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Use Basal Diameter to Establish Mixed Species Allometric Equations Predicting Woody Stand Biomass in the Sudano-guinea Savannahs of Ngaoundere, Cameroon

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Little information on allometric relationships for estimating stand biomass in the savannah of Cameroon was available. Allometric relationships for estimating stand biomass were investigated in the sudano-guinea savannah of Ngaoundere, Cameroon. A total of 90 individual woody from sixteen (16) contrasting plant species belonging shrubs and trees were harvested in Dang savannah across a range of diameter classes, from 3 to 35 cm. Basal diameter (D), total height (H) and tree density were determined and considered as predictor variables, while total above-ground biomass, stem, branch and leaf 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 (R2adj), the residual standard error (RSE) and the Akaike Information Criteria. The main results showed that the integration of tree height and density with basal diameter improved in the

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degree of fitness of the allometric equations. The fit allometric stand biomass model for leaf, branch, stem and above ground biomass were the following forms: Ln(LB) = -5.08 + 2.75*Ln(D) – 0.30*Ln(D2Hρ); Ln(BB) = -7.81 + 1.29*Ln(D^2H) – 0.39*Ln(ρ); Ln(SB) = -5.08 + 2.40*Ln(D) +0.50*Ln(H) and Ln(TB) = -5.07 + 3.21*Ln(D) – 0.12*Ln(D^2Hρ) respectively. It is concluded that the use of tree height and density in the allometric equation can be improved for these species, as far as the present study area is concerned. Therefore, for estimating the biomass of shrubs and small trees, the use of basal diameter as an independent variable in the allometric equation with a power equation would be recommended in the Sudano-guinea savannahs of Ngaoundere, Cameroon. The paper describes details of shrub biomass allometry, which is important in carbon stock and savannah management for the environmental protection.

Keywords: Allometry; biomass; Savannah of Ngaoundere; Cameroon.

1. INTRODUCTION

Forest ecosystems contain around 80% of the global aerial carbon stocks of woody plants and 40% of the total stock of terrestrial ecosystems. They play an important role in the global carbon cycle. In Africa, it is estimated that the dense humid forests fix approximately 0.63 MgC. $ha^{-1}.year^{-1}$ [1]. Deforestation of tropical forests contributes about one fifth of total annual anthropogenic greenhouse gas emissions to the atmosphere. It is well established that climate changes from day to day due to the increase in greenhouse gases, but also to excessive cuts of firewood as a source of energy and uncontrolled logging.

CO_2 emissions from deforestation and forest degradation represent around 20% of the annual greenhouse gas emissions in the 1999s, and around 12% in the 2000s [1,2]. This observation has led the scientific community to take a close look at changes in the atmospheric composition of GHGs hydrological cycle and solar gains, as well as changes in the biogeochemical carbon cycle. The Cancún agreements have largely contributed to raising global awareness of environmental problems and prompted governments to enter into negotiations which have led developing countries towards initiatives due to reduce CO_2 emissions from forest deforestation and degradation (REDD+).

The aim of this mechanism is to make the conservation and protection of forests more profitable through a financial incentive. REDD+ covers REDD mechanism which offers remuneration in the form of “carbon credits” to countries reducing their carbon emissions from the destruction and degradation of their forests and, thereby, emissions from associated carbon [3], but also conservation, sustainable forest management and strengthening of forest equipment [4]. However, for this mechanism to be implemented, researchers working in the forestry sector must provide precise estimates of the carbon stocks of different ecosystems, including savannahs under anthropogenic pressure which release CO_2 into the atmosphere.

Knowledge of the biomass of plant formations is an essential aspect for the study and understanding of atmosphere CO_2. Biomass estimation is done under various methods [5]. Destructive methods are tedious, very costly in time, in financial and human resource, despite their precision [6,7]. It is for these reasons that more and more non-destructive methods, less costly in time, human, and financial resources and contributing to the conservation of forest formations, are used [8,9]. They establish the allometric equations for estimating the biomass from the physical parameters of the tree such as their diameter, height or density [10] on a small representative sample of the population of trees, without affecting the physical integrity of the trees. However, these biomass estimation equations vary systematically according to the type of ecosystem, the study site, the age of the stand and the species considered [10,11]. Despite the importance of these allometric equations for the estimation of forest biomass and carbon, very little information exists for tropical savannahs and even less for those of Cameroun [10,12-16]. The objective of this study is to develop multi-specific allometric equations in the Sudano-guinea savannahs of Ngaoundere, Cameroun, taking into account the basal diameter commonly used as a principle input parameter for savannah species.

2. MATERIALS AND METHODS

2.1 Study Site

The study was carried out in Dang located between 7°25'127’’of the North latitude and

13°33'130'' of the East longitude, and 1081 m of altitude. 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 km^2, with an average altitude of about 1200 m and occupies practically the center of Cameroon. The climate is humid sudano-guinea type [17], with a unimodal rainfall distribution. Mean annual rainfall is about 1500 mm. The rainy season extends from April to September and dry season stretches from November to March. Mean annual temperature is 23°C and mean relative annual humidity is 65% [18]. While Ferralitic soils are the dominant types [19], 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 [20]. Vegetation of Adamawa is a humid savannah type, consisting of shruby and savannah trees. These savannahs originally populated with *Daniellia oliveri* and *Lophira lanceolata* [21]. There are also hydromorphic meadows that are sometimes inundated and contain *Hypparrhenia 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* [21]. Now, this vegetation is much reduced under the influence of zoo-anthropic factors such as wild fires and rearing [22,23]. 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.

