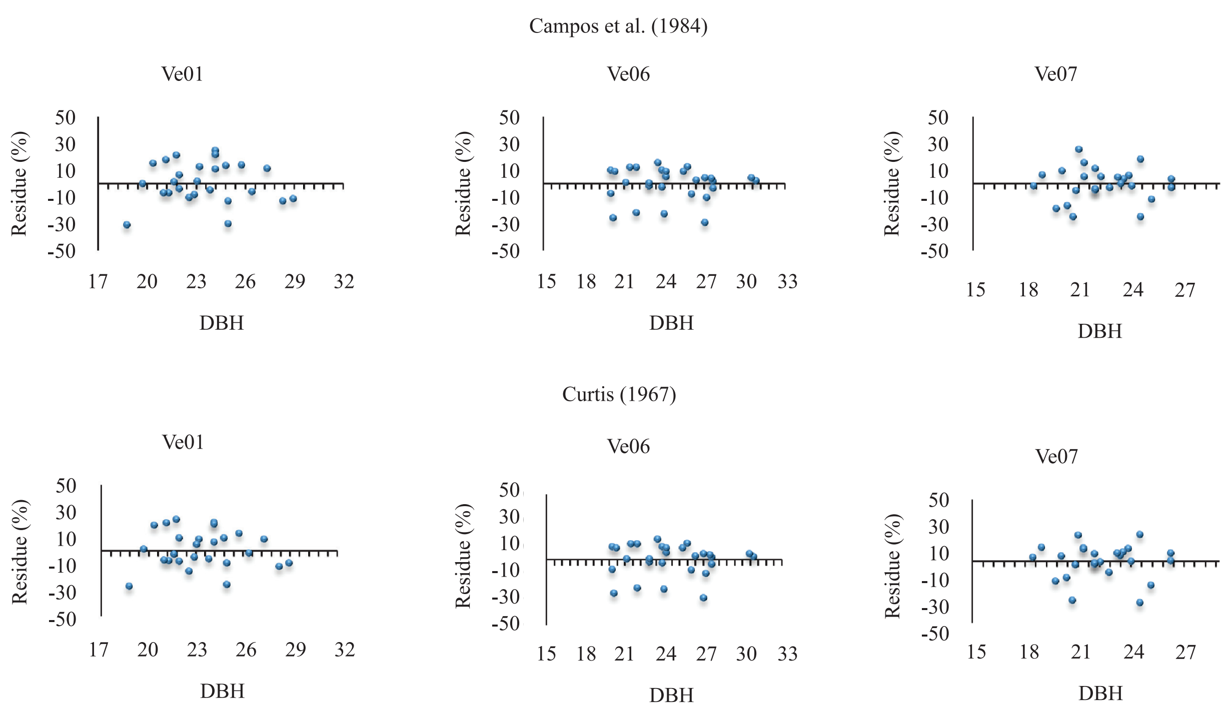

Figure 1. Residues as a function of diameter at breast height (DBH) for two height-diameter models adjusted for three eucalyptus (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones (Ve01, Ve06, and Ve07) in an agrosilvopastoral system.

Junior et al., 2016), *Carapa guianensis* Aubl. and *Swietenia macrophylla* King in Hook in wide-spacing arrangements (Fernandes et al., 2017), and African mahogany species established in AGF systems (Santos et al., 2018). The Schumacher-Hall model was also chosen by Paula et al. (2013), Silva et al. (2020), and Cerqueira et al. (2020) to fit volume equations for eucalypt trees established at different spacings in AGF systems, with good fitting statistics.

Regarding taper statistics, the used models presented a correlation coefficient ($r_{\hat{y}y}$) above 95% (Table 4), which suggests good adjustments to the observed data. However, the Garay model presented a higher correlation ($r_{\hat{y}y}$= 97.20%) and the lowest SQRes and RQEM values.

All parameters were statically significant and VIF<10, indicating no multicollinearity between explanatory variables for the model of Kozak.

There was no significant difference in the tapering of boles according to the F-test of Graybill (1976), which indicates that only one general equation – generated by the Garay model – can be used to estimate the bole profile for the three evaluated clones.

