Original Research Article

Selection of models for above-ground biomass in a *Eucalyptus urophylla* stand

ABSTRACT

The quantification of biomass is an important tool that helps the forest manager to define the course of the enterprise and the best management techniques. In view of this situation, the objective of the present study was to perform the modeling of above - ground biomass in the different components in *Eucalyptus urophilla* stands at 4.5 years of age. The stand is located in the south of Brazil, municipality of São Gabriel. Four plots of 577.5 m² were installed and all DBH and heights of 20% of the trees were measured. Four diameter classes were defined, with 3 trees being felled in each of them. All the biomass was weighed in leaves, branches, bark and wood and through samples the moisture content in each component was determined. The modeling showed reliability of 96% for wood estimation and biomass total. The total biomass was 65 Mg ha^{-1}, of these, 72% of wood. The modeling with stepwise procedure presented good distribution of the residues. Through the easily obtained variables such as DBH and height it is possible to determine the volume of biomass accurately.

Keywords: Forest biomass; eucalyptus productivity; harvest; management.

1. INTRODUCTION

The planted trees sector had a balance of trade of US $ 9.0 billion in 2017, currently representing 1.1% of national GDP and 6.1% of industrial GDP. According to data from IBÁ [1], Brazil has an area of 7.84 million hectares, of which 72.3% are occupied by the genus Eucalyptus sp. Among the segments, 35% of the area comes from the pulp and paper industry, 30% from independent producers, 13% from the steel and charcoal segment, 9% from investors, 10% from panels, solid wood products and 3% others [1].

Compared to other countries, Brazil has the highest average productivity, 35.7 m³ ha^{-1} year^{-1}, in addition to the smallest rotation cycle, 4.8 years [1]. The excellent soil and weather conditions are important factors for such results, however, the selection of superior individuals, hybridization, appropriate techniques of soil management and fertilization, maximized this increase in productivity [2,3].

Wood is the product of higher value, however, components such as bark, branches and tree tops are important bioenergetic sources and are sometimes removed from the site for later conversion through burning [4,5]. However, the complete removal of the tree can cause negative impacts on the soil properties [6], and reductions in the yield of *Eucalyptus globulus* in third rotation after repeated removals of forest residues [7].

The success of a forest enterprise occurs through a great planning, therefore, estimate of the biomass stock, and its projections, trace the direction of the same [8,9]. The low costs and the shortage of time are the main advantages of adopting them [10]. However, it is necessary to quantify a number of individuals through the direct method as a form of adjustment [11].

The selection of the best models should aim at the smallest number of parameters, high precision and independent variables easily obtainable as seen in the present study [12,13]. According to Fonseca et al. [14], the interaction between the two variables is present in most models. The authors emphasize that the DAP is the easiest variable to obtain and the smallest error, being therefore the one with the best correlation with the volume.

In view of the need to obtain forest productivity data quickly and the dilemma related to the impacts of harvesting, the aim of the present study was to model the different components of the biomass through the stepwise procedure and to estimate the biomass above the soil.

2. MATERIAL AND METHODS

2.1 Characterization of the experimental area

The study was conducted in a hybrid of *Eucalyptus urograndis* 3301, derived from a cross between *Eucalyptus urophylla* x *Eucalyptus grandis*. The experiment was located under the central geographic coordinates 29º 47 'S and 55º 17' W in the municipality of Alegrete - RS. The trees were between 45 and 57 months old. The spacing was 2.5 m x 3.5 m, with initial density of 1143 ha^{-1} trees.

The chemical and physical attributes of the soil are presented in Table 1. The soil of the experimental area was classified as typical Distrophic Red Argisol. These soils are deep, well drained, sand-free or sandy-loam surface texture, followed by loamy-sandy loam texture in the deepest horizons. Dystrophic soils show low base saturation (V <50%) in most of the first 100 cm representing low natural fertility soils [15].

Table 1 - Chemical and physical soil attributes of the experimental area in Alegrete-RS.