2.2 Plant Species Selection

In this study, sixteen (16) contrasting and socio-economic species of the Sudano-guinea savannahs of Ngaoundere were used (Table 1).

The experiment involved fifteen (15) deciduous broad-leaved including seven (7) shrub species (*Annona senegalensis*, *Maytenus senegalensis*, *Piliostigma thonningii*, *Psorospermum febrifigum*, *Sygizium guineense* var. *macrocarpum*, *Vitex madiensis* and *Ximenia americana*) and eight (8) tree species (*Entada africana*, *Lannea schimperi*, *Lophira lanceolata*, *Sygizium guineense* var. guineense, *Terminalia glaucescens*, *Terminalia macroptera*, *Vitellaria paradoxa* and *Vitex doniana*) and one (1) semi-deciduous shrub species (*Securidaca longipedunculata*). The distribution area of all plant species is an upland Savannah. *P. thonningii* can also find in fallows and degraded forests, and *S. g.* var. *guineense* and *V. doniana* in the forest gallery. They are a source of income, food, firewood, medicinal substances and soil

Table 1. Selected plant species composition

Families	Species	Growth forms	Habits	Habitats
Annacardiaceae	*Lannea schimperi* (Hochst. ex A. Rich.) Engl.	Tree	Deciduous	SA
Annonaceae	*Annona senegalensis* Pers.	Shrub	Deciduous	SA
Celastraceae	*Maytenus senegalensis* (Lam.) Excell	Shrub	Deciduous	SA
Caesalpiniaceae	*Daniellia oliveri* (Rolfe) Hutch. et Dalz.	Tree	Deciduous	SA
	Piliostigma thonningii Milne-Redh.	Shrub	Deciduous	SA
Combretaceae	*Terminalia glaucescens* Planch.	Tree	Deciduous	SA
	Terminalia macroptera Guill. et Perr.	Tree	Deciduous	SA
Guttifereae	*Psorospermum febrifugum* Spach	Shrub	Deciduous	SA
Myrtaceae	*Syzygium guineense* var. *guineense* (Willd.)DC.	Tree	Deciduous	FG
	Syzygium g. var. macrocarpum (Engl.) F. White	Shrub	Deciduous	SA
Ochnaceae	*Lophira lanceolata* Van Tigh. Ex Keay	Tree	Deciduous	SA
Olacaceae	*Ximenia americana* L.	Shrub	Deciduous	SA
Polygalaceae	*Securidaca longipedunculata* Fres.	Shrub	Semi-Deciduous	SA
Sapotaceae	*Vitellaria paradoxa* Gaertn. F.	Tree	Deciduous	SA
Verbenaceae	*Vitex doniana* Sweet	Tree	Deciduous	FG
	Vitex madiensis Oliv.	Shrub	Deciduous	SA

Savannah (SA) and Forest gallery (FG)

fertility indicators for the farmers of this region [24,25]. Somme of these plant species are now conserved by the farmers in their farms.

2.3 Sampling and Data Collection

After the authorization from the Environment authorities, ninety (90) individual plants were sampled out of sixteen (16) different plant species in the Ngaoundere Savannah. Sampled trees were selected purposively, avoiding suppressed or diseased trees or those with broken tops, hollows, or other damages. These sampled individuals were distributed in the three diameter classes defined by Mamadou [26] and Ahmadou [27], at the rate of thirty (30) individuals for each of the following basal diameter classes: small (3-15 cm), medium (15-25 cm) and large diameter classes (25-40 cm). The basal diameter (at 15 cm from above ground) was adopted because the small height of trees and low-branched in the savannahs [5,28]. 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. [29]. The fresh biomass of each compartment weighed using at scale. To obtain the dry weight, three samples of each compartment and each tree were collected. In the laboratory, samples of stems and branches 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 and leaves) was determined after drying of the samples using the following 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 samples. From the water content of the samples, 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 tree. The density ($g.cm^{-3}$) of these plant species were obtained from the studies of Mamadou [26] and Ahmadou [27].

2.4 Development of Allometric Equations

Allometric equations were established based on three physical parameters of the tree such as basal diameter (D), height (H) and density (ρ), and tree biomass [30]. The simple allometric equation was generally written using the power curve [29,31,32] in the form of:

$$Y = a*X^b$$

Where Y is the dependent variable and X, the independent (explicative) one and a, the coefficient and b the allometric constant. To take into account the heteroscedasticity of data, the formula is often linearized by using the logarithmic transformation [29] through the following formula:

$$Ln(Y)= Ln(a) + b*Ln(X)$$

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, $D^2H\rho$, were also established using the following equations (eq.1 to 5):

$$Ln(B) = a + b*Ln(D) \quad (eq.1)$$

$$Ln(B) = a + b*Ln(D^2H) \quad (eq.2)$$

$$Ln(B) = a + b*Ln(D) + c*Ln(H) \quad (eq.3)$$

$$Ln(B) = a + b*Ln(D^2H) + c*Ln(\rho) \quad (eq.4)$$

$$Ln(B) = a + b*Ln(D) + c*Ln(D^2H\rho) \quad (eq.5)$$

Where B is the biomass (kg), D, H and ρ are respectively the tree basal diameter, total height (m) and density ($g.m^{-3}$), a, b and c are the coefficients of regression.

