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Allometric Equations for Predicting Biomass of *Daniellia oliveri* (Rolfe) Hutch. & Dalz. Stands in the Sudano-Guinea Savannahs of Ngaoundere, Cameroon

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To cite this article:
Tchindebe Alexandre, Ibrahima Adamou, Tchobsala, Mohamadou Laminou Mal Amadou. Allometric Equations for Predicting Biomass of *Daniellia oliveri* (Rolfe) Hutch. & Dalz. Stands in the Sudano-Guinea Savannahs of Ngaoundere, Cameroon. *Ecology and Evolutionary Biology*. Vol. 4, No. 2, 2019, pp. 15-22. doi: 10.11648/j.eeb.20190402.11

Abstract: Allometric relationships for estimating biomass of *Daniellia oliveri* (Rolfe) Hutch & Dalz. stand were investigated in the sudano-guinea savannah of Ngaoundere, Cameroon. A total of 17 individual trees from *Daniellia oliveri* were harvested in Bini-Dang savannah across a range of diameter classes, from 5 to 40 cm. Diameter at breast height (D) and total height (H) were determined and considered as predictor variables, while total above-ground biomass, stem, branch, leaf and root biomass were the output variables of the allometric models. Among many models tested, the best ones were chosen according to the coefficient of determination adjusted (R^2adj), the residual standard error (RSE) and the Akaike Information Criteria. The main results showed that the multiplication of tree H with D in the allometric equation did not improve in the degree of fitness of the allometric equations, except for leaf biomass. The fit allometric biomass of *Daniellia oliveri* model for leaf, branch, stem and root biomass and above ground biomass were the follow: $Ln(Bl) = 3.0303 + 0.744*Ln(D^2H)$; $Ln(Bb) = 3.772 + 2.701*Ln(D)$; $Ln(Bs) = 2.663 + 2.218*Ln(D)$, $Ln(Br) = 2.072 + 1.920*Ln(D)$ and $Ln(Bt) = -2.089 + 2.374*Ln(D)$ respectively. The root biomass represented on average 28% of the total aboveground biomass and these two biomasses were positively and significantly correlated ($r = 0.93$, $p < 0.05$ and $n = 11$). For the *Daniellia oliveri* stands studied, the diameter at breast height (D) alone showed a very strong accuracy of estimation. It is concluded that the use of tree height in the allometric equation can be neglected for the species, as far as the present study area is concerned. Therefore, for estimating the biomass of *Daniellia oliveri*, the use of D as an independent variable in the allometric equation with a power equation would be recommended. The paper describes details of tree biomass allometry, which is important in carbon stock, sylviculture and savannah management.

Keywords: Allometry, Regression, Biomass, *Daniellia oliveri*, Savannah of Ngaoundere, Cameroon

1. Introduction

Daniellia oliveri (Rolfe) Hutch & Dalz. is a species of the Caesalpiniaceae family of the Adamawa sudano-guinea savannahs [1], playing many roles in the production systems of this region [2]. In addition to its ecological and economic functions, it has social and cultural meanings in the northern part of Cameroon. As sources of fodder, young leaves are an important supplement to the feeding of livestock and certain wildlife [3]. It also provides firewood and handicrafts, shade and utilities in traditional medicine [4]. One of the most abundant and characteristic species of the sudano-guinea savannahs of Ngaoundere [5], *D. oliveri* plays an important role in environment protection by carbon stock [6].

At present day, this species is under anthropogenic pressure due to savannah overexploitation by indigenous peoples, transhumants and refugee peoples [7, 8]. This anthropogenic pressure leads to a dangerous and even

irreversible reduction if nothing is done for this agroforestry species and thus jeopardizes its conservation and sustainable management in these savannahs. However, for its important role in fodder production and carbon sequestration, the management of this plant species requires a good knowledge of its biomass and its carbon stock.

During the last ten decades, considerable research efforts have been made in estimating biomass of trees and shrubs in forest ecosystems [9-13] and weakly in sub-Saharan savannah of Africa [14-15], very little in the savannah of Ngaoundere Cameroon [16-18]. For the estimation of this woody biomass, the allometric equations were widely used to prevent the destruction of forest trees, linking different dendrometric measurements of the trees and their above-ground biomass. These allometric relationships are very important for the management of natural and artificial forest resources [19-22]. Because they offered best estimation of woody biomass which is also an important variable in research of carbon emission [22, 23]. Therefore, choosing a suitable model for the development of allometric equation is important in forest and environmental sciences [23, 24].

