

BIOMASS OF *Eucalyptus globulus* IN YOUNG PLANTATIONS IN URUGUAY

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Resumo

Biomassa de Eucalyptus globulus em plantações jovens de Uruguai. Em quatro locais da costa oeste da República Oriental do Uruguai (Algorta, Bequeló, Quebracho e Tres Bocas) quantificou-se a biomassa aérea de plantações de *Eucalyptus globulus* com idades entre 3 e 9 anos. Em 20 parcelas de amostragem de 300 m² 616 árvores foram medidas, selecionando 132 para a quantificação. Em cada árvore foi calculada a biomassa de cinco frações: folhas, galhos verdes, galhos secos, fuste e total aéreo, este último obtido pela adição das frações anteriores. Quatro funções alométricas foram ajustados em três cenários: por local, para o total de locais e para o total de locais, mas identificadas mediante variáveis binária. As funções por local apresentaram a mínima diferença do critério de informação de Akaike (AIC), de modo que em todos os casos foram selecionadas esse tipo de funções. Estimou-se a biomassa por hectare e o incremento médio anual, com valores médios para os locais 1,18 ± 0,45, 1,08 ± 0,18, 0,58 ± 0,22, 11,24 ± 1,86 e 14,20 ± 2,50 Mg ha⁻¹ ano⁻¹ para folhas, galhos verdes, galhos secos, fuste e total aéreo, respectivamente. Através de uma análise de variância por componente foram identificadas diferenças estatisticamente significativas da biomassa anual média entre os locais. Os maiores incrementos foram observados em Bequeló e Tres Bocas, seguido de Quebracho e Algorta. A análise variância incorporou como covariável a densidade da plantação, que resultou ser significativa nos componentes de maiores dimensões.

Palavras-chave: funções alométricas, variáveis binárias, critério de informação de Akaike.

Abstract

In four areas of the western coast of the Oriental Republic of Uruguay (Algorta, Bequeló, Quebracho and Tres Bocas) the aerial biomass of *Eucalyptus globulus* plantations was quantified with ages between 3 and 9 years. In 20 circular plots of 300 m², 616 trees were measured, selecting 132 for quantification. In each tree, the biomass of five components was calculated: leaves, green branches, dry branches, stem and total aerial, the latter obtained by adding the previous components. Four allometric functions were adjusted in three scenarios: by location, for total locations and for total locations, but identified by dummy variables. The functions by location presented minimal difference from Akaike information criterion (AIC), so that in all cases this type of function was selected. The average annual increase in biomass was obtained, with average values for all the localities of 1.18 ± 0.45, 1.08 ± 0.18, 0.58 ± 0.22, 11.24 ± 1.86 y 14.20 ± 2.50 Mg ha⁻¹ year⁻¹ for leaves, green branches, dry branches, stem and total aerial, respectively. An analysis of variance by component identified statistically significant differences in the average annual increase in biomass between locations. The localities with the highest increase were Bequeló and Tres Bocas, followed by Quebracho and Algorta. The analysis of variance incorporated planting density as a covariate, proving to be significant for the components of greater dimensions.

Keywords: allometric functions, dummy variables, Akaike information criterion.

INTRODUCTION

In Uruguay 64% of wood production is used for energy purposes, with *Eucalyptus globulus* being the species with the largest forested area (DGF-MGAP, 2012). The estimation of aerial biomass from these plantations will serve to better characterize this resource, since the measurement units for these products are usually associated with biomass.

Tree biomass is often determined using destructive sampling (PÉREZ-CRUZADO and RODRÍGUEZ-SOALLEIRO, 2011), which according to Gibbs *et al.* (2007) is summarized in three steps, (i) obtaining the green mass of each component, (ii) taking a sample of the components and determining their green and dry mass, and

(iii) obtaining the dry mass of each component using proportions (Dry mass = Green mass * Dry mass_{sample} / Green mass_{sample}).

The allometric function ($biomass = b_0 d^{b_1}$) is internationally the most widely used to determine tree biomass (ANTÓNIO *et al.*, 2007; ZIANIS *et al.*, 2011; KUYAH *et al.*, 2013; PAUL *et al.*, 2013). The coefficient b_1 , called the universal exponent or allometric constant, should have a value of 8/3 (PILLI *et al.*, 2006), although some studies have found lower values (ZIANIS and MENCUCCINI, 2004; PILLI *et al.*, 2006; KUYAH *et al.*, 2013). According to Wang *et al.* (2011) other variables such as tree height have been incorporated to improve biomass estimation (ANTÓNIO *et al.*, 2007; ZEWDIE *et al.*, 2009; ÁLVAREZ *et al.*, 2012); however, their predictive ability is reduced (MONTAGU *et al.*, 2005; PÉREZ-CRUZADO and RODRÍGUEZ-SOALLEIRO, 2011; KUYAH *et al.*, 2012 and 2013). The density of the wood has also been incorporated achieving significant adjustments (KUYAH *et al.*, 2012; ÁLVAREZ *et al.*, 2012), although not in every case (KUYAH *et al.*, 2013).

In general, biomass functions are adjusted by location for each of the considered components, or for the set of locations. In general, the functions for the whole have a lower performance than the functions by location (van BREUGEL *et al.*, 2011; PAUL *et al.*, 2013; VALLEJOS-BARRA *et al.*, 2014) and in some cases have variable results since in some locations there is little error, while in others the errors can be significant. (CHAVE *et al.*, 2005).