Variable	Unidade	Deph (cm)				
		0-20	20-40	40-60	60-80	80-100
SD	g cm^{-3}	1.5	1.6	1.5	1.5	1.4
OM	g kg^{-1}	8.7	8.2	8.3	7.0	5.8
pH (H_2O)		4.4	4.5	4.6	4.6	4.7
Al	$cmol_c$ dm^{-3}	1.1	1.3	1.0	0.9	0.6
Ca		0.5	0.9	1.3	1.4	1.5
Mg		0.4	0.3	0.4	0.4	0.5
P	mg dm^{-3}	2.0	1.7	2.0	1.9	2.0
K		13.5	10.3	8.1	7.8	8.2
Al+H	$cmol_c$ dm^{-3}	4.9	4.4	4.1	3.4	3.4
CTC ef.		2.0	2.5	2.7	2.7	2.7
CTC pH_7		5.8	5.6	5.7	5.2	5.5
V	%	17.7	22.4	29.5	35.5	38.0
m		53.3	50.8	38.4	32.2	23.6

Where: SD = soil density; OM = organic matter; CTC pH7/eff = cation exchange capacity; V% = base saturation; m = saturation by aluminum.

According to the climatic classification of Köppen, the climate is of type Cfa, presenting homogeneous distribution of the precipitation throughout the year. The minimum average temperatures are in the month of June with 14ºC and the hottest month in January 26ºC [16]. Figure 1 shows the meteorological diagram for the municipality of Alegrete during present study. Data were obtained from the Alegrete automatic climatic station [17].

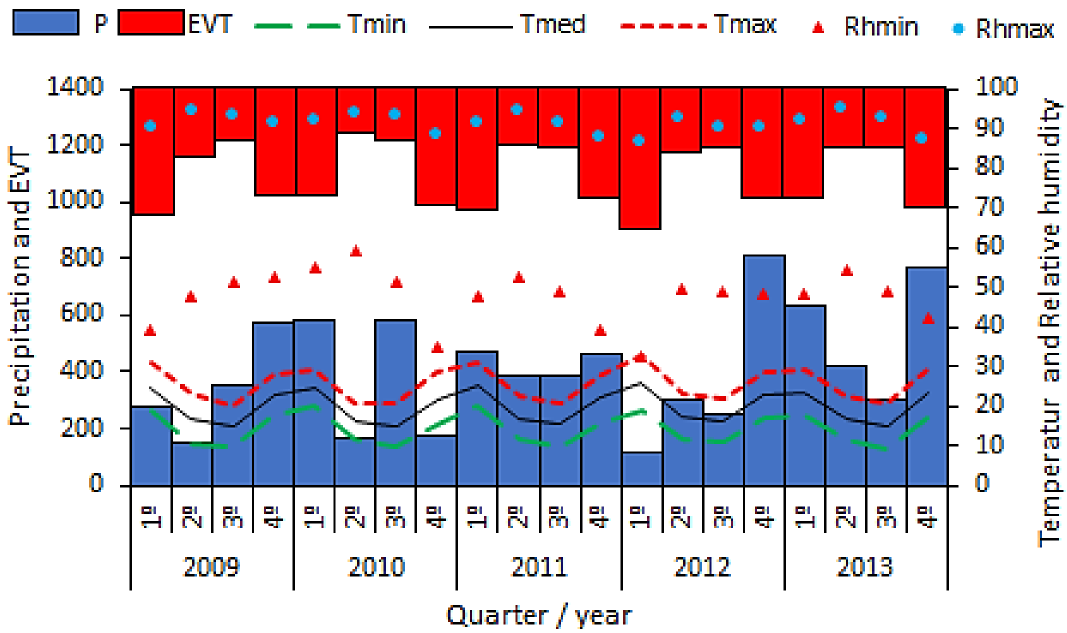

Figure 1 - Diagram of the meteorological variables for the region of Alegrete with the minimum quarterly averages of evapotranspiration (EVT) (mm), precipitation (P) (mm), minimum and maximum temperatures (T) (ºC) and maximum and minimum relative humidity (Rh).
Source: [17].

2.2 Experimental design and data collection

At random, 4 plots with dimensions of 21 m x 27.5 m were demarcated. For the inventory, all the diameters at breast height (DBH) of the individuals were measured in the plot with diametric tape. The height of 20% of the individuals was obtained with the Vertex hypsometer, and the other heights were estimated by means of regression.
In the possession of the data, by means of the formula of Sturges the number of classes was defined [18].

$$K = 1 + 3{,}322 \,.\, (log10\ N)$$

Where: K = number of classes by the Sturges formula; N = number of observations.