Although there may be variations within the same genetic material, dendrometric characteristics, such as the shape of the bole, tend to follow specific patterns inherited from the parent species (Scolforo et al., 2016).

Souza et al. (2016a), however, concluded that statistical measures, being only an estimation, provide incomplete information about the adjustment of the models for tapering of boles. Therefore, a graphic interpretation of the models is necessary to gather as much information as possible before choosing the best model.

The Demaerschalk and Ormerod models tended to underestimate the larger diameter values (Figure 3), but to overestimate the mid-range ones. The Kozak

Table 3. Parameters and statistics of the volumetric models applied to eucalyptus (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones in an agrosilvopastoral system[(1)].

Volumetric model	Clone	Parameter	Estimate	Standard error	p-value	$S_{y.x}$	$\overline{R}^2$
Schumacher-Hall	Ve01	β_0	-9.4551	0.7751	<0.05	0.0415	0.9743
		β_1	2.3951	0.2395	<0.05		
		β_2	0.3726	0.2321	0.1595		
	Ve06	β_0	-9.9858	1.1191	<0.05	0.1623	0.9371
		β_1	2.5983	0.4757	<0.05		
		β_2	0.3922	0.4417	0.3976		
	Ve07	β_0	-7.9038	1.8435	<0.05	0.0427	0.9215
		β_1	2.2001	0.3324	<0.05		
		β_2	0.0971	0.3808	0.8070		
Spurr	Ve01	β_0	-10.3779	1.5071	<0.05	0.0663	0.9223
		β_1	1.0204	0.1548	<0.05		
	Ve06	β_0	-11.9540	-8.7727	<0.05	0.1578	0.9519
		β_1	1.1859	8.9668	<0.05		
	Ve07	β_0	-10.0142	2.0203	<0.05	0.0673	0.8226
		β_1	0.9776	0.2089	<0.05		
Koperzky-Gehrhardt	Ve01	β_0	-0.1441	0.0675	0.0701	0.0461	0.9629
		β_1	0.0011	0.0001	<0.05		
	Ve06	β_0	-0.4815	0.1614	<0.05	0.1835	0.9345
		β_1	0.0019	0.0002	<0.05		
	Ve07	β_0	-0.0466	0.0751	0.5541	0.0424	0.9381
		β_1	0.0010	0.0001	<0.05		

[(1)]$S_{y.x}$, standard error of the estimates; and $\overline{R}^2$, adjusted coefficient of determination.

model showed good residue distribution, with slight underestimation tendencies for the larger diameter values. The Garay model presented the best distribution of the plotted points, with a relative accuracy of the estimated values and without strong tendencies to under- or overestimate the data. A similar behavior was observed for the characterization of the bole profile in *Eucalyptus* spp. and *Pinus* spp. by Campos et al. (2017) and in eucalypt hybrids (*E. grandis* × *E. urophylla*), at spacings of 3.0x2.0 m, by Lustosa Junior et al. (2017).