Another alternative is to consider the set of localities but identifying each one of them by means of Dummy variables. This increases the degrees of freedom for the estimation of population parameters and therefore improves the relative precision of the estimates, which could not be verified by Vallejos-Barra *et al.* (2014); However, António *et al.* (2007) and Zeng *et al.* (2011) report that biomass estimation was improved by incorporating a Dummy variable identifying the origin of the stands.

Akaike Information Criterion (AIC) was used to select functions, since it is a powerful tool for comparing functions (SNIPES and TAYLOR, 2014). Burnham and Anderson (2002) describe it as:

$$AIC = n \log(\hat{\sigma}^2) + 2K$$

Where AIC is the Akaike Information Criterion, n is the amount of data used in the adjustment, $\hat{\sigma}^2 = \sum (y_i - \hat{y}_i)^2 / n$ and k is the total of estimated parameters, including the intercept and $\hat{\sigma}^2$.

The AIC value measures loss of information by a given function (MAZEROLLE, 2006), but by itself its value is not relevant. The important thing is to obtain the difference of the AIC between each adjusted function and the function with the lowest value (BURNHAM and ANDERSON, 2002); so the best function will have a difference equal to zero; with a difference up to 2, the function could be equally satisfactory. A difference between 4 and 7 reduces the significance of the function, while a difference greater than 10 rules out the use of the function.

The hypothesis is that it is possible to model the biomass of different components of *E. globulus* by means of allometric functions, it is also hypothesized that there should be no difference in the average annual increase between the sampled localities. The aim of this study was to select biomass functions for the leaves, green branches, dry branches, stem and total aerial, of *E. globulus* trees growing in the western coast of the Oriental Republic of Uruguay in South America, in order to estimate the average annual increase of the aerial biomass ($Mg\ ha^{-1}\ year^{-1}$) of each of the components and to observe if there are significant differences between the four locations sampled.

MATERIALS AND METHODS

In the sedimentary basin of the west coast of the Oriental Republic of Uruguay, the company EUFORES has unmanaged plantations of *Eucalyptus globulus* L. According to the Köppen-Geiger climate classification, the region is characterized by a temperate and humid climate with hot summers (Cfa) (INIA, 2011). Cruz *et al.* (2000) characterize this zone with an average annual rainfall of 1,174 mm and average monthly temperatures ranging from 10.5 to 22.5 °C. The relief is of high and medium plains with soft, sometimes flattened hills and strong hills, which are no higher than one hundred meters above sea level.

The measurements were taken on 20 circular plots of 300 m² in 4 geographical locations (6 in Algorta, 6 in Bequeló, 6 in Quebracho and 2 in Tres Bocas) where EUFORES has young plantations. The planting density varied between 733 and 1267 trees ha⁻¹ with ages between 3 and 9 years. The plots were representative of the average growth of trees in each locality, based on data from permanent plots of the owner company.

In the plots the diameter at breast height (DBH) of all trees was recorded (616 in total), with a calliper of parallel arms, graduated to the millimeter. A total of 132 trees representative of the measured diameter classes were upturned (40 in Algorta, 42 in Bequeló, 36 in Quebracho and 14 in Tres Bocas). The height of the trees was obtained by measuring the length of each one of them, once they were turned over, using a distance measuring device, graduated to the millimeter. Determining height in this way is common in some studies (ÁLVAREZ *et al.*, 2012; KUYAH *et al.*, 2013). Each tree was divided into four components: green branches, dry branches, leaves and stem. The branches were separated from the stem with an axe or pruning shears when their size allowed. The

leaves were manually separated from the branches and the stem was cut into two-meter-long logs. Additionally, the diameters of each of the logs were recorded, in order to calculate the volume of the stem, by adding the Smalian volume of each of the logs.

In the field, the green mass of the components was obtained using a Thunderbird field balance with an accuracy of 200 g. A sample of each component was sent to the laboratory recording the green mass with a My Weigh KD 600 electronic balance with an accuracy of 1 g. Later, when the samples reached a constant mass in a Venticell oven at 65 °C, their dry mass was obtained. The dry mass of each tree component was calculated by multiplying the ratio between the dry and green mass of the sample obtained in the laboratory by the green mass recorded in the field. The fifth component, the total aerial dry mass of the tree, resulted from the addition of the dry mass of the components recorded in the field. The basic density of the stem wood was obtained by dividing the dry mass of the stem by the volume of the latter.

The entire statistical analysis was performed with the free statistical program R version 3.4.0. Four non-linear functions ([1] to [4]) were adjusted for each component in each of the locations. The non-linear adjustment method (nls), which uses the Gauss-Newton method, was used for regression adjustment.

$$B = b_0 d^{b_1} \quad [1]$$

$$B = b_0 d^{b_1} \rho \quad [2]$$

$$B = b_0 d^{b_1} h^{b_2} \quad [3]$$

$$B = b_0 d^{b_1} h^{b_2} \rho \quad [4]$$

Where B is the biomass of each component (kg), d is the diameter at breast height (cm), h is the total height (m), ρ is the basic density of the stem (kg m^{-3}), b_0 is the regression constant and b_i are the regression coefficients ($i = 1$ and 2).

