__ORIGINAL RESEARCH ARTICLE__

COMPONENTS OF TREE BIOMASS IN AN INTEGRATED CROP-LIVESTOCK-FOREST SYSTEM

ABSTRACT

Aims: This study performed the adjustment of volumetric models, and determined the biomass of *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid cultivated in a crop-livestock-forest integration system (CLF).

Study design: The experimental area consists of a crop-livestock-forest integration system where trees are hybrids clones of seven year old *Eucalyptus grandis* x *Eucalyptus urophylla*.

Place and duration of study: This work was carried out at Fazenda Santa Brígida, Ipameri, Goiás (Brazil).

Methodology: A forest inventory of the area was carried out in October 2015 when the tree component was fully developed. Diameter at breast height (DBH) (at 1.30 m) and total height (H) of trees were measured in the field and categorized according to 4 classes. Afterwards, 12 trees were felled, which were cubed and compartmentalized to determine the volume and biomass of their components. The volumetric models developed by Schumacher & Hall and Ogaya were applied to obtain determination coefficients.

Results: The average DBH was 18.28 cm and the average H was 23.47 m. The highest volumes of wood were observed in the diametric classes that presented the largest number of individuals, however in the class of higher DBH an average individual volume of 0.36 m^3 of wood was observed. The total biomass of *Eucalyptus* was 56.64 Mg ha^{-1}, being 83.70% wood, 6.52% in branches, 6.37% in bark and 3.40% in leaves.

Conclusion: The volumetric models developed by Schumacher and Hall as well as Ogaya were found to be applicable for estimating the volume of wood in CLF systems, where both

showed a determination coefficient of 0.866.

Keywords: *compartmentalization; eucalyptus; CLFS; volume*, *modeling*

1. INTRODUCTION

Crop-livestock-forest (CLF) integration has been proposed as an economically viable production technology for the recovery and renovation of degraded areas in the Cerrados, a vast tropical savanna ecoregion of Brazil [1]. The main habitat types of the Cerrado include: forest savanna, wooded savanna, park savanna and gramineous-woody savanna. Savanna wetlands and gallery forests are also included.

In addition to the formation or recovery of pastures, this technique favors the production of grain cultivars along with the exploitation of tree biomass production, either simultaneously, sequentially, or rotationally [2]. The intensification of the production has several benefits to the producer and the environment, such as: improving the physical, chemical, and biological conditions of the soil, increasing the cycling and efficiency for the use of nutrients, reducing production costs of agriculture and livestock, opening new areas for production, as well as diversifying and stabilizing the income of the producer [3]. The included tree component biomass promotes benefits ranging from soil protection to availability of nutrients and organic matter in the soil by the deposition of leaves and tree branches [4,5].

Eucalyptus has been presented as a good option in the integrated CLF due to its rustic nature, rapid growth, great utilization, and economic value in the market, being an alternative for farmers interested in wood production [6]. The rapid growth of the eucalyptus in Brazil can be explained by the large investment of the companies in order to achieve the demand of the silvicultural products. The high productivity of stands planted by the Brazilian forest companies is recognized worldwide, due to the higher average productivity the minimum time required until harvesting, continuous investment in research on genetic improvement and silvicultural. The preservation and maintenance of native forests to preserve the biodiversity, makes planted forests even more important for preservation, because they have high productivity in a short period of time, avoid exploration of natural forests. These plantations, besides providing different products, also help with carbon sequestration, while also maintaining animal biodiversity [7,8].

In the integration of CLF, one of the challenges lies in the careful planning of the system in defining short, medium, and long-term actions. The competition for light between forest species and agricultural and pastoral crops requires special attention, as this directly influences the productivity of the system. However, this competition can be reduced by selecting genetic material, adapting the planting arrangement of the tree component, and silvicultural treatments, which, in addition to adding value to the wood, also allows for greater light entry into the integration system that contributes to the maintenance or increase in the productivity of the other components, as pasture and agricultural culture [9,2].

The configuration of tree component arrangements may influence plant height, diameter of breast height (DBH), and volume of wood. Clemente [10] verified that integrated systems with single and double row arrangements provided higher volumes of wood. In their study, Oliveira et al. [11] verified higher volumes of *Eucalyptus* wood in integrated systems with forages, than in monoculture.

The balanced relationship between the integrated CLF components is important for the expression of the productive potential of the species involved. In the case of tree species, especially the fast-growing ones such as *Eucalyptus*, accumulation and biomass production are influenced by age of trees, among other factors. In the juvenile phase, accumulation is higher in the canopy components, whereas a greater increase of biomass in the trunk component is perceived over time [12].

