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Original Paper

Allometric Equations for the Biomass Prediction in *Azadirachta indica* Plantations in Sub-Saharan Africa: A Case Study from Cameroon

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Abstract

This study took place in the Far North region of Cameroon. It aimed at developing and standardizing a specific allometric equation to neem Agroforets in Sub-Saharan Africa. A sample of twenty (20) individuals of Azadirachta indica was cut over all the diameter classes, located between 5 and 105 cm. The dbh and height were measured. B*iomass of the compartments of leaves, branches and trunks were determined after drying and weighing. Different allometric equations between biomass and two tree parameters (diameter and height) were tested. The adjusted coefficients of determination (R2aj), the residual standard error (RSE) and the Akaike information criterion (AIC) were used to choose the best models. The main results show that there is a positive and significant relationship between the height of trees and diameter ($R2 = 0.98$; $n = 20$ and $p < 0.05$). The best model for the prediction of the total Above Ground Biomass (AGB) in Azadirachta indica plantations is* $AGB = e^{(- 0.456 + 1.673 x \ln (DBH))}$ *with a coefficient of determination adjusted at 0.72.*

Keywords

allometric equations, biomass, Azadirachta indica, Sahelian Zone, Cameroon

1. Introduction

Azadirachta indica is a tree belonging to the Meliaceae family and native to India. Neem is an evergreen tree. It can often reach 20 to 30 m and more rarely 35 to 40 m (Arbonnier, 2002). Neem thrives on lean, stony or sandy soils. Recognized for its medicinal properties, neem is omnipresent in traditional Indian culture, whether in science, medicine or in the cultural field (Arbonnier, 2002). Very early on, neem was the subject of research (Arbonnier, 2002). Indeed, the first medical writings refer to the beneficial properties of fruits, stones, oil, leaves, bark and roots (Arbonnier, 2002). Each part is used in Ayurvedic medicine. Present in many sub-Saharan countries, the neem is the tree of a thousand virtues. Its leaves and fruits, which are made into oil, are widely used in medicine. Neem oil is indicated to treat digestive disorders, and to fight against parasites thanks to its anti-mite and insect repellent properties (Arbonnier, 2002). It is effective in relieving eye and ear inflammation, as well as respiratory tract diseases such as bronchitis (Arbonnier, 2002). In agriculture, the insecticidal properties of neem leaves are being studied with a view to developing a natural plant insecticide. Its fruits, which are made into oil, are also a perfect natural insecticide, harmless to humans and animals. When applied to the skin on irritations, redness, acne and wounds, neem calms all itching (Arbonnier, 2002).

Nowadays, studies must be directed more towards the development of more precise allometric equations of the biomass of different ecosystems, considerable research efforts have been carried out in the estimation of biomass of Azadirachta indica plantations in forest ecosystems. (Brown et al., 1989; Brown, 1997; Ibrahima et al., 2002, Djomo et al., 2010; Laminou Manzo et al., 2015) still very little in the savannas of Ngaoundéré Cameroon (Mamadou, 2014; Ahmadou, 2014; Halilou, 2015). For the estimation of this woody biomass, allometric equations are widely used to avoid the destruction of forest woody trees, relating different dendrometric measurements of the tree to its above-ground biomass. These allometric relationships are very important for the management of natural and artificial forest resources (Baker et al., 2004; Chave et al., 2005; Malhiet al., 2006; Nogurez et al., 2008). Because, they offer better estimates of the biomass of woody forest trees, which is also an important variable in carbon emissions research (Ketterings et al., 2001; Nogurez et al., 2008). Therefore, the choice of an appropriate model for the development of allometric equations is important in forest and environmental sciences (Ketterings et al., 2001; Khan et al., 2005).

