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Allometric equation based on DBH for predicting tree and shrub stands biomass in the sudano-guinea savannahs of Ngaoundere, Cameroon

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Abstract

The sustainable management of savannahs for their contribution to the reduction of greenhouse effects inevitably requires knowledge of their carbon stock. Thus, a study on the establishment of multi-species allometric equations for estimating woody biomass from 3 standard physical variables used in forestry (DBH, wood height and density) was conducted in the Sudano-guinea savannahs of Ngaoundere Cameroon. A sample of one hundred and fifty (150) individuals belonging to 16 species was carried out in the savannahs and distributed over all the classes of diameter, ranged from 10 to 60 cm. The diameter at breast height of these individuals and their height were measured. After felling, the woody plant was divided into branches, stems, and leaves including the twigs, and their biomass was determined after drying and weighing. Different allometric equations between biomass and these three tree parameters were tested. The analysis of the selection criteria of the best models (Adjusted determination coefficients (R^2aj), the residual standard error (RSE) and the Akaike information criterion (AIC)) made possible to select the best following equations: Ln(B) = -1.61+0.32Ln(D)+0.36Ln (DH*p), with R^2aj = -0.477 and AIC = 275.22 for leaves; Ln(B)= -1.78+1.07in(D) + 0.35Ln(DH*p), with R^2aj = 0.688 and AIC = 280.79 for the branches, Ln(B) -1.54 +0 .64Ln(D) +0.38Ln(D'H*p), with R^2aj = 0.640 and AIC= -184.78 for the stems and Ln(B)= -0.10 + 0.72Ln(D) + 0.33Ln(D'H*p), with R^2aj = 0.736 and AIC=180.24 for the total biomass. These equations provide a contribution to the reliable and rapid estimation of the carbon stock of the Ngaoundere savannah in the context of evaluating the contribution of the Sudano-guinea savannahs to climate change mitigation.

Keywords: Biomass, Allometric Equation, Savannas of Ngaoundere, Adamawa, Cameroon

1. Introduction

The upsurge in pollution, deforestation and environmental degradation has prompted international communities to interfere in government practices relating to the environment. Thus, polluting countries are called upon to subsidize developing countries for initiatives to reduce CO_2 emissions aimed at deforestation and degradation, but also at conservation, sustainable management of forests and strengthening of forestry equipment (IUCN, 2009) [33].

This initiative aims to make the conservation and protection of forests more profitable through a financial incentive. Indeed, REDD+ covers REDD mechanisms. The latter proposes to offer compensation in the form of "carbon credits" to countries that reduce their emissions from the destruction and degradation of their forests and, therefore, the associated carbon emissions (Gibbs *et al*., 2007) [25]. However, for this mechanism to be implemented, researchers working in the forestry field must provide precise estimates of the carbon stocks of different ecosystems, which, under the pressure of felling and burning release CO_2, in the atmosphere. Indeed, plant formations have a biomass made up of approximately 50% carbon (Nair, 2012) [48] and their felling and burning lead to its release into the atmosphere.

The Adamawa region, like the rest of Cameroon, is not spared from the degradation of natural resources. Qualitative observations that prove that the plant formations of Adamawa Highlands are various and now change now (Rippstein, 1930). The facts are evident in peri-urban areas where natural vegetation cover has virtually disappeared. It is now represented only by a few thin plants of *Daniellia oliveri*, *Albizia zygia*, *Vitex doniana* and *Sterculia sp* (Tchotsoua *et al.*, 2009) [68]. The plateau

being therefore covered at more than 90% by shrub or tree savannahs is maintained by man through the use of space as a field of culture and paints and in particular by the use of bush fires in dry season (Risppstein 1977) [55]. Without these anthropic activities, it has been demonstrated by Piot (1969) [53] and by Rippstein and Baudet (1977) [55], that the vegetation of the Adamawa would evolve towards open forest. The Ministry of the Environment, Protection of Nature and Sustainable Development (Menepded, 2014 and 2015) carried out in 2014 and 2015 an inventory of land degradation data in order to delimiting reforestation areas in the 3 northern regions Cameroon. This study showed that the northern regions of Cameroon are considered to be among the most affected by land degradation (Atlantis group, 2015, 2014) [4]. Therefore, knowledge of vegetation biomass seems essential for the study and the understanding of carbon stocks and the contribution of their flux to the atmosphere (Robert *et al*., 2003) [57].

