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Stand Structure, Allometric Equations, Biomass and Carbon Sequestration Capacity of *Acacia mangium* Wild. (Mimosaceae) in Côte d'Ivoire

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Abstract

In addition to bioenergy production, *Acacia magium,* a fast growing species, plays a major role in climate change mitigation through carbon sequestration from the atmosphere. The objective of this study was to improve estimates of aboveground biomass of 3, 7 and 11 years old stands of *Acacia mangium* set up through natural regeneration at Anguédédou in Côte d'Ivoire. Tree measurements were done in circular plots of 615 m^2 located at the center of each stand. 24 trees of circumference at breast height (cbh) between 31 and 116 cm were felled, weighed and measured. Multiple linear regressions were used to develop allometric equations linking aboveground biomass of trees to cbh and/or height. The carbon stock and sequestration capacity of each stand was assessed using these predictive models. The average cbh was 39.4 cm, 73.5 cm and 91.4 cm respectively for 3, 7 and 11 years old stands with a density ranging between 845 trees·ha^{-1} and 553 trees·ha^{-1}. The allometric equations for biomass estimation were Btotal aboveground = $\exp(-3.455 + 2.081 \times \ln(C))$, Btrunk = $\exp(-5.153 + 1.681 \times \ln(C) + 1.056 \times \ln(H))$, Bbranches = $\exp(-2.005 + 0.498 \times \ln(C^2 \times H))$, Bleaves = $\exp(-2.415 + 1.339 \times \ln(C))$. Total height had no influence on total and leaf biomass but increased precision of trunk and branch biomass. The carbon sequestration capacity of aboveground biomass was highest in *Acacia mangium* stand of 7 years old with 45.14 $teqCO_2 \cdot ha^{-1} \cdot year^{-1}$ and lowest in the 3-year stand with 33.90 $teqCO_2 \cdot ha^{-1} \cdot year^{-1}$.

Keywords

Acacia mangium, Natural Regeneration, Allometric Equation, Aboveground Biomass, Carbon Stock and Carbon Sequestration

1. Introduction

Climate change has become a major concern for the world. Poor countries suffer the most of the adverse effects of global warming, given their vulnerability, lack or insufficient resilience and capacity to adapt (Makundi, 2014). The land use change that represents between 10% and 20% of total carbon emissions is exacerbated by the conversion of tropical forests into cultivated and overexploited land, which considerably disrupts global carbon cycles (IPCC, 2007; Werf, 2009). In Côte d'Ivoire, over 85% of the forest cover was lost between 1880 and 2008, under the combined effect of agricultural expansion and logging (SOFRECO, 2009). This deforestation could continue further by 2030, if suitable measures are not taken.

Faced with these problems, the country has been committed since 2011 to the International Mechanism for Reducing Emissions from Deforestation and Forest Degradation (REDD+) implemented in the United Nations Framework Convention on Climate Change (UNFCCC). This mechanism should enable developing countries to benefit from financial compensation for their efforts of reducing deforestation, forest degradation and increase forest carbon stocks and forest conservation (UNFCCC, 2009). Assessments of forest carbon stocks are therefore critical for countries planning to contribute on climate change mitigation impacts through their forest activities (Picard et al., 2012). One of the strategic options is to use fast-growing species such as *Acacias*, Albizias, etc. to increase carbon stocks and also to meet the high demand of fuel for domestic energy.

Many studies have been undertaken since 1980 by Ivorian forest research on Australian *Acacias* and other fast-growing forest species (Dupuy & N'Guessan, 1991; Krisnawati et al., 2011). These plants today offer agro-ecological and socio-economic potentialities through their ability to improve soil fertility, produce wood energy, timber and serve as windbreaks (Peltier & Ballé, 1993). *Acacia* sp. plantations created by agroforestry systems or pure plantations can shoot one year after final tree cuttings (Gnahoua et al., 2014; Krisnawati et al., 2011; N'Guessan et al., 2013) through natural regeneration. In addition to bioenergy production, *Acacias* also play a major role in climate change mitigation through sequestration of carbon emitted in the atmosphere (Bakayoko, 2009; Bakayoko et al., 2012; Benbrahim et al., 2014; Doumbia, 2014; Krisnawati et al., 2011). However, huge efforts are still needed to determine the best methodologies for CO_2 assessment with reliable results.