However, this work had the aim of adjusting volumetric models and determining the biomass of the *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid cultivated in an integrated crop-livestock-forest (CLF) system in Ipameri / Goiás (Brazil).

2. MATERIALS AND METHODS

This study was carried out at Fazenda Santa Brígida in the municipality of Ipameri – Goiás (Brazil), located at 17^{o} 39’22” south latitude and longitude west of 48^{o} 12’22”, and at an altitude of 800 m a.s.l. [11]. According to the classification of Köppen-Geiger [13], the climate of the region is Aw (tropical savannah with dry season in winter), and the average temperature of the region varies between 22 and 23^{o}C. The mean annual rainfall is between 1200 and 1400 mm, having a wet period of seven months from October to April, and the remaining five months characterize the dry season.

According to Embrapa [14], the soil of the experimental area is classified as red latosol, being naturally acidic and with low base saturation with good drainage and sand-clay texture.

The experimental area consists of an integrated crop-livestock-forest system that tends towards the east-west direction. Tree planting was carried out with clones of the hybrid *Eucalyptus grandis* x *Eucalyptus urophylla* (GG 100) in 2008 in an area of approximately four hectares (ha). The trees were arranged in double rows (1 m x 1 m x 26 m), occupying 1.4 ha of the total area of the system [11].

Before establishment of the seedlings, soil acidity was corrected with the use of two tons per hectare of dolomitic limestone and one ton of gypsum. At planting, the base fertilization used was 400 kg ha^{-1} of yoorin thermophosphate and 180 grams (g ha^{-1}) of NPK formulation 06-30-30, supplemented with 0.4 g ha^{-1} of zinc, 0.2 g ha^{-1} copper, and 0.2 g ha^{-1} boron. The half of this composition was incorporated into the bottom of the planting pit, and the remainder was distributed 20 days after planting in two lateral holes located 10 cm from the seedlings.

15 months after of planting, a pruning was performed, and at 30 months, the third cover fertilization was applied using NPK formulation 00 - 00 - 36 with the addition of 0.2 g ha^{-1} of copper and 0.6 g ha^{-1} of boron per plant, provided in continuous fillet in the crown projection.

2.1 Determination of *Eucalyptus* biomass

The forest inventory of the area was carried out in October 2015 when the tree component was fully developed, seven years after planting. DBH (diameter at breast height at 1.30 m above soil level) and H (total height of trees) were measured in the field with the aid of a caliper and the use of a clinometer. For the of DBH and H measurements, a systematic sampling was carried out with regular intervals on every sixth tree line in which measurements were made on the two individuals that composed it.

Based on the data obtained from the forest inventory, the trees were distributed in four classes of diameters (Table 1). Subsequently, three individuals were felled for sampling in each diameter class, considering the lower, middle, and upper limits, totaling 12 trees.

Table 1. Diametric distribution (cm) of Eucalyptus in the integrated CLF system.

Class interval	Class center	Number of sampled individuals
9 ⊢—⊣14	11.5	16
14.1 – ⊣19	16.5	59
19.1 – ⊣24	21.5	80
24.1 – ⊣29	26.5	6

After the trees were felled, they were subjected to rigorous sampling, according to the method developed by Smalian and described by Finger [15]. The height points for taking diameters with and without bark were: 0.10 m, 0.30 m, 1.30 m, 2.30 m, and so on, at one meter intervals up to full height.

After measuring the diameters, the trunk was sectioned into 1 m long logs to the point where the diameter was seven centimeters (commercial diameter). From there, up to a diameter of three centimeters was considered as tip of the trees, and the remaining portions to the apex were considered branches. For the determination of the dry weight of wood, the methodology developed by Schumacher [16] was used, in which three samples were taken along the trunk. The total height of the tree was divided into three sections, and the midpoint of each third of the tree was taken to compose the sample. Each sampling point was composed of the complete disc of the tree cylinder that had a thickness of ten centimeters.

After sectioning, the logs were weighed both with and without bark to determine the wet weight of the wood and bark. The tree canopy, in turn, was divided into two components: leaves and branches. These components were also weighed in the field and properly sampled to determine the dry weight in the laboratory, as well as to determine wood biomass (WB), branch biomass (BB), and leaf biomass (LB).

The biomass samples were sent to the Forest Ecology Laboratory (ECOFLOR) of the Federal University of Goiás. They were placed in a force air circulation oven at 65ºC for drying until the weight of the samples remained stable to obtain the dry mass of the components with a precision digital scale (0.01 g).