With these same functions ([1] to [4]) an adjustment was made for the total number of locations, which considered the data from all locations together. Finally, another adjustment was made for total locations, with four non-linear functions ([5] to [8]), where each location was identified by dummy variables.

$$B = (b_0 L_1 + b_1 L_2 + b_2 L_3 + b_3 L_4) d^{(b_4 L_1 + b_5 L_2 + b_6 L_3 + b_7 L_4)} \quad [5]$$

$$B = (b_0 L_1 + b_1 L_2 + b_2 L_3 + b_3 L_4) d^{(b_4 L_1 + b_5 L_2 + b_6 L_3 + b_7 L_4)} \rho \quad [6]$$

$$B = (b_0 L_1 + b_1 L_2 + b_2 L_3 + b_3 L_4) d^{(b_4 L_1 + b_5 L_2 + b_6 L_3 + b_7 L_4)} h^{(b_8 L_1 + b_9 L_2 + b_{10} L_3 + b_{11} L_4)} \quad [7]$$

$$B = (b_0 L_1 + b_1 L_2 + b_2 L_3 + b_3 L_4) d^{(b_4 L_1 + b_5 L_2 + b_6 L_3 + b_7 L_4)} h^{(b_8 L_1 + b_9 L_2 + b_{10} L_3 + b_{11} L_4)} \rho \quad [8]$$

Where b_j ($j = 0, 1, \dots, 3$) are the regression constants, b_k ($k = 4, 5, \dots, 11$) are the regression coefficients and L_m ($m = 1, 2, \dots, 4$) are the binary variables that identify each location. L_1 is 1 if the location is Algorta and 0 in any other case, L_2 is 1 when considering the location Bequeló and 0 in any other case, L_3 is 1 if the location is Quebracho and 0 in any other case and L_4 is 1 when considering the location Tres Bocas and 0 in any other case.

A total of 120 function settings were made: 80 function settings per location (5 components * 4 locations * 4 functions per location) and 40 global settings (5 components * (4 global functions + 4 global dummy functions)). In order to make the adjustments of the various functions comparable, the Akaike information criterion (AIC) was calculated by component and for each location, then the differences were obtained in relation to the lowest AIC, as recommended by Burnham and Anderson (2002) and Burnham *et al.* (2011); selecting those functions with the minimum values of this difference. As some of the selected functions incorporated the height of the trees, functions ([9] to [11]) were adjusted to estimate this variable in those trees where it was not measured. An adjustment was made for each location and another for all locations, so that a total of 15 function adjustments were made.

$$h = b_0 d^{b_1} \quad [9]$$

$$h = b_0 \exp(b_1/d) \quad [10]$$

$$h = b_0 + b_1 d \quad [11]$$

The regression adjustment for stem density was not significant so the probability density function that best represented the basic stem density was determined, with the intention of giving readers the inverse integral to estimate the density at a certain probability. With the selected functions, the biomass of each of the plots was estimated and the existence of statistically significant differences in the increase of biomass per hectare between

the localities was determined using an analysis of parametric variance. The analyzed variable was the average annual increase of biomass per hectare (MAI Mg B ha⁻¹) and as there was variation in planting density, the number of trees ha⁻¹ from each plot was included as a covariate. The assumptions of this analysis were verified with the Shapiro-Wilk and Levene tests. When there were statistically significant differences between the sources of variation these were identified with Duncan's multiple comparison test.

RESULTS

The mean annual increment (MAI) in diameter at breast height and height was used to characterize each locality (Table 1). Both increases diminished as the age of the plots increased. Over 5 years of age, regardless of location and planting density, the MAI in d and height did not exceed 2.50 cm year⁻¹ and 2.73 m year⁻¹, respectively. The largest increases were obtained in Bequeló up to 5 years of age. The increase was equal to or greater than 3.37 cm year⁻¹ and 3.02 m year⁻¹, for the diameter at breast height and the height, respectively. These increases are associated with lower planting densities (≤ 1034 trees ha⁻¹). No clear trend was observed in the decrease or increase of the MAI in diameter at breast height and height with fluctuation in the number of trees ha⁻¹.

Table 1. Dendrometric description of locations

Tabela 1. Descrição dendrométrica dos locais

Location	Age (years)	MAI d (cm year ⁻¹)	MAI h (m year ⁻¹)	Trees ha ⁻¹ average	ρ average (kg m ⁻³)
Algorta	4	2.92	3.11	1,267	485.5
	5	2.41	2.51	1,034	482.1
	8	1.76	1.93	1,033	530.4
Bequeló	3	4.36	3.85	833	496.2
	4	3.36	3.26	1,034	488.4
	5	3.37	3.02	733	518.2
	6	2.50	2.73	1,233	537.0
Quebracho	8	1.80	2.12	956	549.6
Tres Bocas	9	1.82	2.05	1,134	536.5

Source: Vallejos-Barra, *et al* (2014), available at < <https://www.ipef.br/publicacoes/scientia/nr101/cap01.pdf> >

300 Akaike information criteria (AIC) were calculated, which were transformed into the same amount of differences of AIC (

Table 2). The number of AICs (300) exceeded the number of adjustments (120), since the AIC was obtained by location, function and component (240 AIC) and also by function and component for all locations (60 AIC).