Several methods are often used to determine aboveground biomass. Among these methods are biomass expansion factors and the destructive method for allometric equations. The biomass expansion factors (BAFs) are used to convert volumes from direct inventory data or direct field measurements (diameter, height) to total aboveground biomass (IPCC, 2006). The most commonly used method for estimating carbon stocks is the destructive method and the development of allometric equations (Djomo et al., 2010; Fayolle et al., 2013; Ngomanda et al., 2014; Djomo & Chimi, 2017). In Côte d'Ivoire from 73 allometric equations developed for 32 species, there is only one equation for *Acacia mangium*. Among these equations, fifty-four (54) allowed to evaluate only commercial volume, 15 trunk, stump and branches, and two for branches only (Henry, 2010). None of these equations comply fully for estimation of biomass (Genet et al. 2011), including trunk, branches, twigs, leaves and fruits. Henry et al. (2010) showed that improper selection of models for biomass estimation can lead up to 20% - 40% uncertainty on carbon stock estimates. In this context, the development of allometric equations for biomass estimation that takes into account all compartments including stump, trunk, branches, leaves, and fruits is becoming a national priority. Therefore, the aim of this study was to develop allometric equations that take into account all the compartments of the aboveground biomass. The specific objectives of the study were to:

- characterize three *Acacia mangium* stands of 3, 7 and 11 years old obtained from natural regeneration;
- develop allometric equations for estimating total aboveground biomass and also biomass of other tree compartments such as trunk, branches and leaves;
- evaluate the carbon sequestration potential of *Acacia mangium* at different ages.

2. Material and Methods

2.1. Study Site

The study was carried out in 2014-2015 at CNRA (National Center for Agronomic Research) forestry research station located within Anguédédou Forest (**Figure 1**). The station was created on March 25, 1965 and the management done by the former Centre Technique Forestier Tropical-Côte d'Ivoire (CTFT-CI) for forestry research. It has an area of 176 ha and includes many mono-specific stands or multi-species forest and agroforestry stands from former agricultural fallows with manioc, maize, etc. (Adou, 1986). This station allows CNRA to carry out research activities on silviculture of local and exotic species, agroforestry, improve forest resources management, reforestation and study on energy properties of wood. Anguédédou Forest is located in a moist evergreen forest in the Southern part of Côte d'Ivoire, about twenty (20) kilometers on the Bouaké/Abidjan road (SODEFOR, 1996). It lies between latitude north 5˚22' and 5˚26' and longitude west 4˚04' and 4˚13'. Its altitude varies from 40 m to 100 m asl (Adou, 1986). This forest belongs to the rainforest area linked to sand and sandstone of the Continental Terminal characterized by the abundance of *Thurraeanthus africana* (Avodiré), *Heisteria parvifolia* (Amimimon), *Xylopia acutiflora* (Elo with small leaves), *Monodora myristica* (Adou, 1986; Guillaumet & Adjanohoun, 1971).

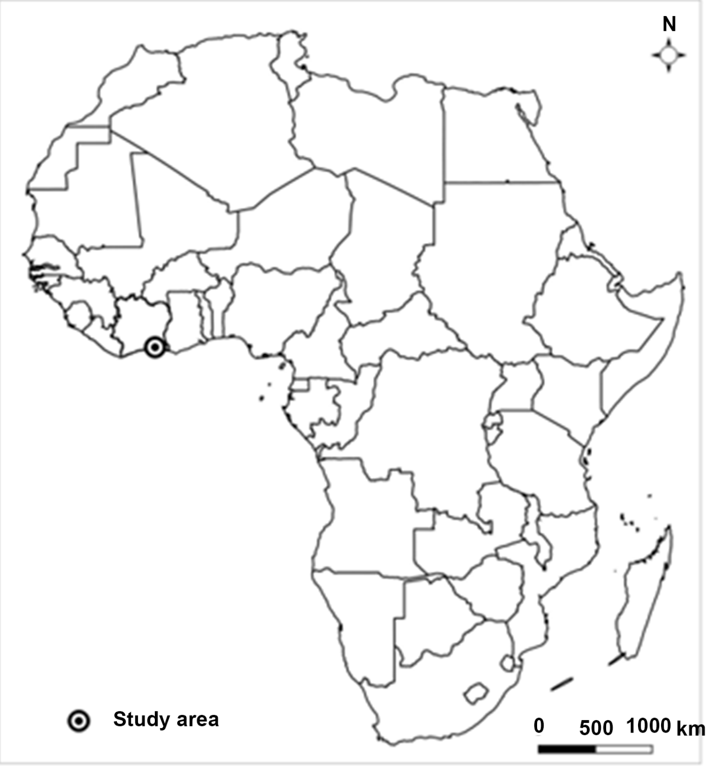

Figure 1. Map of the location of the study area in Côte d'Ivoire.

