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BIOMASS EQUATIONS FOR CAATINGA SPECIES

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ABSTRACT: The objective of this work was to determine the proportions of stem, branches and leaves in relation to total dry aboveground biomass and adjust statistical models to estimate the biomass of the main species in an area of Caatinga. The number of trees cut and with the determined total aboveground biomass was 15 for *Anadenanthera colubrina*, *Aspidosperma pyrifolium*, *Cnidoscolus quercifolius*, *Mimosa ophthalmocentra*, *Mimosa tenuiflora*, and *Poincianella bracteosa*, and 30 for *Bauhinia cheilantha* and *Croton heliotropiifolius*. The data of total dry aboveground biomass were used as dependent variables and the diameter at breast height and total height of individuals per species were used as the independent variables for adjusting the models. Eight models were tested for each species and for all grouped species. Traditional statistical criteria was used for selecting the best equation. The proportions of the species were quantified for both their biomass compartments and for the total biomass, showing great variation between species and individuals of the same species. Dry aboveground biomass equations were developed with good precision statistics and can therefore be used for estimating biomass in Caatinga regions.

Keywords: Regression analysis, diameter at breast height, total height.

EQUAÇÕES DE BIOMASSA PARA ESPÉCIES DA CAATINGA

RESUMO: O objetivo deste trabalho foi determinar as proporções de fuste, galhos e folhas em relação a biomassa total seca acima do solo e ajustar modelos estatísticos para estimativa da biomassa das principais espécies arbustivo-arbóreas em uma área de Caatinga. O número de indivíduos abatidos e com a biomassa aérea total determinada foi de 15 para *Anadenanthera colubrina*, *Aspidosperma pyrifolium*, *Cnidoscolus quercifolius*, *Mimosa ophthalmocentra*, *Mimosa tenuiflora*, *Poincianella bracteosa* e, de 30 para *Bauhinia cheilantha* e *Croton heliotropiifolius*. Para ajuste dos modelos foram utilizados os dados de biomassa total seca acima do solo coletados como variável dependente e as variáveis independentes foram o diâmetro à altura do peito e a altura total dos indivíduos por espécie. Foram testados oito modelos para cada uma das espécies e para todas as espécies agrupadas. Para a seleção da melhor equação utilizou-se os tradicionais critérios estatísticos. As proporções de biomassa das espécies foram quantificadas, tanto para os seus compartimentos, quanto para o total e apresentaram uma grande variação entre espécies e indivíduos da mesma espécie. Equações de biomassa aérea seca foram ajustadas com boas estatísticas de precisão, podendo ser utilizadas para a sua estimativa de biomassa de maneira confiável em regiões de Caatinga.

Palavras-chave: Análise de regressão, diâmetro à altura do peito, altura total.

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1. INTRODUCTION

The Caatinga is present in all Northeastern Brazilian states and in Minas Gerais, totaling 11% of Brazil's territory or 844,453 km^2, with great socio-economic and ecological importance. Among Brazilian biomes, it is considered as a dry tropical formation that presents high species diversity and great heterogeneity regarding the habitat conditions (ARAÚJO, 2005a).

In Pernambuco it occupies the largest phytogeographic area of the state (ANDRADE-LIMA, 2007). It presents a variety of species that distinguish it from the sets that form the other Brazilian typologies, which include an expressive number of rare and endemic taxa, although it is quite altered. The species of this typology present adaptations to the water deficit of the region such as deciduous, succulence, aculeus and thorns, predominance of shrubs and trees of small to medium size, and discontinuous canopy coverage (ANDRADE-LIMA, 2007).

Several studies point out vegetation with different physiognomies ranging from predominantly herbaceous vegetation to arboreal vegetation, with differences in floristic composition between each type (ALBUQUERQUE et al., 2012).

The Caatinga has high floristic diversity for a biome with a strong restriction to growth due to water deficiency. In areas of a few hectares there is generally great dominance of a few species, often two or three of them covering more than 50% of the density and basal area, and the dominant species are different from one area to another (SAMPAIO, 2010).

The biomass production of the Caatinga is considered low in relation to other biomes. In general, this occurs due to the high temperature and low humidity of the air and precipitation, and consequently great losses by evapotranspiration. When the losses are higher than the water uptake by the roots and conduction in the stems, the photosynthetic tissues dehydrate and the stomata close. As a result, water losses are reduced, and also the entry of CO_2 and biomass production (MENEZES; SAMPAIO, 2000).

Quantifying the biomass of a shrub-arboreal individual, a shrub-tree species or an ecosystem can be done by direct or indirect methods. Basically, the direct method involves cutting and weighing all the compartments (roots, stem, branches and leaves) of the individuals in a given area, depending on the sampling level that is to be achieved. In spite of presenting more robust results, costs, time, area size, species diversity and the non-cutting ability of most vegetation typologies due to Brazilian legislation make it difficult to implement this method.

Indirect methods based on mathematical equations (regression analysis) become a reliable and robust alternative for estimating biomass, although direct determination is necessary at the first moment to adjust the equations. The comprehensiveness level of the estimates increases using this method, reducing the financial costs of obtaining the shrub-tree biomass of an area. In general, model adjustments can be made for each compartment (root, leaf, branch or stem) or the whole set, depending on the level of information one wants to obtain. The chosen mathematical equations should take into account the location where they were developed, included species, the sampling level considered, size and age classes, errors subject to estimates, among others (SOMOGY et al., 2006).

