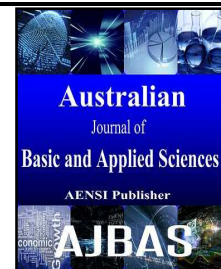




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Comparison of methods for estimating total volume of *Araucaria angustifolia* (Bertol.) Kuntze

¹Ana Paula Marques Martins, ¹Luciane Naimeke Schmidt, ¹Vinicius Costa Cysneiros, ¹Sebastião do Amaral Machado, ²Afonso Figueiredo Filho

¹ Federal University of Paraná, Department of Forest Science, Av. Lothário Meissner, 631, Jardim Botânico, 80210-170, Curitiba, Paraná, Brazil.

² State University of Midwest, Department of Forest Engineering, Ro. PR 153, km 7, Riozinho, 84500-000, Irati, Paraná, Brazil

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ABSTRACT

This study was based on data from *Araucaria angustifolia* (Bertol.) Kuntze homogeneous plantations with 24 years old, located in Quedas do Iguacu county, state of Paraná. The objective of this research was to evaluate the performance of different methods for estimating total volume for this specie. The compared methods were the volumetric equations from Schumacher-Hall, Husch and Spurr, the two diameters method and the artificial form factor. Selection of the best volume equation was based on: adjusted coefficient of determination, standard error of estimate in percentage and graphical analysis of residuals. Comparison of methodologies was made by analysis of variance (ANOVA) and the F value to detect significant differences between treatments, in which each method was considered as a treatment, and the volume obtained by Smalian was considered the control treatment. Test of Tukey was applied if necessary. Among the tested volumetric equations, the Schumacher-Hall one showed better performance according to the used evaluation criteria. Relating to the method of the two diameters, the portion of the stem that propitiated the most correlated volume with the total volume was that one between the diameters measured at 1.30 and 3.30 meters above ground. The analysis of variance showed absence of significant differences between treatments, then the application of the Tukey test was not required. Comparing the accuracy of the three methods of obtaining total volume of *Araucaria angustifolia* it was found that the most suitable volumetric model was that one from Schumacher-Hall, followed by the method of the two diameters. The form factor is the method less recommended for such estimate, since that it showed higher values of standard deviation of the differences, sum of the square of residuals and percentage of residuals.

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INTRODUCTION

The *Araucaria angustifolia* is a native species known popularly as Brazilian pine, Parana pine or simply pine. It presents average growth when compared to some exotic species; it is also the native conifer of greater economic expression of the country (Scheeren *et al.*, 1999). The natural range of this species comprising the states of Rio Grande do Sul, Santa Catarina, Parana and Sao Paulo. There are isolated occurrences of this species in Rio de Janeiro and Minas Gerais States (Hueck, 1972).

Standing out to occupy the upper canopy, the *A. angustifolia* is the main species of the mixed ombrophilous Forest, and its wood has excellent quality and commercial value, being used for various purposes. Due to this, the araucaria had been heavily

exploited in the past century, which led to its inclusion in the list of endangered species (Brasil, 2015; Scheeren *et al.*, 1999). According to Machado and Siqueira (1980), the woody industry added to indiscriminate burning for agriculture purposes led to a drastic reduction in many places, being rare to find primary forests of *A.angustifolia* with large areas.

Although it has significant commercial value, plantations of this species are still insignificant compared to the areas of commercial plantations of pine and eucalyptus genera. This can be explained by lower volume growth, demand for good site quality and lack of knowledge about the different procedencies, silvicultural and nutritional techniques that provide better relationship productivity/production cost (Hoppe and Caldeira, 2003).

Corresponding Author: Ana Paula Marques Martins, Federal University of Paraná, Department of Forest Science, Av. Lothário Meissner, 631, Jardim Botânico, 80210-170, Curitiba, Paraná, Brazil.

Due to these factors, are sought growth potential responses in *Araucaria angustifolia* plantations. Volume is one of the most important variables for the knowledge of timber potential available in forest stands, and the most common procedure to estimate this variable is from the use of volumetric equations (Oliveira *et al.*, 2011).