It is observed that the differences equal to zero are only found in the functions adjusted for each of the locations. Both adjustments for the total number of locations, in their great majority, were not significant since the differences were greater than 10.

The selected functions, those with a difference equal to zero, are presented in (

Function	Location	Adjustment by location					Adjustment for total locations				
		Leaves	Green branches	Dry branches	Stem	Total aerial	Leaves	Green Branches	Dry branches	Stem	Total aerial
1	Algorta	0.0	0.0	0.0	22.8	25.5	4.0	2.8	12.4	23.7	27.7
2		4.6	0.8	1.7	7.3	5.3	6.0	2.1	14.8	8.2	5.9
3		1.8	2.0	1.6	0.1	0.2	18.9	6.4	14.5	7.1	5.0
4		6.2	2.0	3.6	0.0	0.0	19.2	4.8	16.0	16.2	14.2
5							12.0	12.0	12.0	34.8	37.5
6							16.6	12.8	13.7	19.3	17.3
7							19.8	20.0	19.6	18.0	18.0
8							24.2	20.0	21.6	18.1	18.2
1	Bequeló	23.9	20.8	0.0	68.4	28.5	28.3	24.9	5.3	93.8	57.2
2		25.2	18.3	6.0	56.2	9.4	29.6	22.2	10.5	85.4	46.3
3		3.4	7.8	1.6	27.8	20.0	20.0	25.3	8.4	43.4	35.7
4		0.0	0.0	7.2	0.0	0.0	16.1	20.5	14.1	29.2	23.8
5							35.9	32.8	12.0	80.4	40.5
6							37.2	30.3	18.0	68.2	21.4
7							21.4	25.8	19.6	45.8	38.0
8							18.0	18.0	25.2	18.0	18.0
1	Quebracho	0.0	14.1	10.7	29.3	18.8	5.9	19.5	27.8	63.1	45.1
2		0.6	11.0	5.5	19.2	0.9	9.4	15.1	26.5	43.3	19.8
3		1.3	1.9	3.4	28.0	20.6	4.7	21.5	27.3	44.7	38.1
4		2.4	0.0	0.0	0.0	0.0	8.1	16.6	24.3	6.9	7.2
5							12.0	26.1	22.7	41.3	30.8
6							12.6	23.0	17.5	31.2	12.9
7							19.3	19.9	21.4	46.0	38.6
8							20.4	18.0	18.0	18.0	18.0
1	Tres Bocas	3.0	1.6	0.1	17.0	12.9	6.5	12.4	1.7	30.5	28.2
2		0.0	0.0	0.0	12.3	4.3	2.7	9.6	1.0	24.7	20.5
3		4.6	2.6	1.4	8.7	10.8	9.1	14.7	3.9	16.5	20.2
4		1.4	0.4	1.3	0.0	0.0	5.8	12.4	3.3	8.1	10.8
5							15.0	13.6	12.1	29.0	24.9
6							12.0	12.0	12.0	24.3	16.3
7							22.6	20.6	19.4	26.7	28.8
8							19.4	18.4	19.3	18.0	18.0
1	All locations	41.5	48.0	6.2	141.6	94.3	58.3	71.5	41.7	215.2	176.7
2		44.5	40.4	9.2	98.4	28.5	60.4	59.4	46.1	172.3	118.4
3		4.4	13.7	0.0	50.6	53.9	49.5	72.6	42.7	97.1	107.5
4		0.0	0.0	5.0	0.0	0.0	42.2	57.5	45.4	62.8	61.7
5							53.5	60.0	18.2	153.6	106.3
6							56.5	52.5	21.2	110.4	40.5
7							22.4	31.7	18.0	68.6	71.9

Table 3) where the function [4] adjusted for each of the locations has the highest frequency.

Since function [4], selected for several components, incorporates the tree heights, functions ([9] to [11]) were adjusted to estimate the height in those trees where it was not measured.

Height per location has better adjustment indicators (Table 4), as happened with the biomass adjustments
(

Table 2). In Table 5 the coefficients of selected functions are presented.

Table 2. AIC differences in functions that estimate biomass according to function, component and location.
Tabela 2. Diferença do AIC em funções que estimam a biomassa por função, componente e localidade.

