Climate Change Adaptation and Mitigation Options through strengthening carbon Management in Central Africa: Biomass allometric models of *Khaya senegalensis* (Desr.) A. Juss (meliaceae) in Cameroon

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Abstract

This study focused on the development of allometric models of *Khaya senegalensis* in order to establish a basis for calculating carbon stocks. The research was carried out in the Adamawa, North and Far North region of Cameroon. The weighing of the samples of each part (stem, branch, leaf) of the sample of trees composed of 60 feet of *Khaya senegalensis* and their drying in the oven made it possible to know the dry biomass of each subject. Adjusted coefficients of determination (Adj.R^2), residual standard error (RSE) and Akaike's information criterion (AIC) were used to choose the best models. Thus, the tested models presented varied performances. The various analyzes have confirmed that the diameter at breast height (DBH) is the variable that offers the best correlation with above-ground (AGB) and below-ground (BGB) biomass. The best selected models are: $\ln(\text{AGB}) = 1.004 - 0.054 * \ln(D)$ and $\ln(\text{BGB}) = -3.009 + 0.016 * \ln(D)$ (Adamawa); $\ln(\text{AGB}) = 0.004 + 0.054 * \ln(D)$ and $\ln(\text{BGB}) = -1.301 + 0.116 * \ln(D)$ (North); $\ln(\text{AGB}) = 0.004 + 1.084 * \ln(D)$ and $\ln(\text{BGB}) = -0.002 + 0.016 * \ln(D)$ (Far North). The best models selected for the global equations for the three regions are: $\ln(\text{AGB}) = 0.504 + 3.048 * \ln(D)$ and $\ln(\text{BGB}) = -0.109 + 0.306 * \ln(D)$. Models were proposed to estimate the carbon of *Khaya senegalensis* in Cameroon.

Introduction

Africa is the continent most vulnerable to the impacts of climate change (Thiam et al. 2014). Forest ecosystems play a key role in mitigating the adverse effects of climate change, by absorbing carbon dioxide, one of the main greenhouse gases responsible for global warming (Ganame et al. 2021). Indeed, they constitute real carbon sinks, both in the vegetation and in the soil. Among forest ecosystems, tropical forests with 7% of the world's land surface (Ganame et al. 2021), alone absorb around 40 to 50% of terrestrial carbon (Ganame et al. 2021). Estimation of biomass is an essential step in assessing the carbon stock of forest ecosystems (Goetz et al. 2015).

The biomass of forest ecosystems is generally estimated through allometric equations using the dendrometric parameters of trees as variables (Bayen et al. 2015; Chabi et al. 2016; Fayolle et al. 2018). The lack of reliable allometric equations specific to Sahelian ecosystems has led to the use of pantropical models (Chave et al. 2014), generating uncertainties in the estimation of the biomass of African forests (Djomo et al. 2010, Henry et al. 2010). Tree biomass, which includes the biomass of stems, branches, leaves and roots, is an important store of atmospheric carbon (Xue et al. 2016; Ganame et al. 2021). The abundance of a tree's above-ground biomass is an indicator of its ability to efficiently sequester atmospheric carbon through the process of photosynthesis (Dimobe et al. 2018a). As a result, several studies have focused on estimating above-ground biomass to the detriment of below-ground biomass, the assessment of which remains difficult and is not very precise (Mensah et al. 2017; Djomo & Chimi 2017; Dimobe et al. 2018a; Balima et al. 2019). Tree biomass can be assessed either by the direct method, by the indirect method, or by remote sensing techniques. The most commonly used and most accurate method is the direct so-called destructive method (Fayolle et al. 2013).

Efficient estimation of the biomass of forest ecosystems requires the use of precise allometric equations (Ganame et al. 2021). The development of these equations requires the collection of biomass data from standing trees by the destructive method (Djomo and Chimi 2017). However, the unavailability of accurate biomass estimation equations hinders the assessment of biomass of forest ecosystems in African countries (Henry et al. 2011) and the inclusion of these forests in climate change mitigation. The allometric models developed in African countries are limited to humid forests (Fayolle et al. 2013; Djomo and Chimi 2017). According to (Djomo and Chimi 2017), the lack of adequate mathematical models for estimating the biomass of African forest ecosystems has led to an overuse of the equations developed by Chave et al. (2014).

However, the accuracy of these global models is questionable, given that the allometric equations are closely dependent on the abiotic conditions of the sites and the structural characteristics of the species (Djomo et al. 2016). Biomass information, site and species specific, is therefore needed to improve the accuracy of biomass estimates for African forests. This results in a lack of precise information on biomass stocks hampering the assessment of the contribution of the country's forest ecosystems in the mitigation of climate change through carbon sequestration. Therefore, mathematical models must be developed to estimate the biomass of forest ecosystems in Cameroon. The resurgence of extreme climatic phenomena such as droughts and floods are manifestations of this climate change. The risks associated with this change affect every continent, and affect all socio-economic sectors of populations (Ganame et al. 2021). It is therefore urgent to identify the mechanisms for reducing the concentration of GHGs in the atmosphere. Hence the objective of this work is to develop allometric models for predicting above and belowground biomass of *Khaya senegalensis* in the Adamawa region, North and Far North of Cameroon.

Materials And Methods

Study sites

The study took place in three agro-ecological zones of Cameroon: Sudano-Guinean zone (Adamawa region), Sudano-Sahelian zone (North region) and Sahelian (Far-North region). The Adamawa region lies between latitude 6° and 8° North and longitude 11° and 16° East with an area of 63701 km² (Awé et al. 2021). The North region is located between latitude 9° 18' North and longitude 13° 23' East with an area of 68 090 km² (Awé et al. 2021). The Far North region is located between latitude 11°00' North and longitude 14°30' East with an area of 34263 km² (Awé et al. 2021)(Fig.1).