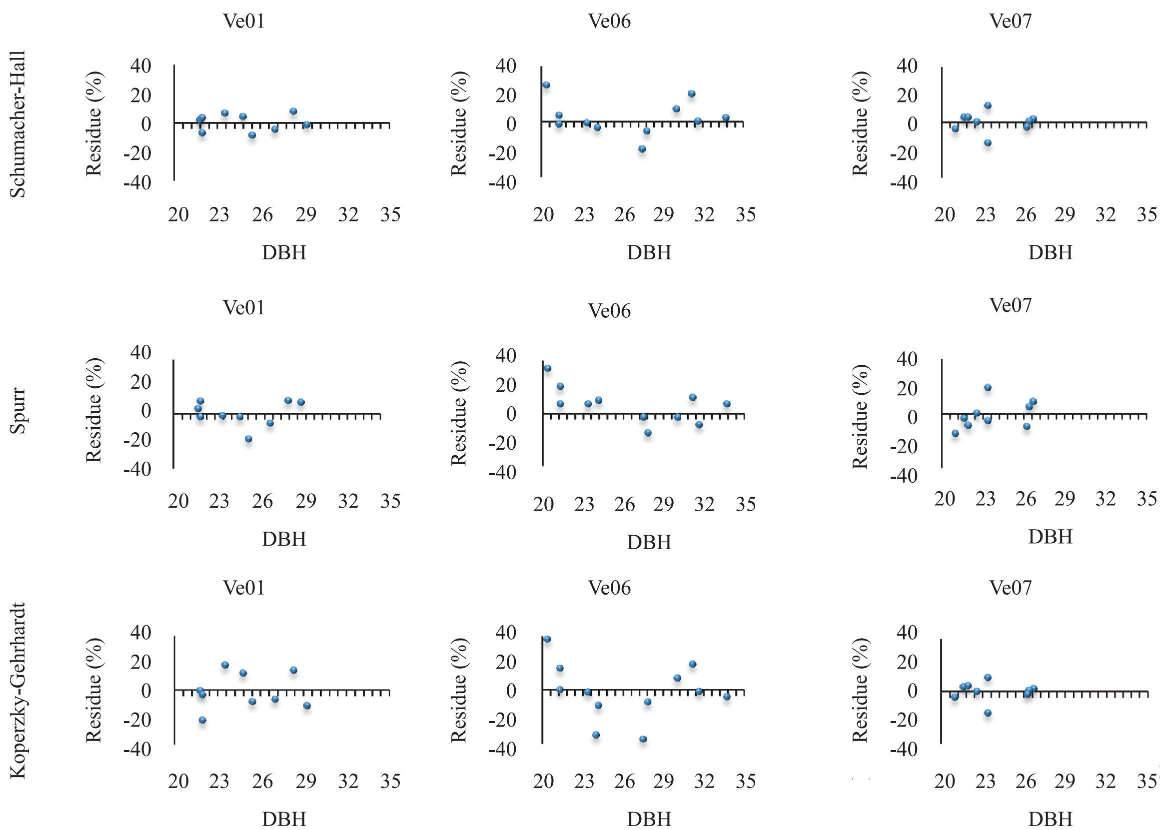

Figure 2. Residues as a function of diameter at breast height (DBH) for three volumetric models applied to three eucalyptus (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones (Ve01, Ve06, and Ve07) in an agrosilvopastoral system.

Table 4. Parameters and statistics for taper models applied to eucalyptus (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones in an agrosilvopastoral system[(1)].

Taper model	β_0	β_1	β_2	β_3	SQRes	$r_{\hat{y}y}$	Bias	RQEM
Demaerschalk	0.3884	1.0187	-1.1641	1.0373	1398.61	0.9665	-0.0604	1.7972
Kozak	1.2803	-5.5672	7.2272	-	1324.30	0.9683	-0.0392	1.7488
Ormerod	1.2000	2.0442	-	0.5000	1533.04	0.9632	-0.2810	1.8816
Garay	1.2401	4.9543	0.1929	0.4993	1172.35	0.9720	-0.0415	1.6454

[(1)]β_0, β_1, β_2, and β_3, model parameters; SQRes, square of the residuals; $r_{\hat{y}y}$, correlation coefficient between estimated and observed values; and RQEM, square root of the mean error.

Müller et al. (2014) also found that the model of Garay presented the best results for the estimation of the bole profile of *E. grandis* and *A. mangium* trees established in a mixed AGF system, which supports both the findings of the present study and the conclusion that, similarly to the AGF system, the Garay model also performs well at larger spacings.

According to the graphical analysis of the tree bole profile, the model of Kozak is inconsistent regarding the greatest height values, and diameter presents an unusual biological growth. Tang et al. (2017) analyzed several models capable of estimating the bole profile of *Betula alnoides* Buch.-Ham. and also identified inconsistencies when using this same model. Therefore, it can be concluded that the Kozak model does not fit well for broadleaf species.

The Demaerschalk and Ormerod models adequately represent the bole profile for lower height values. However, these models show a sudden diameter reduction in the upper part of the generated graph and, consequently, a more disproportional taper than that observed in the field (Figure 4).