Ecosystem biomass estimates are essential information for issues related to forest management and climate, and are a useful tool in assessing nutrient cycling, carbon sequestration and storage, for example. The important thing is to evaluate the biomass production and distribution of multiple use shrub-tree species, aiming at increasing the availability of wood and forage in a certain region, allowing its rational exploitation and contributing to the preservation of native species (GOLLEY et al., 1978).

When it is desired to accurately estimate the total biomass in a given wood ecosystem, it is necessary to know the biomass contribution of the dominant species and to take into account the whole range of the species size or set of species in that area (EAMUS et al., 2000). When considering the total biomass, adjustments in equations are better than the adjustments considering the distinct compartments of the species (stem, branches and leaves) individually, probably because in joining these compartments the deviations of one part are compensated for by the deviations in the opposite direction of another part (SILVA; SAMPAIO, 2008).

There are works for the Caatinga that directly or indirectly estimate both the aboveground and underground biomass of its vegetation (SAMPAIO; FREITAS, 2008; SAMPAIO, 2010; SAMPAIO; COSTA, 2011; MENEZES et al., 2012; CABRAL et al., 2013; COSTA et al., 2014; ALBUQUERQUE et al., 2015; ALVES et al., 2017). But there are few studies that develop biomass equations for species, groups of species and even for different parts of plants in this typology, and the independent variables that have correlated well with this biomass are generally diameter at breast height, diameter at ground level, total height, basal area at ground and chest level, wood density, crown area, number of branches, or the combination of these (SAMPAIO; SILVA, 2005; SILVA; SAMPAIO, 2008; ALVES JÚNIOR, 2010; SAMPAIO et al. 2010; FERRAZ, 2011; ABREU, 2012; MENDONÇA et al., 2013).

In this context, the objective of this work was to determine the proportions of stem, branches and leaves in relation to the total dry aboveground biomass and to adjust statistical models for estimating the biomass of the main shrub-tree species in an area of Caatinga, thereby contributing to the development of sustainable management and for carbon stock estimates.

2. MATERIAL AND METHODS

2.1. Study area

The present work was developed in an area of 50 ha within the Fazenda Itapemirim, owned by Agrimex Agroindustrial Excelsior S.A. The farm has a total area of approximately 6,000 ha and is located in the municipality of Floresta, in the state of Pernambuco with access by highways PE-360, BR-232 and BR-110. The headquarters of the farm is situated at the geographical coordinates 8°33′20,9″S Latitude and 37°56′27,4″W Longitude, about 360 km from the city of Recife (Figure 1). The study area is part of the *Depressão Sertaneja Meridional* ecoregion, which is among the regions most impacted by human action with few protected areas. The vegetation can be classified as Woody Steppe-Savanna, being divided into two strata: upper shrub-arboreal, sparse; and the other as lower grassy-woody (Brazilian Institute of Geography and Statistics - *IBGE*, 2012). The soil is classified as Chronic Luvisol, characterized by being shallow and abruptly changing its texture.

The region's climate is BS'h according to the Köppen climate classification, which refers to a hot semi-arid climate characterized by aridity, water deficiency and unpredictable rainfall ranging from 268 to 1000 mm, and very high average annual temperatures with values ranging from 26 to 28ºC (IBGE, 2012).

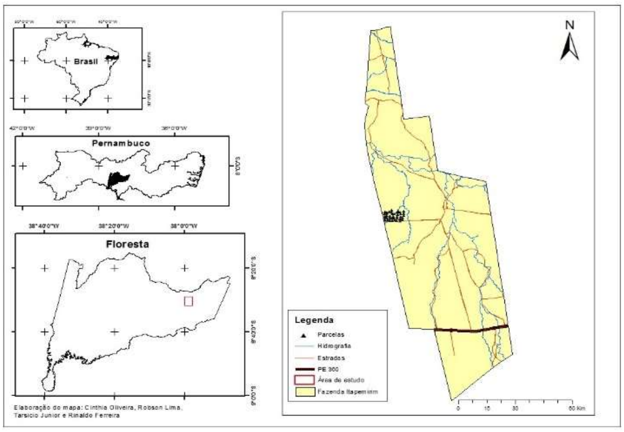

Figure 1. Location of the study area in the municipality of Floresta, state of Pernambuco, Brazil. Source: Lima et al. (2017).

Figura 1. Localização da área de estudo, no município de Floresta, estado de Pernambuco, Brasil. Fonte: Lima et al. (2017).

2.2 Sample structure and data collection

The history of the study area shows the establishment and monitoring of 40 permanent plots since 2008, with dimensions of 20 x 20 m (400 m²) which are 80 m apart with 50 m of the border, totaling a sample area of 1.6 ha. The site is considered preserved (with little cutting history), probably only the removal of forest products for eventual maintenance of fences that limit the farm and grazing by animals (mainly goats) in an extensive and uncontrolled way.

All individuals with circumference at 1.30 m (CBH) ≥ 6 cm were identified and labeled on their CBH when installing the plots in 2008, aiming to standardize the measurement site. Measurements were remeasured in 2011, 2012 and 2013, and the recruited individuals were inserted in the database, meaning those that reached the minimum CBH stipulated in the remeasurement years, while the dead and fallen trees were also recorded.