Function	Location	Adjustment by location					Adjustment for total locations				
		Leaves	Green branches	Dry branches	Stem	Total aerial	Leaves	Green Branches	Dry branches	Stem	Total aerial
1	Algorta	0.0	0.0	0.0	22.8	25.5	4.0	2.8	12.4	23.7	27.7
2		4.6	0.8	1.7	7.3	5.3	6.0	2.1	14.8	8.2	5.9
3		1.8	2.0	1.6	0.1	0.2	18.9	6.4	14.5	7.1	5.0
4		6.2	2.0	3.6	0.0	0.0	19.2	4.8	16.0	16.2	14.2
5							12.0	12.0	12.0	34.8	37.5
6							16.6	12.8	13.7	19.3	17.3
7							19.8	20.0	19.6	18.0	18.0
8							24.2	20.0	21.6	18.1	18.2
1	Bequeló	23.9	20.8	0.0	68.4	28.5	28.3	24.9	5.3	93.8	57.2
2		25.2	18.3	6.0	56.2	9.4	29.6	22.2	10.5	85.4	46.3
3		3.4	7.8	1.6	27.8	20.0	20.0	25.3	8.4	43.4	35.7
4		0.0	0.0	7.2	0.0	0.0	16.1	20.5	14.1	29.2	23.8
5							35.9	32.8	12.0	80.4	40.5
6							37.2	30.3	18.0	68.2	21.4
7							21.4	25.8	19.6	45.8	38.0
8							18.0	18.0	25.2	18.0	18.0
1	Quebracho	0.0	14.1	10.7	29.3	18.8	5.9	19.5	27.8	63.1	45.1
2		0.6	11.0	5.5	19.2	0.9	9.4	15.1	26.5	43.3	19.8
3		1.3	1.9	3.4	28.0	20.6	4.7	21.5	27.3	44.7	38.1
4		2.4	0.0	0.0	0.0	0.0	8.1	16.6	24.3	6.9	7.2
5							12.0	26.1	22.7	41.3	30.8
6							12.6	23.0	17.5	31.2	12.9
7							19.3	19.9	21.4	46.0	38.6
8							20.4	18.0	18.0	18.0	18.0
1	Tres Bocas	3.0	1.6	0.1	17.0	12.9	6.5	12.4	1.7	30.5	28.2
2		0.0	0.0	0.0	12.3	4.3	2.7	9.6	1.0	24.7	20.5
3		4.6	2.6	1.4	8.7	10.8	9.1	14.7	3.9	16.5	20.2
4		1.4	0.4	1.3	0.0	0.0	5.8	12.4	3.3	8.1	10.8
5							15.0	13.6	12.1	29.0	24.9
6							12.0	12.0	12.0	24.3	16.3
7							22.6	20.6	19.4	26.7	28.8
8							19.4	18.4	19.3	18.0	18.0
1	All locations	41.5	48.0	6.2	141.6	94.3	58.3	71.5	41.7	215.2	176.7
2		44.5	40.4	9.2	98.4	28.5	60.4	59.4	46.1	172.3	118.4
3		4.4	13.7	0.0	50.6	53.9	49.5	72.6	42.7	97.1	107.5
4		0.0	0.0	5.0	0.0	0.0	42.2	57.5	45.4	62.8	61.7
5							53.5	60.0	18.2	153.6	106.3
6							56.5	52.5	21.2	110.4	40.5
7							22.4	31.7	18.0	68.6	71.9
8							18.0	18.0	23.0	18.0	18.0

Table 3. Selected functions for biomass and adjustment indicators by component and location.

Tabela 3. Funções selecionadas para biomassa e indicadores do ajuste por componente e localidade.

Component	Location	Function	b ₀	b ₁	b ₂	Sb ₀	Sb ₁	Sb ₂	EEE	R ² A	AIC
Leaves	Algorta	[1]	7.917E-3	2.410	-	5.970E-3	0.261	-	1.9	0.76	51.4
	Bequeló	[4]	4.522E-4	3.463	-2.235	3.181E-4	0.334	0.380	2.7	0.75	85.8
	Quebracho	[1]	1.672E-2	2.145	-	1.102E-2	0.223	-	1.9	0.81	47.6
	Tres Bocas	[2]	2.697E-6	3.004	-	4.121E-6	0.505	-	2.3	0.85	25.8
Green branches	Algorta	[1]	1.335E-2	2.273	-	1.200E-2	0.312	-	2.6	0.65	74.6
	Bequeló	[4]	6.378E-5	4.569	-2.757	7.127E-5	0.532	0.582	3.3	0.66	103.1
	Quebracho	[4]	2.432E-3	3.416	-2.612	2.565E-3	0.367	0.581	3.0	0.82	82.2
	Tres Bocas	[2]	3.121E-8	4.561	-	6.374E-8	0.667	-	3.0	0.88	32.5
Dry branches	Algorta	[1]	6.139E-1	0.682	-	3.713E-1	0.223	-	1.5	0.25	34.3
	Bequeló	[1]	1.482E-1	1.078	-	1.066E-1	0.257	-	1.2	0.33	15.3
	Quebracho	[4]	1.283E-4	3.572	-2.187	1.964E-4	0.436	0.772	1.0	0.79	2.1
	Tres Bocas	[2]	3.138E-5	1.900	-	7.477E-5	0.801	-	2.1	0.46	22.1
Stem	Algorta	[4]	1.132E-4	2.091	0.503	4.083E-5	0.141	0.164	9.5	0.95	183.3
	Bequeló	[4]	5.086E-5	1.552	1.282	1.230E-5	0.097	0.121	6.3	0.98	157.1
	Quebracho	[4]	9.677E-5	1.920	0.721	2.951E-5	0.066	0.143	5.1	0.99	119.9
	Tres Bocas	[4]	3.562E-6	1.500	2.220	3.537E-6	0.232	0.500	7.7	0.99	59.6
Aerial total	Algorta	[4]	2.149E-4	2.130	0.307	5.839E-5	0.106	0.120	9.0	0.97	178.9
	Bequeló	[4]	1.844E-4	1.939	0.508	5.385E-5	0.119	0.146	9.8	0.96	194.3
	Quebracho	[4]	2.538E-4	2.105	0.277	8.904E-5	0.079	0.167	7.3	0.99	146.2
	Tres Bocas	[4]	1.406E-5	2.015	1.328	1.422E-5	0.252	0.523	9.6	0.99	66.0

Where b₀ is the regression constant, b₁ and b₂ are the regression coefficients, Sb_i is the standard error of the regression constant if i = 0 and of the regression coefficients if i = 1 or 2, EEE is the standard error of estimation in kilograms, R² A is the adjusted coefficient of determination and AIC is Akaike information criterion.