The model that best resembles the individuals in the field, with an adequate distribution of the estimated points along the various sections of the trees, is that of Garay, as shown in the graphical representation of the bole profile. In general, the equation of this model presented the best estimation of the bole profiles in the evaluation of the statistical parameters of the models, the graphs of the relationship between the estimated x observed data (Figure 3), and the average bole profiles for the tapering models (Figure 4).

The satisfactory performance of the model of Garay, for both monocultures and the AGF systems, shows that it is highly capable of estimating and representing the shape of tree boles. It is also highly flexible and can describe subtle variations in the shape of the boles for a wide variety of species (Souza et al., 2016b).

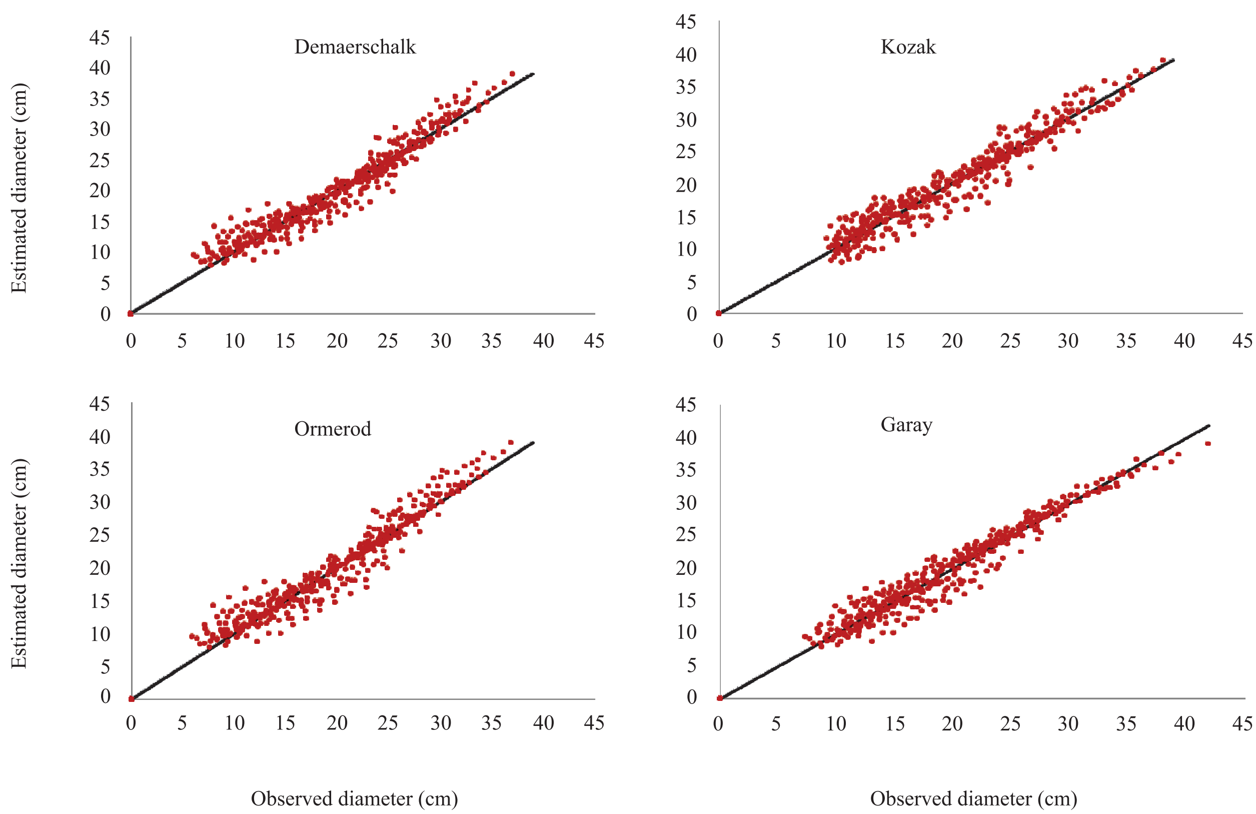

Figure 3. Relation of the observed x estimated values for the equations of four taper models applied to eucalyptus (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones in an agrosilvopastoral system.