2. Method

2.1 Study Site

The study is taking place more precisely in the departments of Diamaré, capital of Maroua; Mayo-Danay, Yagoua capital; Mayo-Kani capital Kaélé and Mayo-Tsanaga capital Mokolo. Geographically, the Far North is located between 10 °N and 13 °N in the heart of the tropical zone with a Sudano-Sahelian climate (Djarmaila, 2011). It shares common and porous borders with Chad, Nigeria and Niger. On the physical level, this region is divided into three natural sub-regions which are the Mandara Mountains, the Diamaré plain and the flood zones of Logone and Chari. Each sub-region has natural characteristics (Djarmaila, 2011). With a population of 3,480,414 inhabitants, the Far North region is the most populous region in northern Cameroon. It is made up of six departments, namely Diamaré, Mayo-Danay, Mayo-Kani, Mayo-Sava, Logone and Chari and Mayo-Tsanaga. Its soil is ferruginous and clayey with low penetration. The scarcity of precipitation conditions the type of vegetation. It is very disparate and dominated by the "nemie" resulting from reforestation projects. This scarcity is explained by demographic pressure, urban planning and industrialization which have significantly reduced natural woody species (Djarmaila, 2011).

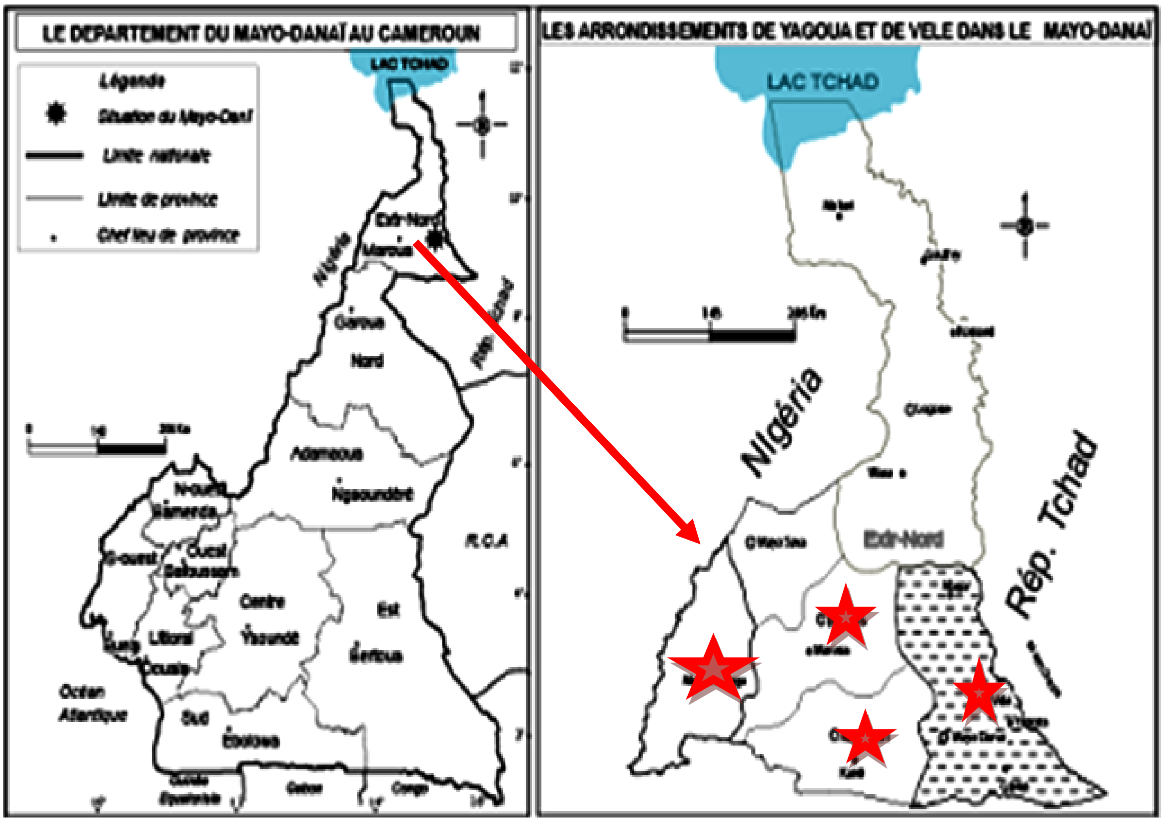


Figure 1. Location Map of Study Sites.

Source: Marquis et al. (2011).

2.2 Data Collection

To carry out this study, the direct method based on cutting down Azadirachta indica trees was used. The individuals were selected on the basis of their health status, their distance from each other, their diameter at breast height (at 1.30 m from the ground). Then a distribution of the DBH (cm) classes was carried out, by measuring the circumferences of 20 trees in the field. Four diameter classes were retained: (5; 30 cm), (] 30; 55 cm]), (] 55; 80 cm]), (] 80; 105 cm [). Thus, the 20 trees were selected at random and marked in the Far North region of Cameroon.