Of the 24 species registered in the study area during the five years, only the eight species with the highest importance value, and consequently those with the highest absolute density were selected based on the phytosociological inventory. These species represent 91.6% of the total density of the study area, considering that an individual corresponds to a stem that can be obtained from sprouts or bifurcations below 0.30 m in height. The nomenclatures follow the pattern suggested by Angiosperm Philogeneny Group III (APG III, 2009).

The species were as follows: *Anadenanthera colubrina* var. cebil (Griseb.) Altschul (angico), *Aspidosperma pyrifolium* Mart. (pereiro), *Bauhinia cheilantha* (Bong.) Steud. (mororó), *Cnidoscolus quercifolius* Pohl (faveleira), *Croton heliotropiifolius* Kunth (quebra-faca), *Mimosa ophthalmocentra* Mart. ex Benth (jurema de embira), *Mimosa tenuiflora* (Willd.) Poir. (jurema preta) and *Poincianella bracteosa* (Tul.) L.P.Queiroz (catingueira).

2.3 Data collection

The biomass collection and determination for the eight species were performed based on the diametric structure found in the forest inventories and which has been applied in studies in this region (ALVES et al., 2017; ABREU, 2012). Each species had individuals sampled in 5 circumference classes at 1.30m from the soil (CBH) with amplitudes of 6 cm, from a minimum CBH of 6 cm. The classes and their amplitudes (cm) are as follows: Class I (6.0-12.0 cm), Class II (12.1-18.0 cm), Class III (18.1-24.0 cm), Class IV (24.1-30.0 cm) and Class V (> 30.0 cm).

There were 15 individuals cut and their total aboveground biomass was determined for *A. colubrina*, *A. pyrifolium*, *C. quercifolius*, *M. ophthalmocentra*, *M. tenuiflora* and *P. bracteosa*, while the same occurred with 30 trees for *B. cheilantha* and *C. heliotropiifolius*. The individuals were cut down in a plot close to the permanent plots. This field has authorization for cutting by the State Environmental Agency of Pernambuco (*CPRH*), via a state management plan. The individuals were chosen in a random way and avoiding partially cut, burned or fallen plants in order to cover the classes of predicted circumference.

The trees were felled and the individuals were separated into the following compartments: stem, leaves, thin (CBH <6 cm) and thick branches (CBH ≥ 6 cm), and then weighing (wet weight in kg) using a portable digital scale. A representative and random sample was drawn for each compartment, which was weighed in the field (wet weight of the sample in kg). The sample size ranged from 0.05 to 2.0 kg. For the stems, the sample was represented by a small 20-cm-long stele removed at 1.30 m from the ground.

All wet samples were labeled and taken to the Dendrology Laboratory of the Forest Science Department of *UFRPE*, where drying was carried out in a forced circulation oven at 70ºC until stabilization of the dry weight (dry weight of the sample in kg). The dry biomass of each aboveground component part of the sampled shrub-tree individuals was obtained by calculations taking into account the direct proportion of the quantities.

2.4 Proportions of aboveground biomass

The proportions of dry aboveground biomass (%) were done for each of the eight species using column charts created in Microsoft Excel (2010). The calculation considered the average biomass proportions of each compartment (stem, thick branches, thin branches and leaves) in relation to the total biomass of all individuals cut down for each species. The information was organized by CBH classes as previously described, and for grouping all individuals.

2.5 Equation adjustments

For adjusting the statistical models, the total dry aboveground biomass (B_i in kg) data were collected as the dependent variable, while the independent variables were the diameter at breast height (DBH_i in cm) and total height (HT_i in m) of the individuals by species. This database also had information from Alves et al. (2017) and Abreu (2012) that were collected from adjacent areas to this study. In total, 30 pairs of data were used for each of the species, except for *M. tenuiflora*, which were only 15 pairs. In total, 225 data pairs were used in adjusting the equations for all species.

Table 1 shows the linear and non-linear models tested to obtain the total dry aboveground biomass equations for each of the studied species. The following conditions were tested for the regression analysis: homogeneity of variance, normality and independence of residues with the Bartlett, Shapiro-Wilk and Durbin-Watson tests, respectively.

We used traditional statistical criteria in selecting the best equation for each of the species: adjusted coefficient of determination (R^2_{aj}), standard error of the estimate in percentage ($S_{yx}\%$), graphical analysis of the distribution of residuals ($\hat{E}_i\%$) and the Furnival Index (FI%) corrected by Silva; Bailey (1991) so that it was possible to compare equations with dependent variables of different natures. The coefficient of determination expresses the amount of the total variation explained by the regression, where the higher its value, the better the equation. However, the corrected Furnival Index gives an idea of the dispersion between the observed and estimated values, so the smaller it is, the better the equation (SCHNEIDER et al., 2009). The Levenberg-Marquardt algorithm was used to fit non-linear statistical models. All data analyzes were performed through IBM SPSS 20.0, SAS 9.0 and Microsoft Excel (2010) programs.

3. RESULTS

3.1. Biomass proportions

A. colubrina, *A. pyrifolium*, *C. quercifolius*, *M. tenuiflora* and *P. bracteosa* presented a higher stem proportion in relation to the other compartments in all CBH classes, except for class V for *A. pyrifolium* and *P. bracteosa*. The proportion of thin branches and leaves is greater than that of thick branches in the lower classes, but this pattern is reversed with the increase in CBH. The average total proportion was approximately 50% for stem, between 20 and 25% for thick branches, between 15 and 25% for thin branches and 5% for leaves (Figure 2).