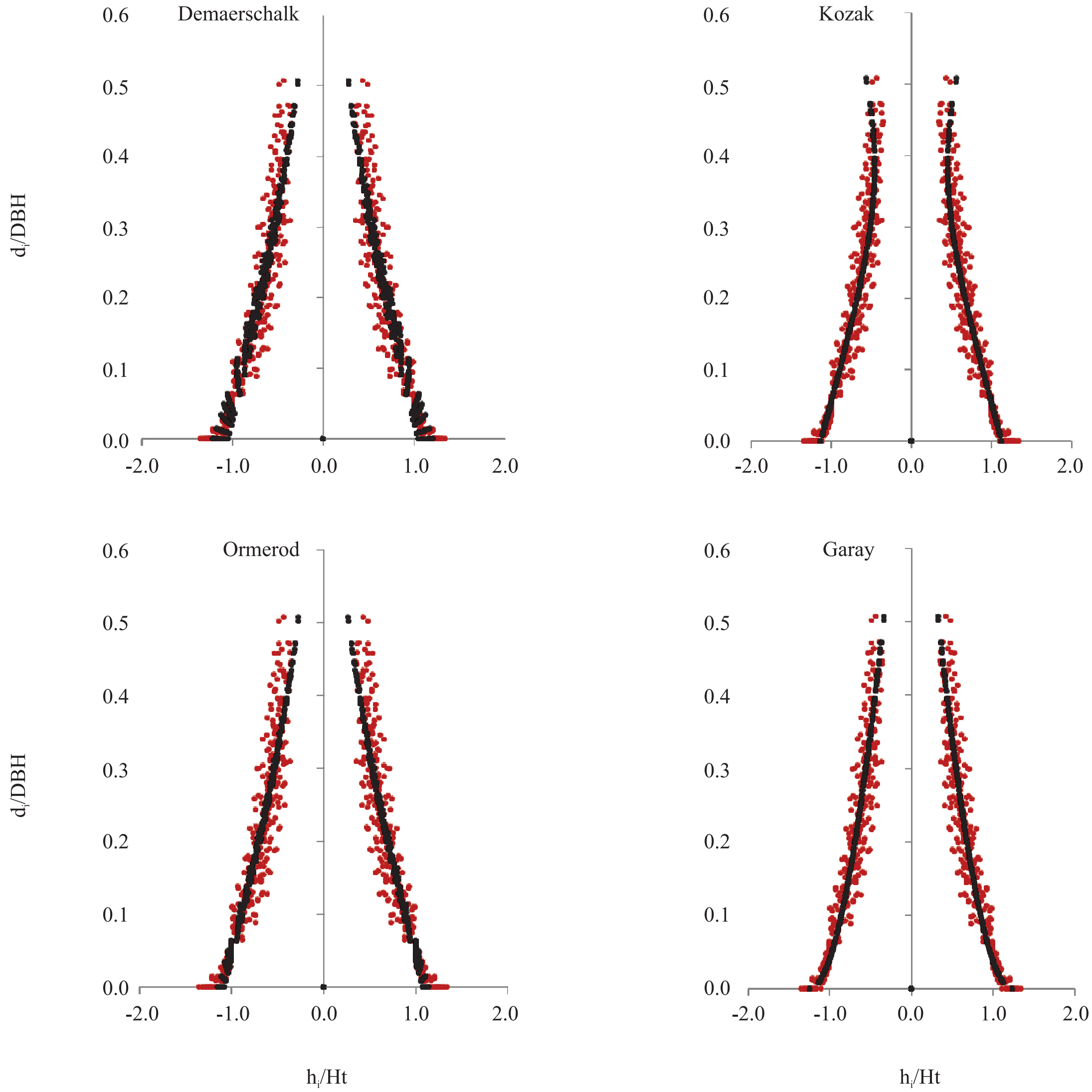

Figure 4. Dispersion of di/DBH data as a function of hi/HT observed and estimated by four taper models. Black dots represent the observed values, and red dots represent the values estimated by the models. di/DBH, diameter outside bark (cm) at a given height (m)/diameter outside bark at 1.3 m above the ground, i.e., diameter at breast height (DBH, cm); and hi/Ht, height (m) where a given diameter occurs outside bark (cm)/total height (m).