Criteria for the Selection

The socio-economic and environmental importance, density, availability, topography and size of *Khaya senegalensis* (Meliaceae) were the main reasons for the choice of this species.

Data collection

Sampling method was conducted from January 2020 to June 2021. Five sampling plots of 50 m x 50 m each were established randomly in each of the stands. To conduct this study, the direct method was employed to determine the biomass of each tree. A total of 60 sample trees belonging to *Khaya senegalensis* were harvested for biomass estimation and allometric equation parameterization in the Adamawa (20 sample trees belonging to *Khaya senegalensis*), North (20 sample trees belonging to *Khaya senegalensis*) and Far North (20 sample trees belonging to *Khaya senegalensis*) region of Cameroon. Selection of each individual tree was based on diameter at breast height (1.3 m aboveground). The individuals were grouped into three DBH classes: 0–20 cm, 20–40 cm, 40–60 cm, 60–80 cm. For each sample tree the DBH and total height (H) of the stand trees were first recorded. Trees were felled close to ground level. The trees were selected to ensure a representative distribution of diameter classes within the sampling plots. Individuals were selected on the basis of their availability and the absence of human exploitation (traces of pruning or limping) or disease. Before the trees were felled, the diameters of the individuals with bark were determined using a tape and the total height was determined using a clinometer. The individuals were then cut 5 cm from the ground using a chainsaw and divided into compartments: the leaves; branches and stem. The stem and large branches were cut into small pieces, and bagged and weighed with a scale in the field.

All 60 trees selected for destructive sampling were excavated for belowground tree component analysis. Once excavated, the main tree components were treated as by Mugasha *et al.* (2013) as follows: (i) Root crown was cleaned to remove soil and weighed for green weight. (ii) All broken roots (roots not excavated) were measured for top diameter at breakage point on the root crown. Tap root was followed to the point where its diameter was nearly equal to the top diameter of the largest side root, and its weight was included to the weight of root crown. (iii) From each sample tree, 3 main roots (small, medium and big) were selected and traced to minimum diameter of 1 cm. The top diameter and weight of each sample root were measured and recorded. When main roots enter obstacles (stone or another tree) the end point diameter was measured.

A sample from each compartment was taken and dried in an oven for 48 hours, at a temperature of 70 ° C for the leaves and 105 ° C for the stem, branch discs. The water contents of the samples of leaves, branches and trunks will be calculated according to the following formula:

$$TE (\%) = ((MH-MS) / MS) * 100 \quad (1)$$

Where: TE is the water content of the samples in percentage,

MH and MS are respectively the wet mass (Kg) and the dry mass (Kg) of the sample.

From the water content of the samples, the total dry masses of the fractions were calculated as follows:

$$MST = 100 * MHT / (100 + TE) \quad (2)$$

Where: MST is the total dry mass

MHT is the total wet mass (Kg).

The total dry masses are called biomass and expressed in Kilograms (Kg).

Data Analysis

Biomass equations using DBH and H as the independent variable were developed and were regressed against the leaves, branches, stem, above and below ground Biomass allometric model of individual trees were derived from 20 sample trees in the Adamawa, North and Far North region of Cameroon.

We first used the distance of Cook's residuals to identify outliers of explanatory and response variables (Ganame et al. 2021). We then examined the theoretical relationship between the response variable and the explanatory variables, testing the linear, logarithmic, exponential and power regression models. The response variable is the biomass expressed in kg and the explanatory variables are the diameter at breast height (DBH) and tree height (H). The best theoretical model retained to develop the equations for predicting the biomass of leaves, branches, stem, AGB and BGB of the tree for this species is the power model:

$$B = a * D \quad (3)$$

where B is the biomass, D is the diameter and, a and b, the coefficients of regression (Picard et al. 2012; Tchindebe et al. 2019; Ganame et al. 2021).

The following models were considered for estimating Biomass (*B*, kg dry weight) from DBH, H where *a*, *b* and *c* are coefficients (Picard et al. 2012; Nam et al. 2016; Adam et al. 2018):

$$\ln(B) = a + b * \ln(D) \quad (\text{Eq.1}) \quad (4)$$

$$\ln(B) = a + b \cdot \ln(D^2) \quad (\text{Eq.2}) \quad (5)$$

$$\ln(B) = a + b \cdot \ln(D) + c \cdot \ln(H) \quad (\text{Eq.3}) \quad (6)$$

$$\ln(B) = a + b \cdot \ln(D^2H) \quad (\text{Eq.4}) \quad (7)$$

The logarithmic transformation of the data generally leads to a bias in the estimation of Biomass (Chave et al. 2005; Mascaró et al. 2014; Ganame et al. 2021); a correction is therefore necessary and consists in multiplying the estimated Biomass by a correction factor (CF) which is calculated as follows:

$$CF = \exp(RSE^2/2) \quad (8)$$

CF is a number always greater than 1 (Djomo et al. 2016).

Three criteria were used to measure the robustness and precision of the models in the estimation of above-ground biomass. They are in order of importance:

Adjusted coefficient of determination (Adjusted. R^2), where STS: Sum of Total Squares and SRS: Sum of Residual Squares.

AIC or Akaike Information Criterion obtained by the following formula:

$$AIC = -2 \ln(L) + 2p \quad (9)$$

(L "Likelihood" or Probability at which the predicted model is correct to the unknown true and p: Total number of parameters of the model) (Akaike 1981).