Before the trees were felled, the DBHs of individuals were determined using a tape measure. The height was determined after felling, using a decameter. To fell the trees, the 20 individuals were cut 10 cm from the ground using a chainsaw. Once felled, the trees are separated into compartments (leaves, branches and trunk) using a chainsaw and machete. The trunks and branches were cut into logs approximately 1.20m long. The various components thus separated are introduced according to the compartments of the tree into plastic bags and then weighed using a balance (dynamometer) with a capacity of 150 ± 5 kg to determine the fresh biomass. The wooden discs were made on the trunks and branches. On wooden discs exceeding 30 cm in diameter, a ¼ fraction was retained on each disc and then weighed using an electronic scale in the field. A sample of trunk disc, branch and a leaf sample were taken and marked. For trunks and branches, the markings are made directly on the discs using the marker. The leaves were sampled and weighed in the field on each individual slaughtered. The total wet mass of the different leaf, branch and trunk compartments are noted. All of these collected samples were immediately stored in plastic paper bags and brought back to the laboratory to determine their fresh weight. The sawdust from each wood compartment was weighed in the field and their weights are added to the total mass of the compartment considered.

The water content of samples of leaves, branches and trunks will be calculated according to the following formula: $TE (\%) = ((MH-MS) / MS) * 100$ Where TE is the water content of the samples as a percentage, MH and MS are the wet mass (Kg) and dry mass (Kg) of the sample, respectively 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 wet mass (Kg). The total dry masses are called Biomass and expressed in Kilograms (Kg).

2.3 Statistical Analysis

2.3.1. Statistical Analysis Model

In order to estimate the above-ground biomass of trees, we adjusted predictive models of dry biomass according to the explanatory variables of Diameter at Breast Height (DBH); the total height (Ht) and the density of the wood. The mathematical model commonly used to predict Biomass has been adopted: $B = aDb$ Where B is Biomass, D is the DBH of the tree, a and b are the adjustment coefficients. After logarithmic transformation of the collected data, allometric equations will be established between the leaf, trunk, branch and total biomass and the physical parameters of the tree. These mathematical models are:

Biomass was predicted using diameter as an explanatory variable. Three models were obtained.

$Ln (B) = a + bln (D) + \varepsilon$ (Model 1)

Two models taking into account 2 parameters of the shaft, the diameter and the height

$Ln (B) = a + b ln (D2H) + \varepsilon$ (Model 2)

$Ln (B) = a + b ln (D) + cln (H) + \varepsilon$ (Model 3)

Where B is the Biomass (Kg), D is the DBH (diameter at breastheigh in English) (cm), H is the total height (m), a is the regression constant, b, c are the regression coefficients.

2.3.2 Model Selection Criteria

Four criteria were used to measure the robustness and precision of the models in estimating above-ground biomass (Chave et al., 2005). These are in order of importance: Coefficient of determination R2 and the associated p-value: This coefficient, between 0 and 1, gives an idea of the proportion of the variability explained in the above-ground biomass by the model. The closer it is to 1, the better the model. The calculated p-value makes it possible to test the null hypothesis of a non-significant correlation between the explained variables and the explanatory variables ($p > 0.05$).

$R2 = 1\text{-}SCR / SCT$

Where SCT: Sum of Total Squares and SCR: Sum of Residual Squares. AIC or Akaike Information Criterion: The best model minimizes the value of the AIC obtained by the following formula: $AIC = -2\ln(L) + 2p$ Where L "Likelihood" or Probability to which the predicted model is correct and p: Total number of parameters of the model. RSE or Residual standard error:

The more a model has a weak CSR, the better it is:

RSE = Standard deviation (ε_i) where $\varepsilon_i = \ln(AGB\ obs) - \ln(AGB\ pred)$

Where Ɛi: Residual error; AGBobs: Measured above-ground biomass; AGBpréd: Predicted above-ground biomass.

2.3.3 Model Prediction

The logarithmic transformation of the data generally leads to a bias in the estimation of Biomass (Duan, 1983; Chave et al., 2005), a correction is necessary and consists in multiplying the estimated Biomass by a correction factor (CF) which is calculate as follows: $CF = \exp\{RSE^2 / 2\}$; the CF is a number always greater than 1.