2.2 Data analysis

In order to relate the DBHs and biomass components of each tree, linear regressions were performed for each component: wood, bark, branches, and leaves. For the volumetric models, the DBH and the total height of the tree were considered the independent variables, and the total volumes and the trunk with the bark were dependent variables. Four volumetric models, one single-entry and three double-entry, were chosen because they were the most used for the quantification of the production in forest stands and have not yet been tested in integrated CLF systems. The models tested are described in Table 2.

Table 2. Volumetric models tested.

Author	Type	Model
Husch	Single entry	$V = \beta_0 + \beta_1 DAP$
Ogaya	Double entry	$V = DAP^2 (\beta_0 + \beta_1 H)$
Schumacher & Hall (log)	Double entry	$V = \beta_0 + \beta_1 Ln(DAP) + \beta_2 Ln(H)$
Spurr (log)	Double entry	$V = \beta_0 + \beta_1 Ln(DAP^2 H)$

DBH= diameter at breast height; H = total height; β_0 = value of the height estimated when the diameter is zero; β_1 = slope of the line, which corresponds to the value of the first derivative; β_2 = rate of change in volume (m³) as height (m) variation occurs with constant DBH (cm); β_3 = coefficient of the multivariate model.

The volumetric models were adjusted and evaluated by means of adjustment and precision statistics, following the importance proposed by Draper and Smith [17]: graphical analysis of the residues; estimate of the standard error in percentage (Syx%) that indicates the proximity between the estimated values and those observed and the closer to zero the model and the determination coefficient (R2) that shows how much the dependent variables are explained by the independents and, in this case, the closer to a better model.

3. RESULTS AND DISCUSSION

3.1 Determination of eucalyptus biomass

The integrated crop-livestock-forest (CLF) system evaluated presents a density of 303 trees per hectare. This occupied 33.65% of the area designated to the system and an average production of 0.18 m^3 of wood per tree, totaling a volume of wood without bark of 54.80 m^3 ha in the studied system. The remaining 66.35% were destined to other economic activities within the integration, such as agricultural and forage production.

After performing the forest inventory, the diameter distribution was analyzed, and four diameter classes were obtained. It is notable that the height, density, and volume of wood without bark were higher in class III, being 30.33 m, 151 trees ha^{-1}, and 40.06 m^3 ha^{-1}, respectively (Table 3). Through the dendrometric characteristics of this integrated CLF system, it is possible to verify a trend in relation to the height behavior of the plants and their DBHs, being that the DBH tends to increase as the height linear increases . This is contrary to the expected behavior in more homogeneous forest stands where trees with higher heights and smaller diameters are observed. More than the standard can be seen in other eucalyptus studies, depending on the clone and the management used in the area, as well as Miguel et al [18] observes in homogeneous plantation of *E. urograndis* in Niquelandia, GO and Lemos-Junior et al [19] in CFL with same specie in Cachoeira Dourada, GO.

Table 3. Dendrometric characteristics of *Eucalyptus grandis* x *Eucalyptus urophylla* grown in the integrated CLF system at Fazenda Santa Brígida in the municipality of Ipameri / Goiás / 2015.

Diameters Classes (cm)	Mean height (m)	mean DBH (cm)	Density(tree. ha^{-1})	Volume of wood without bark ($m^3.ha^{-1}$)
I (9-14)	12.58	10.45	30	1.25
II (14,1-19)	20.73	14.53	111	9.45
III(19,1-24)	30.33	21.57	151	40.06
IV(24,1-29)	30.22	26.55	11	4.04
Total	23.47	18.28	303	54.80

Generally, resource availability tends to be higher in stands with less density of less trees, reflecting higher growth in broader plantations [20]. This fact can be observed in this study because in spite of the densification of the trees in the planting lines, the spacing between the eucalyptus ridges provides greater light availability in this integrated CLF system. This causes the effect observed in the height as demonstrated by Miguel et al [18] in homogeneous plantation of E. urograndis in Niquelandia, GO, DBH and wood volume as demonstrated by Lemos-Junior et al [19] in CFL with same specie in Cachoeira Dourada, GO, that can be attributed more to the lesser effect of resource competition than to continuous plantings where the height and DBH ratio are inversely related. Different spacing and thinning regimes late in the life of the stand presented the highest values of basal area production. The choice of the best thinning regime for Eucalyptus clonal material will vary according to the plantation objective [21].