RSE or Residual standard error obtained by the following formula:

$$RSE = \ln(AGB_{obs}) - \ln(AGB_{pred}) \quad (10)$$

where RSE: Residual standard error; AGB obs: Measured above-ground biomass; AGB pred: Predicted above-ground biomass.

The selection of the best allometrics developed for the prediction of the biomass was made on the basis of several statistical parameters. Thus, the lower the residual standard error (RSE), Akaike information criterion (AIC), and the strong adjusted R^2 , the better the model will be (Picard et al. 2012; Chave et al. 2014).

The prediction equation for the total biomass of *Khaya senegalensis* is obtained by combining the best equations of the four compartments of this species in each region. The paired t-test was used to test the significance of the difference between the predicted biomass and the observed biomass. The heteroskedasticity of the selected models was verified by graphically analyzing the trend of estimation errors between predicted values and observed values (Dimobe et al. 2018b; Ganame et al. 2021). The estimation error was calculated using the formula proposed by Mbow et al. (2013):

$$\% \text{ Bias} = (\text{Predicted biomass} - \text{Measured biomass}) / \text{Measured biomass} * 100 \quad (11)$$

The statistical analyzes were carried out with Excel 2020 and R i386 3.1.2 software.

Results

Measurable Parameters Dendrometric and Pearson's Correlation between Diameters, Height with Biomass

Between the three regions, the dendrometric parameters (Dbh and H) of *Khaya senegalensis* are more important in the northern region with an average Dbh (37.32cm) and an H (14.22 m) compared to the other two regions (Table 1). Pearson's correlation shows that in the three regions, the leaf and branch compartments are significantly related to diameter and height, while other components such as stem, AGB and BGB are significantly related only to Diameter but not significant with height (Table 2).

Modelling allometric equations tests by regions

Table 3 shows the analysis of variance and confirms that all the regression coefficients of the models tested are statistically significant ($p < 0.001$). These coefficients differ between the biomass of *Khaya senegalensis* inventoried in the three regions for the same model, with RSE and AIC ranging from 0.308- 0.682 kg and 9.74- 18.65 kg respectively, while their Adj.R² varies from 0.60-0.98.

Selection of the Best Models by regions

The Dbh parameter provided a satisfactory model fit for stem biomass, AGB and BGB in all three regions (Table 4). Leaves and branch biomass are best predicted from $D^2 \times h$ in all three regions (Table 4). These best equations are shown in (Table 4 and Fig.1, Fig.2, Fig.3 and Fig.4) show their adjustments.

Global Modelling allometric equations tests for the three region

Table 5 shows the analysis of variance confirms that all the regression coefficients of the models tested are statistically significant ($p < 0.001$). These coefficients differ between the biomass of *Khaya*

senegalensis inventoried in the three regions for the same model, with RSE and AIC ranging from 0.318- 0.533kg and 10.63- 18.55 kg respectively, while their Adj.R² varies from 0.90-0.98.

Selection of the Best Global Models and validation for the three regions

The Dbh parameter provided a satisfactory model fit for stem biomass, AGB and BGB in all three regions (Table 6). Leaves and branch biomass are best predicted from $D^2 \times h$ in all three regions (Table 6). These best equations are shown in Table 6 and Fig.5 show their adjustments.

The t-test shows that there is no significant difference between the observed values and the predicted values of leaf biomass ($t = 0.16$; $p\text{-value} = 0.87$), branch biomass ($t = 0.18$; $p\text{-value} = 0.85$), stem biomass ($t = 0.20$; $p\text{-value} = 0.77$), AGB ($t = 0.29$; $p\text{-value} = 0.73$), and BGB ($t = 0.14$; $p\text{-value} = 0.91$). The linear regression line between the biomass predicted from the additive model and the observed biomass is almost coincident with the line of equation $y = x$ for all biomasses (Fig. 5). These models therefore produce fewer errors in the prediction of the biomass of *Khaya senegalensis*.

Discussion

The allometric models developed vary from one compartment to another. This would be linked to the variation in biomass observed between different parts of the species (Ganame et al. 2021). The choice of method and mathematical model for adjusting the parameters must be considered judiciously in estimating the biomass of woody plants (Ganame et al. 2021). The leaf biomass, branch biomass, stem biomass, total biomass (AGB) and belowground biomass (BGB) of individuals were fitted using the linear form of the power model. This mathematical model has been widely used in the literature for the prediction of standing biomass of woody species in Europe (Zianis and Mencuccini 2004) and Africa (Henry et al. 2011; Fayolle et al. 2013; Djomo et al. 2013; Djomo et al. 2016; Mensah et al. 2016a; Xiang et al. 2016; Aabeyir et al. 2020; Ganame et al. 2021). It provides reliable results for several types of biomass prediction; given its elasticity (Bayen 2016; Amani 2016). The sample size was 60 individuals. Indeed, the size of the sample in the development of allometric models is variable in the literature and takes into account the resources and time allocated to the study (Tchindebe et al. 2019). Some allometric biomass equations have been constructed from a limited number of individuals, 26 trees (Guendehou et al. 2012), 20 trees (Mbow et al. 2013), 38 trees (Thiam et al. 2014), 17 trees (Tchindebe et al. 2019), 20 trees (Tchindebe et al. 2020). Others incorporate very few large diameter trees, 1 to 79 cm in diameter (Djomo et al. 2010).