However, the volume of trees can also be obtained by other methods, in which there may be mentioned the method of the two diameters and the form factor. Franco (1996) tested the method of two diameters for *Eucalyptus calmadulensis* and found that this method propitiated reliable estimates of the total and commercial volume, outside and inside back, also being considered of easy work. Schröder *et al.* (2013), in a study comparing different techniques for estimating volume of *Eucalyptus grandis*, found that the methodologies that employed form factor to estimate total volume did not produce robust estimates.

Thus the objective of this study was to compare the performance of volumetric equations, method of two diameters and form factor for estimating total volume of *Araucaria angustifolia*, and identify which of these methods provides more accurate estimates.

MATERIAL AND METHODS

Characterization of the study area:

The study area comprises homogeneous stands of *Araucaria angustifolia*, located in the Quedas do Iguaçu County, central-southern of Paraná.

According to the Köppen (1936) classification, the region has climate Cfa type, mesothermal humid subtropical, with hot summers and seldom frosts, with a tendency of concentration of rains in the summer months. The average temperature of the warmest month is greater than 22 ° C and the coldest month, less than 18 ° C, without dry season (Iapar, 2015). The predominant types of soils in the study area are latosols and Nitossolos (Embrapa, 2015).

Data collection:

For this study were felled thirty trees of *Araucaria angustifolia* 24 years old which were cubed according to the Smalian method. To this end, the diameters were measured at heights of 0.1; 0.7; 1.3 and at every two meters up to the insertion point of the first branch, and after this, at every meter up to the total height. The trees were selected aiming to cover the whole diameter distribution of the stand.

Estimates of total volume outside bark:

The total volume outside bark was obtained by three methodologies: volumetric equations, method of the two diameters and form factor.

They were fit three traditional volumetric models obtained from the forest literature to estimate total volume outside bark of every tree (Table 1), which have the dependent variable volume (v) as a function of the independent variables diameter at breast height (d) and total height of the tree (h).

Table 1: Models adjusted for total volume estimate of *Araucaria angustifolia* in Quedas Iguaçu – Paraná.

Author	Model
Schumacher-Hall	$\ln(v) = b_0 + b_1 \ln(d) + b_2 \ln(h)$
Husch	$\ln(v) = b_0 + b_1 \ln(d)$
Spurr	$v = b_0 + b_1(d^2h)$

Where: v : total individual volume (m³); d : diameter at breast height (measured at 1.30 meters from the ground) (cm); h : total height (m); b_0 , b_1 , b_2 : model coefficients to be estimated.

To enable comparison between logarithmic and non-logarithmic equations we used the Meyer correction factor (FM) (1), and subsequently recalculated the standard error of estimate (S_{xy} %) and the adjusted coefficient of determination (R^2_{aj}).

$$FM = e^{0,5 (S_{yx})^2} \quad (1)$$

Where e : exponential and S_{yx} : standard error of the estimate.

The method of two diameters (2), shown by Borders and Silva (1993), seeks to evaluate the stem portion which has the highest correlation with total or commercial volume of a tree. Thus, diameters were measured at various heights of the stem, and then calculated the volumes of the short logs. The diameters used were those corresponding to the heights: 0.1; 0.7; 1.30 and 3.30 meters.

$$v = b_0 + b_1(d_1^2 + d_2^2) \quad (2)$$

Where v is the estimated total volume; d_1 and d_2 are measured diameters (used as independent

variables in the model); b_0 and b_1 are the coefficients to be estimated.

To determine the portion of the trunk whose volume was more highly related to the total volume, we applied the Pearson correlation test (r) (3).

$$r = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(\sum(x_i - \bar{x})^2)(\sum(y_i - \bar{y})^2)}} \quad (3)$$

Where x_i : volume of logs between the two diameters taken; \bar{x} : average volume of logs; y_i : observed stem volume, and; \bar{y} : average total volumes outside bark.

The parameters used for the selection of the models were the R^2_{aj} (4), the S_{xy} % (5), and also the graphic analysis of residuals.

$$R^2_{aj} = 1 - \left[(1 - R^2) \frac{n-1}{n-p-1} \right] \quad (4)$$

$$S_{xy}\% = \frac{S_{xy}}{\bar{y}} * 100 \quad (5)$$

Where n : number of observations; p : number of model coefficients; R^2 : coefficient of determination.

Such statistics were applied to select volumetric equations and help to identify the pair of diameters most suitable for the method of two diameters.