Table 4. Differences of the AIC in functions that estimate the height according to function, component, and location.

Tabela 4. Diferença do AIC em funções que estimam a altura por função, componente e localidade.

Function	Adjustment	By location				All locations
		Algorta	Bequeló	Quebracho	Tres Bocas	
9	Per location	0.0	0.0	12.8	3.2	2.4
10		2.5	4.9	0.0	0.0	0.0
11		1.1	0.6	25.1	6.0	16.3
9	For all locations	6.8	16.0	35.3	20.5	61.8
10		10.5	21.3	32.8	22.5	71.2
11		7.1	14.8	40.8	20.5	66.6

Table 5. Selected functions for height and adjustment indicators according to location

Tabela 5. Funções selecionadas para altura e indicadores do ajuste por localidade.

Location	Function	b ₀	b ₁	Sb ₀	Sb ₁	EEE	R ² A	AIC
Algorta	[9]	3.522	0.536	0.649	0.0687	2.0	0.66	56.5
Bequeló	[9]	3.099	0.575	0.626	0.0737	1.9	0.60	53.8
Quebracho	[10]	26.448	-5.816	0.957	0.484	1.4	0.89	24.3
Tres Bocas	[10]	31.907	-8.107	1.904	0.933	1.3	0.90	7.8

Where b₀ is the regression constant, b₁ is the regression coefficient, Sb_i is the standard error of the regression constant, if i = 0 and of the regression coefficient if i = 1, EEE is the standard error of estimation in meters, R² A is the adjusted coefficient of determination and AIC is the Akaike information criterion.

The biomass functions [2] and [4] require the estimation of the stem density, but this variable did not present a connection with the recorded variables, so it was decided to select the probability density function that

represented this variable. Of the thirty functions tested, the Logistics function [12] was selected, which obtained a Kolmogorov-Smirnov test statistic of 0.044, with a probability of 0.96. To obtain the basic density of the stem at a specific probability [14], the inverse density function was calculated, clearing the basic density of the distribution function [13], which is the integral of function [12]. The values estimate for μ and σ were 525.83 and 29.15 respectively.

$$f(\text{basic density}) = \frac{\exp\left(\frac{\text{basic density}-\mu}{\sigma}\right)}{\sigma \left(1 + \exp\left(\frac{\text{basic density}-\mu}{\sigma}\right)\right)^2} \quad [12]$$

$$\text{Probability} = \frac{1}{1 + \exp\left(-\frac{\text{basic density}-\mu}{\sigma}\right)} \quad [13]$$

$$\text{basic density} = \mu + \sigma \ln\left(\frac{\text{probability}}{1-\text{probability}}\right); 0 < \text{probability} < 1 \quad [14]$$

The quantification of the aerial biomass of each component on the 20 plots (Table 6) was made considering the selected functions (

Function	Location	Adjustment by location					Adjustment for total locations				
		Leaves	Green branches	Dry branches	Stem	Total aerial	Leaves	Green Branches	Dry branches	Stem	Total aerial
1	Algorta	0.0	0.0	0.0	22.8	25.5	4.0	2.8	12.4	23.7	27.7
2		4.6	0.8	1.7	7.3	5.3	6.0	2.1	14.8	8.2	5.9
3		1.8	2.0	1.6	0.1	0.2	18.9	6.4	14.5	7.1	5.0
4		6.2	2.0	3.6	0.0	0.0	19.2	4.8	16.0	16.2	14.2
5							12.0	12.0	12.0	34.8	37.5
6							16.6	12.8	13.7	19.3	17.3
7							19.8	20.0	19.6	18.0	18.0
8							24.2	20.0	21.6	18.1	18.2
1	Bequeló	23.9	20.8	0.0	68.4	28.5	28.3	24.9	5.3	93.8	57.2
2		25.2	18.3	6.0	56.2	9.4	29.6	22.2	10.5	85.4	46.3
3		3.4	7.8	1.6	27.8	20.0	20.0	25.3	8.4	43.4	35.7
4		0.0	0.0	7.2	0.0	0.0	16.1	20.5	14.1	29.2	23.8
5							35.9	32.8	12.0	80.4	40.5
6							37.2	30.3	18.0	68.2	21.4
7							21.4	25.8	19.6	45.8	38.0
8							18.0	18.0	25.2	18.0	18.0
1	Quebracho	0.0	14.1	10.7	29.3	18.8	5.9	19.5	27.8	63.1	45.1
2		0.6	11.0	5.5	19.2	0.9	9.4	15.1	26.5	43.3	19.8
3		1.3	1.9	3.4	28.0	20.6	4.7	21.5	27.3	44.7	38.1
4		2.4	0.0	0.0	0.0	0.0	8.1	16.6	24.3	6.9	7.2
5							12.0	26.1	22.7	41.3	30.8
6							12.6	23.0	17.5	31.2	12.9
7							19.3	19.9	21.4	46.0	38.6
8							20.4	18.0	18.0	18.0	18.0
1	Tres Bocas	3.0	1.6	0.1	17.0	12.9	6.5	12.4	1.7	30.5	28.2
2		0.0	0.0	0.0	12.3	4.3	2.7	9.6	1.0	24.7	20.5
3		4.6	2.6	1.4	8.7	10.8	9.1	14.7	3.9	16.5	20.2
4		1.4	0.4	1.3	0.0	0.0	5.8	12.4	3.3	8.1	10.8
5							15.0	13.6	12.1	29.0	24.9
6							12.0	12.0	12.0	24.3	16.3

