

Full Length Research Paper

Volumetric models for *Eucalyptus grandis* x *urophylla* in a crop-livestock-forest integration (CLFI) system in the Brazilian cerrado

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The influence of the forest component in the crop-livestock-forest integration system depends on several factors, among which are the plant species used and the row spacing established in system deployment. Therefore, the objective of this study was to characterize the tree component dendrometrically using *Eucalyptus grandis* x *urograndis* individuals from the CLFI system and to determine the model fit with volumetric models of homogeneous stands. The study area consists of a six year old CLFI system of *Eucalyptus grandis* x *urophylla*, located at the municipality of Cachoeira Dourada – GO. Forest inventory and volume measurement were carried out through the Smalian method. The hypsometric relations of *Eucalyptus urograndis* were adjusted to seven volumetric models. The arrangement proposed in the crop-livestock-forest integration system (CLFI) was efficient. The models tested (Näslund, Ogaya, Schumacher & Hall, Spurr logarithmic, Honner, Takata and Husch) showed adjustments above 87%, where the models Näslund (99.53%) and Ogaya (99.17%) had the best fit.

Key words: Näslund, Ogaya, wood production.

INTRODUCTION

The economic growth in Brazil is highly connected to the agricultural and livestock sector (Macedo, 2009). Activities involving agricultural and livestock production are the main sources of financial income and, consequently, the main land use conversion and human

occupation factors since the 70s in the Cerrado biome (Klink and Machado, 2005; Sano et al., 2008).

The agricultural and livestock sector has undergone major transformations due to the increase in production costs and more competitive market, demanding

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increased productivity, quality and profitability, without harming the environment. An alternative that has stood out in the last years to reach these objectives is to use an integration system that incorporates agricultural, livestock and forestry activities, in a single spatial and/or temporal dimension, seeking a synergistic effect between the agroecosystem components for the sustainability of the production unit, while contemplating its environmental suitability and the enhancement of the natural capital (Balbino et al., 2011).

The area planted with trees in Brazil reached 7.60 million hectares in 2013. In the same year, Brazilian consumption of wood from planted trees for industrial use was 185.3 million cubic meters (m^3) (IBÁ, 2014). Different planting systems have been adopted in the last decades to combine production and economic growth, mitigating the negative impacts which the agricultural production can exert on natural ecosystems (Macedo, 2009). The crop-livestock-forest integration (CLFI), also known as agrosilvopastoral system, is one of the systems recognized as an alternative to encourage the recovery of degraded areas and environmental conservation, in addition to the financial gains from agricultural and livestock production (Macedo, 2009; Paciullo et al., 2011). Mixed crop-livestock farming systems comprise a key element of the world's land use and agricultural production. About 25 M km^2 of land is used worldwide for mixed farming (de Haan et al., 1997; Euclides et al., 2010), including most of the world's croplands and 30-40% of its grazing area. Rainfed mixed farming systems alone produce just under half the beef, a third of sheepmeat and half of milk of the world (Steinfeld et al., 2006). In Australia, mixed crop-livestock farming has also been a major and longstanding feature of agricultural land use; in 2010, about 0.35-0.40 M km^2 of land, a third of the agricultural zone, was occupied by farms, operating both cropping and livestock enterprises (Bell and Moore, 2012).

The crop-livestock (CLI), crop-forest (CFI), livestock-forest (LFI), crop-livestock-forest (CLFI) integrated production systems are different production systems, intentionally combined, which enable the diversification of economic activities on the property (same physical and temporal space), however large, medium or of family farms. Thereby, such integrated systems provide viable and sustainable production. The integration consists entirely on the diversification and integration of different production systems (EMBRAPA, 2015).

The CLFI consists primarily of intercropping products derived from the three components (crop, livestock and forest) in the same area, where each activity tends to benefit each other and facilitate the maintenance of ecosystem balance, in addition to the recovery of degraded areas (especially degraded pastures). The model also provides income diversification, as it provides marketing of more than one product (Macedo, 2009; Paciullo et al., 2011; Balbino et al., 2012; Castro, 2013).