Four classes of diameter were defined: 9.0 - 12.0; 12.1-15.0; 15.1 - 18.0 and 18.1 - 21.0. For each diametric classes three trees were felled (DBH lower, upper and middle limit.).
Trees were felled 5-10 cm above ground level. The trunk was subdivided into base, middle and top. The tree trunk was peeled and separated from the bark. The leaves were separated from the branches and then all components of the biomass were weighed in the field.

For the determination of dry biomass, 3 wood samples and 3 bark samples at the base, middle and top positions of the tree were removed. For the leaf and branch component, a sample of each was obtained. The samples were weighed in a precision field scale, packed in paper containers and then dried in a greenhouse for renovation and forced air circulation at 70 ºC until reaching constant weight. By means of the difference between wet and dry weight it was possible to determine the moisture content for each component of the tree and in the sequence the dry biomass. By means of the difference between wet and dry weight, the dry biomass content was defined. [19].

$$\text{Dry content (\%)} = 1 - \frac{(ww - dw)}{ww}$$

Where: ww = wet sample weight; dw = dry sample weight.

The specific leaf area (AFE) was determined through an aliquot of leaves (100 g). The leaves of the sample were photographed and then processed in the UTHSCSA software, Image tool for Windons version 3.0 © [20], to determine leaf area. Based on the humid biomass of the samples, leaf area was extrapolated to total leaf biomass of each sampled plant, determined in m^2 $tree^{-1}$.
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2.3 Statistics and Data Analysis

For the modeling of the independent variables DBH (diameter at breast height) and H (height), SPSS Software 20.0 was used [21]. The choice of equations and variables considered the Stepwise method (Criterion: Probability of $P \leq 0.05$). The combination of the independent variables were as follows: d (diameter at breast height), h (total height), d², d³, h², h³, dh, (dh) ², (dh) ³, d².h, d. (dh), 1 / d², 1 / d³, 1 / h, 1 / h², 1 / h³, 1 / dh, 1 / ³, 1 / d².h, 1 / d.h², 1 / d³.h, 1 / d.h³, in addition to the neperian logarithms of each of these combinations above.

The verification of the determinants was by the Durbin-Watson test in which it evaluates the independence of the residues, that is, the dependence between the terms or correlation. The choice of the models considered the analysis of the following statistical indices: adjusted coefficient of determination R² aj., Standard error of the absolute estimate Syx, standard error of the relative estimate Syx (%), probability of error $P \leq 0.05$, F and residue graphical analysis%. The chosen models were used to estimate the biomass of the other trees of the plot, being the same in the sequence extrapolated per hectare [21].

3. RESULTS AND DISCUSSION

3.1 Dendrometric characteristics

The diameter classes showed normal distribution, that is, the largest number of trees are around the mean diameter of the stand. When considering the sum of classes 2 and 3, about 91% of the trees have a diameter between 12.1 and 18 cm. Figure 2. According to Finger [18], the highest frequencies in commercial plantations are around the average.

The inventory carried out at 4.5 years showed a density of 900 trees per hectare. The average diameter was 15.2 cm and an average height of 17.3 meters. The total volume of wood was 171.9 m³ ha^{-1} year^{-1}, representing an average annual increase of 38.2 m³.

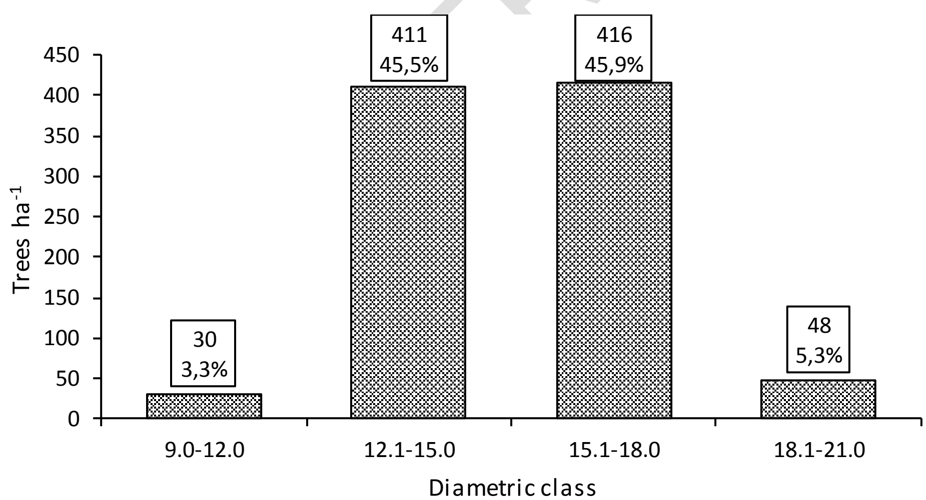

Figure 2 - Diameter distribution and frequency of trees by class.