The climate is hot and humid of subequatorial type with uneven rainy seasons (Eldin, 1971), characterized by low temperatures of 24˚C - 34˚C, high humidity of 80% - 90%, and precipitation that reaches 1766 mm per year (Pega, 2008). The ombrothermic diagram of the Abidjan region of the period between 2002 and 2012 shows 4 seasons: 1) a major rainy season from March to July, 2) a small rainy season from October to November, 3) a large dry season from December to February, and 4) a small dry season from August to September. The relief of the area consists of valleys and lowland plateaus varying from 40 to 60 m in the South and 70 or 100 m in the North. It belongs to the area which extends from the Fresco region in the west to Ghana in the east, over more than 440 km. The width of this plateau is about 25 to 30 km, except to the west of Bandama where it gradually decreases (SODEFOR, 1996). The area is drained by Banco in east, Niangon (the main river of the research station) at the Center and Anguédédou in the west, which are three small rivers (Adou, 1986). This area is located on a plateau belonging to the Lower Côte d'Ivoire sedimentary basin. This basin consists essentially of continental neogene sediments called tertiary or continental terminal sand, generally constituted by coarse detrital deposits, the most common of which is clayey and ferruginous sand (10 to 30 m thick) (Perraud, 1971). Other facies such as clays, lateritic sandy clays, exceptionally non-clayey sand can also be encountered. Potentially fertile, these soils are subject to leaching and/or podzolisation (Adou, 1986).

Acacia mangium is native from Australia (North Queensland), western Papua

New Guinea and the provinces of Irian and Maluku in Indonesia (Benbrahim et al., 2014; Gnahoua et al., 2014; Dupuy & N'Guessan, 1991; N'Guessan & N'Goran, 1999; N'Guessan & Soro, 2006). Its natural range is between 1˚ and 18˚ South latitude. Beyond its natural range, this tree can be found in Asian countries such as Cambodia, China, Japan, Philippines, Thailand and Vietnam. *Acacia mangium* plantations are estimated to be over 600,000 ha throughout the humid intertropical zone, especially in Southeast Asia (Gnahoua & Louppe, 2003). Outside the Asian continent, *Acacia mangium* is used in reforestation in several African countries including Côte d'Ivoire, Senegal, Guinea, Benin, Cameroon, Democratic Republic of Congo, etc. In Côte d'Ivoire, experimental private plantations (PHCI, PALMINDUSTRIE, SODEFOR, etc.) of the species were created in Port Bouët, Oume, Dabou, La Mé, Assinie-France, Mopri, Yapo, San Pédro, Korhogo and Anguédédou (N'Guessan, 1991).

2.2. Data Collection

2.2.1. Sampling Technique

The stands were subdivided into 3, 7 and 11 years old of *Acacia mangium* corresponding to the different stages of development. These stands were regenerated naturally one year after the final cut of the stands planted at 3 m × 3 m spacing after burning of the litter which stimulates spontaneous germination of the fallen seeds (N'Guessan et al., 2013). A circular plot with a radius of 14 m (615 m^2) was installed in each *Acacia Magium* stand. Within each plot, all trees were counted, and the height and diameter (circumference) taken at 1.30 m aboveground measured (Ekoungoulou et al., 2014). To enable appropriate size distribution, tree sampling approach (CTFT, 1989) based on diametric or circumference structure enabled tree selection for destruction for allometric equations development. Hence, at least one tree was selected per diameter class and per stand to be felled. A total of 24 trees between of cbh between 31 and116 cm were felled and weighed entirely corresponding to 13 trees in the 3-year stand, 6 trees in the 7-year stand, and 5 trees in the 11-year stand. The inconsistency in number of trees in the three stands was due to the fact that it was laborious to felled and process bigger trees.