The logarithmic transformation of data generally leads a bias in the biomass estimation [33,34]. A correction is therefore necessary and consisted to multiply the estimated biomass by a correction factor which was calculated as follows: CF = exp ($RSE^2/2$) [35,36]; CF is the number always high to 1. Some criteria were used to select the best predictive models when calculated. In addition to the adjusted coefficient of determination (R^2adj) 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 [34]. Statistical analysis were perform with Excell 2016 and Ri 386 3.1.2 software.

3. RESULTS

3.1 Basal Diameter, Height and Biomass Distributions

Stand basal diameter, height, and density varied from 3.82 to 33.76 cm, from 1.40 to 7.00 m, and from 0.02 to 0.96 $g.cm^{-3}$, with average of 14.67 cm, 3.24 m and 0.34 $g.cm^{-3}$ respectively (Table 2).

Aboveground biomass (AGB) ranged from 0.33 to 241.07 kg with average of 37.59 kg. For the compartments, the leaf biomass ranged from 0.07 to 16.61 kg, that of the branches from 0.03 to 177.37 kg and that of the stems from 0.17 to 56.79 kg, with the respective averages of 3.46, 22.23 and 12.01 kg. The branches accumulated more biomass than the other compartments with a rate of 59.14% of the total above-ground biomass, followed by that of stems (31.94%).

3.2 Allometric Equations

Five models of allometric equations were developed for each compartment, with 90 individual trees of 16 plant species for the aboveground biomass. The allometric relationships of biomass of different compartments to diameter, height and density of species were positive and significant ($P < 0.001$) with the high adjusted coefficient of determination ranged from 0.698 to 0.865 (Table 3).

Regression coefficients (a, b and c) varied from -7.86 to -4.49, from 0.73 to 4.14 and from -0.39 to 0.57 respectively for a, b and c. These coefficients differed among compartments for the same model. The model taking into account only the basal diameter as the physical parameter of the tree (eq.1) was significant ($p<0.001$) for each of the four compartments of trees, with the adjusted coefficient of determination varying between 0.722 and 0.861. These high adjusted coefficients of determination showed that more than 70% of these relationships were explained by the single parameter, the basal diameter.

By integrating the height of tree and density of the plant species in four models (2 – 5), no improvement was obtained in the precision with the equations 2 (Eq.2) predicting the biomass of all compartments, with the equations 3 (Eq.3) predicting the biomass of leaves and with the equations 4 (Eq.4) predicting the biomass of stems. The coefficient of determination adjusted of model 2 (Eq.2), integrating the basal diameter squared multiplied by the height (D^2*H) in the fit of form $Ln(B) = a + b*Ln(D^2H)$ for all compartments (0.698; 0.755; 0.848 and 0.849), that of model 3 (Eq.3) integrating the basal diameter (D) and height (H) in the fit of the form $Ln(B) = a + b*Ln(D) + c*Ln(H)$ for biomass of leaves (0.719) and that of model 4 (Eq.4) integrating the basal diameter squared multiplied by the height (D^2H) and density (ρ) in the fit of the form $Ln(B) = a + b*Ln(D^2H) + c*Ln(\rho)$ for biomass of stems (0.847) were lower than those of model 1 (Eq.1) integrating only basal diameter. Contrary, the model 5 (Eq.5) integrating the basal diameter (D) and basal diameter squared multiplied by the height and density ($D^2H\rho$) in the fit of the form $Ln(B) = a + b*Ln(D) + c*Ln(D^2H\rho)$ improved the precision of model 1 (Eq.1) for biomass of all compartments, except for that of stems. Their adjusted coefficients of determination were higher and their RSE and AIC were lower than those of medel 1 (Eq.1).

Table 2. Distribution of basal diameter (D), height (H), density (ρ) and compartment biomasses of 90 individual trees from field survey in the Ngaoundere savannahs of Cameroon

Items	Tree parameters			Compartments			AGB (kg)
	D(cm)	H (m)	ρ ($g.cm^{-3}$)	LB(kg)	BB(kg)	SB(kg)	
Average	14.67	3.24	0.34	3.46	22.23	12.01	37.59
STDEV	6.83	4.29	0.25	3.47	37.51	14.80	53.41
Minimum	3.82	1.40	0.02	0.07	0.03	0.17	0.33
Maximum	33.76	7.00	0.96	16.61	177.37	56.79	241.07

Leaf biomass (LB), branch biomass (BB), stem biomass (SB), aboveground biomass (AGB)

Table 3. Models used and values of coefficients of regressions adjusted between biomass (kg), D (cm), H (m), and ρ (g.cm^{-3}) of 90 individuals of 16 plant species in the savannahs of Ngaoundere, Cameroon