The species (tree, pasture or culture) to be used must have a cooperation behavior, where one species complements, completes or assists the development of the other. The species interact in influencing nutrient cycling for each, the availability of lighting each plant strata receive and improving microclimatic conditions becoming more favorable environment for the development for all groups. The influence of the forest component (trees) on a system depends on several factors, among which are the plant species used and the spacing established in system deployment (Paciullo et al., 2011; Pezzopane et al., 2015).

Therefore, the main objective of this study was to characterize the dendrometry and adjustment of volumetric models for *Eucalyptus grandis* x *urograndis* in a crop-livestock-forest integration system (CLFI) located in southern State of Goiás.

MATERIALS AND METHODS

Study area

This study was conducted in a Technology Reference Unit (TRU; Unidade de referência Tecnológica) of Embrapa, located in the Boa Vereda Farm, municipality of Cachoeira Dourada – GO (Southern state of Goiás, Brazil; latitude 18°29'30" and longitude 49°28'30"). The farm is located at an average altitude of 459 m with regards to sea level, within the Cerrado biome.

Climatic characteristics

According to Köppen, the climate is Aw (tropical weather with a dry season in winter). This climate type is typical of the tropical humid climates, with two well defined seasons – dry winter and wet summer, average annual temperature of 24°C and average annual precipitation of 1.340 mm occurring from October to March (Alvares et al., 2013).

Land use and characteristics

The prevailing soil of the area is a clayey Oxisol. The study area is 15 hectares, and consists of a crop-livestock-forest integration system (CLFI). In this CLFI, six years old eucalyptus occur, planted in triple lines (3 x 2 m), with brachiaria pasture (*Urochloa brizantha* (Stapf) Webster) in the space between the three triple lines (14 m) and grazing animals, rotated with other areas, at three heads per hectare (Figure 1).

Forest inventory

The forest component studied was an *Eucalyptus grandis* x *urograndis* clone planted in February 2009, following an arrangement of rows in three lines of trees spaced three meters between rows, two meters between plants and 14 meters between lines. The forest inventory of the crop-livestock-forest integration system, comprising the tree component (eucalyptus clones) was carried out in November 2014. The diameter at breast height (DBH: diameter at 1.30 m in height relative to ground level) was measured. Height measurement and estimation values were obtained as follows. Three specimens were randomly selected,

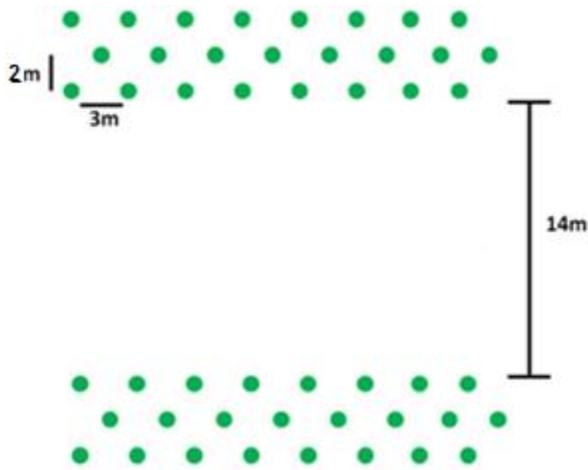


Figure 1. Outline of the area showing the arrangement of the eucalyptus trees in the crop-livestock-forest integration system at Cachoeira Dourada, Goiás.

disregarding plants located at the edges. Then, the diameter of the three specimens and height of a specimen located between the three were obtained.

The total height of the trees was estimated using an electronic inclinometer, (Haglof), and the DBH using a bevel gauge (adapted from Venturoli, 2015). Regular intervals of 12 m between each site were used to determine sampling sequence. Tree density was calculated, based on the spacing among trees (between rows and lines).

Rigorous tree scaling and volume

The trees were separated into five classes according to the rule of Sturges (Machado et al., 2010) after the forest inventory. The first class comprises trees of DBH values ranging from 5 to 10 cm, the second DBH from 10 to 15 cm, the third 15 to 20 cm the fourth 20 to 25 cm and the fifth class had DBH from 25 to 30 cm. The first class was excluded for having only two individuals. Three individuals were considered to represent each of the other classes, namely the trees with DBH with values of the extremities and the center of the class. The trees were harvested and subjected to a rigorous tree scaling, following Smalian (Soares et al., 2006), with sections of 1.0 m in length until the total height of each tree is obtained.