The logarithmic model is frequently used [25] with a general equation in the form of $B = aD^b$ (commonly presented as a logarithmic form) where B is the biomass, D the diameter at breast height of the tree, a and b are the regression coefficients. Furthermore, there are two (2) or three (3) independence explanatory variables in the allometric relationships for estimating tree biomass. In most of study, the diameter at breast height of the tree has been used as the same explanatory and independent variable in the allometric equation [26-29]. Therefore, the integration of other explanatory variables such as tree height (H) sometime ensures greater accuracy of the allometric equation for some species [30-32]. Some allometric equations were developed in the savannah of Africa from various tropical species [33-34]. It is clear that woody species are different mainly by allometry because of their different density and the stem shape. That is why, the development of specific allometric equations is essential for accuracy in estimating the carbon stock for each important species and each ecosystem. The aim of this study is the development of mono-specific allometric equations to accurately estimate biomass of the *Daniellia oliveri* and to deduce the ratio between the above and above-ground biomass in the sudano-guinea savannah of Cameroon.

2. Materials and Methods

2.1. Study Site

The study was carried out in Dang located in between 7° 25'127''of the North latitude and 13°33'130'' of the East longitude and 1081 m of altitude asl. The area belongs to Adamawa's sudano-guinea savannah, which constitutes a vast plateau located between the 6th and 8th degree of latitude North and between the 11th and 15th degree of longitude East. This region covers approximately 72,000 km², with an

average altitude of about 1000 m and occupies practically the center of Cameroon. The climate is humid sudano-guinea type [35], with a unimodal rainfall distribution. Mean annual rainfall is about 1500 mm. The rainy season extends from July to September and dry season stretches from November to March. Mean annual temperature is 23°C and mean relative annual humidity is 65% [36]. While Ferralitic soils are the dominant types [37], with rich clay (40 à 60%), low organic matter (less than 1%), low soil exchange capacity from 15 to 20 meq/100g and the pH 4.7 to 5.6 [38]. Vegetation of Adamawa is a humid savannah type, consisting of shruby and woody savannahs. These savannahs originally populated with *Daniellia oliveri* and *Lophira lanceolata* [5]. There are also hydromorphic meadows that are sometimes inundated and contain *Hypparhenia rufa*, forest galleries with *Syzygium guineense* var. *guineense* and *Berlinia grandifolia*, fallow lands and savannahs, occasionally used as grazing lands which are composed of *Acacia hockii*, *Afzelia Africana* [5]. Now, this vegetation is much reduced under the influence of zoo-anthropic factors such as wild fires and rearing [38, 39]. Agriculture is still traditional. Livestock remains the main economic activity practiced by the more than 20% of the rural population. Other activities like hunting, fishing and crafts are practiced at artisan level in the region. The most relevant problems in the region include the permanent decline soil fertility, damages by Striga on cereals and termites on crops.

2.2. Sampling and Data Collection

After the authorization n° 263/ASAA/DRFOF/AD/SRF of the regional Delegate of the Ministry of Forestry of Wildlife (MINFOF), seventeen (17) individual trees of *Daniellia oliveri* with various diameter at breast height (DBH), and total height (H) were sampled in the Ngaoundere Savannah. Sample trees were selected purposively, avoiding suppressed or sick trees or those with broken tops, hollows, or other damages. These sampled individuals were distributed in the three diameter classes defined by Mamadou [16] and Ahmadou [17], at the rate of six (6) individuals for the small diameter classes (5 – 15 cm), six (6) individuals for the intermediate diameter classes (15 - 25 cm) and five (5) individuals for the large diameter classes (25 - 40 cm). The trees were felled as close to ground level as possible and after felling, each tree was separated into trunk, branches and leaves, based on the method described by Picard et al. [41]. The root excavation was made by 11 individual trees in which 4 from the small diameter classes, 3 from the intermediate diameter classes and 4 of the large diameter classes. The fresh biomass of each compartment weighed using a scale. To obtain the dry weight, three samples of each compartment and each tree were collected. In the laboratory, samples of stems, branches and roots were oven-dried at a constant temperature of 105°C and leaves at 75°C to a constant weight after 72 hours. The water content (WC) in the various compartments (stem, branches, leaves and roots) was determined after drying of the samples using the formula by WC (%) = ((FM-DM/ DM)*100, with WC is the water