Table 1. Mathematical models tested to obtain equations of dry aboveground biomass for eight species in an area of Caatinga in the municipality of Floresta, Pernambuco, Brazil.
Tabela 1. Modelos estatísticos testados para obtenção de equações de biomassa total seca acima do solo para oito espécies em uma área de Caatinga no município de Floresta, Pernambuco, Brasil.

Number	Model	Author
1	$Y_i = \beta_0 * \left(DBH_i^{\beta_1}\right) * \left(HT_i^{\beta_2}\right) + \varepsilon_i$	Shumacher-Hall
2	$lnY_i = \beta_0 + \beta_1 * ln(DBH_i) + \beta_2 * ln(HT_i) + \varepsilon_i$	Shumacher-Hall (linear)
3	$Y_i = \beta_0 + \beta_1 * \left(DBH_i^2 * HT_i\right) + \varepsilon_i$	Spurr
4	$lnY_i = \beta_0 + \beta_1 * ln\left(DBH_i^2 * HT_i\right) + \varepsilon_i$	Spurr (linear)
5	$Y_i = \beta_0 * [1 - exp(-\beta_1 * DBH_i)]^{\beta_2} + \varepsilon_i$	Chapman-Richards
6	$Y_i = \beta_0 * (DBH_i)^{\beta_1} + \varepsilon_i$	Power
7	$Y_i = \beta_0 * (DBH^2)^{\beta_1} + \varepsilon_i$	Power
8	$Y_i = \beta_0 * \left(DBH_i^2 * HT_i\right)^{\beta_1} + \varepsilon_i$	Power

In which: Y_i = total dry aboveground biomass (kg); β_0, β_1 and β_2 = coefficients of the models; DBH = diameter at breast height (cm); HT = total height (m) and ε_i = random error.

M. ophthalmocentra presented a different pattern from the other species. The proportion of stem biomass did not exceed 45% in the five classes, being less than 40% in the majority. The proportions of thick branches increase and those of thin branches and leaves decrease along the classes, but the proportion of thin branches is superior to that of the stem in the first two classes. This species presents identical proportions of stem and thin branches (38%) in the total biomass average, and only 20% of thick branches and close to 3% for leaves (Figure 2).

B. cheilantha and *C. heliotropiifolius* are species that did not present great dimensions. The proportions indicate that *B. cheilantha* has very close stem and branch proportions (approximately 45%) and thick branches and leaves not exceeding 10 and 5%, respectively. However, the stem biomass for *C. heliotropiifolius* is above 50%, and the thin branches close to 35%, while the thick branches and leaves present the same pattern as *B. cheilantha* (Figure 2).

3.2 Biomass equations

The model adjustment results with all the coefficients of the significant equations are presented in Table 2 ($p \leq 0.05$) as well as the adjusted coefficient of variation (R_{aj}^2) greater than 0.70 (inclusion criteria). The adjustment result of four models (5, 6, 7 and 8) were selected for *A. colubrina* through the inclusion criteria, but the best equation was that of the Chapman-Richards model (5), because it presented greater R_{aj}^2 and lower FI% in relation to the others (Table 2), as well as more homogeneous residuals distribution.

The model adjustment results presented in Table 2 for *A.pyrifolium* and *B. cheilantha* show great similarity between the precision statistics of equations 1 and 8, in addition to discrete variation between the residuals distribution. The two equations (1 and 8) with their respective coefficients can be used to estimate the total dry aboveground biomass soil for both species. However, due to the need to recommend the most accurate equation for each of the eight studied species, equation 8 is chosen for *A.pyrifolium* because it presents slightly superior R_{aj}^2, and equation 1 for *B. cheilantha* due to the lower FI% value.

Of the five models selected for *C. quercifolius* within the inclusion criteria (3, 4, 6, 7 and 8), three models (6, 7 and 8) presented better R_{aj}^2 (%), FI(%) and residuals, but were practically identical in the equation adjustments. Due to these similarities, the recommended equation to calculate the total dry biomass estimate was 6 because it did not use the independent HT variable which was difficult to obtain, and the combination of the independent variable diameter at breast height squared (DBH^2), resulting in less slowness for the total dry aboveground biomass estimates for this species (Table 2).

C. heliotropiifolius had the models 1, 2, 3, 4 and 8 analyzed, but the Shumacher-Hall equation is suggested for the biomass estimation, since it presented lower FI (%) and more homogeneous residuals. From the five selected models for *M. ophthalmocentra* (1, 2, 5, 6 and 7), only 1 and 2 deserve attention because they present the best precision statistics, and equation 2 is indicated for estimating the biomass of this species because it has smaller FI(%) and more homogeneous residuals.

The selected models for *M. tenuiflora* were 3, 4, 6 and 7, and equations 6 and 7 presented identical and more accurate statistics than the others. In this case, the most suitable for estimating biomass is equation 6, since it does not need to make combinations with the independent variable, facilitating estimation of the dependent variable. For *P. bracteosa* the data were better fitted to the models 1, 3, 6, 7 and 8, but equation 3 is indicated for this species because it presents greater R_{aj}^2, lower FI (%)(Table 2) and more homogeneous residuals than the other equations.

The best results for the set of species were those from models 2 and 4. Equation 2 was chosen because it presented higher R_{aj}^2 and lower FI (%).

Table 3 presents the nine best equations suggested for estimating total dry aboveground biomass for the main Caatinga species.

Figure 3 shows the graphical residuals distribution only for the nine best equations selected for estimating the total dry aboveground biomass for each analyzed species and for the grouping of species.