Indeed, power models generally remain extrapolable with good reliability because they are based on a fractal allometric model which is invariant at all scales (Picard et al. 2012); which explains their wide use in biomass prediction equations for the benefit of logarithmic or polynomial models. The logarithmic

transformation of the variables carried out in this study remains necessary to reduce the deviations that may exist in a real environment, and to satisfy the conditions of normality and homoscedasticity of the residuals (Chave et al. 2005; Ganame et al. 2021). The allometric models developed with DBH as the sole explanatory variable were the most efficient for the prediction of stem biomass, AGB and BGB of *Khaya senegalensis* studied.

The precision of the measurement of the explanatory variables is very decisive in the development of allometric equations (Picard et al. 2012). DBH can be easily measured in the field with greater accuracy than other dendrometric parameters. In addition, this variable is always available in the inventory data. Numerous studies have also shown that DBH is the explanatory variable most commonly used for predicting the biomass of different compartments of woody species (Henry et al. 2011; Kuyah et al. 2012; Vahedi et al. 2014; Picard et al. 2015; Ganame et al. 2020).

However, the use of this variable alone did not allow an optimal prediction of the biomass of leaves and branches. The incorporation of total height was therefore necessary to improve the quality of prediction of the biomass of leaves and branches of *Khaya senegalensis* in the regions studied. Some authors believe that the use of DBH alone as an explanatory variable would lead to an increase in the predicted biomass (Chave et al. 2005; Ganame et al. 2020). Others, on the other hand, have shown that the use of DBH alone as an explanatory variable underestimates the prediction of biomass (Alvarez et al. 2012). Furthermore, Xue et al. (2016) and Dong et al. (2018) recommend adding a second variable to solve the uncertainty problem in the biomass assessment by DBH. Previous studies have shown that incorporating height as a second variable improves the prediction performance of elaborate equations (Ngomanda et al. 2014; Picard et al. 2015; Mensah et al. 2017; Dimobe et al. 2018a; Dimobe et al. 2018b; Ganame et al. 2020) and has the advantage of increasing the potential of applicability of the equations to different sites (Sawadogo et al. 2010). However, height alone cannot be a good variable for predicting biomass (Oliveras et al. 2013). Biomass prediction models vary according to different tree compartments. The results of these studies are similar to those obtained by Sawadogo et al. (2010); Dimobe et al. (2018a) in Burkina Faso; Henry et al. (2010) in Ghana; Traoré et al. (2018) in Côte d'Ivoire and Ganame et al. (2021) in Burkina Faso who showed a variation in allometric equations depending on the parts of the tree.

The logarithmic CF is a simple and straightforward statistical tool for eliminating systematic biases produced by converting the estimated logarithmic value to the original untransformed scale (Tchiendebe et al. 2020). However, previous studies indicated that CF are generally small compared to the variation generated by the biomass estimate and therefore can be omitted (Tchiendebe et al. 2020). In the present study, the CF values for all component biomass equations were relatively low. Therefore, our results indicate that few errors were introduced when using the logarithmic transformation to fit allometric equations to biomass data.

Conclusion

This study shows that the allocation of tree biomass varies depending on the compartment of *Khaya senegalensis* in three regions of Cameroon. Power-type allometric models fit well to the above-ground and below-ground biomass of the different compartments of *Khaya senegalensis*. The study also highlighted the specificity of allometric equations according to the parts of the tree. It emerges from these results that the DBH is the only explanatory variable which makes it possible to predict with satisfaction the biomass of the trunks, AGB and BGB of *Khaya senegalensis*. These results invalidate our first hypothesis, which states that only the composite variables better predict the biomass of the different compartments of *Khaya senegalensis*. In contrast, incorporating height as a second explanatory value improves the performance of leaf and branch biomass prediction. All the models developed have a fairly good predictive capacity with regard to the small differences observed between the values observed and those predicted. The established allometric models can be used to estimate the biomass of *Khaya senegalensis* by component under similar environmental conditions.

Declarations

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Conflict of interest statement

None declared.

References

- Aabeyir R, Adu-Bredu S, Agyare WA, Weir MJC (2020) Allometric models for estimating aboveground biomass in the tropical woodlands of Ghana, West Africa. *For Ecos* 7:41
- Adam SN, Jusob I (2018) Allometric model for predicting aboveground biomass and Carbon stock of Acacia plantations in Sarawak, Malaysia. *BioRessources* 13(4):7381-7394
- Akaike H (1981) Likelihood of a model and information criteria. *J Econ* 16:3–14
- Awé DV, Noiha NV, Zapfack L (2021) Carbon management for savannah ecosystems in Central Africa: a case study from Cameroon. *Inter J Low-Carbon Tech* 00 :1–9
- Balima LB, Nacoulma BMI, Bayen P, Dimobe K, Kouamé FN, Thiombiano A (2019) Aboveground biomass allometric equations and distribution of carbon stocks of the African oak (*Afzelia africana* Sm.) in Burkina Faso. *J For Res* 1-13

Bayen P, Bognounou F, Lykke AM, Ouédraogo M, Thiombiano A (2015) The use of biomass production and allometric models to estimate carbon sequestration of *Jatropha curcas* L. plantations in western Burkina Faso. *Env Dev Sus* 18:143-156

Chabi A, Lautenbach S, Orekan VOA, Kyei-Baffour N (2016) Allometric models and aboveground biomass stocks of a West African Sudan Savannah watershed in Benin. *Carb Bal Manag* 16:1-18

Chave J, Rejou MM, Burquez A, Chidumayo E, Colgan MS, Delitti WBC, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martinez Yrizar A, Mugasha WA, Muller-Landau HC, Mencuccini M, Nelson BW, Ngomanda A, Nogueira EM, Ortiz-Malavassi E, Péliissier R, Ploton P, Ryan CM, Saldarriaga JG, Vieilledent G (2014) Improved allometric models to estimate the aboveground biomass of tropical trees. *Glob Change Biol* 20:3177-3190