Statistical data analysis

The DBH and height of each plant were related to determine the hypsometric relations of the *Eucalyptus urograndis*. A linear regression (95% significance) was conducted to assess the relationship between the variables, observing the regression coefficient and residue distribution. A total of seven models were adjusted. The DBH was measured at 1.30 m height (X_1 ; cm), and the total tree height (X_2 , m) were the independent variables and the total and stem volumes, with the bark were the dependent variables. The volumetric models used are described below:

$$\text{Näslund: } Y = \beta_0 X_1^2 + \beta_1 X_1^2 X_2 + \beta_2 X_1 X_2^2 + \beta_3 X_2^2;$$

$$\text{Ogaya: } Y = X_1^2 (\beta_0 + \beta_1 X_2);$$

$$\text{Schumacher \& Hall: } Y = \beta_0 X_1^{\beta_1} X_2^{\beta_2};$$

$$\text{Logaritimica de Spurr: } Y = \beta_0 (X_1^2 X_2)^{\beta_1};$$

$$\text{Honner: } Y = X_1^2 / (\beta_0 + \beta_1 X_2);$$

$$\text{Takata: } Y = (X_1^2 X_2) / (\beta_0 + \beta_1 X_1);$$

$$\text{Husch: } Y = \beta_0 X_1^{\beta_1}.$$

Where:

X_1 = Diameter at breast height (DBH; cm); X_2 = height (m); β_0 = estimated height value when the diameter is zero; β_1 = slope of the line, corresponding to the value of the first derivative; β_2 = rate of change in volume (m^3) as height (m) variation occurs, with constant DBH (cm); β_3 = coefficient of the multivariate model.

The adjusted coefficient of determination, the corrected and percentage residual standard error, and graphical analysis of residues were used as model selection criterion. Coefficient of determination (R^2) shows how much of the variation of the dependent variable is explained by the independent variables. Therefore, coefficient of determination values close to 1 indicates better fit and other criteria.

The residual standard error (S_{yx}) measures the average dispersion between the observed and estimated values along the regression line. Smaller residual standard error values indicate better fit. The residual standard error had to be transformed in the models where the characteristic of interest or dependent variable undergoes transformation.

The coefficient of determination and the residual standard error were not used alone to assess the model accuracy, given that these measures may provide distorted information regarding model adjustment. A graphic residue analysis was used in complement. This analysis is decisive in assessing model quality, once it enables the detection of possible bias in estimating the dependent variable along the regression curve.

RESULTS

Dendrometric characterization

The crop-livestock-forest integration system has 845 trees per hectare (177 dead and 668 live trees per hectare). Most *E. urograndis* trees (327 individuals per hectare) in the system occur within the 20 - 25 cm DBH class, followed by the 15 - 20 class (289 individuals) (Table 1). The individuals of these two classes comprise 91% of the trees of the integration system.

The average DBH of the trees was 18.63 cm and the average estimated height was 23.88 m. The average volume per tree is 0.378 m^3 , total increase of $0.063 \text{ m}^3/\text{year}/\text{tree}$ (Figure 2).