The form factor (6) was also calculated basing on the formula:

$$f_{1,3} = \frac{volarv}{volcil} \quad (6)$$

Where $f_{1,3}$: artificial form factor; *volarv*: Cubed tree volume by the Smalian formula; *volcil*: volume of the cylinder corresponding to the cross-sectional area calculated at 1.30 meters above ground.

After calculating the form factor for each tree, it was calculated their arithmetic means. Therefore, the estimated volume (7) for each tree was calculated as follows:

$$v = g * h * \bar{f}_{1,3} \quad (7)$$

Where v : total volume (m³); h : total height (m); $\bar{f}_{1,3}$: average artificial form factor; g : cross-sectional area (m²) where $g = d^2\pi / 40000$, and d : diameter at breast height (cm); π : 3.14159265.

Comparison of methods for obtaining volume:

To identify statistically significant differences between the tested volume methods was performed by the F test from the analysis of variance (ANOVA). Once observed significant differences between treatments it was applied the multiple comparison Tukey test at 5% of significance level. The tests were conducted in an experiment with a completely randomized design with four treatments, each method was considered a treatment, with 30 repetitions each. For this analysis, the cubed volume according to Smalian was considered the first treatment or control.

To evaluate the accuracy of each method for assessing the total volume outside bark for *Araucaria angustifolia*, they were calculated the additional statistics: bias (D), standard deviation of differences (SD), sum of the square of the relative deviation (SQRR), percentage of residuals (PR) (Table 2), beside the residual graphic analysis.

Table 2: Statistics used to evaluate the performance of the methods for total volume estimation for *Araucaria angustifolia* in Quedas do Iguaçu – Paraná.

Statistics	Formula
Bias (D)	$(\sum \text{Diff}_i) / N$
Standard Deviation of Differences (SD)	$[\sum (\text{Diff}_i - v_i)^2 / (N - 1)]^{0,5}$
Sum of Squared of Relative deviation (SQRR)	$\sum (\text{Diff}_i / v_i)^2$
Percentage of Residuals (PR)	$\sum (\text{Diff}_i / v_i) * 100 / N$

Where: Diff_i = volume deviations ($v_i - \hat{v}_i$) (m³); v_i = observed volume (m³); \hat{v}_i = Estimated volume (m³); N = number of trees.

To determine which method has greater accuracy of estimates was performed the ranking of the performance of each approach for each statistic used in Table 2; score 1 was attributed to the method of better performance and 3 for the worse. Equal values received identical grades. Thereafter it was carried out summation of the values, and the method with the lowest score was considered the one of the

best performance to estimate total volume for the data set.

RESULTS AND DISCUSSION

Selection and Adjustment of volumetric models:

Statistical evaluation parameters and estimated coefficients for each of the adjusted volumetric equations are presented in Table 3.

Table 3: Coefficients and statistics of each volumetric equation.

Model	b_0	b_1	b_2	R^2_{aj}	IA	S_{xy} %
Schumacher-Hall	-10,229155	1,82257091	1,28129423	0,9737	0,9768	8,26
Husch	-7,6185896	2,17407237		0,9526	0,9608	10,54
Spurr	0,06334537	0,00004192		0,9769	0,9787	7,78

Where: b_0 ; b_1 ; b_2 : estimated coefficients; R^2_{aj} : adjusted coefficient of determination; S_{xy} %: standard error of estimate in percent.

According to the criteria used for selection, the Schumacher – Hall volumetric equation was that one with the best performance, although a slight advantage of the Spurr equation, the Schumacher-Hall equation shows better graphic distribution of residuals, the Spurr equation overestimates the volume in the first diameter classes (Figure 1). Analyzing the dendrometric characteristics and soil effects on the growth of *A. angustifolia*, Santos (2006) found satisfactory adjustment and accuracy results for the Schumacher-Hall model, which corroborates with the findings in the present study. Likewise, Oliveira *et al.* (2011) mention the Schumacher-Hall model as the best one for volumetric estimate of a plantation of *A. angustifolia* in Rio Negro-PR.

Adjustment and model selection by the methods of the two diameters:

The results for the Pearson's correlation (r) between the volume of small logs and the total volume of trees, the statistical parameters of evaluation and the estimated coefficients for each of the adjusted equations are presented in Table 4.