4. DISCUSSION

4.1. Biomass proportions

When analyzing the average proportions of total dry aboveground biomass (%) in each compartment, it can be observed that the range of variation in the biomass percentages of the compartments in relation to the whole is smaller than in the absolute values, showing that these species grow proportionally, closely, and have similarity between some species (Figure 2).

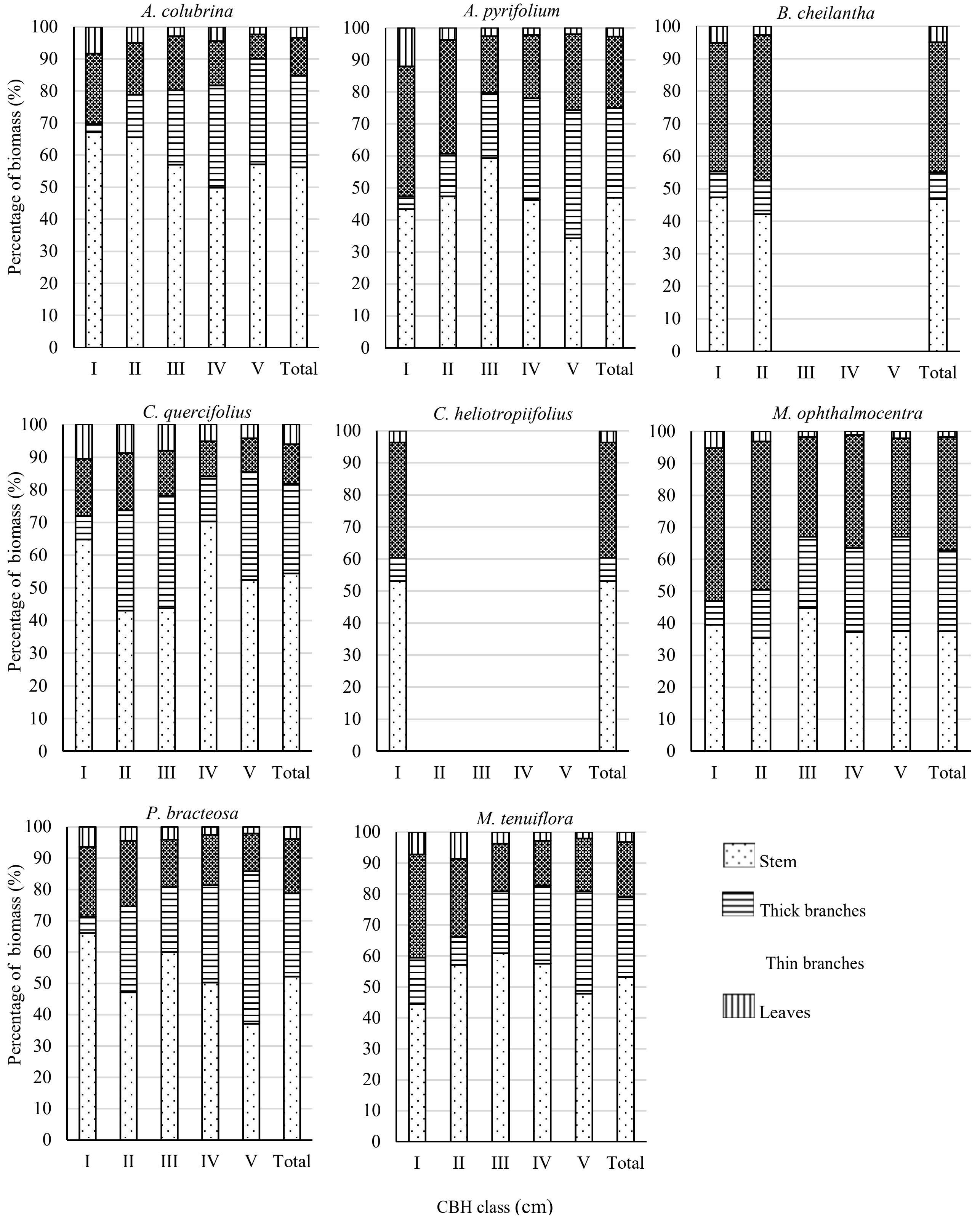

Figure 2. Proportion of total dry aboveground biomass (%) in each compartment per CBH class (cm) for the eight analyzed species in an area of Caatinga in the municipality of Floresta, Pernambuco, Brazil.
Figura 2. Proporção de biomassa seca total acima do solo (%) em cada compartimento por classe de CAP (cm) para as oito espécies analisadas em uma área de Caatinga no município de Floresta, Pernambuco, Brasil.

Table 2. Number, parameters and statistics of the selected equations for calculating total dry aboveground biomass for each of the eight species in an area of Caatinga in the municipality of Floresta, Pernambuco, Brazil.
Tabela 2. Número, coeficientes e estatísticas das equações de biomassa total seca acima do solo selecionadas para cada uma das oito espécies em uma área de Caatinga no município de Floresta, Pernambuco, Brasil.