2.2.2. Biomass of Tree Compartments

After felling, each tree was separated into trunk, branches, leaves and fruits and the fresh biomass of each compartment weighed using a 500 kg scale. To obtain the dry weight of the trunk, three samples each of 4 cm thick were collected at the collar, at 1.30 m aboveground and at the top of the trunk (22 cm of circumference or 7 cm of diameter) of each tree (Girard, 1992). Samples of leaves and branches (three samples of 4 cm thick) were also 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 amount of water (H%) in the various compartments (stem, branches and leaves) was determined after drying of the samples using the formula by

$H\% = \left(\left(W_f - W_o\right)\right) / W_f \times 100$, with W_f the fresh weight of the sample and the W_o weight of the sample after drying. The dry weight of each compartment was determined using the relationship $W_o = W_f \times \left(1 - H\%/100\right)$ with W_o the dry weight of the compartment under consideration, W_f the fresh weight of this compartment and $H\%$ the amount of water in the sample of the compartment (Girard, 1992). The total dry weight of each tree was estimated by adding the dry weight of the various compartments of the tree.

3. Data analysis Structure of Stands

The stand structure showing the distribution and the variability of the number of stems per diameter class was used with the class interval of 4 cm. Other stand parameters such as density (number of trees per hectare), mean circumference, average height, mean annual increment, basal area were analyzed.

The mean circumference correlates strongly with stand volume. Moreover, for even stands, the distribution of trees by circumference class at breast height follows a normal distribution (Snowdon et al., 2002; Rondeux, 1993). The formula used for determining the average diameter (circumference) was $D_m = \frac{\sum f_i \cdot x_i}{\sum f_I}$ with D_m the mean diameter (circumference) of the considered stand in cm, f_i the frequency of the class i and x_i the circumference in cm of the tree at the center of the class i. The average height was obtained using the following formula (CTFT, 1989): $H_m = \sum H_i \times N^{-1}$ with H_m the mean total stand height, H_i the total height of the tree i and N the number of trees sampled. The average annual increment was determined from the formula $A_m = D_m \times A^{-1}$ with Cm the average diameter (circumference) of the stand and A the stand age. The basal area is the sum of the area per hectare, of the cross-sections of the trees taken at 1.30 m above ground, expressed in $m^2 \cdot ha^{-1}$. When the basal area of the average tree was equal to the average stand area (Pardé & Bouchon, 1988), the basal area G of the stand was estimated using the following relationship (CTFT, 1989) $G = C_m^2 \times d \times \left(4\pi\right)^{-1}$ where G is the basal area in $m^2 \cdot ha^{-1}$, Cm the average circumference in m and d the stand density in $N \cdot ha^{-1}$.

3.1. Development of Allometric Equations

Allometric equations are relations that link biomass with one or two independent variables such as diameter and height (Lotfi, 2008). Most allometric equations use diameter at breast height taken at 1.30 m (dbh). The models most frequently found in the literature for biomass estimation are of two types: the power model and the polynomial model (Henry et al., 2011). In this study, the power model was used because polynomial models frequently exhibit abnormal behavior outside their validity domain (e.g., negative predicted values). The most frequently used mathematical formula for adjusting a biomass is $B = aD^b$ (Picard et al., 2012), where B is the total dry aboveground biomass, D the diameter at breast height (ddh) and a, b the regression coefficients. To take into account the heteroscedasticity of the data (Djomo et al., 2010; Djomo et al., 2016), this formula is often modified using the logarithmic transformation through the relation $In(B) = a + b \times InD$ (Niklas, 1993; Djomo et al., 2010; Picard et al., 2012; Djomo et al., 2016). The data from this study were adjusted by the following three models:

$$\ln(AGB) = a + b \times \ln(D); \quad (1)$$

$$\ln(AGB) = a + b \times \ln(D^2 \times H); \quad (2)$$

$$\ln(AGB) = a + b \times \ln(D) + c \times \ln(H) \quad (3)$$

where AGB is the total or compartment aboveground biomass in kg, D the circumference taken at 1.30 m aboveground in cm and H the total height of the tree in m. The three models were repeated with the circumference to allow reporting regression equations with circumferences as input variables.

The first step in the analysis of the data was the graphical exploration which allowed visualizing the relationships between variables from a point cloud in order to get an idea of the type of model to be adjusted. Although the graphs of the non-transformed and log-transformed data looked similar, the log-transformed data had a correlation coefficient higher in all the scenarios tested and the log-transformation was therefore selected (**Figure 2**). The logarithmic transformation of the data generally leads to a bias in the estimation of biomass (Parresol, 1999; Chave et al., 2005), which was corrected by multiplying the estimated biomass by a correction factor (CF) determined by the relation $CF = RSE^2/2$ (Djomo et al., 2016; Djomo & Chimi, 2017).