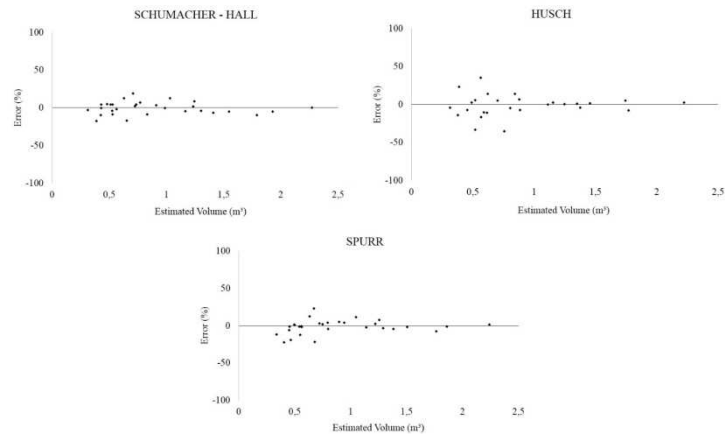


Fig. 1: Graphical Distribution of residuals for the adjusted volumetric equations.

Table 4: Estimated coefficients, correlation and selection of statistics calculated for each equation generated by the method of two diameters for each tested stem portion.

Stemportions	Volume				
	r	R^2_{aj}	$S_{xy}\%$	b_0	b_1
0,1 - 0,7	0,9488	0,8967	17,42	0,009778	0,000370
0,1 - 1,3	0,9542	0,9074	16,49	0,000296	0,000385
0,1 - 3,3	0,9652	0,9291	14,42	-0,008166	0,000404
0,7 - 1,3	0,9699	0,9385	13,44	-0,071380	0,000483
0,7 - 3,3	0,9812	0,9614	10,65	-0,079934	0,000509
1,3 - 3,3	0,9842	0,9675	9,77	-0,086108	0,000532

Where: b_0 ; b_1 : estimated coefficients for the regression; r : Pearson's correlation coefficient; R^2_{aj} : adjusted coefficient of determination; $S_{xy}\%$: standard error of the estimate in percentage.

According to Table 4, it is observed that the portion of the stem that propitiate more correlated with the total volume outside back, was that one corresponding to the diameters measured at 1.30 and 3.30 meters above ground, presenting the largest correlation coefficient from Pearson and very close to 1, indicating a strong correlation between the volume of the selected portion and the total volume.

Reinforcing the choice of this portion of the trunk, it is possible to observe that it also led to the best results in terms of other selection of statistics, ie greater R^2_{aj} (0.9675) and lower $S_{xy}\%$ (9.77%) and still good graphic distribution of residuals (Figure 2).

Analyzing the results obtained by this method (Table 4), it is observed negative effect of variability of the stem base shape on the accuracy of estimates;

the worst results were obtained when using small logs close to the ground.

Franco *et al.* (1997) testing the method of two diameters for estimating volume of *Eucalyptus camaldulensis*, found as the most efficient, the portion of the stem between 1.3 and 3.0 meters, and lists the highest errors for the small logs closer to the ground pointing out evident the lower efficiency of those which are influenced by the variable shape of the base of the tree.

Estimated volume by the average artificial form factor method:

From the calculated arithmetic mean form factor (0.582614), they were estimated the volumes of every tree and them was done the graphic of residuals distribution as shown Figure 3.

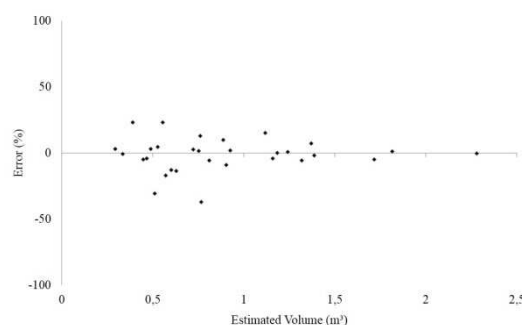


Fig. 2: Residuals distribution on the estimated volume by the method of two diameters.