Biomass estimation is done using various methods (Bognounou *et al*., 2008) [6]. Destructive methods are tedious, very costly in time, financial and human resources despite their precision (Cissé *et al*., 1980; Zabek *et al*., 2006) [15, 72]. It is for these reasons that more and more non-destructive methods, less costly in time, in human, and financial resources, and contributing to the conservation of forest, are used (Andrew *et al*., 1979; Savadogo *et al*., 2007) [3, 61]. Allometric equations for estimation of biomass from the physical parameters of the tree such as the diameter, the height, or the density of the tree were developed (Tchindebe *et al*., 2019, Tchindebe *et al*., 2020; Mamadou *et al*, 2020) [65, 66, 40], without reaching the physics integrity of it, and from a representative sample of the population of trees without leading to significant destruction of ecosystems. However, the biomass estimation equations known as allometric equations vary systematically according to the type of ecosystem, the study site, the age and the species considered (Saint-André *et al*., 2005; Henry *et al*., 2010: Fatemi *et al*., 2011) [60, 28, 22]. Despite their importance, few allometric equations exist in tropical countries and even fewer in Central Africa where phytomass measurements have been relatively recent (Deans *et al*., 1996: Djomo *et al*., 2010; Henry *et al*., 2010, 2011, Vielledent *et al*., 2012; Fayolle *et al*., 2013, Mamadou, 2014, Ahmadou, 2014, Tchindebe *et al*., 2019, Tchindebe *et al*., 2020; Mamadou *et al*, 2020) [16, 17, 28, 27, 71, 23, 39, 1, 65, 66, 40]. The objective of this study is to develop multi-specific allometric equations in the Sudano-guinea savannahs of Ngaoundere Cameroon according to the standard measurement methods used in forestry.

2. Materiel and Method

2.1 Study site

Our research is carried out in the savannahs of Ngaoundere which themselves belong to the Adamawa plateau located between the 6th and the 5th degree of North latitude, the 10th and the 16th degree of East longitude. Its extends over about 72.000 km, with an average altitude of about 1.200 m, in the center of Cameroon. The climate of this region is a Sudano-guinea altitude type, at humid tendency (Suchel, 1987) [63], with a long rainy season (April-October) and a short dry season (November-March). The average annual precipitation is of 1500 mm, with peaks of rainfall in July and September. The annual average temperature between the periods 1989 and 2020, for the city of Ngaoundéré is 23°C and the relative humidity is 65% (Carrière, 1989) [12]. The dominant soils are weakly ferralitic (Boutrais, 1974) [7], red in color developed on old basalts (Humbel, 1971) [30], rich and clay (40 to 60%), low in organic matter (less than 1%), with a low capacity for cation exchange (15-20 meq/100g) and a pH between 4.7 and 5.6 (Brabant and Humbel, 1974) [9]. The Adamawa vegetation is a humid savannah with *Daniellia oliveri* and *Lophira lanceolata* (Letouzey, 1968) [37], which, nowadays, are in a regressive dynamic under the effects of anthropisation (Mapongmetsem, 2006 [42] and Sufa Kankes, 2017). This savannah is differentiated into grassy savannahs at *Imperata* generally from agriculture; and shrubby savannahs with *Annona senegalensis*, *Bridellia ferruginea Terminalia glaucescens* with ashy foliage, *Hymenocardia acida*, *Piliostigma thonningii* with the notable presence of *Aframomum latifolium* and carpet of Andropogone more diversified; finally, in tree savannahs with *Daniellia oliveri*, *Combretum molle*, *Parkia biglobosa*, *Syzygiun guineensis* var. *guineense*, *Syzygiun guineensis* var. *macrocarpum* and *Vitellaria paradoxa*. The appearance of this vegetation is influenced by zoo-anthropic actions (Ibrahima & Abib Fanta, 2008) [31]. Multifaceted cropping practices and the breeding of local populations undermining this vegetation which is regressing more and more.

Three study sites were chosen at Dang, Tchabbal and Falaise. These sites are located along the Ngaoundere - Garoua road axis following an altitudinal gradient varying from 1030 to 1500 m. The other characteristics of these sites, their geographical location and their dominant vegetation formation are given in Table 1.