Table 2 shows the dendrometric characteristics of the *Eucalyptus urograndis* stands at 4.5 years of age.

Table 2 - Dendrometric characteristics in *Eucalyptus urograndis* stands at 4.5 years in Alegrete, southern Brazil.

Inventory				
N (ha^{-1})	DBH (cm)	H (m)	G (m² ha^{-1})	Vwb (m³ ha^{-1})
900	15.2	17.3	16.5	171.9
IMA Vwb (m³ ha^{-1})			LAI (m² m^{-2})	
38.2			3.4	

Where: N = number of trees ha^{-1}; DBH = diameter at breast high; H = high; G = basal area; Vwc = volum with bark; AAI = average annual increment; LAI = leaf area index.

Evaluating the growth in diameter and height of a clone of *E. urophylla* x *E. grandis* implanted under agrosilvipastoril management with 4.5 years, Neto et al [22] found average DBH of 16.8 and 16.4 cm, being thus similar to the present study. This result is attributed to the maturity of the stand. Both the stand of the present study and de Neto et al [22] were at an average age of 4.5 years.

In an inventory carried out on a hybrid *Eucalyptus urophylla* x *E. globulus* at 10 years of age, Viera et al. [23] found an average DBH of 20.2 cm, height of 28.7 and volume with bark of 444 m³ ha^{-1}. As expected, the population maturity reflected in the findings by the researchers. For Viera et al. [23] the DBH, high and volume were higher, but the leaf area index was apparently lower: 2.55. Studies point to exponential behavior for the LAI as a function of population maturity. In the early stages the LAI grows rapidly and reaches a peak, then a reduction is observed until the harvest period of the trees [24,25].

According to Momolli et al [26], in the *Eucalyptus saligna* stands at 10 years of age, the volume of wood was 546 m³ ha^{-1}, representing an average annual increase of 55 m³ ha^{-1}. These findings reinforce the idea that the maturity of stand is determinant.

3.2 Biomass modeling

The variables tested by the stepwise procedure in the SPSS statistical software [21] show that for the bark, branch and height components, only the DBH variable was selected to estimate its biomasses. For the leaf, wood and total biomass components, the interaction between the DBH and the height Table 3 was selected.

Developing modeling in a 10-year-old *Eucalyptus saligna* stand Momolli et al. [26] found interaction between DBH and height for all models chosen. In *Eucalyptus urophylla* x *E. globulus* at 10 years old, Viera et al. [23] also selected the DBH variable to estimate the bark component. These variations may be related to species characteristics, with *Eucalyptus saligna* showing natural peeling. The species of the present study does not have natural mismatch, thus, the increase or decrease of DBH explains considerably the amount of bark.

Table 3 - Equations used to estimate the biomass of each component and height of a stand of *Eucalyptus urograndis* at 4.5 years.

Variable	Model
Wood	$Y = b_0 + b_1 . (DBH^2H)$
Bark	$Y = b_0 + b_1 . (\sqrt[2]{DBH})$
Branch	$Y = b_0 + b_1 . (\sqrt[2]{DBH})$
Leaf	$Y = b_0 + b_1 . (DBH^2H)^2$
Total	$Y = b_0 + b_1 . (DBH^2H)$
High	$Y = b_0 + b_1 . (1/DBH^2)$

Table 4 presents the coefficients of the models and the statistics for each of the selected models. It is observed that all ($P \leq 0.05$) were 0. Coefficients of determination higher than 0.9 were verified for the components wood, leaf and total of the biomass. The lowest coefficients were verified for height and bark. Regarding the standard error of the estimate relative to the bark presented the highest percentage.

The modeling of the different components of the biomass was also performed by Viera et al. [23]. While in the present study the lowest adjustment was for the bark component R^2 aj 0.74, Viera et al. [23] show that the lowest adjustment occurred for the leaves 0.86. For Momolli et al. [26] the adjustments were much higher than the other authors, being the smallest adjustment for height with R^2 aj of 0.97.