3. Result

3.1 Distribution of Dendrometric Parameters and Biomass

The distribution of the biomass parameters is presented in Table 1. The diameter varies between 5.41 and 101.91 cm with an average of 53.66 cm; the height of the stand varies from 4.19 to 20.19 m with an average of 16.68 m. As for the biomass, Foliar biomass varies between 12.5 and 175 kg, that of Branches from 34.5 to 872 kg, and that of trunks between 22.5 to 603 with respective averages of 93.75; 453.25 and 312.75 kg. The coefficient of variation in biomass is respectively 7.14; 3.95; 3.73 in leaves, branches and trunks.

Table 1. Dendrometric and Biomass Parameters

Item	DBH (cm)	H(m)	Bfol(kg)	Bbranch(kg)	Btronc(kg)	Btot(kg)
Average	53.66	16.68	93.75	453.25	312.75	819.25
Minimum	5.41	4.19	12.5	34.5	22.5	71.5
Maximum	101.91	20.19	175	872	603	1567

CV	5.3	20.77	7.14	3.95	3.73	4.56

3.2 Allometric Equations between Biomass, Diameter and Heights

Three models of allometric equations were developed for each compartment, with 20 individuals. The relationships between the biomass of the different compartments and the different parameters considered are positive and significant (P <0.001) with high adjusted coefficients of determination, located between 0.49 and 0.75 (Table 2). The regression coefficients (a, b and c) vary from -1 to -0.97; from 0.42 to 3.26 and from -2.07 to -0.08 respectively for a, b and c. These coefficients differ between compartments for the same model. The model taking into account only the diameter as a physical parameter of the tree (Eq. 1 and 4) is significant (p<0.001) for each of the four compartments of the trees, with adjusted coefficients of determination varying between 0.72 and 0 , 77. These high adjusted coefficients of determination compared to those of the 2 other models (Eq.2 and Eq.3) show that more than 70% of these relationships are explained by the tree diameter alone. By integrating the height of the tree in the two models Eq.2 and Eq.3, no improvement was obtained in the precision with the equations predicting the biomass of the leaves and the total biomass, except that of the branches and the trunks. . For these latter compartments, the equation Eq.2 integrating the diameter squared multiplied by the height (D2 * H) in the fit, of the form ln (B) = a + b * ln (D2H), improves the models . The adjusted coefficient of determination of these models is between 0.64 - 0.67 and their residual standard errors (RSE) are low (0.06-0.49) compared to models taking into account only the diameter (0, 72-0.77).

To select the best model predicting the biomass of each compartment, in addition to the adjusted coefficient of determination (R2aj), the residual standard error (RSE) and the Akaike value (AIC) which make it possible to assess the precision and accuracy models has been taken into account. The adjusted coefficients of determinations (R2aj) of the four best models selected for each of the three compartments and the total biomass are higher, their ESR and their AIC are lower than the values of the other models. These best equations are shown in Table 2 and Figures 2 a, b, c and d show their fits.

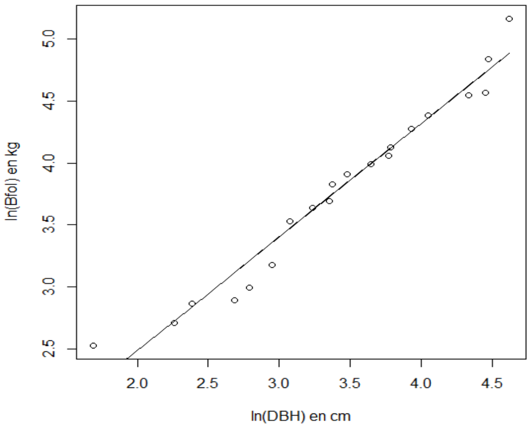
Table 2. Allometric Equations between Biomass, Diameter and Heights