Species	Model	β_0	β_1	β_2	$R^2_{adjusted}$	S_{yx}	$S_{yx}\%$	$FI\%$
Anadenanthera colubrina	5	48,7255	0,1435	2,4096	0,89	3,20	20,69	32,5
	6	1,7527	1,1265	-	0,86	3,55	22,94	36,6
	7	1,7531	0,5632	-	0,86	3,55	22,94	36,6
	8	1,4905	0,4069	-	0,84	3,83	24,75	39,5
Aspidosperma pyrifolium	1	0,7271	0,8176	0,6229	0,74	2,18	27,01	42,4
	6	1,0110	1,1361	-	0,71	2,28	28,25	45,0
	7	1,0109	0,5681	-	0,71	2,28	28,25	45,0
	8	0,7858	0,4550	-	0,75	2,15	26,64	42,5
Bauhinia cheilantha	1	0,0699	2,2115	0,8155	0,97	0,18	12,09	19,0
	2	-2,7776	2,1672	0,9313	0,94	0,14	65,11	18,6
	4	-2,8746	1,0523	-	0,94	0,14	64,41	18,7
	6	0,1543	2,4831	-	0,94	0,27	17,87	28,5
	7	0,1543	1,2416	-	0,94	0,27	17,87	28,5
	8	0,0568	1,0531	-	0,97	0,19	12,54	20,0
Cnidoscolus quercifolius	3	3,9444	0,0186	-	0,79	2,41	27,20	43,4
	4	-0,6664	0,5237	-	0,72	0,35	17,52	46,2
	6	0,6064	1,4216	-	0,82	2,26	25,51	40,7
	7	0,6064	0,7108	-	0,82	2,26	25,51	40,7
	8	0,4896	0,5387		0,82	2,29	25,78	41,1
Croton heliotropiifolius	1	0,1868	1,2764	0,9401	0,76	0,38	18,96	29,7
	2	-1,6887	1,2224	0,9761	0,71	0,20	31,81	29,3
	3	0,6522	0,0582	-	0,76	0,38	19,15	30,5
	4	-1,5518	0,7158	-	0,70	0,20	32,21	30,2
	8	0,2219	0,7065	-	0,76	0,38	19,11	30,5
Mimosa ophthalmocentra	1	6,0137	1,7250	-1,338	0,90	3,38	19,80	31,0
	2	1,1118	1,7371	-0,9536	0,88	0,23	9,04	30,0
	5	43,6748	0,2103	2,9584	0,75	5,47	32,04	50,3
	6	2,2018	1,1066	-	0,71	5,83	34,16	54,5
	7	2,2016	0,5533	-	0,71	5,83	34,16	54,5
Mimosa tenuiflora	3	3,0407	0,0458	-	0,89	3,22	22,12	34,11
	4	-1,6100	0,7850	-	0,92	0,25	10,58	29,45
	6	0,5084	1,7121	-	0,94	2,44	16,79	25,90
	7	0,5084	0,8561	-	0,94	2,44	16,79	25,90
Poincianella bracteosa	1	0,6221	1,1061	0,6840	0,83	4,38	24,40	38,3
	3	6,6205	0,0341	-	0,85	4,20	23,40	37,3
	6	0,9765	1,5126	-	0,75	5,41	30,12	48,0
	7	0,9767	0,7563	-	0,75	5,41	30,12	48,0
	8	0,6173	0,5957		0,84	4,33	24,08	38,4
All species	1	0,8905	1,2189	0,2333	0,74	4,98	47,63	78,0
	2	-1,2884	1,6102	0,4343	0,85	0,43	23,46	42,9
	4	-1,4991	0,7290	-	0,84	0,44	23,69	43,5
	5	55,8948	0,1176	2,2982	0,74	4,92	47,11	77,2
	6	0,9867	1,3692	-	0,73	5,03	48,12	79,0
	7	0,9867	0,6846	-	0,73	5,03	48,12	79,0
	8	0,8471	0,5034	-	0,73	5,06	48,39	79,4

Table 3. Mathematical equations suggested for estimating total dry aboveground biomass in an area of Caatinga in the municipality of Floresta, Pernambuco, Brazil.
Tabela 3. Equações matemáticas sugeridas para a estimativa da biomassa aérea seca em uma área de Caatinga, no município de Floresta, Pernambuco, Brasil.

Species	Equation	R^2_{aj}	$S_{yx}(\%)$	$FI(\%)$
Anadenanthera colubrina	$Bs_i = 48.7255 * [1 - exp(-0.1435 * DBH_i)]^{2.4096}$	0.89	20.69	32.5
Aspidosperma pyrifolium	$Bs_i = 0.7858 * (DBH_i^2 * HT_i)^{0.4550}$	0.75	26.64	42.5
Bauhinia cheilantha	$Bs_i = 0.0669 * (DBH_i^{2.2115}) * (HT_i^{0.8155})$	0.97	12.09	19.0
Cnidoscolus quercifolius	$Bs_i = 0.6064 * (DBH_i)^{1.4216}$	0.82	25.51	40.6
Croton heliotropiifolius	$Bs_i = 0.1868 * (DBH_i^{1.2764}) * (HT_i^{0.9410})$	0.76	18.96	29.7
Mimosa ophthalmocentra	$lnBs_i = 1.1118 + 1.7371 * \ln(DBH_i) - 0.9536 * \ln(HT_i)$	0.88	9.04	30.0
Mimosa tenuiflora	$Bs_i = 0.5084 * (DBH_i)^{1.7121}$	0.94	16.79	25.9
Poincianella bracteosa	$Bs_i = 6.6205 + 0.0341 * (DBH_i^2 * HT_i)$	0.85	23.40	37.3
All species	$lnBs_i = -1.2884 + 1.6102 * \ln(DBH_i) + 0.4343 * \ln(HT_i)$	0.85	23.46	42.9

In which: BS= total dry aboveground biomass (kg); DBH = diameter at breast height (cm); HT = total height (m); $R^2_{aj}(\%)$ = adjusted coefficient of determination in percentage; S_{yx} (%) = standard error of the estimate in percentage and $FI(\%)$= Furnival Index in percentage.