Table 1: Characteristics of study sites

Variables	Dang	Tchabbal	Falaise
Geographical reference	N:7°25’6’’ and E:13°33’130’’	N:7°35’5’’ and E:13°33’54’’	N:7°37’6’’ and E:13°33’12’’
Altitudes (m)	1056	1265	1440
Distance from Ngaoundere town (km)	13	25	35
Dominant vegetal formation	shrubby savannahs	Tree savannahs	
Soil	Ferralitic soils on granite		
Texture	Clayey		

2.2 Plant Species choice

Sixteen (16) plant species characteristic of the Ngaoundere savannah and of socio-economic interest for the local populations were chosen (Table 2). These plant species are from a hand, food sources for men and livestock, source of income for farmers, indicators of soil fertility, etc... and play a role in the traditional pharmacopoiea and on the other hand and threatened by human activities, particularly by logging (Mapongmetsem *et al.*, 1998; Tchotsoua, 2009, Rodrigue *et al*., 2017, Massai *et al*., 2019) [44, 68, 58, 45]. They are also part of the species studied in the research program on the domestication of local plant species interest and the

functioning of savannah ecosystems (Ibrahima *et al.*, 2006; Mapongmetsem *et al*., 2008) [32, 43]. These species are mostly medium-sized shrubs between 3 and 4 m (*Annona senegalensis, Entada africana, Maytenus senegalensis, Piliostigma thonningii, Psorospermum febrifugum, Securidaca longepedunculata, Vitex madiensis, Ximenia americana*), and trees taller than 6 m (*Lannea schimperi, Lophira lanceolata, Syzygium guineense* var. *guineense* et *Syzygium guineense* var. *macrocarpum, Terminalia glaucescens* et *Terminalia macroptera, Vitellaria paradoxa* and *Vitex doniana)*. These are mostly deciduous species, which lose their leaves in the dry season, except *S. guineense* var. *guineense* and *V. doniana* which are evergreen.

Table 2: Plant species sample and their habitat

Family	Species	Growing form	Leaves habit	Habitat
Annonaceae	*Annona senegalensis*	shurb	Deciduous	Savannah
Mimosaceae	*Entada africana*	shurb	Deciduous	Savannah
Anacardiaceae	*Lannea schimperi*	tree	Deciduous	Savannah
Ochnaceae	*Lophira lanceolata*	tree	Deciduous	Savannah
Celastraceae	*Maytenus senegalensis*	shurb	Deciduous	Savannah
Fabaceae	*Piliostigma thonningii*	shurb	Deciduous	Savannah
Hypericaceae	*Psorospermum febrifugum*	shurb	Deciduous	Savannah
Polygalaceae	*Securidaca longepedunculata*	shurb	Deciduous	Savannah
Myrtaceae	*Syzygium guineense* var. *guineense*	tree	Evergreen	Forest gallery
Myrtaceae	*Syzygium guineense* var. *macrocarpum*	shurb	Deciduous	Savannah
Combretaceae	*Terminalia glaucescens*	tree	Deciduous	Savannah
Combretaceae	*Terminalia macroptera*	tree	Deciduous	Savannah
Sapotaceae	*Vitellaria paradoxa*	tree	Deciduous	Savannah
Lamiaceae	*Vitex doniana*	tree	Ever green	Forest gallery
Lamiaceae	*Vitex madiensis*	shurb	Deciduous	Savannah
Olacaceae	*Ximenia americana*	shurb	Deciduous	Savannah