The maximum and minimum diameter found in this integrated CLF ranged from 9.4 to 28.25 cm, and the highest tree density were located in classes II and III, which consequently contributed with a higher volume of wood within the CLF system (Figure 1). In its study with Eucalyptus clones GG100 (*E. grandis* x *E. urophylla*) of 4.5 years, Cerdeira [22] observed a diametric variation between 5.0 and 17.1 cm. Cerdeira [22] also reported that the classes of greater diameter were those that presented the greater number of individuals, a DBH variation close to that of the present study, but the central classes were those with the highest number of individuals. Thus, we highlight that CLF present higher production of trees with higher diameter class, being relevant for the production of wood with noble purpose and greater value added by planted individuals.

Although Class IV presents the highest average wood volume per tree of 0.36 m^3, its contribution to the system is around 10%, among the individuals of lower number present in this class. However, classes III and II were the ones that concentrated the largest number of individuals, being responsible for 86.4% of the wood produced in this area of the integrated CLF with an average volume of 0.26 and 0.08 m^3, respectively, per individual within the classes.

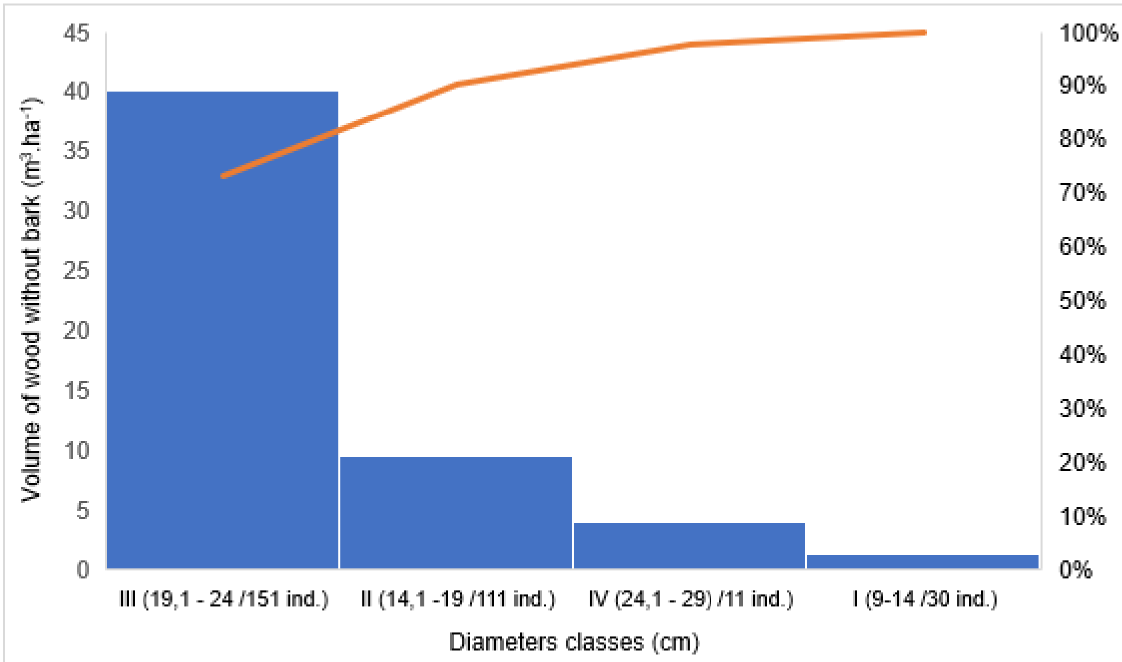

Figure 1. Volume of wood (m^3 ha^{-1}) in different diametric classes of Eucalyptus trees in an integrated crop-livestock-forest system in Ipameri / Goiás.

When evaluating three 32-month-old eucalyptus trees (*E. urophylla* x *E. grandis*), Torres et al [6] found volumes of wood without bark ranging from 0.01 to 0.24 m^3 for DBHs between 6.79 and 20.8 cm. These results are similar to those verified in the present work in the corresponding diametric classes.

The total biomass produced by the hybrid GG 100 in this integrated CLF was 56642.76 kg ha^{-1}, and the trees belonging to class III contributed the most in this production. In general, 38303.00 kg ha^{-1} of biomass were quantified through individuals with DBH between 19.1 and 24 cm 24.1 and 29 cm, contributing 67.62% of the total produced (Table 2.4).

Among the components analyzed in the eucalyptus, the wood biomass contributed the most to the total biomass of the integrated CLF trees with 83.70%, followed by the branches with 6.52%. Considering the trunk biomass (wood + bark), this was 90.07% and the contribution of the canopy (leaves + branches) was 9.92% (Table.4).

Table 4. Eucalyptus wood biomass (WB), bark biomass (KB), branch biomass (BB), and leaf biomass (LF) with seven years of integrated CLF cultivation in Ipameri / Goiás.