Dimobe K, Mensah S, Goetze D, Ouédraogo A, Kuyah S, Porembski S, Thiombiano A (2018) Aboveground biomass partitioning and additive models for *Combretum glutinosum* and *Terminalia laxiflora* in West Africa. *Biom Bioenergy* 115:151-159

Djomo AN, Chimi CD (2017) Tree allometric equations for estimation of above, below and total biomass in a tropical moist forest: Case study with application to remote sensing. *For Ecol Manag* 391:184-193

Djomo AN, Ibrahima A, Saborowski J, Gravenhorst G (2010) Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa. *For Ecol Manag* 260 :1873-1885

Dong L, Zhang LLF (2018) Additive biomass equations based on different Dendrometric variables for two dominant species (*Larix gmellini* Rupr. and *Betula platyphylla* Suk.) in natural forests in the Eastern Daxing'an Mountains, Northeast China. *Forests* 9(5):261.

Fayolle A, Ngomand A, Mbasi M, Barbier N, Bocko Y, Boyemba F, Couteron P, Fonton N, Kamdem N, Katembo J, Kondaoule HJ, Loumeto J, Maïdou HM, Mankou G, Mengui T, Mofack GII, Moundounga C, Moundounga Q, Nguimbous L, Nchama NN, Obiang D, Asue FOM, Picard N, Rossi V, Senguela YP, Sonké B, Viard L, Yongo OD, Zapfack L, Medjibe VP (2018) A regional allometry for the Congo basin forests based on the largest ever destructive sampling. *For Ecol Manag* 430 :228-240

Ganamé M, Bayena P, Ouédraogo I, Balima LH, Thiombiano A (2021) Allometric models for improving aboveground biomass estimates in West African savanna ecosystems. *Trees, Forests and People* 4 : 100077

Ganamé M, Bayen P, Dimobe K, Ouédraogo I, Thiombiano A (2020) Aboveground biomass allocation, additive biomass and carbon sequestration models for *Pterocarpus erinaceus* Poir. in Burkina Faso. *Heliyon* 6. <https://doi.org/10.1016/j.heliyon.2020.e03805>

Goetz SJ, Hansen MC, Houghton RA, Walker W, Laporte N, Busch J (2015) Measurement and monitoring needs, capabilities and potential for addressing reduced emissions from deforestation and forest degradation under Measurement and monitoring needs, capabilities and potential for addressing reduced emissions from deforestation. *Environmental Research Letters* 10: 2-25

Henry M, Besnard A, Asante WA, Eshun J, Adu BS, Valentini R (2010) Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. *For Ecol Manag* 260(8):1375-1388

Kuyah S, Dietz J, Muthuri C, Jamnadass R, Mwangi P, Coe R, Neufeldt H (2012) Allometric equations for estimating biomass in agricultural landscapes: II. Belowground biomass. *Agri Ecos Envi* 158:225-234

Mbow C, Verstraete MM, Sambou B, Diaw AT, Neufeldt H (2013) Allometric models for aboveground biomass in dry savanna trees of the Sudan and Sudan Guinean ecosystems of Southern Senegal. *J For Res* 19:340-347

Mensah S, Veldtman R, Seifert T (2017) Allometric models for height and aboveground biomass of dominant tree species in South African Mistbelt forests. *Southern Forests* 79(1):19-30

Mugasha WA, Eid T, Bollandas OM, Malimbwi E, Chamshama SAO, Zahabu E, Katani JZ (2013) Allometric models for prediction of above- and belowground biomass of trees in the miombo woodlands of Tanzania. *For Ecol Manag* 310:87-101

Mugasha WA, Mwakalukwa EE, Luoga E, Malimbwi RE, Zahabu E, Silayo DS (2016) Allometric Models for Estimating Tree Volume and Aboveground Biomass in Lowland Forests of Tanzania. *Int J For Res* 4:1-13

Ngomanda A, Obiang NLE, Lebamba J, Mavouroulou QM, Gomat H, Mankou GS, Loumeto J, Iponga DM, Ditsouga FK, Koumba RZ, Bobé KHB, Okouyi CM, Nyangadouma R, Lépengué N, Mbatchi B, Picard N (2014) Site-specific versus pantropical allometric equations: Which option to estimate the biomass of a moist central African forest? *For Ecol Manag* 312: 1-9

Picard N, Rutishauser E, Ploton P, Ngomanda A, Henry M (2015) Should tree biomass allometry be restricted to power models? *For Ecol Manag* 353:156-163

Picard N, Saint-André L, Henry M (2012) Manual for building tree volume and biomass allometric equations: from field measurement to prediction. Rome : Food and Agricultural Organization of the United Nations and Montpellier, Centre de Coopération Internationale en Recherche Agronomique pour le Développement, 215 pp.