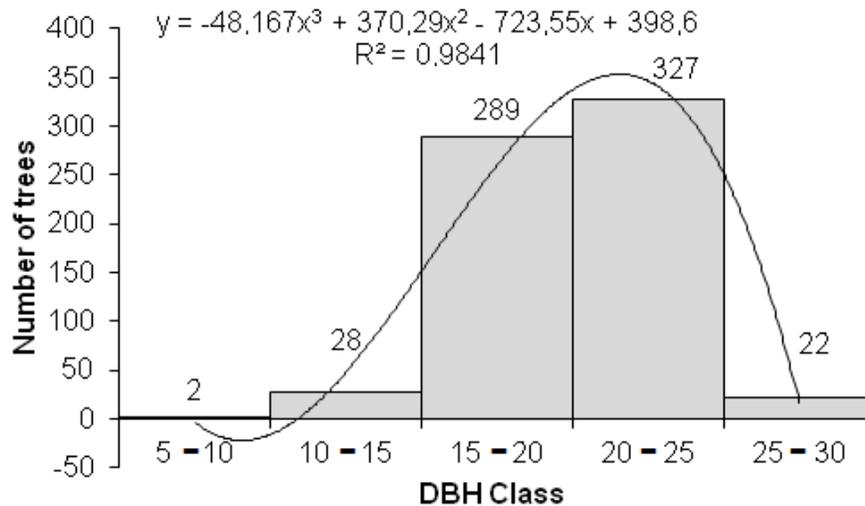
Volumetry

The average volume per tree at six years of age in the CLFI integrated system is 0.378 m^3 . The total volume is $259.93 \text{ m}^3/\text{ha}$, with an annual increase of $43.32 \text{ m}^3/\text{ha}/\text{year}$. The annual increase in volume per tree is $0.063 \text{ m}^3/\text{year}$. The DBH class 20 - 25 cm had the highest contribution (Table 2).

About 52.24% of the trees in the eucalyptus plantation exhibited DBH values in the 20 - 30 cm class, and

Table 1. Characteristics of the inventory of the eucalyptus forest of the crop-livestock-forest integration system of Cachoeira Dourada, Goiás.

Characteristics	Values
Number of trees (N/ha)	845
Number of dead trees (N/ha)	177
Average DBH (cm/tree)	18.63
Average height (m/tree)	23.88
Average volume (m ³ /tree)	0.378
Total volume (m ³)	259.93

**Figure 2.** Distribution of the diameter (DBH) of the eucalyptus trees of the crop-livestock-forest integration system of Cachoeira Dourada, Goiás.**Table 2.** Wood volume for the Eucalyptus of the integrated crop-livestock-forest system located at Cachoeira Dourada, Goiás.

Class	Number of trees	Volume (m ³)	Volume (m ³ /ha)	Volume (m ³ - population)
5 - 10	2	-	-	-
10 - 15	28	0.127	3.58	5.97
15 - 20	289	0.284	82.12	136.86
20 - 25	327	0.491	160.78	267.97
25 - 30	22	0.611	13.44	22.40
Total	668		259.93	433.22

43.26% in the 15 - 20 cm class. Therefore, over 95% of the trees had diameter between 15 and 30 cm. Volumetry by DBH class in the crop-livestock-forest integration system (CLFI) is shown in Figure 3.

Hypsometric relations

Figure 4 shows the hypsometric equations for Eucalyptus

grandis x *urograndis* and the DBH residue distribution. The adjustments for volumetric models for *E. urograndis* in the crop-livestock-forest integration system (CLFI) are shown in Table 3. The models of Näslund (99.5%) and Ogaya (99.1%) were considered the most predictive and efficient to predict wood volume in the CLFI. Still, all tested models have model adjustments above 87%, with statistical significance and low standard error. Residue distribution is shown in Figure 5.

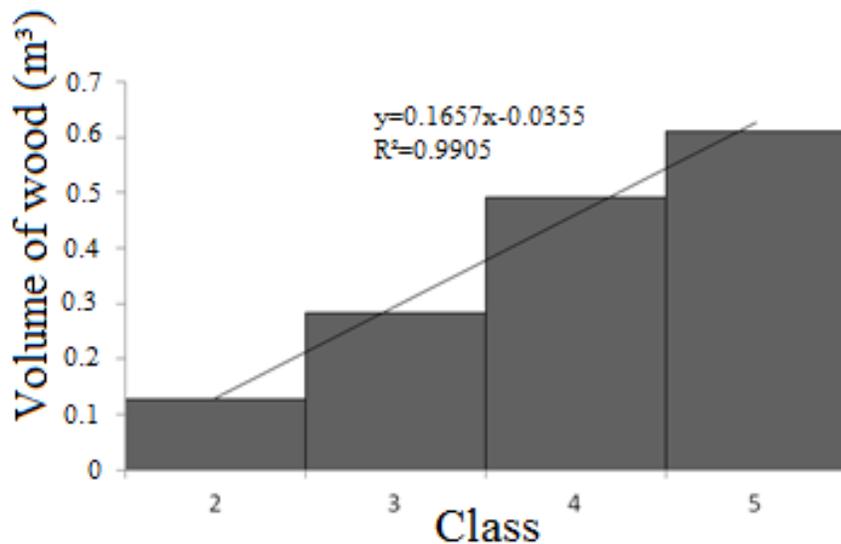


Figure 3. Volume per class of Eucalyptus of the crop-livestock-forest integrated system in Cachoeira Dourada, Goiás.