Conclusions

1. Individual equations must be fitted for height-diameter and volumetric estimations for each of the three evaluated eucalypt (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones – VE01, VE06, and VE07 –, whereas a single taper equation can be adjusted with data from all clones.

2. The height-diameter model proposed by Campos is efficient to generate total height estimates for each clone individually.

3. The Schumacher-Hall model is efficient to estimate the volume outside bark of the three studied clones.

4. The model of Garay is efficient to describe the entire profile of eucalypt stems.

References

ABRANTES, K.K.B.; PAIVA, L.M.; ALMEIDA, R.G. de; URBANO, E.; FERREIRA, A.D.; MAZUCHELI, J. Modeling the individual height and volume of two integrated crop-livestock-forest systems of *Eucalyptus* spp. in the Brazilian Savannah. **Acta Scientiarum. Agronomy**, v.41, e42626, 2019. DOI: https://doi.org/10.4025/actasciagron.v41i1.42626.

CAMPOS, B.P.F.; SILVA, G.F. da; BINOTI, D.H.B.; MENDONÇA, A.R. de; LEITE, H.G. Descrição do perfil do tronco de árvores em plantios de diferentes espécies por meio de redes neurais artificiais. **Pesquisa Florestal Brasileira**. v.37, p.99-107, 2017. DOI: https://doi.org/10.4336/2017.pfb.37.90.1181.

CAMPOS, J.C.C.; LEITE, H.G. **Mensuração florestal**: perguntas e respostas. 5.ed. Viçosa: Ed. da UFV, 2017. 636p.

CAMPOS, J.C.C.; RIBEIRO, J.O.; PAULA NETO, F. **Inventário florestal nacional, reflorestamento**: Minas Gerais. Brasília: Instituto Brasileiro de Desenvolvimento Florestal, 1984. 126p.

CERQUEIRA, C.L.; ARCE, J.E.; VENDRUSCOLO, D.G.S.; DOLÁCIO, C.J.F.; COSTA FILHO, S.V.S. da; TONINI, H. Tape modeling of eucalyptus stem in crop-livestock-forestry integration systems. **Floresta**, v.49, p.493-502, 2019a. DOI: https://doi.org/10.5380/rf.v49i3.59504.

CERQUEIRA, C.L.; MÔRA, R.; TONINI, H.; ARCE, J.E.; LISBOA, G. dos S.; DINIZ, C.C.C.; CARVALHO, S. de P. Modelagem do volume de eucalipto em sistema de integração lavoura-pecuária-floresta. **Advances in Forestry Science**, v.7, p.1213-1221, 2020. DOI: https://doi.org/10.34062/afs.v7i4.9910.

CERQUEIRA, C.L.; MÔRA, R.; TONINI, H.; VENDRUSCOLO, D.G.S.; LANSSANOVA, L.R.; ARCE, J.E.; DINIZ, C.C.C. Efeito do espaçamento e arranjo de plantio na relação hipsométrica de eucalipto em sistema consorciado de produção. **Nativa**, v.7, p.763-770, 2019b. DOI: https://doi.org/10.31413/nativa.v7i6.7643.

CURTIS, R.O. Height-diameter and height-diameter-age equations for second-growth Douglas-fir. **Forest Science**, v.13, p.365-375, 1967.

DRAPER, N.R.; SMITH, H. **Applied regression analysis**. 3rd ed. New York: J. Wiley & Sons, 1998. 736p. DOI: https://doi.org/10.1002/9781118625590.

FERNANDES, A.M.V.; GAMA, J.R.V.; RODE, R.; MELO, L. de O. Equações volumétricas para *Carapa guianensis* Aubl. e *Swietenia macrophylla* King em sistema silvipastoril na Amazônia. **Nativa**, v.5, p.73-77, 2017. DOI: https://doi.org/10.5935/2318-7670.v05n01a12.