2.3 Sampling and data collection

After authorization from environmental officials, one hundred and fifty 150 individuals belonging to 16 plant species were sampled in the three sites at a rate of 50 individuals per site. So as to minimize the interdependence of the observations, that is to say that characteristics of a tree do not influence those of another. The main choices criteria for individuals are their availability and the absence of human exploitation (trace pruning or lopping), disease or physical abnormality. These sampled individuals were divided into three diameter classes ([5-15 cm[, [15-25 cm[and [25-40 cm[) defined by Mamadou (2014) [39] and Ahmadou (2014) [1], at a rate of fifty (50) individuals for each. After measuring their diameter at breast height (DBH) on bark using a tape measure and their height using a clinometer, these individuals were cut at 20 cm from the ground using a chainsaw and divided into compartments of leaves, branches and trunks following the method of Picard *et al*. (2012) [52]. The remaining part of the stem (2 cm) was cut using a machete. Their total wet masses were determined using a scale in the field. A sample of each category for each individual was taken and brought back to the laboratory to determine their total dry mass, after drying at oven, *Memmert* for 48 hours at a temperature of 75°C for the leaf samples and 105°C for the branch and stem samples. The water content of the leaf, branch and stem samples were calculated using the following formula: TE (%) (MH-MS/MS)*100, where TE is the water content of the samples in percentage, MH and MS respectively the fresh and dry masses (Kg) of the sample. From the water content of the samples, the total dry masses of the fractions were calculated as follows: MST = 100*MHT/ (100+TE), where MST is the total dry mass and MHT is the total fresh mass (Kg). The specific density was obtained in the studies of Halilou (2015) [26].

2.4 Development of equations

The allometric equations were established between the physical parameters of woody plants (DBH (D), height (H) and density (p)) and the Biomass of leaves, stems, branches and total (Lotfi, 2005). The mathematical model commonly used to develop allometric equations has been adopted (Picard *et al.*, 2012 [52], Nelson *et al.*, 1992, Heney *et al.*, 2012):

$$Y = a*X^b$$

Y is the response variable and X the explanatory variable, a and b being the adjustment coefficients. Thus, in the case of adjusting biomass tariffs or volume, simple linear regression using biomass as the response variable (Y) will generally be of little use. The logarithm transformation (i.e., In (Y)) solves this problem, since the linear regressions used in the context of the tariff adjustment will almost always be regressions on log-transformed data according to the formula:

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

After the logarithmic transformation of the data collected, the allometric equations were established between the leaf, branch, stem and total biomasses, and the physical parameters of the tree (diameters, height and density). These mathematics equations are:

- A model using a single parameter which is the DBH (D)

$$Ln(B) = a + bLn(D) \quad (1)$$

- Two models taking into account in addition to the diameter, the height of the ligneous as additional explanatory parameter.

$$Ln(B) = a + bLn(D^2H) \quad (2)$$

$$Ln(B) = a + bLn(D) - cLn(H) \quad (3)$$

- Two models taking into account in addition to the diameter and the height, the density (p) of the ligneous

as additional explanatory parameter

$$Ln(B) = a + bLn(D^2H) + cLn(\rho) \quad (4)$$
$$Ln(B) = a + bLn(D) + cLn(D^2H\rho) \quad (5)$$

Where B is the biomass (Kg), D the diameter (cm), H the total height (m), ρ the density (cm), a is the regression slope, b and c are the regression coefficients.

The logarithmic transformation of the data generally leads to a bias in the estimate of the biomass (Duan, 1983, Chace *et al*., 2005) [21, 13]. A correction is necessary and consists of multiplying the estimated biomass by a correction factor (CF), which is calculated as: CF= exp{RSE²/2} (Djomo *et al*., 2016, Djomo and Chimi, 2017) [19, 20]; the CF is a number always greater than 1. To evaluate and compare the quality of adjustment of a model, several criteria are used (Schlaegel, 1987; Parreial, 1999 and Tedeschi, 2006 [69]). The adjusted coefficient of determination (R^2aj), the residual standard error (FSE) and an information criterion of Akaike (AIC) have been used (Bozdogan 1982; Burnham and Anderson, 2002 [10], 2004 [11]). Akaik's information criterion is calculated as follows: AIC= -2Ln (L) + 2p; with p the number of model parameters and L the maximized likelihood. These criteria make possible to select the best models. The weaker of AIC and RSE and the higher the R^2aj, the better the model will be (Chave *et al.*, 2005) [13]. All these statistical analyzes were carried out with the Excel software and the allometric equations developed in the R i38 3.3.3 software.

3. Results

3.1 Distribution of dendrometric and biomass parameters

The distribution of dendrometric parameters and biomass is presented in Table 3. The diameter varies between 3.50 and 35.00 cm with an average of 12.72 cm. Plant height varies from 1.46 to 11.00 m, with an average of 4.21 m. For the biomass, that of the leaves ranges from 0.30 to 24.58 kg, for branches from 0.93 to 177.37 kg, and that of the stem from 2.50 to 66.70 kg, with respective averages of 4.39 kg, 28.42 kg and 16.29 kg. The branches accumulate more biomass than the other compartments, with a rate of 66.02% of the total biomass, followed by the stem (24.83%).