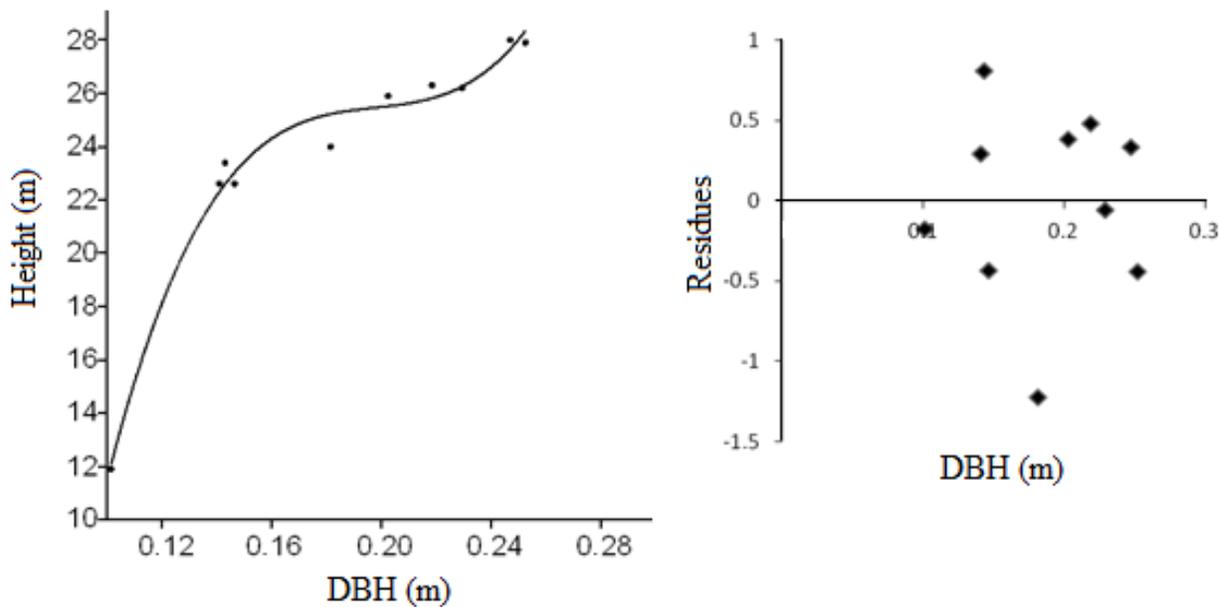


Figure 4. A. Hypsometric equations for *Eucalyptus grandis* x *urograndis* (X: DBHS; Y: Height $Y=13832.2X^3-8204.41X^2+1633.21X-83.64$; $R^2= 0.9838$ $p= 0.000$). B. Distribution of the residues of the DBH of *Eucalyptus grandis* x *urograndis* in a crop-livestock-forest integration system at Cachoeira Dourada, Goiás.

DISCUSSION

The eucalyptus volume in the crop-livestock-forest integration system is 259.93 m³/ha for the entire area of the system. However, the volume increases to 433.22 m³/ha when only the Eucalyptus area is accounted for separately. Vieira et al. (2012), studying an 18-month old

population of the hybrid *Eucalyptus urograndis*, found a volume of only 21.2 m³/ha, explained by the low age of the plants. Thus, there is an estimated gain in volume of approximately 79 m³/ha/year considering the current volumetry in this study, using a six and a half old population. In a later study, Vieira et al. (2013) found a volume of 444.3 m³/ha in a ten year old population of *E.*

Table 3. Adjustments of volumetric models for *E. urograndis* in a crop-livestock-forest integration system located at Cachoeira Dourada, Goiás.