content of the sample, FM and DM are respectively the fresh and dry mass (Kg) of the sample. From the water content of the sample, the total dry mass (TDM) of each compartment has been calculated using the following formula, TDM = 100 * TFM/(100 + WC), with TFM and TDM are respectively the total fresh and dry mass (Kg). The total dry mass of each tree was estimated by adding the dry mass of the various compartments of the trees.

2.3. Data Analysis

The allometric equations have been established between the physical parameters of the tree such as diameter (D) and height (H), and tree biomass [42]. The simple allometric equation was generally written using the power curve [41, 43, 44] in the form (1):

$$y=ax^b \tag{1}$$

where Y is the dependent variable and X is the independent variable, and a the coefficient and b the allometric constant. To take into account the heteroscedasticity of data [12, 45], the formula is often linearized by using the logarithms [41], as follows (2):

$$Ln(y)=Ln(a)+bLn(x) \tag{2}$$

where Ln(a) and b are the intercept and slope of the regression line, respectively. The Ln(a) and b are obtained by the method of least squares. In this study, the allometric relationships of the biomass and different dimensions such as D, D^2H, were also established using following equations (3 to 5):

$$Ln\ (B) = a + b* Ln(D) \tag{3}$$

$$Ln\ (B) = a + b*Ln(D^2H) \tag{4}$$

$$Ln\ (B) = a + b*Ln(D) + c*Ln(H) \tag{5}$$

Where B is the biomass (kg), D and H are respectively the tree diameter and total height (m), a, b and c are the coefficient of regression.

The logarithmic transformation of data generally leads a

bias in the biomass estimation [20, 46]. A correction is therefore necessary and consisted to multiply the estimated biomass by a correction factor which was calculated as follows: CF = exp $(RSE^2/2)$ [45, 47]; CF is the number always high to 1. Some criteria were used to select the best predictive model when calculated. In addition to the coefficient of determination adjusted (R^2aj) and the value of the statistic signification (P), the residual standard error (RSE) and the Akaike information criteria (AIC) were calculated. RSE represents the standard deviation between the observed value and its prediction. The Akaike information criterion is a measure of the quality of the model used for the set of data considered. It allows to compare several models and to make the selection of the best model. AIC = -2Ln (L) + 2p, where p is the number of parameters in the model and L the maximum likelihood. These criteria make possible to judge the goodness of the model's fit; more the last criteria are low, best will be the model [20]. Statistical analysis were performed with excel 2016 and Ri 386 3.1.2 software.

3. Results

3.1. Diameter, Height and Biomass Distributions

Stand diameter and height varied from 7.54 to 34.49 cm and from 5 to 10.5 m, with average of 19 cm and 7.40 m respectively (Table 1). Aboveground biomass (AGB) and below ground biomass (BGB) ranged from 19.29 to 749.87 and from 6.79 to 103.85 kg respectively with respective average of 185.02 and 47.53 kg. The biomass accumulated in roots represented 20.44% of the total biomass. For the compartments, the leaf biomass ranges from 5.03 to 31.87 kg, that of the branches from 5.66 to 464.39 kg and that of the stems from 7.15 to 188.20 kg, with the respective averages of 23.02kg, 100.84kg and 61.16kg. The branches accumulate more biomass than the other compartments with a rate of 54.50% of the above-ground biomass, followed by stems (33.06%).

Table 1. Rank of diameter at breast height (D), height (H), and compartment biomass of D. oliveri from field survey calculation in Ngaoundere savannahs of Cameroon.

Items	D (cm)	H (m)	Compartments			AGB (kg)	BGB (kg)
			LB (kg)	BB (kg)	SB (kg)		
Average	19.25	7.40	23.02	100.84	61.16	185.02	47.53
STDEV	7.60	1.90	25.05	119.90	51,96	192.68	33.09
Minimum	7.54	5.00	5.03	5.66	7.15	19.29	6.79
Maximum	34.49	10.50	31.87	464.39	188.20	749.87	103.85

Leaf biomass (LB), branch biomass (BB), stem biomass (SB), aboveground biomass (AGB) and Bolow ground biomass (BGB).