Class	Class I (9-14 cm)	Class II (14.1-19 cm)	Class III (19.1-24 cm)	Class IV (24.1-29 cm)	Total of components
LB (kg ha^{-1})	169.80	615.93	992.19	149.23	1927.15 (3.40)*
KB (kg ha^{-1})	393.60	1008.29	1974.81	318.41	3695.11 (6.52)
BB (kg ha^{-1})	139.31	859.96	2363.32	245.73	3608.32 (6.37)
WB (kg ha^{-1})	1540.81	9918.34	32972.68	2980.35	47412.18 (83.70)
Total Biomass	2243.52 (3.96)	12402.52 (21.90)	38303.00 (67.62)	3693.72 (6.52)	56642.76

* Values in parentheses refer to the percentage of component contribution in relation to total biomass.

Evaluating biomass components in eucalyptus stands with different ages, [16] verified a trunk biomass around 80.3% for plantations with 8 years, a result that is consistent with the present study.

In the present work, it was verified that the order of contribution of biomasses in the different components was Wood>Braches>Bark>Leaves (Figure 2). These results were similar to those verified by Giumarãres et al [23] in Allegrete//RS in homogeneous plantation of *E. dunni* with four years of age and those reported by Benatti [24] in Campos das Vertentes/MG using eucalyptus clones I-144 with 6.5 years of age. Regarding biomass, it should be pointed out that the 8-year-old crops present about 80% of the biomass in the tree trunks shows the potential of planting, at this age, already for biomass for energy production, since most of the biomass of the planting may be removed and used as fuel.

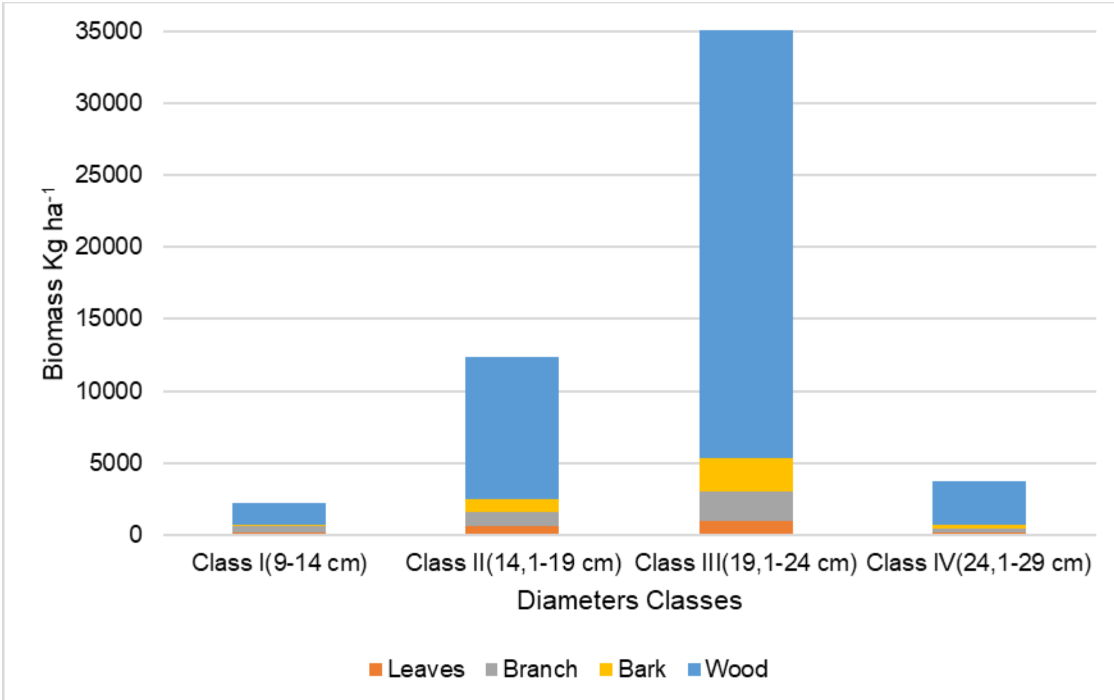

Figure 2. Contribution of eucalyptus biomass from different components and diametric classes in the integrated CLF system in the Ipameri / Goiás municipality.

Different results to the present work were observed by [25] when working with *E. benthamii* in an CLF at 12 months of age, [26] with *Eucalyptus* sp. of three years of age and [27] in eucalyptus in the agroforestry system of 18 months, where they verified the inversion in the production of leaves and bark. This explains the effect of biomass distribution during the different tree development phases, as the first one focused on leaf expansion and the second on the development of trunks and leaf area limitation [28,16].