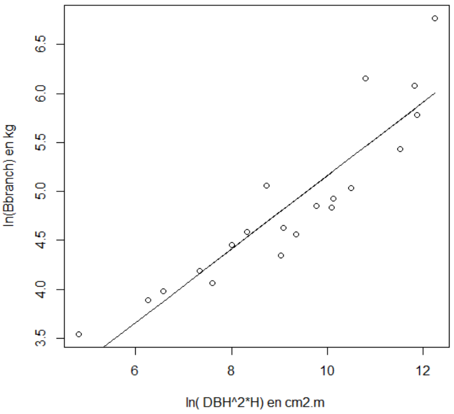
Allometric model	Coefficient			Selection criteria						
	a	b	c	R^2adj	RSE	AIC	N	CF	P-Value	F-Ratio
Foliar biomass										
Ln(B)=a+bLn(DBH)	-1.05	1.21		0.77	0.52	34.91	20	1.14	2.20E-07	64.98
Ln(B)=a+bLn(DBH^2H)	-0.97	0.42		0.75	0.53	35.92	20	1.15	3.49E-07	60.88
Ln(B)=a+bLn(DBH)+cLn(H)	-1.05	1.28	-0.08	0.75	0.54	36.88	20	1.16	2.26E-06	30.74
Branch biomass										
Ln(B)=a+bLn(DBH)	-0.94	1.50		0.61	0.47	39.03	20	1.12	1.48E-06	49.34

Ln(B)=a+bLn(DBH ^{2}H)	-0.74	0.51		0.67	0.06	32.03	20	1	5.88E-06	39.96
Ln(B)=a+bLn(DBH)+cLn(H)	-1.00	2.56	-1.26	0.49	0.70	47.47	20	1.28	2.97E-06	29.49
Biomass trunks										
Ln(B)=a+bLn(DBH)	-0.83	1.51		0.61	0.76	49.87	20	1.33	1.82E-06	47.85
Ln(B)=a+bLn(DBH ^{2}H)	-0.55	0.50		0.64	0.49	54.14	20	1.13	1.29E-05	35.19
Ln(B)=a+bLn(DBH)+cLn(H)	-0.93	3.26	-2.07	0.62	0.59	60.85	20	1.19	1.51E-07	45.45
Above-ground biomass										
Ln(B)=a+bLn(DBH)	-0.45	1.67		0.72	0.81	52.51	20	1.39	1.15E-06	51.24
Ln(B)=a+bLn(DBH ^{2}H)	-0.33	0.57		0.70	0.84	53.83	20	1.42	2.10E-06	46.83
Ln(B)=a+bLn(DBH)+cLn(H)	-0.47	2.00	-0.38	0.71	0.83	54.25	20	1.41	9.52E-06	24.63

Table 3. Best Models Selected

Biomass	Allometric models	**R^{2}adj**	**RSE**	**AIC**
Leaves	Ln(B)=-1.0509+1.2137Ln(DBH)	0.77	0.52	34.91
Branches	Ln(B)=-0.7443+0.5107Ln(DBH)	0.67	0.06	32.03
Trunks	Ln(B)=-0.55028+0.50530Ln(DBH)	0.64	0.49	54.14
Total	Ln(B)=-0.4568+1.6733Ln(DBH)	0.72	0.81	52.51





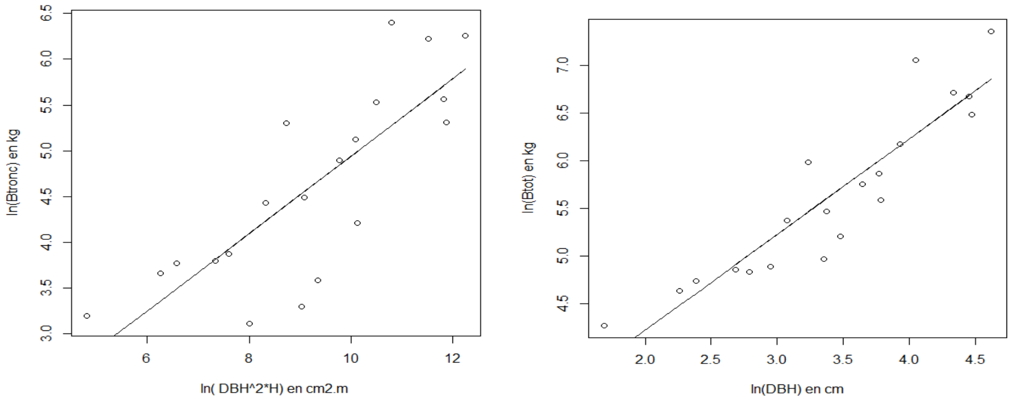


Figure 2. Regressions of the Leaf (a), Branch (b), Trunk (c) and Total Biomass (d) Biomass Models

Relationship between diameter and height

The relationship between height and diameter of trees best fits the linear function (Figure 3). This correlation between these two variables is positive and significant, with a coefficient of determination of 0.98; P <0.05 and n = 20.