Table 3: Limits and average values of dendrometric and biomass of plant compartments

Parameter	DBH (cm)	Hight (m)	Density (g.mm^{-3})	Compartments			
				Bfol (Kg)	Bbran (kg)	Btr (kg)	Btot (kg)
Average	12.72	4.21	0.53	4.39	28.42	16.29	49.10
Sd	5.88	1.69	0.08	3.71	34.34	13.01	48.88
Min	3.50	1.46	0.33	0.30	0.93	2.50	5.30
Max	35.00	11.00	0.87	24.58	177.37	66.70	268.65

Bfol: leaves biomass; Bbran: branch biomass; Btr: stem biomass; Btot: total biomass. sd: standard deviation, Max: maximum and Min: minimum.

3.2 Development of allometric models

The first model (1) using the DBH as the only measurement parameter, is tested across the compartments. It presents an adjusted determination coefficient (R^2aj) varying from 0.458 for the leaves to 0.719 for the total biomass, with an AIC ranging from 193.30 for the total biomass to 284.81 for the biomass of branches and RSE from 0.443 to 0.617 (Table 4). By integrating the height in the model (1), we obtain two models (model 2 and 3) which improve the model 1 for all compartments, except model 2 not improving model 1 for the branch compartment (Table 4). The adjusted R² of models 2 and 3 are higher than those of model 1 for all compartments, except the branch compartment for model 2. These adjusted R² pass for model 1 to model 2, from 0.458 to 0.474 for the leaves, from 0.599 to 0.627 for the stem, from 0.719 to 0.727 for the total biomass.

The integration of the density in models 2 and 3 gives models 4 and 5. The latter models improve, except model 5, all others for all compartments, with higher adjusted R² than all other models (Table 4). These adjusted R² vary from 0.477 to 0.736 respectively for the leaves and total biomass compartments. Values RSE and AIC have also undergone improvements with model 5 and vary from 180.24 to 280.79 for AIC and from 0.434 to 0.607 for RSE, respectively for total biomass and branch compartment.

Table 4: Parameter of adjustment between biomass (kg) and plant parameters (DBH, H, and ρ) of individuals of 16 plant species of the Ngaoundere savannah

N0	Models	a(se)	b(se)	C(se)	RSE	R^2aj	AIC	CF	P
	Leaves biomass								
1	ln(B)= a + bln(D)	-1.79(0.27)	1.21(0.11)	/	0.607	0.458	279.84	1.20	<0.001
2	ln(B)= a + bln(D²H)	-1.83(0.26)	0.48(0.04)	/	0.598	0.474	275.30	1.20	<0.001
3	ln(B)= a + bln(D) + cln(H)	-1.86(0.27)	1.04(0.13)	0.36(0.16)	0.598	0.472	276.64	1.20	<0.001
4	ln(B)= a + bln(D²H) +cln(ρ)	-1.56(0.35)	0.48(0.04)	0.38(0.32)	0.597	0.475	275.89	1.20	<0.001
5	ln(B)= a +bln(D)+cln(D²Hρ)	-1.61(0,27)	0.32(0.36)	0.36(0.14)	0.596	0.477	275.22	1.19	<0.001
	Branch biomass								
1	ln(B)= a + bln(D)	-1.96(0.27)	1.94(0.11)	/	0.617	0.677	284.81	1.21	<0.001
2	ln(B)= a + bln(D²H)	-1.92(0.27)	-1.92(0.04)	/	0.622	0.672	287.11	1.21	<0.001
3	ln(B)= a + bln(D) + cln(H)	-2.03(0.27)	1.78(0.13)	0.35(0.16)	0.610	0.685	282.15	1.20	<0.001
4	ln(B)= a + bln(D²H) +cln(ρ)	-1.66(0.36)	0.75(0.24)	0.38(0.34)	0.621	0.673	287.84	1.21	<0.001
5	ln(B)= a +bln(D)+cln(D²Hρ)	-1.78(0.28)	1.07(0.37)	0.35(0.14)	0.607	0.688	280.79	1.20	<0.001
	Stem biomass								
1	ln(B)= a + bln(D)	-0.50(0.21)	1.24(0.08)	/	0.465	0.599	200.03	1.11	<0.001
2	ln(B)= a + bln(D²H)	-0.56(0.20)	0.49(0.03)	/	0.449	0.627	189.22	1.11	<0.001