Sawadogo L, Savadogo P, Tiveau D, Dayamba SD, Zida D, Nouvellet Y, Oden PC, Guinko S (2010) Allometric prediction of above-ground biomass of eleven woody tree species in the Sudanian savanna woodland of West Africa. *J For Res* 21:475-481

Tchindebe A, Ibrahima A, Tchobsala, Mohamadou LMA (2019) Allometric Equations for Predicting Biomass of *Daniellia oliveri* (Rolfe) Hutch. & Dalz. Stands in the Sudano-Guinea Savannahs of Ngaoundere, Cameroon. *Ecol Evol Biol* 4(2): 15-22

Tchindebe A, Tchobsala, Amadou MLM, Ahmadou H, Adamou I (2020) Species-Specific Allometric Equations for Predicting Biomass of *Faidherbia albida* (Del.) A. Chev. In the Sudano-sahelian Savannahs of Far-North, Cameroon. *J Agri Ecol Res Inter* 21(6):33-44

Thiam S, Sambou B, Mbow C, Guisse A (2014) Élaboration de modèles allométriques d'Acacia Sénégal L. Willd pour l'analyse du carbone ligneux en milieu sahélien : cas de la zone sylvopastorale au Sénégal. Afri Science 10(3):304-315

Traore S, Djomo AN, N’guessan AK, Coulibaly B, Ahoba A, Gnahoua GM, N’guessan EK, Adou Yao CY, N’Dja JK, Guede NZ (2018) Stand structure, allometricequations, biomass and carbon sequestration capacity of Acacia mangium Wild(Mimosaceae) in Cote d’Ivoire. Open J For 8: 42-60

Vahedi AA, Mataji A, Babayi KS, Eshaghi RJ, Hodjati SM, Djomo A (2014) Allometric equations for predicting aboveground biomass of beech-hornbeam stands in the Hyrcanian forests of Iran. J For Science 60: 236-247

Xue Y, Yang Z, Wang X, Lin Z, Li D, Su S (2016) Tree biomass allocation and its model Additivity for Casuarina equisetifolia in a tropical forest of Hainan Island, China. PlosOne 11(3): 1-20

Tables

Table 1. Measurable Parameters Dendrometric

Régions	Item	DBH	H
Adamawa	Minimum	4.76	2.98
	maximum	22.89	15.87
	Mean (sd)	13.82	9.42
North	Minimum	5.76	5.58
	maximum	68.89	22.87
	Mean (sd)	37.32	14.22
Far-North	Minimum	5.32	3.51
	maximum	38.75	18.87
	Mean (sd)	22.03	11.19

Dbh: Diameter at Breast height, H: Height.

Table 2. Pearson’s Correlation between Diameters, Height with Biomass

	Item	Dbh (cm)	H (m)
Adamawa	Leaves	0.86***	0.79***
	Branches	0.90***	0.75***
	stem	0.76***	0.28ns
	AGB	0.88***	0.32ns
	BGB	0.90***	0.35ns
North	Leaves	0.95***	0.88***
	Branches	0.90***	0.73***
	stem	0.87***	0.28ns
	AGB	0.88***	0.23ns
	BGB	0.95***	0.35ns
Far-North	Leaves	0.89***	0.68***
	Branches	0.93***	0.70**
	stem	0.85***	0.28ns
	AGB	0.89***	0.38ns
	BGB	0.93***	0.35ns

Dbh: Diameter at Breast height, H: Height.

Table 3. Models parameters and performance criteria for biomass estimation

Régions	Compartments	Models	Regressions coefficients			Adj.R ²	RSE	AIC	FC
			a(sd)	b(sd)	c(sd)				
Adamawa	Leaves	4	-0.254(0.03)**	1.304(0.11)**		0.83	0.545	11.65	1.16
		5	0.054(0.00)***	-0.011(0.01)*		0.82	0.533	12.94	1.15
		6	0.402(0.31)**	0.119(0.18)**	0.571(0.12)**	0.80	0.587	17.76	1.18
		7	0.321(0.14)***	-0.525(0.01)***		0.95	0.508	10.07	1.13
	Branches	4	-1.043(0.05)*	0.321(0.21)**		0.75	0.584	11.13	1.18
		5	-1.021(0.06)**	0.752(0.41)**		0.70	0.503	10.24	1.13
		6	-1.053(0.04)**	0.158(0.01)*	0.882(0.65)*	0.73	0.554	12.23	1.16
		7	-1.514(0.18)***	0.250(0.12)***		0.97	0.502	10.11	1.13
	Stem	4	2.026(0.21)**	-1.052(0.11)***		0.94	0.601	10.10	1.19
		5	-2.167(0.30)***	0.815(0.48)**		0.69	0.654	12.11	1.23
		6	-2.103(0.37)**	0.253(0.15)***	0.371(0.26)**	0.60	0.617	10.20	1.20
		7	-2.812(0.71)***	2.020(0.58)***		0.65	0.658	14.21	1.24
	AGB	4	1.004(0.47)**	-0.054(0.00)***		0.98	0.403	10.08	1.08
		5	-0.302(0.22)**	2.716(0.29)**		0.82	0.458	10.54	1.11
		6	0.254(0.19)*	-0.029(0.01)**	0.002(0.00)***	0.85	0.488	10.47	1.12
		7	-0.198(0.10)**	0.295(0.14)***		0.83	0.465	10.62	1.11
	BGB	4	-3.009(0.78)**	0.016(0.00)***		0.96	0.511	9.74	1.13
		5	2.012(1.01)*	-0.173(0.08)**		0.75	0.593	18.65	1.19
		6	-1.921(0.35)**	0.033(0.02)**	0.001(0.00)***	0.80	0.682	10.68	1.26
		7	0.193(0.06)**	1.102(0.65)***		0.75	0.575	10.52	1.17
North	Leaves	4	-0.053(0.02)**	1.054(0.24)**		0.77	0.457	15.65	1.11
		5	0.014(0.01)**	-0.211(0.12)***		0.82	0.593	15.94	1.19
		6	0.002(0.00)****	0.183(0.12)*	0.271(0.18)**	0.73	0.497	17.76	1.13
		7	0.121(0.03)**	-0.325(0.19)**		0.95	0.431	14.87	1.09
	Branches	4	-0.043(0.02)**	0.581(0.28)***		0.75	0.540	11.13	1.15
		5	-0.021(0.00)**	0.452(0.33)*		0.70	0.581	10.24	1.18
		6	-0.053(0.01)**	0.128(0.10)*	0.802(0.40)*	0.73	0.538	12.23	1.15
		7	-0.574(0.28)*	0.217(0.13)**		0.98	0.529	10.11	1.15
	Stem	4	0.026(0.00)***	-1.052(0.23)***		0.94	0.413	11.10	1.08
		5	-0.167(0.01)**	0.815(0.41)*		0.69	0.463	12.11	1.11
		6	-0.103(0.00)**	0.253(0.07)**	0.215(0.03)**	0.63	0.444	12.07	1.10
		7	-0.812(0.02)**	2.020(0.06)***		0.66	0.452	12.51	1.10
	AGB	4	0.004(0.00)***	0.054(0.00)*		0.95	0.522	15.05	1.14
		5	-0.302(0.02)**	0.006(0.00)***		0.83	0.545	16.54	1.16
		6	0.254(0.07)**	-0.029(0.01)*	0.002(0.00)***	0.81	0.580	15.74	1.18
		7	-0.198(0.02)**	0.295(0.07)***		0.80	0.576	16.54	1.18
	BGB	4	-1.301(0.05)***	0.116(0.02)**		0.90	0.312	10.45	1.04
		5	0.012(0.00)***	-0.073(0.01)**		0.72	0.319	16.04	1.05
		6	-1.921(0.11)**	0.233(0.18)**	0.031(0.01)**	0.70	0.320	14.92	1.05
		7	0.003(0.01)	1.102(0.01)		0.77	0.315	13.87	1.05
Far-North	Leaves	4	-0.001(0.00)***	1.004(0.41)**		0.87	0.405	10.25	1.08
		5	0.004(0.00)***	-0.011(0.00)***		0.82	0.343	12.33	1.06
		6	-0.002(0.00)***	0.103(0.01)***	0.003(0.00)***	0.83	0.407	17.36	1.08
		7	0.021(0.01)**	-0.005(0.00)***		0.95	0.308	10.18	1.04
	Branches	4	-0.043(0.01)**	0.321(0.11)**		0.75	0.584	11.03	1.18
		5	0.021(0.01)*	0.752(0.22)**		0.70	0.598	10.24	1.19
		6	0.053(0.02)***	0.158(0.00)***	0.887(0.32)*	0.74	0.572	12.23	1.17
		7	-0.134(0.04)*	0.250(0.08)***		0.98	0.554	10.01	1.16