3.2. Allometric Equations

Three models of allometric equation were developed for any compartment, with 17 individual tree for the above-ground biomass and 11 individual trees for the below ground biomass. The allometric relationships of biomass of different

compartments to diameter and height of *D. oliveri* were positive and significant (P < 0.001) with the high coefficient of determination adjusted ranged from 0.828 to 0.962 (Table 2). Regression coefficients (a, b and c) varied from -4.218 to -2.072, from 0.744 to 2.701 and from 0.128 to 0.382 respectively for a, b and c. These coefficients differed among

compartments for the same model. The model taking into account only the diameter as the physical parameter of the tree (3) was significant (p < 0,001) for each of the four compartments of trees, with the coefficient of determination varying between 0.836 and 0.962. These high adjusted coefficients of comparison with those of the other 2 models (4 and 5) showed that more than 80% of these relationships were explained by the single diameter.

Table 2. *Parameters of adjustments between biomass (kg), DBH (cm) and height (m) the individuals of Daniellia oliveri in the savannahs of Ngaoundere, Cameroon.*

Allometric models	A	b	C	R^2adjusted	RSE	N	CF	AIC
Leaf biomass								
ln(B)=a+bln(D)	-2.692 (0.60)	1.883 (0.20)		0.836	0.365	17	1.068	17.870
ln(B)=a+bln(D^2H)	-3.030 (0.63)	0.744 (0.08)		0.836	0.364	17	1.068	17.838
ln(B)=a+bln(D)+cln(H)	-2.887 (0.70)	1.689 (0.39)	0.382 (0.66)	0.828	0.373	17	1.072	19.476
Branch biomass								
ln(B)=a+bln(D)	-3.772 (0.56)	2.701 (0.19)		0.923	0.342	17	1.060	15.706
ln(B)=a+bln(D^2H)	-4,218 (0.63)	1.063 (0.08)		0.914	0.362	17	1.067	17.582
ln(B)=a+bln(D)+cln(H)	-3,889 (0.66)	2.583 (0.37)	0.229 (0.62)	0.918	0.353	17	1.064	17.545
Stem biomass								
ln(B)=a+bln(D)	-2.663 (0.34)	2.218 (0.11)		0.955	0.210	17	1.022	-0.852
ln(B)=a+bln(D^2H)	-3.023 (0.41)	0.872 (0.05)		0.944	0.235	17	1.028	2.973
ln(B)=a+bln(D)+cln(H)	-3.889 (0.40)	2.583 (0.23)	0.229 (0.38)	0.918	0.353	17	1.064	17.545
Above ground Biomas								
ln(B)=a+bln(D)	-2.089 (0.34)	2.374 (0.11)		0.962	0.207	17	1.021	-1.291
ln(B)=a+bln(D^2H)	-2.477 (0.40)	0.934 (0.05)		0.951	0.234	17	1.027	2.755
ln(B)=a+bln(D)+cln(H)	-2.178 (0.40)	2.284 (0.22)	0.175 (0.38)	0.959	0.213	17	1.023	0.451
Below ground biomass								
ln(B)=a+bln(D)	-2.072 (0.53)	1.920 (0.18)		0.918	0.265	11	1.035	5.826
ln(B)=a+bln(D^2H)	-2.366 (0.58)	0.751 (0.07)		0.912	0.274	11	1.038	6.578
ln(B)=a+bln(D)+cln(H)	-2.129 (0.67)	1.850 (0.47)	0.128 (0.81)	0.908	0.281	11	1.040	7.791

Coefficient of regression model (a, b and c), specimen number (N), coefficient of determination adjusted (R²adj), correction factor (CF), residual standard error (RSE) and Akaike information criteria (AIC).