3	ln(B)= a + bln(D) + cln(H)	-0.58(0.20)	1.05(0.10)	0.40(0.12)	0.449	0.626	190.59	1.11	<0.001
4	ln(B)= a + bln(D²H) +cln(ρ)	-1.47(0.31)	0.61(0.04)	0.19(0.24)	0.444	0.635	186.88	1.10	<0.001
5	ln(B)= a +bln(D)+cln(D²Hρ)	-1.54(0.30)	0.64(0.29)	0.38(0.10)	0.441	0.640	184.78	1.10	<0.001
	Total biomass								
1	ln(B)= a + bln(D)	-0.27(0.20)	1.56(0.08)	/	0.448	0.719	188.80	1.11	<0.001
2	ln(B)= a + bln(D²H)	-0.28(0.19)	0.61(0.03)	/	0.442	0.727	184.51	1.10	<0.001
3	ln(B)= a + bln(D) + cln(H)	-0.34(0.19)	1.39(0.09)	0.36(0.11)	0.435	0.734	181.25	1.10	<0.001
4	ln(B)= a + bln(D²H) +cln(ρ)	-0.10(0.26)	0.61(0.03)	0.25(0.24)	0.442	0.727	185.42	1.10	<0.001
5	ln(B)= a +bln(D)+cln(D²Hρ)	-0.10(0.20)	0.72(0.27)	0.33(0.10)	0.434	0.736	180.24	1.10	<0.001

Parameters a, b and c are coefficients of adjustment of models. (se): standard deviation, R²aj: adjusted determination coefficient, CF: Correction Factor, RSE: Residual Standard Error and AIC: Akaike's information criterion.

3.3 Selection of the best models

The selection of the best models tested is made by analyzing the criteria taking into account of R²aj, RSE and AIC. The models that exhibit the lowest AIC and RSE and the highest R²aj are the best models. Thus, the best model for each of the compartments, leaves, branches, stems and total biomass is model 5, which is in the form of Ln(B) = a +bLn(D)+cLn(D²H*p). The adjusted coefficients of determination (R²aj) of the five best models selected for each of the three compartments and the total biomass are higher, their RSE and their AIC are lower than the values of the other models. These best equations are shown in Table 5 and Figure 1.

Table 5: Best models for all of plant compartments

Compartiments	Model	R²aj	RSE	AIC
Leaf biomass	Ln(B) = -1.61 + 0.32Ln(D) + 0.36Ln(D²Hρ)*1.19	0.477	0.596	275.22
Branch biomass	Ln(B) = -1.78 + 1.70Ln(D) + 0.35Ln(D²Hρ)*1.20	0.688	0.607	280.79
Stem biomass	Ln(B) = -1.54 + 0.64Ln(D) + 0.38Ln(D²Hρ)*1.10	0.640	0.441	184.78
Total biomass	Ln(B) = -0.10 + 0.72Ln(D) + 0.33Ln(D²Hρ)*1.10	0.736	0.434	180.24

A, b and c are coefficients of adjustment of models. (se): Standard Deviation, R²aj: Adjusted Determination Coefficient, CF: Correction Factor, RSE: Residual Standard Error and AIC: Akaike's Information Criterion.