Two criteria were used to select the best predictive model, the residual standard error (RSE) and the Akaike information criterion (AIC). RSE represents the standard deviation between the observed value and its prediction, estimated by the relation $RSE = \sqrt{SSE/(n-2)}$ where SSE is the sum of squared errors between the observed value and the prediction and $n-2$ the number of degrees of freedom. The Akaike Information Criterion (AIC) is a measure of the quality

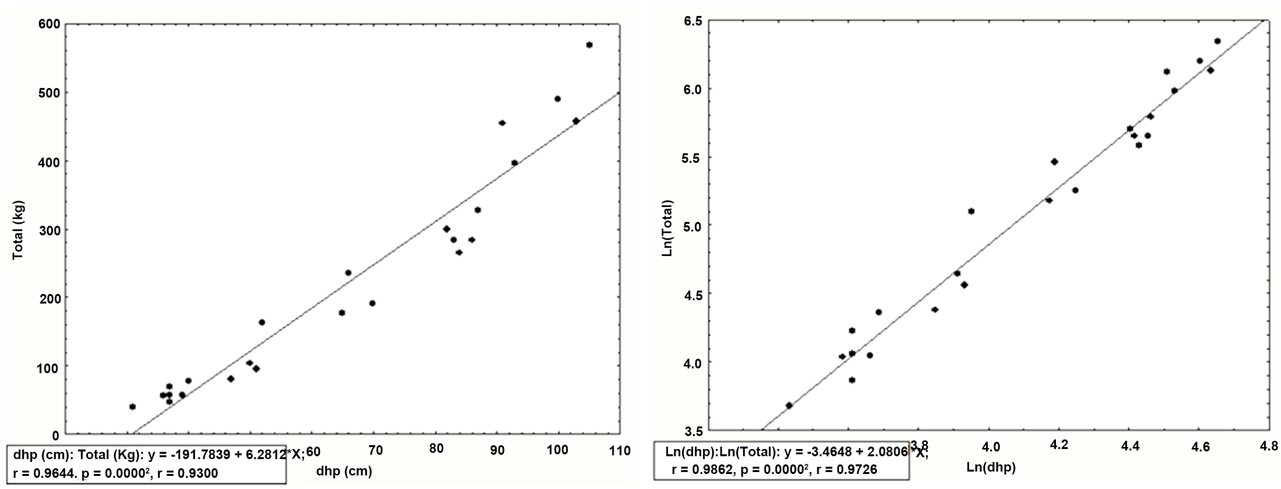

Figure 2. Representation of the scattered plot of the total aboveground biomass without log-transformation (left) and with log-transformation (right).

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. $AIC = -2\ln(L) + 2p$ 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; the lower the criteria, the better the model (Chave et al., 2005; Saint-André et al., 2015).

3.2. Determination of Carbon Stock

The total biomass per hectare Bh (t·ha^{-1}) was determined using the formula $Bh = \sum_i (B_c)/S$ with B_c the biomass in compartment c (trunk, branches, leaves), i the number of trees used and S the surface area considered. The carbon content in wood of 50% (IPCC, 2003) allowed estimating the carbon stock CS per hectare (tC·ha^{-1}) using the relation $CS = Bh \times \%$. The annual carbon sequestration capacity C of aboveground biomass per hectare per year (tC·ha^{-1}·year^{-1}) was estimated using the relationship $C = CS \times A^{-1}$ in which A is the age of the stand. Since the CO_2 equivalent is the measure of greenhouse gas emissions, the conversion of the carbon equivalent (eqC) into carbon dioxide equivalent ($eqCO_2$) was done by multiplying C by 44/12, where 1 eqC = 3.66 $eqCO_2$.

The biomass expansion factor (BEF) which is a factor used to convert trunk biomass to total biomass (Mavouroulou, 2012) was estimated in this study using the formula BEF = Total Biomass/Trunk Biomass.

The data of this study were compiled with Excel spreadsheet and the linear regressions analyzed with R software version 3.1.1 (2014-07-10).