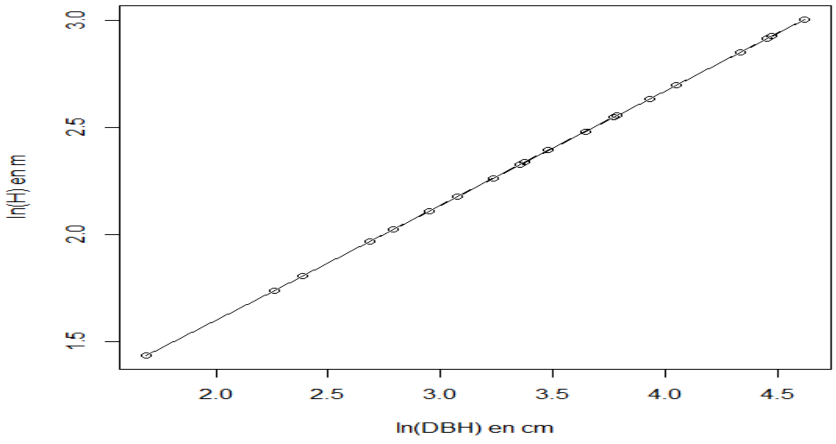


Figure 3. Relationship between DBH and Height

4. Discussion

The study established allometric equations for estimating the biomass of leaves, branches, trunks and total biomass in the diameter range of 5 to 105 cm. Determining the specific equations for this species is important for the precise determination of its production, the precise estimation of the carbon stock and the sustainable management of its population. Indeed, according to Bognounou et al. (2008), the establishment of allometric equations for the prediction of biomass by species makes the overall estimate of the biomass of a woody stand more reliable. The sample size was 20 individuals. In fact, 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 (Picard et al., 2012). Allometric models have been developed with a number of trees greater than 100 (Brown, 1997; Chave et al., 2005). However, other models focused on a number of trees less than 20 (Larwanouet al., 2010; Ebuyet al., 2011). The allometric equations were developed from the 2 physical variables which are the diameter and the height of the tree, taking into account the Akaike information criterion (AIC) and the Residual Standard Error (RSE) (Chave et al., 2005). Thus, four models were selected. For the total biomass, the Eq.1 model taking into account only the diameter is the best model. Its AIC and RES values are the lowest and its adjusted coefficient of determination is the highest. It shows that the height significantly influences the biomass. Indeed, height is a function of diameter (Chave et al., 2005; Fayolle et al., 2013). This result is similar to that of Bagnoud and Kouyaté (1996) in Mali. As with total biomass, the best model for leaf biomass is the Eq.1 model which is not influenced by height (Traoré et al., 2018). On the other hand, the best equation for estimating the biomass of branches and trunks is obtained with model Eq.2, integrating the diameter squared multiplied by the height (D2H), with RSE = 0.06-0.49; AIC = 32.03-54.14 and R2aj = 0.64-0.67. These results are different from those reported by Djomo et al. (2010) and Vahedi et al. (2014).

5. Conclusion

Reached the end of this present work, the main objective of which was to develop and standardize an allometric equation specific to *Azadirachta indica* plantations in Cameroon. We were able to establish the mono-specific allometric equations for the estimation of the biomass of leaves, branches, trunks and the above-ground biomass of *Azadirachta indica* in the Sahelian zone of Cameroon from the data of 20 individuals. Three models were tested as well as the standard residual error (RSE), the adjusted coefficient of determination (R2aj) and the Akaike Information Criterion (AIC) were used to select the best allometric equations. Tree height did not influence the model estimating leaf biomass and aboveground biomass. On the other hand, for the precision of the estimate of the biomass of the branches and trunks, the height of the tree influenced on the model. Overall, the contribution of underground biomass could provide improved precision in biomass quantifications or carbon stock rate in mono-specific *Azadirachta indica* plantations in Central Africa.

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