7						22.6	20.6	19.4	26.7	28.8	
8						19.4	18.4	19.3	18.0	18.0	
1	All locations	41.5	48.0	6.2	141.6	94.3	58.3	71.5	41.7	215.2	176.7
2		44.5	40.4	9.2	98.4	28.5	60.4	59.4	46.1	172.3	118.4
3		4.4	13.7	0.0	50.6	53.9	49.5	72.6	42.7	97.1	107.5
4		0.0	0.0	5.0	0.0	0.0	42.2	57.5	45.4	62.8	61.7
5							53.5	60.0	18.2	153.6	106.3
6							56.5	52.5	21.2	110.4	40.5
7							22.4	31.7	18.0	68.6	71.9
8							18.0	18.0	23.0	18.0	18.0

Table 3). All functions are incorporated in DAP, in addition function [2] and [4] required the basic density, which was obtained by using a 50% probability. Finally, with function [4] the tree heights had to be estimated as well, using the results of Table 5.

Table 6. Aerial biomass MAI estimation ($\text{Mg ha}^{-1} \text{ year}^{-1}$) per location and component.

Tabela 6. Estimación do IMA da biomassa aérea ($\text{Mg ha}^{-1} \text{ ano}^{-1}$) por localidade e componente.

Location	Age	N (Trees ha^{-1})	Leaves	Green branches	Dry branches	Stem	Total aerial
Algorta	4	1,267	1.038	1.234	1.031	12.881	16.195
	5	1,033	0.768	0.903	0.684	9.438	11.829
	8	1,033	0.681	0.784	0.472	8.455	10.415
Bequeló	3	833	1.729	1.198	0.658	11.425	15.317
	4	1,033	1.590	1.122	0.630	12.139	15.863
	5	733	1.495	1.294	0.458	11.910	15.313
	6	1,233	1.496	1.139	0.566	13.240	16.674
Quebracho	8	956	0.664	0.894	0.250	8.792	10.623
Tres Bocas	9	1,133	0.988	1.188	0.453	12.890	15.563

The validity of the analysis of parametric variance in the MAI for aerial biomass was checked, since both the assumption of normality (W-statistician of the Shapiro-Wilk test) and the assumption of homocedasticity (Z-statistician of the Levene test) were not statistically significant (Table 7). This analysis identified significant differences between the means of the locations in each of the components.

Table 7. Analysis of variance and Duncan's multiple range test of aerial biomass MAI ($\text{Mg ha}^{-1} \text{ ano}^{-1}$)

Tabela 7. Análise de variância e proba de rangos múltiplos de Duncan do IMA da biomassa aérea ($\text{Mg ha}^{-1} \text{ ano}^{-1}$)

Analysis of Variance									
Component	W		Z		Value F of Factor (Location)		Value F of covariate (Trees ha ⁻¹)		
Leaves	0.94	(ns)	2.84	(ns)	20.28	(**)	1.36	(ns)	
Green branches	0.96	(ns)	2.95	(ns)	3.81	(*)	1.92	(ns)	
Dry branches	0.91	(ns)	2.37	(ns)	8.52	(**)	2.34	(ns)	
Stem	0.98	(ns)	0.75	(ns)	6.37	(**)	12.01	(**)	
Total aerial	0.98	(ns)	0.45	(ns)	12.56	(**)	9.14	(**)	
Homogeneous locations per component according to Duncan's test (***)									
Location	Leaves		Green branches		Dry branches		Stem		Total aerial
Algorta	0.791	a b	0.921	a	0.621	b	8.902	a	11.179 a
Bequeló	1.623	c	1.213	a b	0.591	b	12.149	b	15.733 b
Quebracho	0.631	a	0.887	a	0.276	a	9.699	a	11.511 a
Tres Bocas	1.072	b	1.308	b	0.444	a b	12.021	b	14.928 b

Where (*) indicates significant statistical differences (probability < 0.05), (**) indicates highly significant statistical differences (probability < 0.01), (ns) reveals that there are no significant differences (probability ≥ 0.05). W is Shapiro-Wilk's statistician and Z is Levene's statistician. F corresponds to Snedecor's F-test statistician and (***) indicates that there are no statistically significant differences between locations with the same sub-index letter in the vertical (probability ≥ 0.05).

DISCUSSION

The increases presented in Table 1 are consistent with those reported by Resquin *et al.* (2012) for locations close to the geographical area of this research, so that the growth observed corresponds to the normal development of a plantation in these locations.

In Figure 1 total biomass and stem biomass are observed according to location. With this distribution of data, it would have been simpler to estimate the biomass of these components if the selected functions had considered the total of localities, since with one function the component under analysis would have been estimated. However, both adjustments for the total number of locations did not prove to be significant since the differences in the AIC, in most cases, were greater than 10 (

Table 2) and as indicated by Burnham and Anderson (2002) the use of these functions should be ruled out.