Models	Coefficients				R ²	S _{yx} (m ³)
	β_0	β_1	β_2	β_3		
Näslund: $Y = \beta_0 DBH^2 + \beta_1 DBH^2 H + \beta_2 DBH \cdot H^2 + \beta_3 H^2$	3.98651	-0.5114	0.00936	0.0008	0.9953	0.0130
Ogaya: $Y = DBH^2 (\beta_0 + \beta_1 H)$	0.01637	0.33212	-	-	0.9917	0.0173
Logarithmic Schumacher & Hall: $Y = \beta_0 DBH^{\beta_1} H^{\beta_2}$	0.47260	2.07027	0.56456	-	0.8793	0.2594
Spurr Logarithmic: $Y = \beta_0 (DBH^2 H)^{\beta_1}$	-1.0474	0.90263	-	-	0.8990	0.2372
Honner: $Y = DBH^2 / (\beta_0 + \beta_1 H)$	-0.1534	327.848	-	-	0.9583	0.0389
Takata: $Y = (DBH^2 H) / (\beta_0 + \beta_1 DBH)$	-0.1310	0.0999	-	-	0.9892	0.0197
Husch: $Y = \beta_0 DBH^{\beta_1}$	-0.3510	3.66667	-	-	0.9607	0.0378

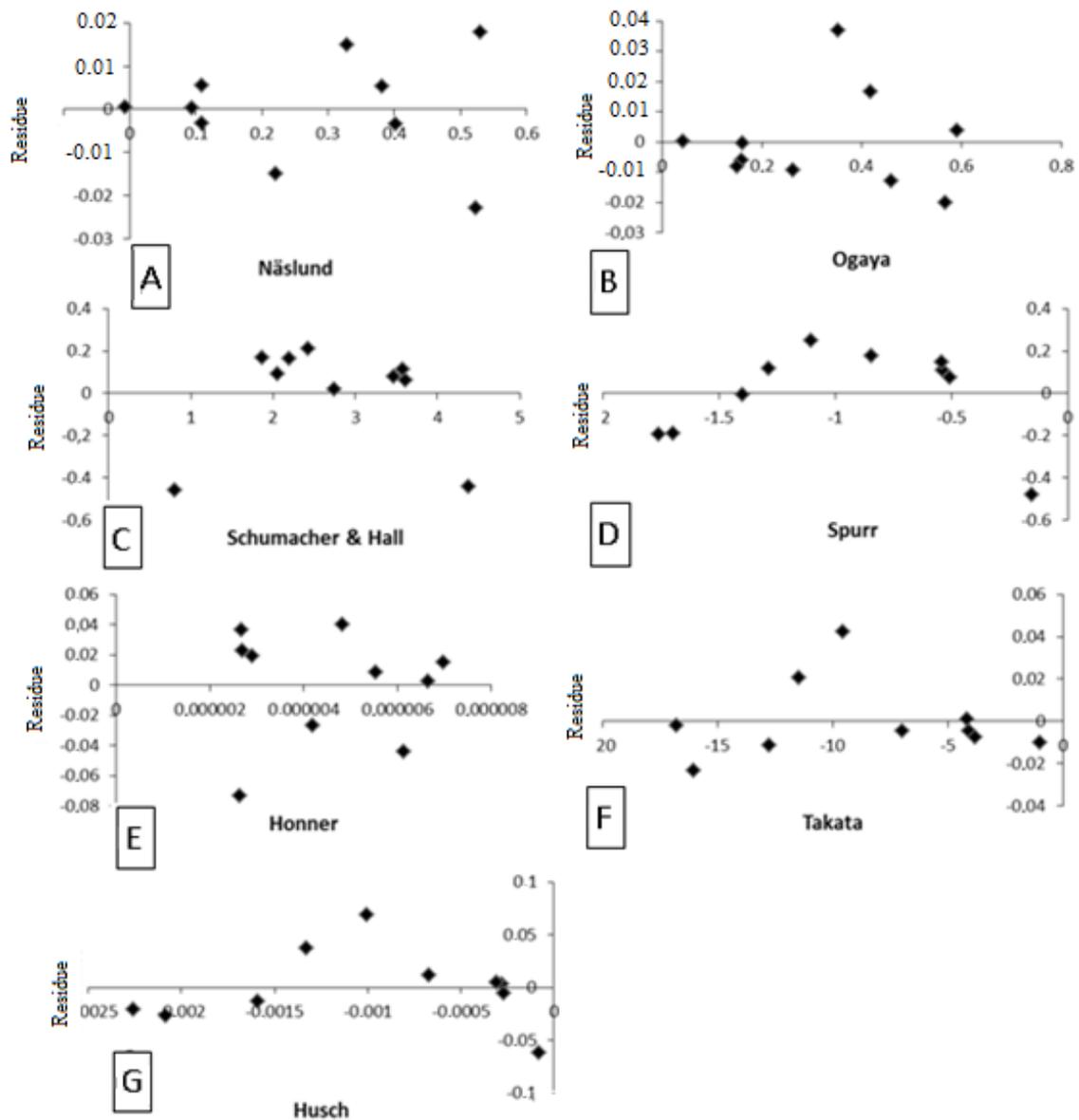


Figure 5. Residue distribution for the volumetric models for *E. urograndis* from a crop-livestock-forest integration system located at Cachoeira Dourada, Goiás.

urophylla x *E. globulus*. Different *Eucalyptus* species yielded volumes of 344.4 m³/ha for six-year-old populations and 414.0 m³/ha for eight-year-old populations in small farms of Santa Catarina (Schumacher et al., 2011).

Different genetic material of six-year-old *E. grandis* and *E. saligna*, in different regions of the state of São Paulo had a volume of wood ranging from 228 to 473 m³/ha (Santana et al., 1999). This pioneering study shows how variable the dendrometric characteristics of the plantation is, taking into account the chosen genetic material and cultural management strategies suitable for the region. Thus, knowing the characteristics of the integrated system becomes relevant to enhance silvicultural practices and obtain improved production yields.

The dynamics existing among the components influences the growth and dynamics of each component within an agrosilvopastoral system (similar to the CLFI). The tree system is a key component, strongly influenced by light entrance and nutrient cycling (Carvalho et al., 2002). Müller et al. (2005) recorded ten year old *E. grandis* producing near 40 m³ of wood for 60 trees (0.67 m³ per trees) in an agrosilvopastoral system located at the zona da mata (state of Minas Gerais) area. These results resemble the ones recorded in this study, and show the relevance of this production system providing results that exceed productivity with regards to volume and biomass when compared with dense stands of eucalyptus.