In his study comparing different commercial clones of eucalyptus in integrated CLF systems in the municipality of Juara/MT, [9] verified that GG100 eucalyptus was the one that allocated the largest biomass in the trunk when planted in double lines corresponding to 62.6% of the total biomass of the trees at 15 months of age, Moreover, this behavior was maintained at seven years, as verified in the present work with the same clone in which this percentage reached 90.07% as predicted by [29].

From a commercial and structural point of view, the objective of the cultivator is to increase the volume of the trunk and to improve the quality of the wood. Less biomass in the branches is desirable since the primary product is the wood for commercialized [9].

In Figure 3, it can be verified through the regression analysis that the linear model was adequate to explain the increase of the biomass of the different components in relation to the DBHs. One can observe an intense relation between these, mainly for wood and bark, and with lower intensity with the branches.

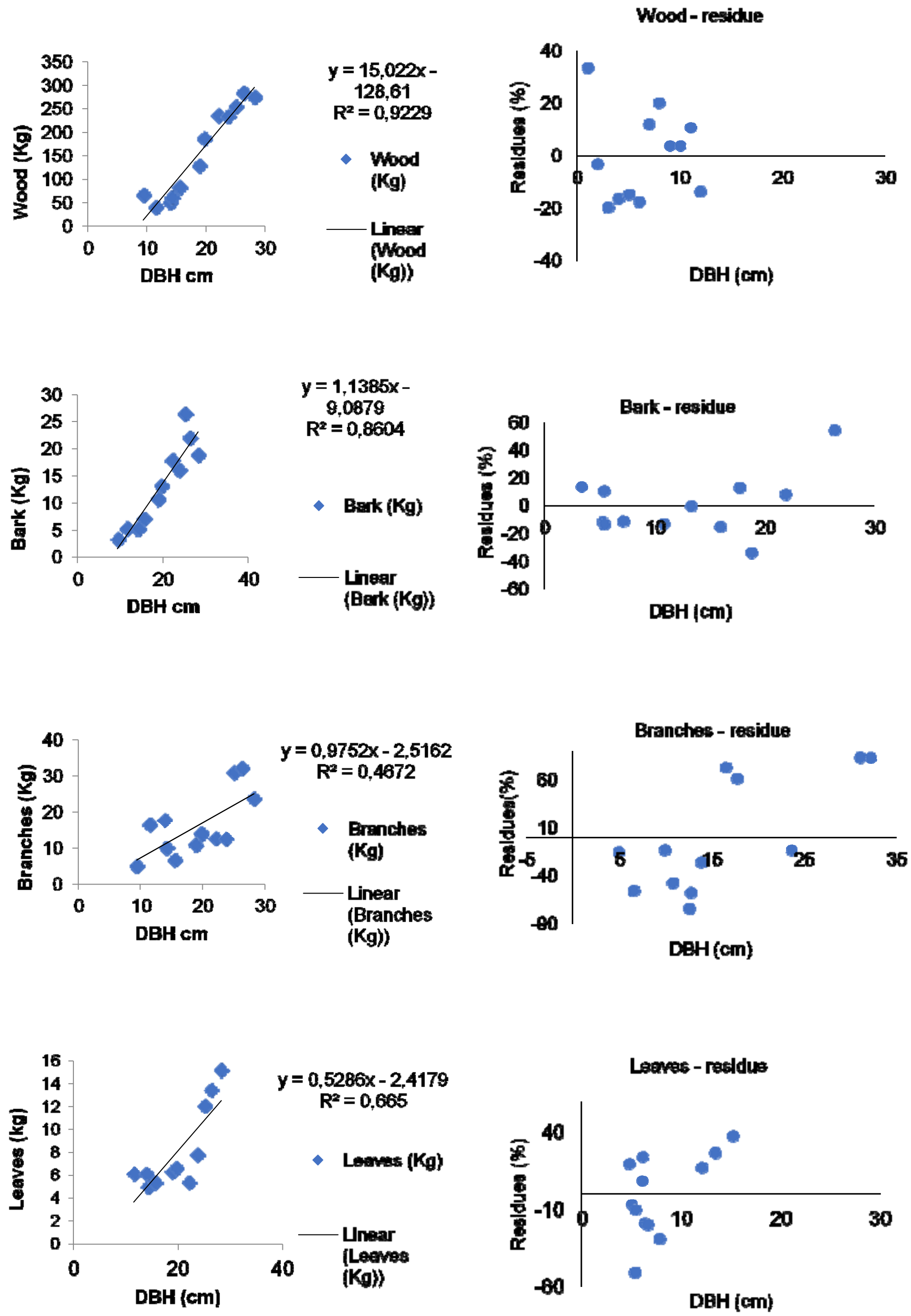

Figure 3. Production of the different components of biomass of *Eucalyptus grandis* x *Eucalyptus urophylla* in relation to DBH in an integrated CLF system in the city of Ipameri / Goiás.