By integrating the height of the tree in both model of 4 and 5, no improvement was obtained in the precision with the equations predicting the biomass of branches, trunk, roots and the total, except that of leaves. For this last compartment, the equation 4, integrating the diameter squared multiplied by the height (D^2*H) in the fit, of the form Ln (Bf) = a + b*Ln (D^2H), improved the model. The coefficient of determination adjusted of this model was high (0.836) and its residual standard error (RSE) was lower (0.364) than the model taking into account only the diameter (0.365). For the other compartment (branches, trunks, roots and their total), the coefficient of determination adjusted to the model taking into account the diameter and the height were lower than those of the model taking into account only the diameter.

To select best model predicting the biomass of each compartment in addition to the coefficient of determination adjusted (R^2adj), the residual standard error (RSE) and the Akaike value (AIC) which enable to evaluate the accuracy of the models have been taken into account. These coefficients of determination adjusted (R^2adj) of the 5 best models selected to each of the compartment and the total biomass were higher, their RSE and their AIC were lower than the value of their models. These best equations were presented in table 2 and the figures 1 and 2.
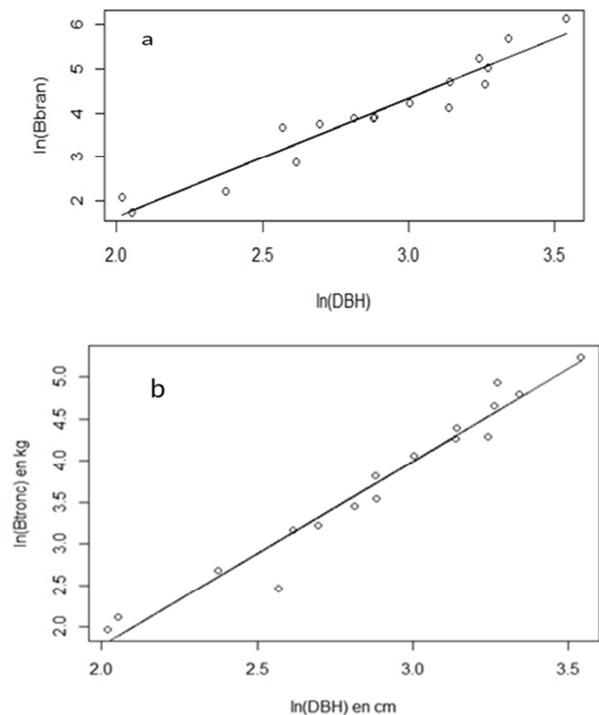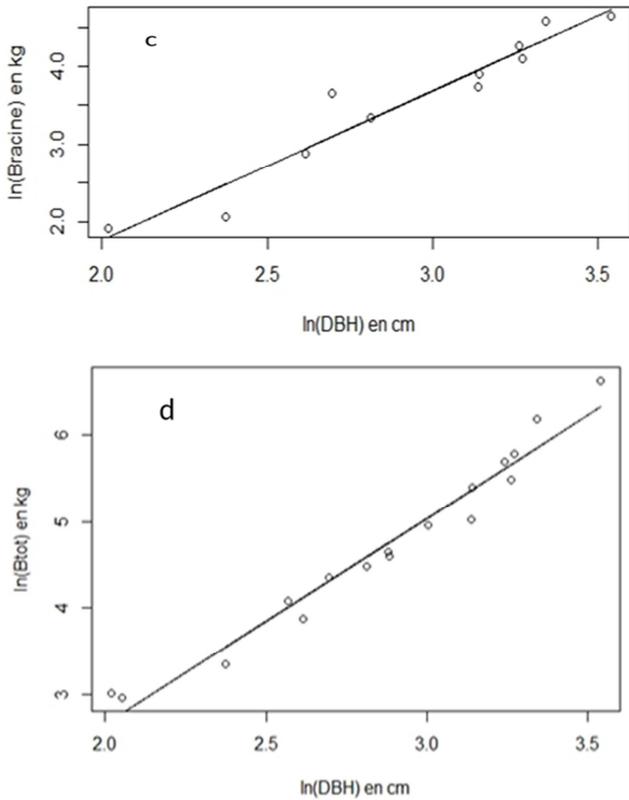
Figure 1. *Linear regressions between diameter and biomasses of branches (a), stems (b), roots (c) aboveground biomass (d).*
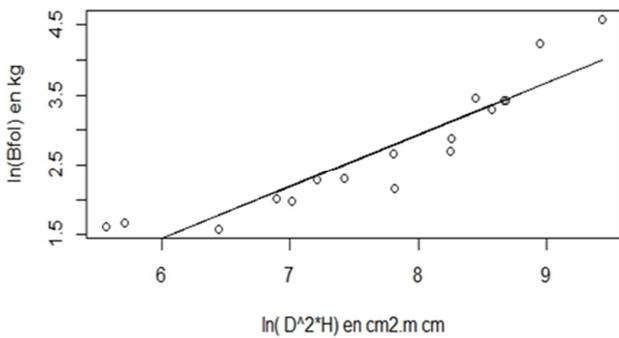