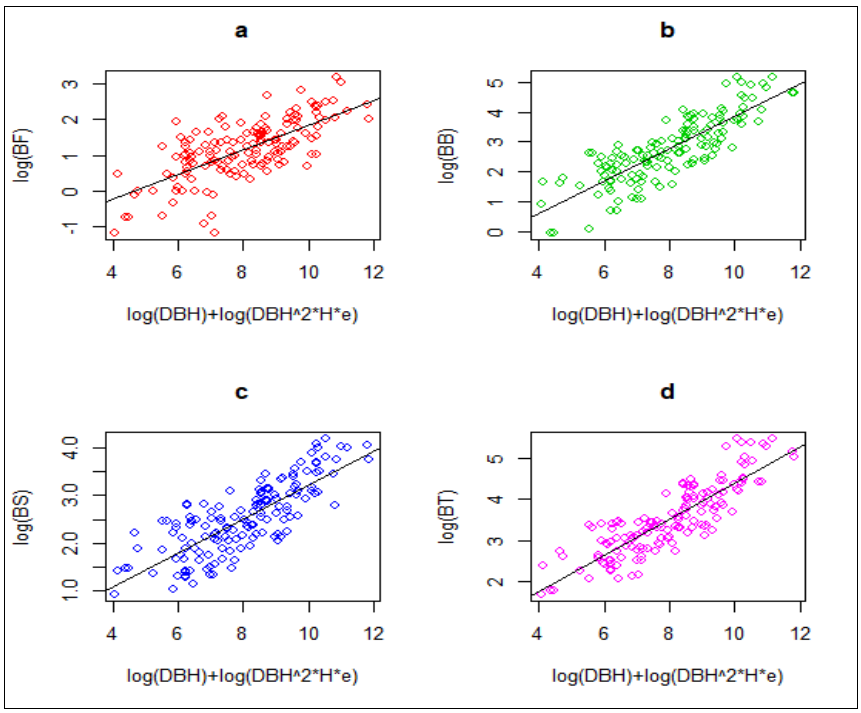

Fig 1: Relationships between parameters (DBH, H, ρ) and biomass of leaves (a), branches (b), stem (c) and total (d)

4. Discussion

Allometric equations for estimating the biomass of woody species in the Sudano-guinea savannahs of Ngaoundere were established in the intervals of diameter and height ranging from 3.5 to 35 cm, and from 1.46 to 11.00 m respectively. These ranges of plant parameters (DBH and height) showed that the sampling integrates a wide range of diameter individuals from the savannahs, often of low height as reported by Kaïré (1999) in the Senegalese savannahs. The proportions of biomass between the compartments and particularly the predominance of branches over the other compartments showed that independently of the intrinsic mode of growth of the individuals, the plant species of the shrubby savannahs have developed more branches than those having grown in wooded savannahs or dense forests. This confirmed the results of Tchindebe *et al*. (2019 and 2020) [65, 66] and Mamadou *et al*. (2020) [40], carried out in the shrubby Sudanian savannahs. They reported that the biomasses of the branches are higher than those of the leaf and stem compartments. On the other hand, Henry *et al*. (2010) [28] showed that the proportions of stem biomass are higher than those of branches in tropical rainforests. The

work of Vahedi *et al*. (2014) [70] also reported similar results in the closed vegetation of Iranian forests.

The R^3aj values of the Ln(B) = a + bLn(D) model for the branch compartment (R^2aj=0.677) are closed to those obtained by Vahedi *et al*. (2014) [70] (R^2aj=0.605) and also by Mamadou (2014) [39] and Ahmadou (2014) [1] (R^2aj =0.67), despite differences in sample sizes. For the other compartments, the R^2aj obtained in their studies were higher than ours. This is explained by the fact that the work of Vabedi *et al*. (2014) was carried out on forest plant species whose growth is governed by forest conditions much more favorable than those of the Savannahs and those of Mamadou (2014) [39] and Amadou (2014) were carried out in the same savannahs as ours, but on individuals smaller in diameter than those used in our study

The two models (2 and 3) experience decrease in the values of their adjusted coefficients of determination (R^2aj) and their residual standard errors (RSE) compared to those of Mamadou (2014) [39] and Ahmadou (2014) [1] (R^2aj = 0.66~0.87 and RSE=0.54-0.98). The reasons for the size of the samples can be cited to justify this discrepancy, but also the height factor introduced into the models can also influence these results since the previous samples were poorly filled with individuals of large diameter and great height. Moreover, the diameter used here is the DBH contrary to the basal diameter used in their equations. The values expressed for our branch compartments (R'aj=0.672 and 0.685) are also approximates those obtained by Vahedi *et al*. (2014) [70] (R'aj=0.621 and 0.614) for the two types of models. The same models developed by Djomo *et al*. (2010) [17] on data from (Ketterings *et al*., 2001; Chave *et al*., 2005; Basuki *et al*., 2009; Navar, 2009; Djomo *et al*., 2010; Rebeiro *et al*., 2011) [35, 13, 5, -, 17] showed R^2 aj (R^2 = 0.97) higher than ours and as we said earlier the plant species are forest trees whose height plays a lot on the improvement of the models.