N°	Allometric models	a (se)	b (se)	c (se)	R^2adj.	RSE	CF	AIC	P
Leaf biomass									
1	Ln(B)=a+bLn(D)	-5.17 (0.38)	2.22 (0.14)	/	0.722	0.695	1.27	194	<0.001
2	Ln(B)=a+bLn(D^2H)	-4.72 (0.37)	0.84 (0.05)	/	0.698	0.724	1.30	201	<0.001
3	Ln(B)=a+bLn(D)+cLn(H)	-5.14 (0.39)	2.15 (0.20)	0.14 (0.25)	0.719	0.698	1.28	196	<0.001
4	Ln(B)=a+bLn(D^2H)+cLn(ρ)	-4.59 (0.33)	0.73 (0.05)	-0.37 (0.07)	0.765	0.638	1.23	180	<0.001
5	Ln(B)=a+bLn(D)+cLn(D^2Hρ)	-5.08 (0.34)	2.75 (0.17)	-0.30 (0.06)	0.770	0.631	1.22	178	<0.001
Branch biomass									
1	Ln(B)=a+bLn(D)	-7.86 (0.56)	3.66 (0.21)	/	0.763	1.028	1.70	264	<0.001
2	Ln(B)=a+bLn(D^2H)	-7.22 (0.53)	1.40 (0.08)	/	0.755	1.043	1.72	267	<0.001
3	Ln(B)=a+bLn(D)+cLn(H)	-7.71 (0.57)	3.35 (0.29)	0.57 (0.37)	0.766	1.020	1.68	264	<0.001
4	Ln(B)=a+bLn(D^2H)+cLn(ρ)	-7.81 (0.50)	1.29 (0.08)	-0.39 (0.11)	0.783	0.982	1.62	257	<0.001
5	Ln(B)=a+bLn(D)+cLn(D^2Hρ)	-7.78 (0.55)	4.14 (0.28)	-0.27 (0.10)	0.773	1.006	1.66	260	<0.001
Stem biomass									
1	Ln(B)=a+bLn(D)	-5.21 (0.31)	2,67 (0.11)	/	0.849	0.566	1.17	157	<0.001
2	Ln(B)=a+bLn(D^2H)	-4.77 (0.29)	1.03 (0.04)	/	0.848	0.567	1.17	157	<0.001
3	Ln(B)=a+bLn(D)+cLn(H)	-5.08 (0.30)	2.40 (0.15)	0.50 (0.20)	0.858	0.549	1.16	153	<0.001
4	Ln(B)=a+bLn(D^2H)+cLn(ρ)	-4.77 (0.29)	1.02 (0.05)	-0.02 (0.06)	0.847	0.570	1.18	159	<0.001
5	Ln(B)=a+bLn(D)+cLn(D^2Hρ)	-5.23 (0.31)	2.60 (0.16)	0.04 (0.06)	0.849	0.568	1.17	159	<0.001
Aboveground biomass									
1	Ln(B)=a+bLn(D)	-5.11 (0.33)	2.99 (0.12)	/	0.861	0.605	1.20	169	<0.001
2	Ln(B)=a+bLn(D^2H)	-4.57 (0.32)	1.14 (0.05)	/	0.849	0.629	1.22	176	<0.001
3	Ln(B)=a+bLn(D)+cLn(H)	-4.99 (0.33)	2.77 (0.17)	0.42 (0.22)	0.865	0.595	1.19	167	<0.001
4	Ln(B)=a+bLn(D^2H)+cLn(ρ)	-4.49 (0.31)	1.08 (0.05)	-0.20 (0.06)	0.862	0.601	1.20	169	<0.001
5	Ln(B)=a+bLn(D)+cLn(D^2Hρ)	-5.07 (0.32)	3.21 (0.16)	-0.12 (0.06)	0.865	0.594	1.19	167	<0.001

Tree basal diameter (D), height (H), and density (ρ). Coefficient of regression models (a, b and c) and standard errors in parenthesis (se), adjusted coefficient of determination (R^2adj), correction factor (CF), residual standard error (RSE), Akaike information criteria (AIC) and significant values (P)

3.3 Selecion of the Best Allometric Equations

To select best models predicting the biomass of each compartment in addition to the adjusted coefficient of determination (R^2adj), the residual standard error (RSE) and the Akaike value (AIC) which enables to evaluate the accuracy of the models were taken into account. These adjusted coefficients of determination (R^2adj) of the 4 best models (0.770, 0.783, 0.858 and 0.865) selected to each of the compartment and the total biomass were higher, their RSE (0.631, 0.982, 0.549 and 0.594) and their AIC (177.67, 257.17, 152.71 and 166.87) were lower than the value of the other models. These best equations were Ln(B) = -5.08 + 2.75*Ln(D) - 0.30*Ln (D^2Hρ) for leaf, Ln(B) = -7.81 + 1.29*Ln(D^2H) + -0.39*Ln(ρ) for branches, Ln(B) = -5.08 + 2.4*Ln(D) + 0.50*Ln(H) for stems and Ln(B) = -5.07 + 3.21*Ln(D) - 0.12*Ln(D^2Hρ) for total biomass and presented in Table 4 and the Fig. 1.