Figure 2. *Linear regressions between (D^2H) and biomasses of leaves.*

3.3. Relationship Between the Root and Above-Ground Biomass

The relationship between the root biomass and other tree compartment biomass were determined (Figure 3). The ratios of these relations varied from 0.28 to 2.14 and showed that the biomass of *D. oliveri* represented an average of 28% of the total above-ground biomass and 214% of leaves. The root biomass as a function of total biomass has been adjusted to a logarithmic function (Figure 4) and the coefficient of determination was 0.916. That means that it exists a positive and significant relationship ($R^2 = 0.9163$, $P < 0.05$ and $n = 11$) between the root biomass and the total above-ground one.
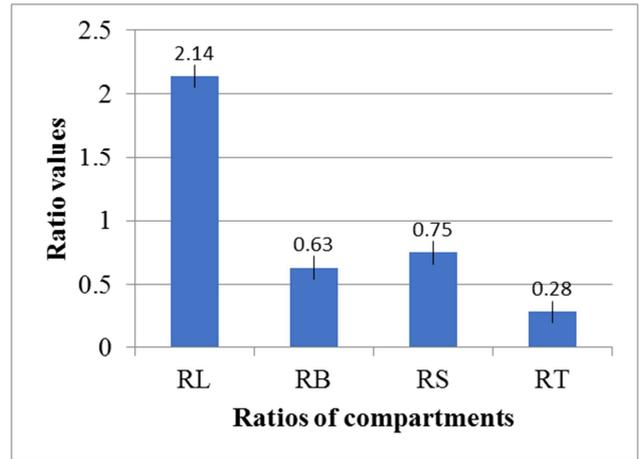

Figure 3. *Ratio between root biomass and leaf biomass (RL), branch biomass (RB), stem biomass (RS) and trunk biomass (RT).*
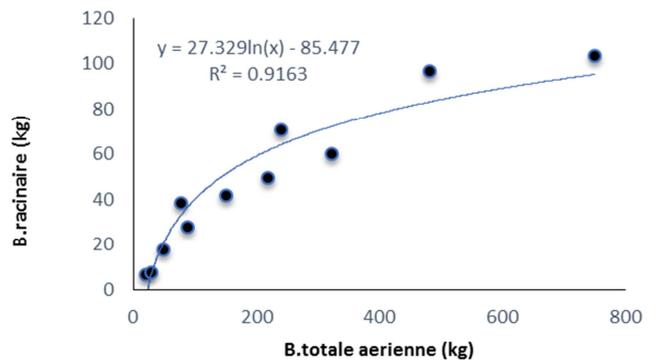

Figure 4. *Nonlinear regression between root biomass and above ground biomass.*

3.4. Relation Between Diameter and Height

The relation between the height and diameter of trees are better adjusted to the linear function (Figure 5). This correlation between these two variables is positive and significant with a coefficient of determination of 0.92 and sample number (n) of 12. The tree height was therefore linked to the diameter in the savannah of Ngaoundere for *D. oliveri*, and increased linearly with the diameter of trees. The bias was very low.
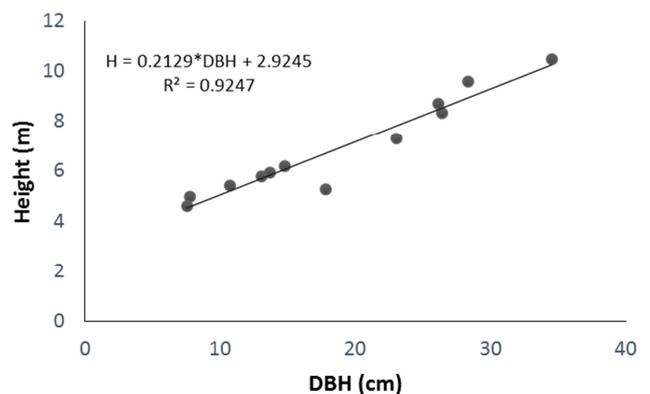