Unlike the two models (model 2 and 3), the three models (model 4 and 5) (equation 4.5; 9.10; 14.15 and 19.20) do not experience significant variations in the values of their coefficients of adjusted determinations (R^2aj) and residual standard errors (RSE) compared to those of Mamadou (2014) [39] and Ahmadou (2014) [1] (R^2aj=0.66~ 0.87 and RSE=0.54-0.98). Their results also presented the three-models as non-improving in the prediction of stem biomass and total biomass. Adding the density reveals a result almost similar to the two models.

Selections of the best allometric equation models are based on one or more criteria (Djomo *et al*., 2010: Kuyah *et al*., 2012; Mbow *et al*., 2013) [17, 36, 46]. Indeed, Kuyah *et al*. (2012) [36] and Mbow *et al*. (2013) [46] used only one criterion. Akaike's criterion was used by Kuyah *et al*. (2012) [36] to estimate tree biomass in Mali, while Mbow *et al*. (2013) [46] developed allometric equations in RSE to select the best models. On the other hand, Fayolle *et al*. (2013) [23] selected the best volume pricing models by combining RSE and AIC. In our study, all these criteria were taken into account to select the best models and that whatever the criterion retained, its values are better than those of the other models tested.

Among the 5 models tested, model 5 (In(B) = a + bLn(D)+cLn(D^2Hp)) taking into account the 3 plant parameters (DBH, height and density) was better at predicting the biomasses of all compartments, as in the studies of Mamadou *et al*. (2020) [40], which showed this model was well suited to predict the biomass of the leaf and aerial compartments. On the other hand, Ahmadou (2014) [1] and Mamadou (2014) [39] carried out in the same savannahs as ours, but on individuals with basal diameters generally lower than ours. They reported that model 1 (Ln(B)= a + bLn(D)) taking into account only the basal diameter performed well for leaves and branches, and model 2 (Ln(B)= a + bLn(D^2H)) was well suited for stems and total biomass. These differences would be justified by the fact that the diameter and the height of the individuals are generally lower than ours, and in their studies, the equations were developed using the basal diameter instead of the diameter at breast height (DBH) as ours.

Other studies have shown that model 1 takes into account the diameter is suited for the biomasses of all compartments for *Daniellia oliveri*, except leaves (Tchindebe *et al*., 2019) [65] and model 2 taking into account the square diameter multiplied by the height (D^2H) of plant was suitable for the leaf biomass of *Daniellia oliveri* (Tchindebe *et al*., 2019) [65] and of all compartments in *Acacia albida* (Tchindebe *et al*., 2020) [66] in the Sudanese savannahs of Cameroon.

5. Conclusion

In short, it was a question of developing allometric equations to better estimate the biomass of woody species in the savannahs of Ngaoundere based on standard parameters of trees used in forestry. The data of 150 trees belonging to 16 plant species allowed us to build allometric models from 3 variables (diameter, height and density of the wood). Thus, the best equation for the prediction of biomass of all the woody compartments is the model 5 (Ln(B) = a + bLn(D) + cLn(D^2Hp)), with for leaves, Ln(B) = -1.61 + 0.32 Ln(D) + 0.36 Ln (D^2Hp) and R^2aj = 0.477, for the branches Ln(B) = -1.78 + 1.07Ln(D) + 0.35Ln(D^2Hp) and R^2aj = 0.688, for the stem Ln(B) = -1.54 + 0.64Ln(D) + 0.38Ln(D^2Hp) and R^2aj=0.640, and for the total biomass Ln(B) = 0.10 + 0.72Ln(D) + 0.33Ln(D^2Hp) and R^2aj= 0.736. These equations developed on the basis of standard measurements (DBH, height) estimate the biomass of savannah species with good precision. These measures can therefore be applied to savannah species in general and those of Ngaoundere Cameroon in particular. However, it is obvious that all savannah species still do not obey the standard measurements and especially for the DBH measurement because of their small size. For a better understanding of the most indicated measurement for savannah plant species, we need to compare these results obtained with models developed on specific measurements of savannah species.

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