4. DISCUSSION

The study established allometric equations for the estimation of the aboveground biomass of the sixteen contrasting plant species in the basal diameter ranged from 4 to 40 cm, including 90 individuals. These species characterized the sudano-guinea savannah of Ngaoundere, Adamawa Cameroon by their abundance, their frequency or their important socio-economic role in these savannahs [21,22,24,25]. The determination of equations of these plant species is important for the accurate estimation of the production, carbon stock and sustainable management of woody stands of these savannahs. This implied the establishment of mixed species allometric equation for estimating woody stands biomass in this study, because there is no enough data to develop allometric equation for each species, even if, according to Bognounou et al. [5], the establishment of allometric equation for biomass predicting by species makes overall estimate biomass of a

Table 4. Best selected allometric models for predicting of compartments and total biomasses

Compartments	Allometric models	a	b	c	R^2adj	RSE	CF	AIC
Leaf biomass	Ln(B)=a+bLn(D)+cLn(D^2Hρ)	-5.08	2.75	-0.30	0.770	0.631	1.22	177
Branch biomass	Ln(B)=a+bLn(D^2H)+cLn(ρ)	-7.81	1.29	-0.39	0.783	0.982	1.62	257
Stem biomass	Ln(B)=a+bLn(D)+cLn(H)	-5.08	2.40	0.50	0.858	0.549	1.16	152
Total biomass	Ln(B)=a+bLn(D)+cLn(D^2Hρ)	-5.07	3.21	-0.12	0.865	0.594	1.19	167

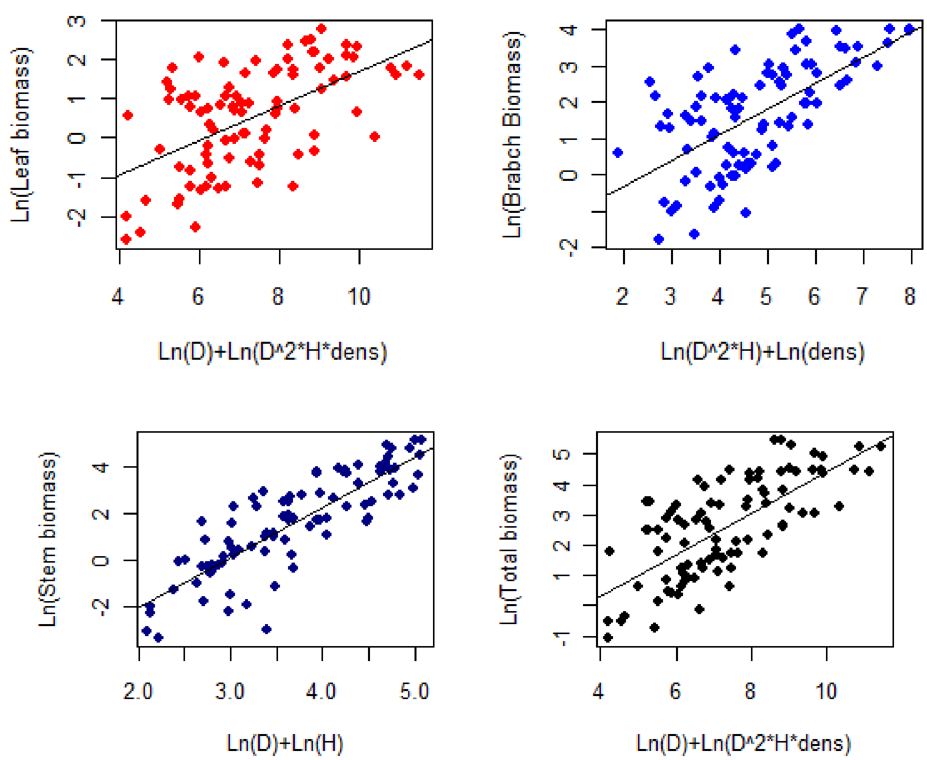

Fig. 1. Regressions models between biomass and tree physical parameters (D, H, and dens) for leaf, branch, stem and total biomasses

woody stand smaller. For Cole et al. [37], the pooled species approach is a reasonable tool if the data base to which it's to be applied included a large number of species or takes important information for entire woody stands. According to Mahmood et al. [38], the development of local models derived from an appropriate sample of representative species can greatly improve the estimation of biomass, as well as Carbon, Nitrogen, Phosphorus, and Potassium in biomass.

DBH defined at 1.3 m above ground, is the standard height internationally recognized, at which the diameter of a tree is measured. Its values are used to develop allometric equations for estimating tree volume, basal area or biomass of individual trees, woody stands, or entire forests [10-16,39]. However, for the plant species of savannahs, characterized by small height and low-branched, the DBH is not applicable. It is necessary to resort to other levels of measurement of stem diameter lower than 1.30 m, called basal diameter, whose height measurement varies according to vegetation types [26,27,28]. The height of forty centimeters (40 cm) has often been retained, as well as that at the ten centimeters (10 cm) above the ground, where the woodcutters cute the trees. Our allometric equations were developed using basal diameter (15 cm above ground) with high adjusted coefficient of determinations, because the study was conducted in the sudano-guinea savannahs dominated by shrubs and low–branched trees. The basal diameter was also related to DBH as shown by Mamadou [26] and Ahmadou [27]. Other studies using basal diameter obtained the best allometry models. In fact, Kaïre [28] used the basal diameter (5 cm above ground) to develop individual and global allometric equations for four species (*Combretum geitonophyllum*, *C. glutinosum*; *Piliostigma thonningii* and *Terminalia macroptera*) in the Senegalese savannahs. He obtained highly significant correlations between biomass and basal diametrer with determination coefficient varying from 0.9461 to 0.9776. Similarly, Gwaze and Stewart [40], working on young plant aged from 16 to 30 months of the 8 species have shown that the basal diameter can be a good tree predictor to develop allometric equations in the savannahs of Zimbabwe. For the coniferous stands, Kim et al. [41] used basal diameter at 20 cm above ground level to develop allometric equations for estimating biomass of pine trees in Southern Korea. Basal diameter under certain vegetation conditions can be used as a good biomass predictor as pointed out Mamadou [26], Ahmadou [27], Halilou [42] and Kaïre [28] in their studies on savannah species.