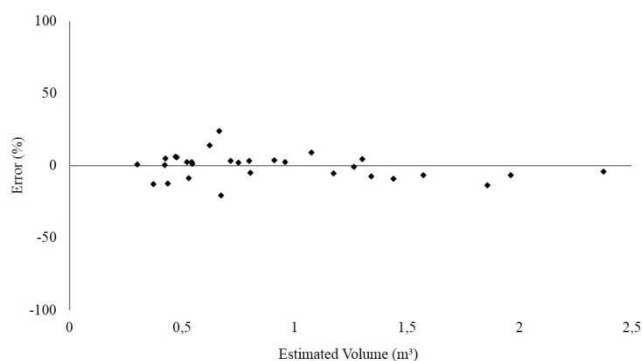


Fig. 3: Distribution of residuals on estimated total volume.

According to Figure 3 it can be observed that the estimated total volumes outside bark using the artificial average form factor have a tendency to overestimate the volumes above 1.3 cubic meters.

Comparison of methods for estimating total volume outside bark:

The analysis of variance (ANOVA) for the estimated volume obtained by the different compared methods are presented in Table 5. It is noted that the F value was not significant at 95% of probability, which confirms the null hypothesis (H_0) that the averages are equal. So it was not necessary to perform the multiple comparison test of Tukey.

Machado *et al.* (2005) comparing different methodologies for *Pinus* volume estimate at different ages and different management regimes in the state of Sao Paulo, did not found significant differences between treatments by the F value from the variance analysis. The treatments used by these authors were: cubed volume by Smalian, volume equation, taper equation and form factor.

Conceição (2004) evaluating the performance of the same volume estimation methodologies used by Machado *et al.* (2005) cited above, but for *Eucalyptus grandis*, also verified no significant differences between treatments by analysis of variance.

Table 5: Analysis of Variance (ANOVA) to compare the four volume estimation methodologies.

Variation source	Degrees of freedom	Sum of Squares	Mean Square	F	P-value
Factor	3	0,003411	0,001137	0,004575	0,999571
Residuals	116	28,82497	0,248491		

Comparing the accuracy of the three volume estimation methods tested in this study (Table 6) by complementary statistics, it is observed lower efficiency of the form factor method, due to higher modular values of standard deviation of differences, sum of square relative residual and percent of residuals. The volumetric model from Schumacher-Hall and the method of the two diameters fitted to the

data set presented good accuracy of estimates, propitiating reliable statistics of deviation of mean values, sum of squared of relative residuals. The same statistics were used by Pelissari *et al.* (2011) in a complementary way to check volumetric models for tropical pine species, being used as a defining criterion of the most appropriate model.

Table 6: Bias (D), standard deviation of differences (SD), sum of the square of the relative deviation (SQRR), and percentage of residuals (PR) to estimate volume outside bark for *Araucaria angustifolia*.

Model	D	SD	SQRR	PR	Ranking
Schumacher-Hall	-0,0028442	1,04456	2,41649	-0,9342	1
Twodiameters	-6,10623E-17	1,031431	3,485351	-1,38209	2
Form fator	-0,012964544	1,065353	4,232091	-0,79546	3

When considered the statistics $S_{xy}\%$ and R^2_{aj} already discussed, the choice of the Schumacher-Hall volumetric model, followed by the method of the two diameters is justified due to minor errors generated by the estimates, which shows good accuracy and adjustment.

In general, the volumetric models found in forest literature exhibit superior performance relatively to the other estimation methods, however, it is proven equivalent efficiency of the method of two diameters. Note that this method eliminates the need for

measurement of height, which according to Soares *et al.* (2007) can be a source of errors in forest inventory, beside optimizing the time of collecting field data. Moreover, depending on the portion of the trunk that has the highest correlation with the total volume, the field work can become impracticable without the aid of specialized equipment or even felling down the tree. The results obtained in this research, show that the best model generated in the method of two diameters requires the measurement

of diameter at the height of 3.3m, which is not accessible directly.

Conclusion:

The Schumacher-Hall volumetric model was the most precise and accurate out of the three tested one for estimate volume of *Araucaria angustifolia* in homogeneous stands followed by the method of the two diameters, and finally by the form factor method.

Although the small differences in precision and accuracy of the tested methods, the analysis of variance not showed significant differences at 5 % level among estimated volumes by the three methods when compared to the control method.

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