Stem	4	0.026(0.00)****	-1.012(0.61)**		0.98	0.403	10.10	1.08
	5	-0.067(0.02)**	0.015(0.00)***		0.78	0.488	12.71	1.12
	6	-1.003(0.28)*	0.053(0.03)**	0.371(0.01)*	0.85	0.450	10.24	1.10
	7	-0.012(0.01)*	0.020(0.01)***		0.88	0.475	12.83	1.11
AGB	4	0.004(0.00)***	1.084(0.51)**		0.97	0.400	11.07	1.08
	5	-1.302(0.31)**	0.436(0.16)*		0.82	0.458	12.86	1.11
	6	0.054(0.01)**	-0.029(0.00)***	0.002(0.01)**	0.78	0.488	16.54	1.12
	7	-0.043(0.04)*	0.295(0.19)**		0.83	0.411	11.54	1.08
BGB	4	-0.002(0.00)***	0.016(0.00)***		0.93	0.370	13.22	1.07
	5	0.012(0.01)*	-0.023(0.01)*		0.74	0.393	16.04	1.08
	6	-1.921(0.19)**	0.033(0.02)**	0.001(0.00)***	0.77	0.382	16.03	1.07
	7	0.013(0.01)**	-0.102(0.01)**		0.76	0.375	15.84	1.07

The coefficients at $p < 0.001$ are significantly different from zero; *: Significant, **: Very significant, ***: Highly significant, Standard deviation (sd), AGB: Aboveground biomass, BGB: Belowground biomass, D: Diameter, H: Height, Coefficient of regression model (a, b and c), coefficient of determination adjusted (Adj.R^2), correction factor (CF), residual standard error (RSE) and Akaike information criteria (AIC).

Table 4. Selection of the Best Models by regions

Régions	Models	Adj.R ²	RSE	AIC
Adamawa	$\ln(\text{Bleaves}) = 0.321 + -0.525 \cdot \ln(D^2H)$	0.95	0.508	10.07
	$\ln(\text{B branches}) = -1.514 + 0.250 \cdot \ln(D \cdot H)$	0.97	0.502	10.11
	$\ln(\text{Bstem}) = 2.026 - 1.052 \cdot \ln(D)$	0.94	0.601	10.10
	$\ln(\text{AGB}) = 1.004 - 0.054 \cdot \ln(D)$	0.98	0.403	10.08
	$\ln(\text{BGB}) = -3.009 + 0.016 \cdot \ln(D)$	0.96	0.511	9.74
North	$\ln(\text{Bleaves}) = 0.121 - 0.325 \cdot \ln(D^2H)$	0.95	0.431	14.87
	$\ln(\text{B branches}) = -0.574 + 0.217 \cdot \ln(D \cdot H)$	0.98	0.529	10.11
	$\ln(\text{Bstem}) = 0.026 - 1.052 \cdot \ln(D)$	0.94	0.413	11.07
	$\ln(\text{AGB}) = 0.004 + 0.054 \cdot \ln(D)$	0.95	0.522	15.05
	$\ln(\text{BGB}) = -1.301 + 0.116 \cdot \ln(D)$	0.90	0.312	10.45
Far-North	$\ln(\text{Bleaves}) = 0.021 - 0.005 \cdot \ln(D^2H)$	0.95	0.308	10.18
	$\ln(\text{B branches}) = -0.134 + 0.250 \cdot \ln(D \cdot H)$	0.98	0.554	10.01
	$\ln(\text{Bstem}) = 0.026 - 1.012 \cdot \ln(D)$	0.98	0.403	10.10
	$\ln(\text{AGB}) = 0.004 + 1.084 \cdot \ln(D)$	0.97	0.400	11.07
	$\ln(\text{BGB}) = -0.002 + 0.016 \cdot \ln(D)$	0.93	0.370	13.22