In all components differences equal to zero were only found in the functions adjusted for each of the locations (

Table 2). This result coincides with that informed by Vallejos-Barra *et al.* (2014) in the estimation of absorbed carbon for the species and agrees with that expressed by van Breugel *et al.* (2011) and Paul *et al.* (2013).

75% of the adjustments presented an adjusted R^2 greater than 0.7, showing a close relationship between the biomass and the explanatory variables considered. The contribution of the height variable was important since 60% of the selected functions incorporated this explanatory variable, which contradicts what was indicated by Montagu *et al.* (2005) and reinforces the points made by Antônio *et al.* (2007). At the same time, the density of the wood was presented in 75% of the selected functions, in accordance with what was expressed by Kuyah *et al.* (2012); nevertheless, it was not possible to relate the density of the wood to the DBH, using a probability density function representing this variable.

The values of the universal exponent were lower than the theoretical value (8/3) in 70% of the selected functions, as was the case for Zianis and Mencuccini (2004), Pilli *et al.* (2006) and Kuyah *et al.* (2013).

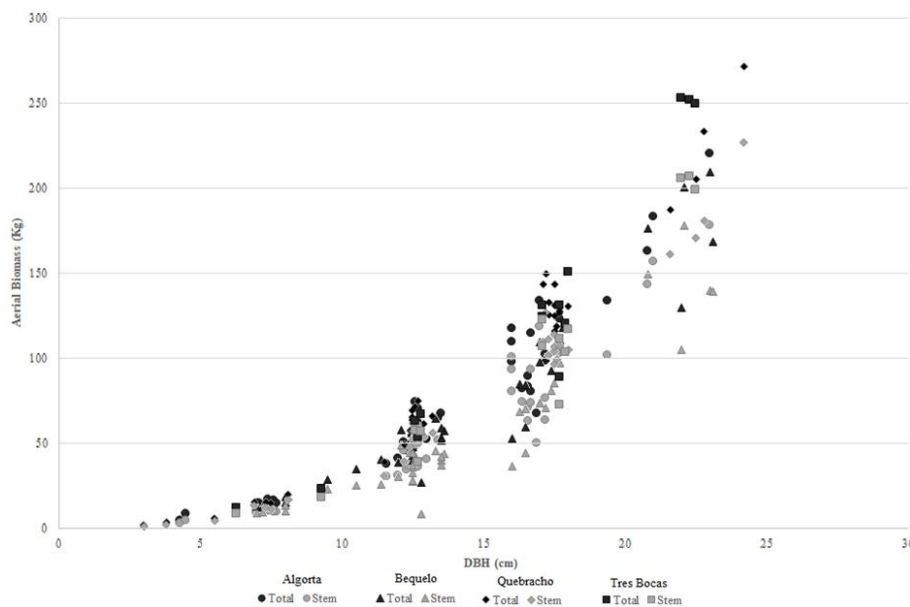


Figure 1. Total and stem biomass according to location

Figure 1. Biomassa total e de fuste segundo localidade

When determining the biomass for the components and their average annual increase (Table 6), the influence of the number of trees per hectare on the quantification of the aerial biomass of the stem and total is highlighted, due to the fact that the greatest increases are achieved with higher planting densities. On the other hand, in the remaining components, the greatest increases are frequently found in the lower planting densities.

The estimation of each component (Table 6) and its subsequent addition differs slightly from the estimates of the total by an average of 0.9% with a range that fluctuates between 0.1 and 2.4%, confirming the consistency among the selected functions.

The recorded increases in the total aerial count coincide with those reported by Zewdie *et al.* (2009), not so in the remaining components, which evidences a differentiated distribution of biomass among the components between the two studies. Pérez-Cruzado and Rodríguez-Soalleiro (2011) obtained an increase in total biomass that fluctuated between 13.9 y 14.6 Mg ha⁻¹ año⁻¹, which indicates some similarity with the results of this research.

The plantation density used as a covariate in the analysis of variance was highly significant for the total aerial and stem component, indicating that this covariate has direct implications for determining the increase in biomass for these components. In the remaining components there was no statistical significance, therefore, the number of trees per hectare considered in this research, did not significantly affect the increase in biomass of leaves, green branches and dry branches.

CONCLUSIONS

The analyzes carried out allow us to conclude that:

- The functions selected corresponded to those adjusted by location, described in Table 3, since they presented the least difference from the AIC.

- For the estimation of the stem and the total aerial the selected function is [4]. Leaves, green branches and dry branches in Algorta locality are estimated with function [1]; for these components in Bequeló and Quebracho function [1] or [4] should be used, as appropriate; on the other hand, in Tres Bocas the estimation of these components should be done with function [2].
- The global functions and the global functions that incorporated dummy variables showed an average difference from the AIC of 30.4, which makes their use impossible.
- The average annual increase of biomass presented statistical differences between the localities conformed by two groups, the one with the highest increase represented by Bequeló and Tres Bocas (15.733 y 14.928 Mg ha⁻¹ year⁻¹ respectively), the other made up of Quebracho and Algorta (11.511 y 11.179 Mg ha⁻¹ year⁻¹ respectively).

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