FERREIRA, A.D.; SERRA, A.P.; LAURA, V.A.; ORTIZ, A.C.B.; ARAÚJO, A.R. de; PEDRINHO, D.R.; CARVALHO, A.M. de. Influence of spatial arrangements on silvicultural characteristics of three eucalyptus clones at integrated crop-livestock-forest system. **African Journal of Agricultural Research**, v.11, p.1734-1742, 2016. DOI: https://doi.org/10.5897/AJAR2016.10990.

GARAY, L. **Tropical forest utilization system**. VIII. A taper model for entire stem profile including buttressing. Seattle: College of Forest Resources, Institute of Forest Products, University of Washington, 1979. 64p.

GRAYBILL, F.A. **Theory and application of the linear model**. North Scituate: Duxbury Press, 1976.

IUSS WORKING GROUP WRB. **World Reference Base for Soil Resources 2014**: International soil classification system for naming soils and creating legends for soil maps: update 2015. Rome: FAO, 2015. 192p. (FAO. World Soil Resources Reports, 106).

JOSEPHS, E.B.; STINCHCOMBE, J.R.; WRIGHT, S.I. What can genome-wide association studies tell us about the evolutionary forces maintaining genetic variation for quantitative traits? **New Phytologist**, v.214, p.21-33, 2017. DOI: https://doi.org/10.1111/nph.14410.

LEMOS-JUNIOR, J.M.; SILVA-NETO, C. de M. e; SOUZA, K.R. de; GUIMARÃES, L.E.; OLIVEIRA, F.D.; GONCALVES, R.A.; MONTEIRO, M.M.; LIMA, N.L.; VENTUROLI, F.; CALIL, F.N. Volumetric models for *Eucalyptus grandis* x *urophylla* in a crop-livestock-forest integration (CLFI) system in the Brazilian cerrado. **African Journal of Agricultural Research**, v.11, p.1336-1343, 2016. DOI: https://doi.org/10.5897/AJAR2016.10806.

LUSTOSA JUNIOR, I.M.; LIMA, M.B. de O.; NASCIMENTO, B.G.; MEIRA JUNIOR, M.S. de; CASTRO, R.V.O. Modelos de afilamento e otimização de multiprodutos de um povoamento de Eucalyptus não desbastado. **Revista de Agricultura Neotropical**, v.4, p.59-65, 2017. Suplemento 1. DOI: https://doi.org/10.32404/rean.v4i5.2216.

MÜLLER, M.D.; SALLES, T.T.; PACIULLO, D.S.C.; BRIGHENTI, A.M.; CASTRO, C.R.T. de. equações de altura, volume e afilamento para eucalipto e acácia estabelecidos em sistema silvipastoril. **Floresta**, v.44, p.473-484, 2014. DOI: https://doi.org/10.5380/rf.v44i3.33149.

O'BRIEN, R.M. A caution regarding rules of thumb for variance inflation factors. **Quality and Quantity**, v.41, p.673-690, 2007. DOI: https://doi.org/10.1007/s11135-006-9018-6.

PAULA, R.R.; REIS, G.G.; REIS, M.G.F.; OLIVEIRA NETO, S.N.; LEITE, H.G.; MELIDO, R.C.N.; LOPES, H.N.S.; SOUZA, F.C. Eucalypt growth in monoculture and silvopastoral systems with varied tree initial densities and spatial arrangements. **Agroforestry Systems**, v.87, p.1295-1307, 2013. DOI: https://doi.org/10.1007/s10457-013-9638-5.

POLIDORO, J.C.; FREITAS, P.L. de; HERNANI, L.C.; ANJOS, L.H.C. dos; RODRIGUES, R. de A.R.; CESÁRIO, F.V.; ANDRADE, A.G. de; RIBEIRO, J.L. Potential impact of plans and policies based on the principles of conservation agriculture on the control of soil erosion in Brazil. **Land Degradation & Development**, v.32, p.3457-3468, 2021. DOI: https://doi.org/10.1002/ldr.3876.

RIBEIRO, A.; FERRAZ FILHO, A.C.; SCOLFORO, J.RS. Tree height prediction in Brazilian *Khaya ivorensis* stands. **Bosque**, v.39, p.15-26, 2018. DOI: https://doi.org/10.4067/S0717-92002018000100015.