The biomass gains of wood and bark due to the increase of the DBH were homogeneous. In other words, as the DAP increased, the biomass of these components also increased, which is justified by the high values of the coefficient of determination presented in the respective regressions (R2 0.9229 and R2 0.8604). While the biomass of leaves and branches did not present significant increases with the increase of DBH (R2 0.6647 and R2 0.4672), which evidences the accumulation of biomass as a function of age. In more developed plantations, the biomass of the leaves and branches decrease [16].

3.2 Adjustments of volumetric models

Table 5 shows the adjustments for the different models tested as a function of height and DBH. Considering the graphical analysis of the residues, the standard error and the determination coefficient, the double entry models of Schumacher & Hall (log) (0.866 and 21.33%) and Ogaya (0.866 and 20.78%) can be considered the most efficient to predict the volume of wood for an integrated CLF system in this spatial arrangement (Figure 4).

Table 5. Adjustments of volumetric models attributed to the eucalyptus plantation used in the integrated crop-livestock-forest system and their estimated coefficients (β), coefficient of determination (R2), and standard error (Syx %).

Models	β 0	β 1	β 2	R2	Syx(%)
Husch	-0.18775	0.031469	-	0.681	35.10
Ogaya	-0.27662	0.00045	0.019777	0.886	20.78
Schumacher & Hall (log)	-8.8478	0.617035	1.848882	0.886	21.33
Spurr (log)	-1.45173	0.207884	-	0.748	31.21