The use of allometric equations presents a source of uncertainty in biomass estimation [43], which can be minimized through a process of selection and critical analysis of the parameters used [44]. Model accuracy and the inclusion of predictors are important considerations when selecting the best fit model [45]. In our study, we have included 90 individuals of 16 species with wood height and density ranging from 3.82 to 33.76 m and from 0.02 to 0.96 $g.cm^{-3}$ respectively. And a model with basal diameter (D), height (H) and woody density (ρ) as identical predictors appeared as the best fits for all compartments compared to other models (Table 3). Their AIC and RSE values were lower and their coefficient of determination adjusted were higher. They have shown that the tree height and density influenced significantly the biomass. These results were similar to those of Nelson et al. [32], Chave et al. [34,46] and Djomo et al. [13] who have shown that the best model for predicting tree biomass were the multi-species allometric models taking into account the D, H and ρ as identical predictors. Contrary, these results differed from those of Bagnoud and Kouyate [47] who have worked on savannah vegetation of Mali. As the total biomass, the best model of branch, and trunk biomasses was the allometric equation which was not influenced by the height as also found by Traore et al. [48].

The selections of the best models of allometric equations are based on one or more criteria [13,49,50]. Indeed, Kuyah et al. [49] used a single Akaike criterion to estimate the tree biomass in Mali. In contrast, Mbow et al. [50] developed allometric equations, the selection of which was based mainly on the low value of the residual standard error (RSE). For each model they developed, the RSE is less than 0.19. Fayolle et al. [15], for their part, selected cubic rate models by combining RSE with AIC. According to them, the best model is the one with the lowest value of AIC and RSE.

5. CONCLUSION

This study established the multi-specific allometric models for predicting biomass of sixteen (16) shrub and tree species in the sudano-guinea savannah of Ngaoundere from 90 individual samples. The allometric models predicting the biomass of leaves, branches, and total biomass were developed with basal diameter, tree height, and density as tree physical parameters, while for the accuracy of allometric model predicting the biomass of stems, only basal diameter and tree height were integrated to model as independent variables. Thus the best models, according to selection criteria, were $Ln(B)= -5.08 + 2.75*Ln(D) – 0.30*Ln(D^2H\rho)$, $Ln(B)= -7.81 + 1.29*Ln(D^2H) – 0.39*Ln(\rho)$, $Ln(B) = -5.08 + 2.40*Ln(D) + 0.50*Ln(H)$, and $Ln(B)= -5.07 + 3.21*Ln(D) – 0.12*Ln(D^2H\rho)$ for leaf, branch, stem, and total biomasses respectively. These results would contribute to improve the estimation of biomass and carbon stock of sixteen species 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, and it also adds vital data in this regard for Adamawa savannahs for which such methods have not been developed enough.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Malhi Y, Grace J. Tropical forests and atmospheric carbon dioxide. Trends in Ecology & Evolution. 2000;15:332-337.
2. Van der Werf G, Morton DC, Defries RS, Olivier JGJ, Kasibhatla PS, Jackson RB, Collatz G, Randerson J. CO2 emissions from forest loss. Nature Geoscience. 2009; 2:737-738.
3. Gibbs HK, Brown S, Niles JO, Foley JA. Monitoring and estimating tropical forest carbon stocks: Making REDD a reality. Environmental Research Letters. 2007;2: 1-13.
4. IUCN. REDD-plus, Champ d'application et des options pour le rôle des forêts dans les stratégies d'atténuation des changements climatiques. Programme de Conservation des Forêts ; 2009.
5. Bognounou F, Sawadogo M, Boussim IJ, Guinko S. Equations d'estimation de la biomasse foliaire de cinq espèces ligneuses soudaniennes du Burkina Faso. Sécheresse. 2008;19(3):201-205.
6. Cissé MI.The browse production for some trees of the Sahel: Relationships between maximum foliage biomass and various physical parameters. In: Le Houerou HN (ed.) Browse in Africa. Addis Ababa: International Livestock Center for Africa ; 1980.
7. Zabek LM, Prescott CE. Biomass equations and carbon content of aboveground leafless biomass of hybrid popular in Coastal British Columbia. Forest Ecology and Management. 2006;223:291-302.
8. Andrew MH, Noble IR, Lange RT. A non-destructive method for estimating the weight of forage on shrubs. Australian Range lands Journal. 1979;1:225-231.
9. Savadogo P, Elfving B. Prediction model for estimating available fodder of two savanna tree species (*Acacia dudgeoni* and *Balanites aegyptiaca*) based on field and image analysis measures. African Journal of Range & Forage Science. 2007; 24:63-71.
10. Henry M, Picard N, Trotta C, Manlay R, Valentini R, Bernoux M, Saint-André L. Estimating tree biomass of sub-Saharan African forests: A review of available allometric equations. Silva Fennica. 2011; 45(3): 477–569.
11. Saint-André L, M'Bou AT, Mabiala A, Mouvondy W, Jourdan C, Rouspard O, Deleporte P, Hamel O, Nouvellon y. Age related equation for above and below ground biomass of a Eucalyptus in Congo. Forest Ecology and Management. 2005; 205:199–214.
12. Deans JD, Moran J, Grace J. Biomass relationships for tree species in regenerating semi-deciduous tropical moist forest in Cameroon. Forest Ecology and Management. 1996;88:215-225.
13. Djomo AN, Ibrahima A, Saborowski J, Gravenhorst G. Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa. Forest Ecology and Management. 2010;260:1873–1885.
14. Henry M, Besnard A, Asante WA, Eshun J, Adu-Bredu S, Valentini R, Bernoux M, Saint-Andre L. Wood density, phytomass variations within and among trees and allometric equations in a tropical rainforest of Africa. Forest Ecology and Management. 2010;260:1375-1388.
DOI: 10.1016/j.foreco.2010.07.040