Modelling procedures are used in decision making processes held to implement and manage native and exotic forest species. Thus, overestimating or underestimating the volume of wood of an enterprise may compromise decision-making. Modelling procedures are the most indicated to evaluate the economic viability of an agroforestry system, obtaining the wood volume data required for evaluation (Salles et al., 2012).

The non-logarithmic models yielded the best results among the models adjusted to estimate the volume of *E. urograndis* in the crop-livestock-forest integration system with regards to fit and predictability, probably due to the homogeneity of eucalyptus trees (clones) and low number of available trees for slaughtering and rigorous scaling (Venturoli and Morales, 2013).

Salles et al. (2012) prefer the Clutter model to adjust tree volumes in CLFI systems, considering it is efficient to estimate volumes. Therefore, the Clutter model shows the relevance of the adjustment of other models and the need to improve prediction and estimations of volumes of tree of agroforestry systems, in order to improve decisions regarding management of the tree component of this system. The adjusted models in this work may be adjusted for other data sets providing information to reduce costs and optimize the management of agricultural systems integrated with planted forests. Thus, these results are the basis for timber volume estimates and biomass of tree in integrated systems and can be

used as a reference for other systems even with other forest species at different spacing.

Conclusion

The arrangement proposed in crop-livestock-forest integration system (CLFI), proves to be efficient. The models tested (Näslund, Ogaya, Schumacher & Hall, Spurr Logarithmic, Honner, Takata and Husch) exhibited adjustment values higher than 87%, whereas the models of Näslund (99.53%) and Ogaya (99.17%) were the best.

Conflict of Interests

The authors have not declared any conflict of interests.

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