B: Biomass, AGB: Aboveground biomass, BGB: Belowground biomass, D: Diameter, H: Height, Coefficient of determination adjusted (Adj.R^2), residual standard error (RSE) and Akaike information criteria (AIC).

Table 5. Global models parameters and performance criteria for biomass estimation

Three Régions			Regressions coefficients			Adj.R ²	RSE	AIC	FC
Compartments	Models		a	b	c				
Global	Leaves	4	-0.001(0.00)***	0.808(0.12)**		0.96	0.409	15.65	1.08
		5	-0.034(0.01)**	-0.098(0.03)*		0.92	0.403	19.94	1.08
		6	0.002(0.00)***	0.804(0.51)**	0.039(0.01)*	0.93	0.407	17.76	1.08
		7	0.027(0.01)**	-0.083(0.03)***		0.98	0.318	14.87	1.05
	Branches	4	-1.098(0.43)***	0.028(0.01)**		0.95	0.533	11.34	1.15
		5	1.025(0.63)*	-0.036(0.01)**		0.90	0.504	10.94	1.13
		6	-1.093(0.61)**	0.105(0.08)**	-0.006(0.00)***	0.93	0.511	12.23	1.13
		7	0.201(0.01)*	-0.230(0.05)***		0.98	0.501	10.88	1.13
	Stem	4	0.024(0.00)***	1.063(0.58)*		0.97	0.323	10.63	1.05
		5	-1.077(0.09)**	0.205(0.11)*		0.93	0.396	17.11	1.08
		6	-0.803(0.47)*	0.103(0.05)**	0.101(0.01)**	0.95	0.358	18.20	1.06
		7	-0.312(0.07)***	1.028(0.04)**		0.94	0.383	14.76	1.07
	AGB	4	0.504(0.02)**	3.048(0.98)*		0.98	0.454	16.07	1.10
		5	-0.002(0.00)***	1.903(0.58)*		0.94	0.458	18.55	1.11
		6	0.698(0.07)*	-0.034(0.01)***	0.102(0.00)**	0.95	0.484	16.98	1.12
		7	-0.198(0.05)**	1.573(0.43)*		0.96	0.464	16.50	1.11
	BGB	4	-0.109(0.06)***	0.306(0.02)**		0.98	0.472	10.80	1.11
		5	3.010(0.25)*	-0.173(0.00)**		0.94	0.493	16.23	1.12
		6	-0.894(0.07)***	0.021(0.00)***	0.301(0.18)*	0.93	0.482	16.59	1.12
		7	0.388(0.05)***	0.967(0.08)***		0.90	0.475	16.75	1.11

The coefficients at $p < 0.001$ are significantly different from zero; *: Significant, **: Very significant, ***: Highly significant, Standard deviation (sd), AGB: Aboveground biomass, BGB: Belowground biomass, D: Diameter, H: Height, Coefficient of regression model (a, b and c), coefficient of determination adjusted (Adj.R²), correction factor (CF), residual standard error (RSE) and Akaike information criteria (AIC).

Table 6. Selection of the Best Global Models

Three regions	Models	Adj.R ²	RSE	AIC
Global	$\ln(\text{Bleaves}) = 0.027 - 0.083 \cdot \ln(D^2 H)$	0.98	0.318	14.87
	$\ln(\text{Bbranches}) = 0.201 - 0.230 \cdot \ln(D \cdot H)$	0.98	0.501	10.18
	$\ln(\text{Bstem}) = 0.024 + 1.063 \cdot \ln(D)$	0.97	0.323	10.63
	$\ln(\text{AGB}) = 0.504 + 3.048 \cdot \ln(D)$	0.98	0.454	16.07
	$\ln(\text{BGB}) = -0.109 + 0.306 \cdot \ln(D)$	0.98	0.472	10.80

B: Biomass, AGB: Aboveground biomass, BGB: Belowground biomass, D: Diameter, H: Height, Coefficient of determination adjusted (Adj.R²), residual standard error (RSE) and Akaike information criteria (AIC).

Figures

Figure 1

Geographic location of the study area

Figure 2

Linear regressions between parameter (D and H) with leaves biomass (a), branch biomass (b), stem biomass (c), aboveground biomass (d), belowground biomass (e) in the Adamawa region.

Figure 3

Linear regressions between parameter (D and H) with leaves biomass (a), branch biomass (b), stem biomass (c), aboveground biomass (d), belowground biomass (e) in the North region.

Figure 4

Linear regressions between parameter (D and H) with leaves biomass (a), branch biomass (b), stem biomass (c), aboveground biomass (d), belowground biomass (e) in the Far-North region.

Figure 5

Regression lines between the predicted biomass and the observed biomass of the different compartments of *Khaya senegalensis* studied.