15. Fayolle A, Doucet JL, Bourland N, Lejeune P. Tree allometry in Central Africa: Testing the validity of pantropical multi-species allometric equations for estimating biomass and carbon stocks. Forest Ecology and Management. 2013;305:29-37.
16. Tchindebe A, Ibrahima A, Tchobsala, Mamadou Laminou MA. Allometric Equations for Predicting Biomass of *Daniellia oliveri* (Rolfe) Hutch. & Dalz. Stands in the Sudano-guinea Savannahs of Ngaoundere, Cameroon. Ecology and Evolutionary Biology. 2019;4(2):15-22.
17. Suchel JB. La répartition des pluies et régimes pluviométriques au Cameroun. Centre de Recherches Africaines, Université fédérale du Cameroun; 1971.
18. Carrière M. Les communautés végétales sahéliennes en Mauritanie (Région de Kaédi), analyse de la reconstitution annuelle du couvert herbacé. Thèse de Doctorat, Université de Paris Sud Orsay, IE. M. V. T. Maisons-Alfort, CENERV., Nouakchott; 1989.
19. Boutrais J. Les conditions naturelles de l'élevage sur le plateau de l'Adamaoua (Cameroun). Cahiers ORSTOM, Série Sci. Hum. 1974;XV(2):145-198.
20. Brabant P, Humbel FX. Notice explicative de la carte pédologique de Poli, n° 51, Carte au 1/50000e, Yaoundé; 1974.
21. Letouzey R. Etude phytogéographie du Cameroun. Ed. Paul Le Chevalier. Paris France; 1968.
22. Tchobsala. Impact des coupes de bois sur la végétation naturelle de la zone périurbaine de Ngaoundéré (Adamaoua). Thèse de Doctorat/Ph.D, Université de Yaoundé I, Cameroun; 2011.
23. Tchobsala, Mbolo M, Souare K. Impact of wood logging on the phytomass and carbon sequestration in the guinea savanna of NgaoundereAdamaoua Region, Cameroon. Global Advanced Reacherch Journal of Environmental Science and Toxicology. 2014;3(3):38-48.
24. Mapongmetsem PM, Kapchie VN, Tefempa BH. Diversity of local fruit trees and their contribution in sustaining the rural livelihood in the northern Cameroon. Ethiopian Journal of Environmental Studies and Management. 2012;5(1):32-46.
25. Ibrahima A, Souhore P, Hassana B, Babba H. Farmers' perceptions, indicators and soil fertility management strategies in the sudano-guinea savannahs of Adamawa, Cameroon. International Journal of Development and Sustainability. 2017;6 (12):2035-2057.
26. Mamadou LMA. Equations de prédiction de la Biomasse de quelques espèces ligneuses des savanes de Ngaoundéré, Cameroun. Mémoire de Master en Biologie des Organismes Végétaux, Faculté des Sciences, Université de Ngaoundéré; 2014.
27. Ahmadou I. Equations de l'estimation de la Biomasse des huit espèces ligneuses de savanes de Ngaoundéré, Cameroun. Mémoire de Master en Biologie des Organismes Végétaux, Faculté des Sciences, Université de Ngaoundéré; 2014.
28. Kairé M. La production ligneuse des jachères et son utilisation par l'homme au Sénégal, Université de Provence Marseille, France; 1999.
29. Picard N, Saint-André L, Henry M. Manuel de construction d'équationsallométriques pour l'estimation du volume et la biomasse des arbres: de la mesure de terrainà la prédiction. Organisation des Nations Unies pour l'alimentation et l'agriculture, et Centre deCoopération Internationale en Recherche Agronomique pour le Développement, Rome, Montpellier; 2012.
30. Lotfi A. Durabilité écologique des paysages agricoles et production de bois, bocage et néobocage. Disertation, Rennes: Université de Rennes 1, Ecole Doctorale Vie, Agro, Santé, UFR Sciences de la Vie et de l'Environnement; 2008.
31. Henry M, Picard N, Trotta C, Manlay R, Valentini R, Bernoux M, Saint-André L. Estimating tree biomass of sub-Saharan African forests: A review of available allometric equations. Silva Fennica. 2012; 45:477-569.
32. Nelson BW, Mesquita R, Pereira JLG, de Souza SGA, Batista GT, Couto LB. Allometric Regressions for improved estimate of secondary forest biomass in the Central Amazon. Foresr Ecology and Management. 1999;117:149-167.
33. Parresol BR. Assessing tree and stand biomass: A review with examples and

critical comparisons. Forest Science. 1999; 45:573-593.

34. Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure J-P, Nelson BW, Ogawa H, Puig H, Riera B, Yamakura T. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia. 2005;145:87–99.

35. Djomo AN, Picard N, Fayolle A, Henry M, Ngomanda A, Ploton P, McLellan J, Saborowski J, Ibrahima A, Lejeune P. Tree Allometry for Estimation of Carbon Stocks in African Tropical Forests. Forestry. 2016; 89: 446-455.

36. Djomo NA, Chimi DC. Tree allometric equations for estimation of above, below and total biomass in a Tropical Moist Forest: Case study with application to remote sensing. Forest Ecology and Management. 2017;391:184-193.

37. Cole TG, Ewel JJ. Allometric equation for four valuable tropical tree species. Forest Ecology and Management. 2006;229:351-360.

38. Mahmood H, Siddique MRH, Costello L, Birigazzi L, Abdullah SMR, Henry M, Siddiqui BN, Aziz T, Ali S, Al Mamun A, Forhad MIK, Akhter M, Iqbal Z, Mondol FK. Allometric models for estimating biomass, carbon and nutrient stock in the Sal zone of Bangladesh. iForest. 2019;12:69-75.

39. Vieilledent G, Vaudry R. A universal approach to estimate biomass and carbon stock in tropical forests using generic allometric models. Ecological Applications. 2012;22:572-583.

40. Gwaze DP, Stewart HTL. Biomass equations for eight exotic tree species in Zimbabwe. Commonwealth Forestry Review. 1990;69(4):337-344.

41. Kim C, Yoo BO, Jung SY, Lee KS. Allometric equations to assess biomass, carbon and nitrogen content of black pine and pine trees in southern Korea. iForest. 2017;10:483-490.

42. Halilou A. Equations de prédiction de la Biomasse de quelques espèces ligneuses de savanes de Ngaoundéré, Cameroun. Mémoire de Master en Biologie des Organismes Végétaux, Faculté des Sciences, Université de Ngaoundéré; 2015.

43. Nam VT, van Kuijk M, Ante NPR. Allometric Equations for Aboveground and Below ground Biomass Estimations in an Evergreen Forest in Vietnam. Plos ONE. 2016;11(6):1-19.e0156827.

DOI: 10.1371/journal.pone.0156827

44. Mahmood H, Siddique MRH, Akhter M. A critical review and database of biomass and volume allometric equation for trees and shrubs of Bangladesh. IOP Conference Series, Earth and Environmental Science. 2016;39:12-57.

DOI: 10.1088/1755-1315/39/1/012057

45. Sileshi GW. A critical review of forest biomass estimation models, common mistakes and corrective measures. Forest Ecology and Management. 2014;329:237–254.

DOI: 10.1016/j.foreco.2014.06.026

46. Chave J, Rejou-Mechain M, Burquez A, Chidumayo E, Colgan MS, Delitti WBC, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez-Yrízar A, Mugasha WA, Muller-Landau HC, Mencuccini M, Nelson BW, Ngomanda A, Nogueira EM, Ortiz ME, Pélissier R, Ploton P, Ryan CM, Saldarriaga JG, Vieilledent G. Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biology. 2014;20:3177–3190.

47. Bagnoud N, Kouyaté AM. Estimation du volume de bois des formations savanicoles de la zone soudanienne (cercle de Sikasso) - Tarifs de cubage pour quelques espèces ligneuses et relations dendrométriques pour le bois de feu. Document Appui à la Recherche Forestière de Sikasso (ARFS) 96/3, Ministère du développement rural et de l'environnement, Institut d'Économie Rurale; 1996.

48. Traoré S, Djomo AN, N'guessan AK, Coulibaly B, Ahoba A, Gnahoua GM, N'guessan EK, Adou Yao CY, N'Dja JK, Guédé NZ. Stand structure, allometric equations, biomass and carbon sequestration capacity of *Acacia mangium* Wild. (Mimosaceae) in Côte d'Ivoire. Open Journal of Forestry. 2018;8:42-60.

49. Kuyah S, Dietz J, Muthuri C, Jamnadass R, Mwangi P, Coe R, Neufeldt H. Allometric equations for estimating biomass in agricultural landscapes: I.

Aboveground biomass. Agriculture Ecosystems and Environment. 2012;158: 216-224.

50. Mbow C, Michel M, Verstraete Bienvenu S, Amadou TD, Henry N. Allometric models for aboveground biomass in dry savanna trees of the Sudan and Sudan–guinean ecosystems of Southern Senegal. Journal of Forestry Researh. 2013;19:340-347.
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