The quality of the genetic material influences the results obtained. When genetic materials from clones are studied, the variability between individuals is reduced, thus better model adjustments are obtained.

Table 4 - Statistics of the regression equations and coefficients for each component of the biomass and height of a stand of *Eucalyptus urograndis* at 4.5 years.

Variable	b_0	b_1	P≤0,05	R²aj.	Syx	Syx%	F	DW
Wood	3.408596	0.011229	0	0.965	5.06	10.1	302	2.48
Bark	-21.084554	7.231694	0	0.74	2.04	30.0	32	1.65
Branch	-25.162592	8.854434	0	0.885	1.55	17.2	84	2.98
Leaf	1.984312	1.162×10^{-7}	0	0.939	0.68	14.3	155	2.22
Total	4.736105	0.015582	0	0.964	7.06	9.7	299	2.71
High	21.413268	-700.204056	0	0.897	0.71	4.0	97	2.14

In Figure 3 we observed the graphical distribution of the residues as a function of the DAP for each dependent variable. The best way to validate the model statistics is through the graphical distribution of the residues [27]. The residue analysis (%) shows good adjustments of the models, that is, they are distributed around the zero mean. However, that the best adjustments were for the variables wood, total and height. Momolli et al [26] also observed greater variability of the residues for the branches, leaves and bark components.

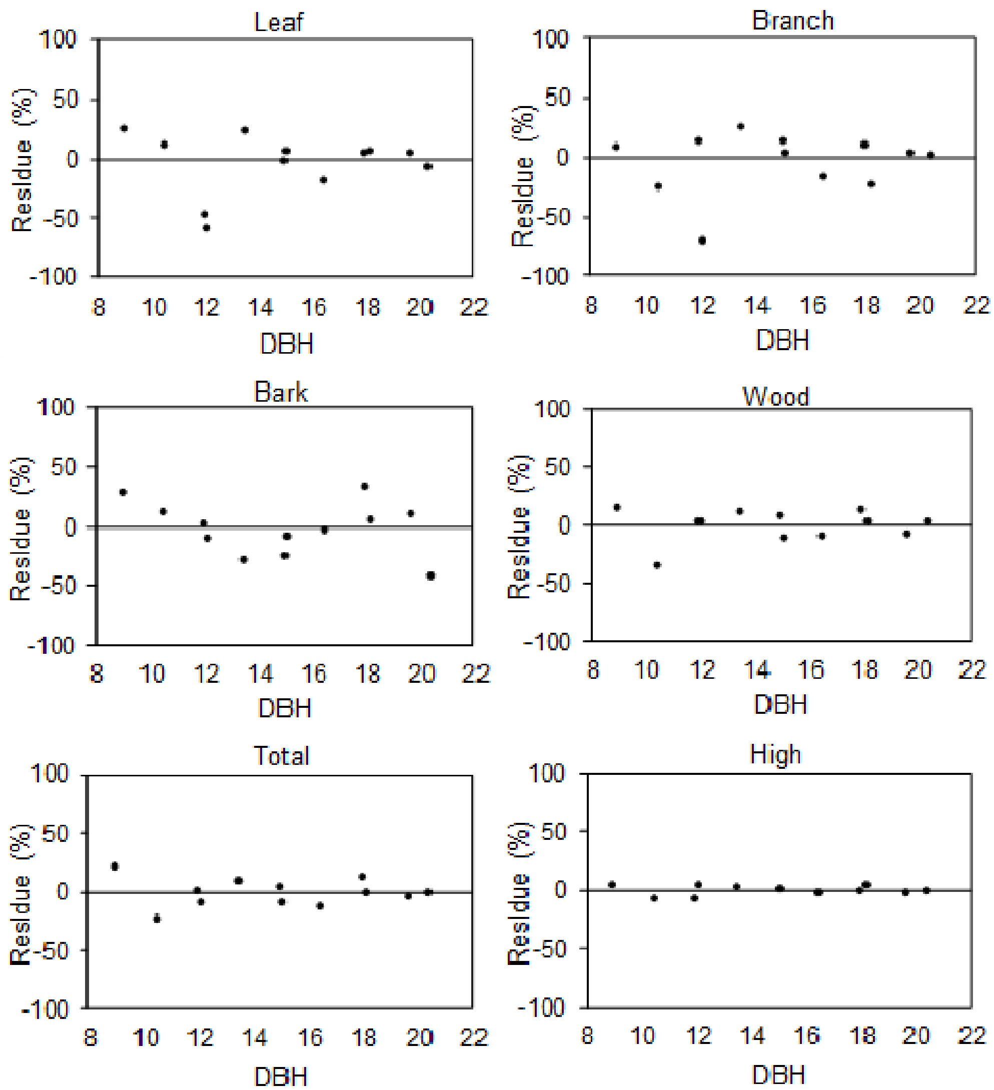

Figure 3 - Distribution of residues (%) as a function of DBH for the different dependent variables adjusted.