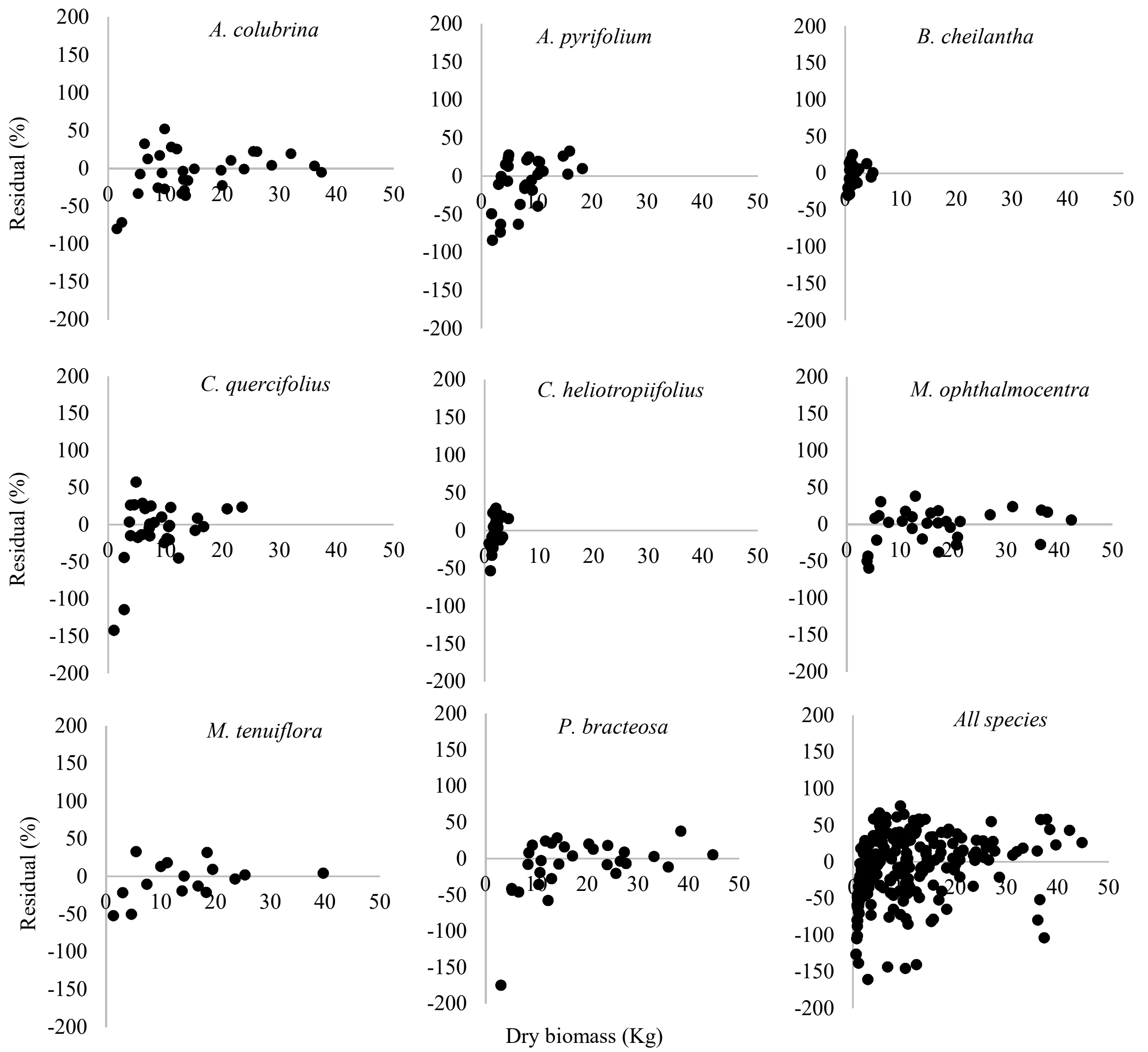

Figure 3. Graphical distribution of the residuals of the selected equations for total dry aboveground biomass for each of the eight species and for all species in an area of Caatinga in the municipality of Floresta, Pernambuco, Brazil.
Figura 3. Distribuição gráfica dos resíduos das equações selecionadas para biomassa seca total acima do solo para cada uma das oito espécies e para todas as espécies em uma área de Caatinga no município de Floresta, Pernambuco, Brasil.

In general, the average proportions of total dry aboveground biomass (%) in each compartment vary due to the growth pattern of each species, and it is not prudent to attribute similarities between genera and botanical families due to the specific characteristics of each species, mainly for *M. ophthalmocentra*.

Comparing both the absolute values and the biomass proportions between different species and/or regions should be done carefully, since other factors in addition to the different methodologies used may influence the production. For Barichello et al. (2005), in addition to environmental factors, the accumulation of biomass can be influenced by plant factors, especially those affecting photosynthesis and respiration (luminosity, temperature, CO_2 concentration in the air, water concentration, soil fertility, diseases, age, structure and arrangement of leaves, distribution and behavior of stomata, chlorophyll content, and accumulation of carbohydrates).