Figure 5. *Relationship between height and DBH of Daniellia oliveri.*

4. Discussion

The study established allometric equations for the estimation of the above- and below-ground biomass in the diameter range between 5 and 40 cm. The species characterized the sudano-guinea savannah of Adamawa by its abundance and its frequency [5]. The determination of specific equation of this species is important for the accurate determination of its production, the accurate estimation of the carbon stock and the sustainable management of its population. In fact, according to Bougnounou *et al*. [33], the establishment of allometric equation for biomass predicting by species makes overall estimate biomass of a woody stand smaller. According to Navar *et al*. [15], an allometric equation by species improved to 12.5% the efficiency of biomass estimation against a global model of woody community.

Allometric equation were developed from the 2 physical variables which are the tree diameter and height, taking into account the Akaike information criteria and the residual standard error [20]. And also 5 models have been selected. The model of the total biomass of equation 3, taking into account the diameter can be considered as the best model. Their AIC and RSE values were lower and its coefficient of determination adjusted was higher. It has shown that the tree height did not significantly influence the biomass. The height was in fact the function of the diameter [20, 48]. This result was similar to that of Bagnoud and Kouyate [49] who have worked on *D. oliveri* in Mali. As the total biomass, the best model of branches, trunks and root biomass was the equation 3 model which was not influenced by the height as found by Traore *et al*. [50]. On the other hand, the best equation for the estimation of leaf biomass was obtained with the model of equation 4, integrating the tree diameter squared multiplied by the height (D^2H), with RSE = 0.364; AIC = 17.836 and R^2adj = 0.836. These results were similar to those of Mamadou Laminou [16] who has shown that the best model for predicting leaves biomass of eight (8) plant species of the wet Ngaoundere savannah was the equation 4 model with RSE = 0.53, AIC = 43.3 and R^2adj = 0.640. Contrary, these results differed from those of Djomo *et al*. [12] and Vahedi *et al*. [51].

The number of sample and diameter range in the development of allometric models found in literature were variable and take into account the resources, site study and time allocated to the study [41]. In fact, Brown [10] and Chave *et al*. [20] used more than 100 sample trees to establish allometric models. However Peltier *et al*. [52], Lawarnou *et al*. [53], Ebuy *et al*. [54] established their models with less than 20 sample trees. In our study, the sample trees (17 trees) used was low but acceptable.

The ratio established in our study was not in adequacy with other results found in literature like those of Poupon [55] and Eumont [56]. We have not found the results for *D. oliveri* in particular, but for wood in general, GIEC [57] has determined a ratio of 0.24 which was not far from the value found in our study. The small difference observed could be due, on one hand to the architecture form of trees [44] of species used in this study and on the other hand to the environment condition which differed in the two studies.

The value of the correlation between the total above-ground biomass and those of the root could be explained by a good balance of development and physiological growth of *D. oliveri* between the above- and below-ground compartments, despite all this anthropogenic pressures exerted on this species in the sudano-guinea savannah of Ngaoundere [58]. So, we can say that the increase of the biomass of the root was strongly linked to that of the above-ground.

5. Conclusion

This study established the mono-specific allometric models for predicting biomass of *Daniellia oliveri* in the sudano-guinea savannah of Ngaoundere from 17 tree samples. The allometric models predicting the biomass of branches, stems, roots and above-ground were developed with diameter as tree physical parameter, while for the accuracy of allometric model predicting the biomass of leaves, tree height need to be integrated to model as an independent variable with tree diameter. These results would contribute to improve the estimation of carbon stock of *Daniellia oliveri* stands in the sudano-guinea savannahs of Ngaoundere. While it may also contribute to the general debate regarding the development and use of allometric equations for estimating biomass and carbon stock in African savannah as a whole, it also adds vital data in this regard for Adamawa savannahs for which such methods have not yet been developed.

Acknowledgements

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