SALLES, T.T.; LEITE, H.G.; OLIVEIRA NETO, S.N. de; SOARES, C.P.B.; PAIVA, H.N. de; SANTOS, F.L. dos. Modelo de Clutter na modelagem de crescimento e produção de eucalipto em sistemas de integração lavoura-pecuária-floresta. **Pesquisa Agropecuária Brasileira**, v.47, p.253-260, 2012. DOI: https://doi.org/10.1590/S0100-204X2012000200014.

SANTOS, F.M.; TERRA, G.; CHAER, G.M.; MONTE, M.A. Modeling the height–diameter relationship and volume of young African mahoganies established in successional agroforestry systems in northeastern Brazil. **New Forests**, v.50, p.389-407, 2019. DOI: https://doi.org/10.1007/s11056-018-9665-1.

SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.Á. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; ARAÚJO FILHO, J.C. de; OLIVEIRA, J.B. de; CUNHA, T.J.F. **Sistema brasileiro de classificação de solos**. 5.ed. rev. e ampl. Brasília: Embrapa, 2018. 356p.

SCHUMACHER, F.X.; HALL, F. dos S. Logarithmic expression of timber-tree volume. **Journal of Agricultural Research**, v.47, p.719-734, 1933.

SCOLFORO, H.F.; CASTRO NETO, F. de; SCOLFORO, J.R.S.; BURKHART, H.; MCTAGUE, J.P.; RAIMUNDO, M.R.; LOOS, R.A.; FONSECA, S. da; SARTÓRIO, R.C. Modeling dominant height growth of eucalyptus plantations with parameters conditioned to climatic variations. **Forest Ecology and Management**, v.380, p.182-195, 2016. DOI: https://doi.org/10.1016/j.foreco.2016.09.001.

SILVA, S.; OLIVEIRA NETO, S.N. de; LEITE, H.G.; ALCÂNTARA, A.E.M. de; OLIVEIRA NETO, R.R. de; SOUZA, G.S.A. de. Productivity estimate using regression and artificial neural networks in small familiar areas with agrosilvopastoral systems. **Agroforestry Systems**, v.94, p.2081-2097, 2020. DOI: https://doi.org/10.1007/s10457-020-00526-1.

SILVA, S.; OLIVEIRA NETO, S.N. de; LEITE, H.G.; OBOLARI, A. de M.M.; SCHETTINI, B.L.S. Avaliação do uso de regressão e rede neural artificial para modelagem do afilamento do fuste de eucalipto em sistema silvipastoril. **Enciclopédia Biosfera**, v.13, p.189-199, 2016. DOI: https://doi.org/10.18677/Enciclopedia_Biosfera_2016_018.

SOARES, C.P.B.; PAULA NETO, F. de; SOUZA, A.L. de. **Dendrometia e inventário florestal**. 2.ed. Viçosa: Ed. da UFV, 2011. 272.p.

SOUZA, C.A.M. de; FINGER, C.A.G.; SCHNEIDER, P.R.; MULLER, I. Modelos de afilamento para *Pinus taeda* L. baseados em pontos de mudança de forma. **Ciência Florestal**, v.26, p.1239-1246, 2016b. DOI: https://doi.org/10.5902/1980509825120.

SOUZA, R.R.; NOGUEIRA, G.S.; MURTA JÚNIOR, L.S.; PELLI, E.; OLIVEIRA, M.L.R. de; ABRAHÃO, C.P.; LEITE, H.G. Forma de fuste de árvores de *Eucalyptus* em plantios com diferentes densidades iniciais. **Scientia Forestalis**, v.44, p.33-40, 2016a. DOI: https://doi.org/10.18671/scifor.v44n109.03.

TANG, C.; WANG, C.S.; PANG, S.J.; ZHAO, Z.G.; GUO, J.J.; LEI, Y.C.; ZENG, J. Stem taper equations for *Betula alnoides* in South China. **Journal of Tropical Forest Science**, v.29, p.80-92, 2017.