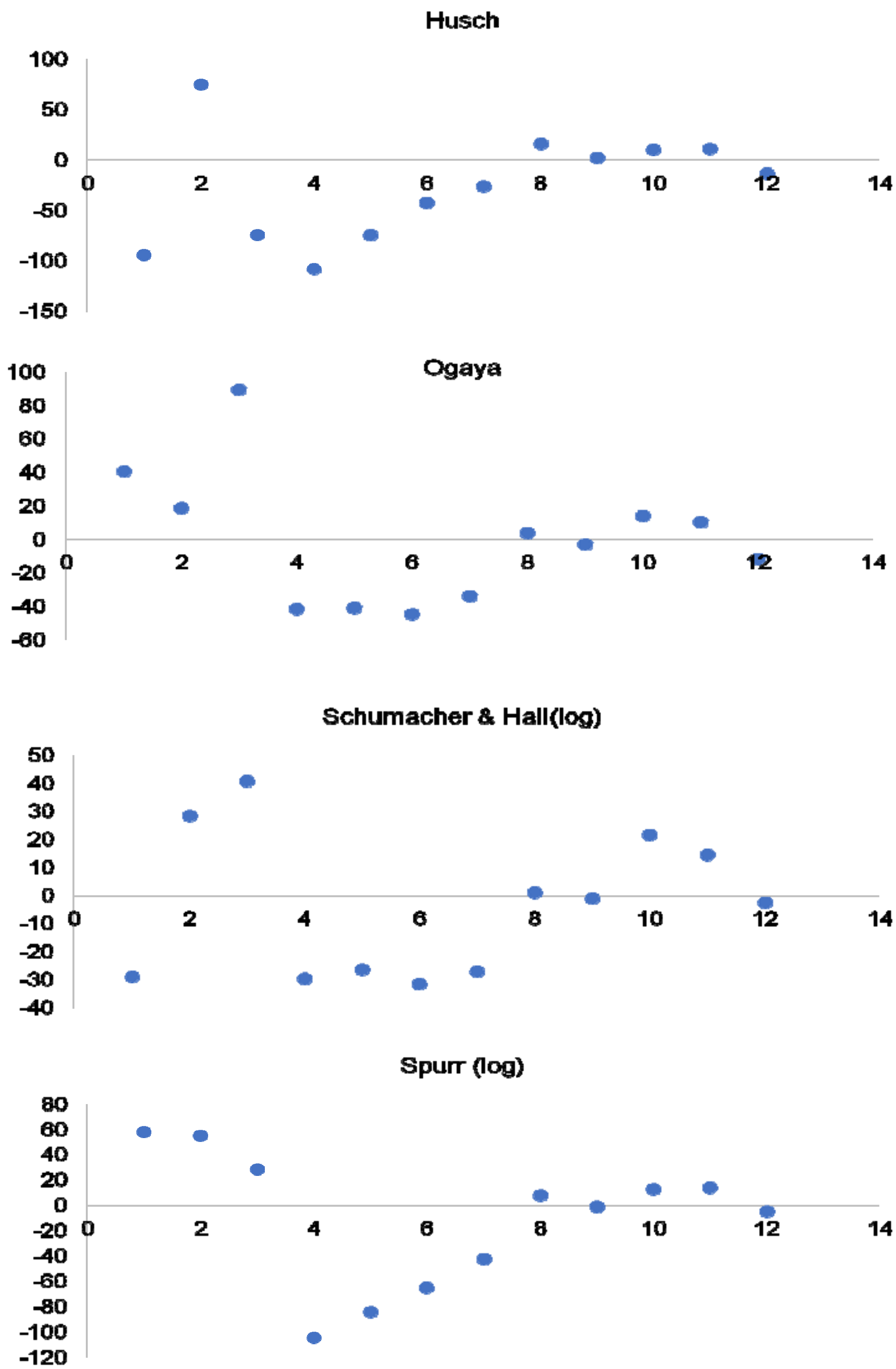

Figure 4. Waste residue distribution of the volumetric models tested for clones of *Eucalyptus grandis* x *Eucalyptus urophylla* in integrated CLF system in the city of Ipameri / Goiás.

However, all models tested had a satisfactory distribution of residues, an R2 ranging from 0.681 to 0.866 and a standard error of less than 35%, which makes it possible to use these models to estimate the volume of wood in the integrated CLF system.

Lemes Junior et al [19] consider the Näslund and Ogaya models as the most efficient to determine the volume of wood in the Integrated CLF system with eucalyptus of six years of age in Cachoeira Dourada / Goiás. These presented coefficients of determination of 99.5 and 99.1%, respectively. However, in spite of verifying a higher coefficient of determination for the Shumacher & Hall model, Miguel [30] observed a standard error that was considered high, another criterion used to indicate the volumetric model was the graphical distribution of the residues. In this scenario, the Takata model was the most suitable for estimating the volume of wood in a settlement of seven years of *E. urophylla* in Niquelândia, north of Goiás.

In their study with a silvipastoril system in the region of Coronel Pacheco/MG, Müller et al [31] tested different volumetric models to estimate the volume of eucalyptus trees, and they found that the Schumacher & Hall model presented the best fit for those conditions, as also verified in the present work. This demonstrated that the Schumacher & Hall model has also been used for the integrated CLF system, since its statistical properties almost always result in non-biased estimates.

With regards to the tree component of the integrated CLF system evaluated, a forest inventory was carried out to verify that at seven years after planting, the total biomass produced by the *Eucalyptus grandis* x *Eucalyptus urophylla* hybrid presented 56.64 Mg ha-1, a mean tree height of 25 m, and a chest height of 18. 222 cm. This biomass presented a distribution with greater quantity in the wood component, followed by the branches, bark, and leaves.

Although crop-livestock-forest integration presents limitations in its operation, this system becomes feasible from an adequate planning that meets the production demands of the property in the short, medium, and long term. Although it is a complex system because of the need to optimize the production conditions of each component, it is necessary to know the ecophysiology of the plants that will make up the integration. Besides the aggregate environmental benefits, this is important to determine if the productivity of the system is satisfactory to meet the social and economic demands and, thus, achieve the precepts of sustainability.

The environmental and productive importance of the integrated CLF system can be considered for the need to deepen the knowledge of the behavior of each component of the integration and prompted the interest in carrying out this research. It can be concluded that, finally, the initial objectives were reached, and it is, therefore, time for these results to be released.

Another aspect to be considered is the need for continuation of this research, both for this region of the Cerrado of Goiás and for the other regions of the country. It is known that many agricultural systems, conducted in an inadequate way, have contributed to the degradation of environmental quality and, due to this condition, seek to maintain production through the opening of new arable areas. Knowledge of crop-livestock-forest integration, as well as studies on the various possibilities of system implementation, are important factors for the productivity of agroecosystem and reduction of negative impacts on the Cerrado and other biomes.

4. CONCLUSIONS

The highest average volume of wood per tree was verified in the highest DBH class; The volumetric models of Schumacher & Hall and Ogaya were efficient to estimate the volume of wood in the integrated CLF system; The biomass of *Eucalyptus grandis* x *Eucalyptus urophylla* was 56.64 Mg ha-1, and 90.07% was present in the components of the trunk, while the others allocated in the canopy. Adequate cultural (debris and thinning) treatment throughout the crop cycle has negatively influenced the development of culture.

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