3.3 Quantification of biomass

Quantifying the biomass of different eucalyptus clones in the state of Pernambuco, Brazil, Alves et al. [28] found 62 mg ha^{-1} for the *Eucalyptus tereticornis* hybrid. However, other clones were much more productive, such as the hybrid *Eucalyptus urophylla* x *E. tereticornis* x *E. pellita* with 139 mg ha^{-1} and *Eucalyptus urophylla* natural crossing with 132 mg ha^{-1}. The authors concluded that 70, 13, 9 and 8% of the average biomass was allocated on the stem, branches, bark and leaf respectively. The productivity among the clones for the researchers varied between 50 and 132 mg ha^{-1}, however, the percentage allocation among the different biomass components was very similar to the present study: 71.9; 12.4; 9.4 and 6.2% for stem, branches, bark and leaf respectively.

Some factors determine the accumulation of total biomass and the different compartments. We can generally cite plant genetics and environmental variability as determinants of these variations [29].

For Viera et al. [23] in a stand of *E. urophylla* x *E. globulus* at 10 years of age, the percentage of leaf + branches was 6.3%, with wood + bark accounting for 93.7%. When considering the sum of wood + bark the contribution reaches 81.3%, while branch + leaf represents 18.6%. According to Larcher [30], during the initial phase of development of the plant the top priority is the production of canopy (leaves and branches). With the growth of the canopies, competition increases, so the trunk diameter begins to increase and the participation of this component increases considerably while the canopy biomass decreases.

Table 5 - Biomass (Mg ha^{-1}) in the different components in *Eucalyptus urograndis* stands at 4.5 years old.

	Biomass				
	Wood	Bark	Branch	Leaf	Total
Mg ha^{-1}	46.84	6.14	8.10	4.04	65.12
%	71.9	9.4	12.4	6.2	100.0

Mg ha^{-1} = tonne per hectare.

Table 6 shows the percentage allocation of aboveground biomass in the four diametric classes evaluated. It is observed that there was no apparent variation between the percentages of each component in the different diametric grades. Schumacher et al. [31] evaluated the percentage allocation in different stages of maturation and verified that the wood + bark participation did not reach 45% initially, however, with the advancement of age and with the increment in diameter, these indexes represent more than 85%.

Table 6 - Relative biomass by diameter classes in *Eucalyptus urograndis* stands at 4.5 years old.

Diametric class	Leaf	Branch	Bark	Wood
	%			
9.0-12.0	7.2	12.8	9.3	70.8
12.1-15.0	5.7	12.9	7.3	74.0
15.1-18.0	6.2	12.3	10.9	70.6
18.1-21.0	7.2	11.5	8.9	72.4

To assess the production of biomass in different genetic materials and eucalyptus age, Santana et al [32] find that with twelve months old, about 58% of the biomass is constituted by the tree tops. This percentage decreases as age increases, reaching 10% at 4.5 years and reducing to 7.5% at 8 years of age.

Quantifying the average of 13 *Eucalyptus urograndis* stands in the Amazon, Spangenberg et al [33] found values very similar to the present study 68.9; 10.5; 17.6 and 3% for wood, bark, branch and leaf respectively. These findings are compatible with the percentages found for the present study.

5. CONCLUSION

The modeling of the wood and total biomass showed excellent coefficients of adjustments and low relative errors. The interaction between DBH and H were selected for these components. Through the graphical distribution of the residues, we conclude that there is no overestimation or underestimation of the estimated biomass. Generally, through technical stepwise it is securely possible to select the best model to estimate the biomass in a stand *Eucalyptus urophylla*.

The total biomass estimated was 65 Mg ha^{-1}, being constituted mainly by the wood component with 72%. The volume was 172 m³ ha^{-1}, representing an average annual increase of 38 m³ ha^{-1}.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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