Studies on the stocks and production rates and biomass accumulation in the Caatinga vegetation are essential information for assessing wood production capacity, the fallow time of itinerante cultivation, carbon sequestration capacity and the productivity potential of the systems, as well as their respective financial gains (SAMPAIO; FREITAS, 2008).

4.2 Biomass equations

The adjustment of the models for each of the eight analyzed species resulted in different results, and the majority overestimated the biomass of the trees with lower mass (Figure 3). This large variation can be attributed to the shape, height, crown size, number and size of the individuals of the shrub-tree species of the Caatinga or the remnants of other successional stages.

The results found when compared with adjusted equations in other studies for the same species or other species in different regions of the Caatinga are considered within the registered limits (SAMPAIO; SILVA, 2005; SILVA; SAMPAIO, 2008; SAMPAIO et al., 2010; ALVES JR., 2010; FERRAZ, 2011; ABREU, 2012; MENDONÇA et al., 2013).

The worst results for precision statistics (R_{aj}^2 and FI) were observed for the *A. pyrifolium* species regarding the 8 species analyzed (Table 2), corroborating Abreu (2012) who recorded approximately 78% for R_{aj}^2 and 19% for $S_{yx}(\%)$ for the two best equations. When observing that the present study used the data used by Abreu (2012) plus other collected samples, we can infer that the increase in sample intensity does not always increase the accuracy of the equations. According to Ferraz (2011), this greater or lesser precision of the equations is related to the characteristics of the Caatinga shrub-tree species, since they present a great variation in form/shape, height, number and size of the branches, and if woody material is considered in the evaluations.

B. cheilantha was the species that presented the highest values of R_{aj}^2 and the lowest $FI\%$ values in relation to the other analyzed species. This result is due to a high correlation between the independent and the dependent variables, because as the diameter increases, the dry mass also increases linearly and positively.

According to Carvalho (2010), *B. cheilantha* is a shrub-tree species in which the largest trees reach about 7.80 m in height and 30 cm of DBH in adult age, with the stem being irregular, very short or bifurcated. The individuals' pattern in the study area differs from what is recorded in the literature for this species, since the analyzed individuals did not present diameters, height or dry biomass above 4.1 cm, 4.9 and 5.0 kg, respectively, and most of them were concentrated in the Class I CBH (cm), with a low variation between the dependent and independent variables, which may suggest that they are young individuals.

For *M. ophthalmocentra*, Sampaio et al. (2010) adjusted power equations with the best dry biomass estimation option among linear, quadratic, exponential and logarithmic models, but the determination coefficient results were lower for the independent variables of isolated DBH (cm), DBH (cm) and H (m), DBH (cm) and crown area (m^2), than those found in this study of 81, 73 and 59%, respectively; however, the error estimates for these equations are not mentioned. These same authors indicated the best power equation for *M. tenuiflora* using only DBH as an independent variable in two Caatinga areas in Serra Talhada and Sertânia/PE, corroborating the results of this study.

For *P. bracteosa*, the results of the precision statistics corroborate those found by Ferraz (2011) when studying dry biomass estimates of 30 individuals in an area of Caatinga (Floresta/PE), obtaining 24 equations with errors between 18.06 and 32.42% and R_{aj}^2 higher than 76%, reaching 93.5%.

In the case of the species *C. quercifolius* and *M. tenuiflora* there was the possibility of choosing between a model with independent variables that are easy to obtain in relation to one with greater difficulty, without compromising the precision of the estimates. This possibility is a widely-used strategy in regression analysis studies in the forest area, since the addition of these variables in the equation, even when they present better statistics, does not always compensate for the encumbrance and longer data collection time.

A.pyrifolium, *B. cheilantha*, *C. heliotropiifolius* and *P. bracteosa* presented close precision statistics among the best equations, so the use of the other equations is not ruled out, and the choice criterion also took into account the researchers' preference due to the little difference between the statistical criteria. When comparing univariate and multivariate statistical methods in selecting 21 independent variables in volumetric models for *Leucaena leucocephala* (Lam.) de Wit, Araújo (2005) concluded that the subjective judgment of the researcher is a criterion that must be taken into account when deciding on selecting the variables in mathematical modeling, since statistics and mathematical processes treat all variables as being equal in terms of cost and ease of measurement.

The general equation presented better precision statistics when compared to the species *A. pyrifolium*, *C. quercifolius* and *C. heliotropiifolius*. This can be attributed to compensating the biomass deviations of one species from another species, but this result does not prevent using specific equations for each species.

In the residuals' distribution the tendency to overestimate biomass in the trees with lower mass was evident, as well as in the great majority of the species which were analyzed separately.

5. CONCLUSIONS

The proportions of dry aboveground biomass for *A. colubrina*, *A. pyrifolium*, *B. cheilantha*, *C. quercifolius*, *C. heliotropiifolius*, *M. ophthalmocentra*, *M. tenuiflora* and *P. bracteosa* were determined for both their compartments (stem, leaves, thick and thin branches) as well as the total.

Dry aboveground biomass equations were developed for *A. colubrina*, *A. pyrifolium*, *B. cheilantha*, *C. quercifolius*, *C. heliotropiifolius*, *M. ophthalmocentra*, *M. tenuiflora* and *P. bracteosa* with reasonable accuracy statistics for all these species, and can be used to reliably estimate this variable in Caatinga regions with similar characteristics to this study.

This information can contribute to the quantification of carbon and nutrient stocks in Caatinga areas.

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