4. Results

4.1. Stands Structures

Figure 3 shows the diameter distribution of the stands studied. For the stands of 3 to 11 years studied, this distribution was unimodal characteristic of regular forests. Within the 3-year-old stand there were four diameter classes ranging from 9 to 24 cm with the highest proportion of individuals (40% trees) in the 12 - 16

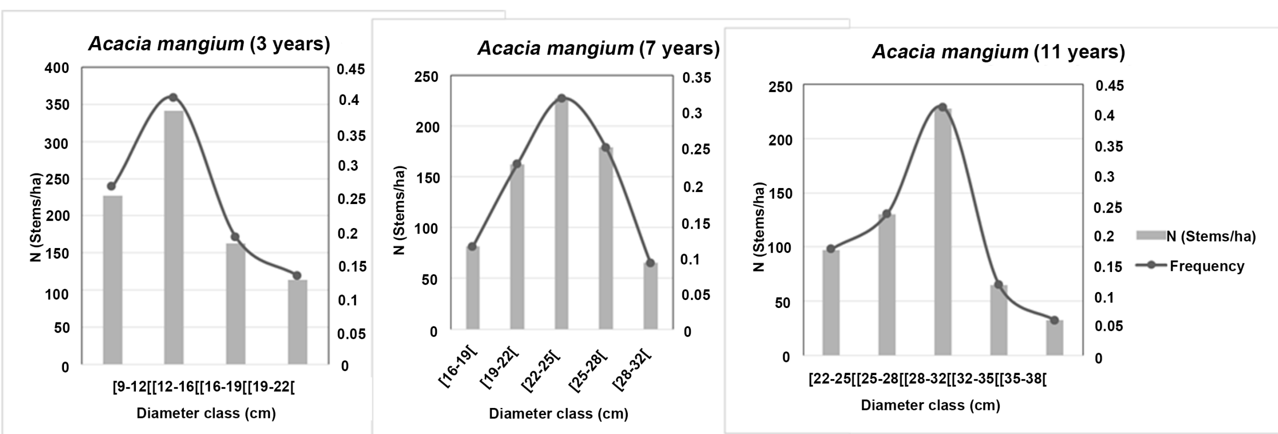

Figure 3. Diameter distribution of the studied stands.

cm class. Within the 7-year stand, there were five diameter classes ranging between 12 and 32 cm with the highest proportion of individuals (32% trees) in the 20 - 24 cm class. Within the 11-year-old stand, there were five diameter classes ranging between 20 and 40 cm with the highest proportion of individuals (41% of trees) in the 28 - 32 cm class.

In Table 1, the main characteristics of the stands showed that the stand structure varies greatly with age. The mean diameter was 12.5 cm for the 3-year stand, 23.4 cm for the 7-year stand and 29.1 cm for the 11-year stand. The average total height was 12.5 m for the 3-year stand, 19.0 m for the 7-year stand and 23.3 m for the 11-year stand. The average basal area was 10.42 $m^2 \cdot ha^{-1}$ for the 3-year stand, 30.75 $m^2 \cdot ha^{-1}$ for the 7-year-old stand, and 36.51 $m^2 \cdot ha^{-1}$ for the 11-year stand. The highest density 845 $stems \cdot ha^{-1}$ was obtained in the 3-year stand and the lowest 553 $stems \cdot ha^{-1}$ in the 11-year stand. The mean annual increase on dbh and height was inversely proportional to the age of the stand. For dbh, it was 2.64 $cm \cdot year^{-1}$ for 11-year stand, 3.34 $cm \cdot year^{-1}$ for 7-year stand and 4.18 $cm \cdot year^{-1}$ for 3-year stand. For height, it was 2.11 $m \cdot year^{-1}$ for 11-year stand, 2.71 $m \cdot year^{-1}$ for 7-year stand and 4.19 $m \cdot year^{-1}$ for 3-year stand.

4.2. Distribution of Tree Biomass

Table 2 presents the distribution of the aboveground biomass by dbh and height for trunk, branches, leaves and total biomass. In the 3-year stand, the total tree biomass varied from 40 kg to 235 kg; the 7-year stand was relatively homogeneous varying from 190 to 327 kg. In the 11-year stand the total biomass varied from 395 to 568 kg. The largest biomass was found in the trunk followed by branches and leaves (Figure 4). The results of this study showed that the trunk stored on average 60%, 72% and 80% of the total biomass in 3-year, 7-year and 11-year stands respectively. The largest leaves was observed in the 3-year stand

Table 1. Stand characteristics by age group.

Main characteristics	Stand age		
	3 years	7 years	11 years
Density ($N \cdot ha^{-1}$)	845	715	553
Dbh (cbh) min (cm)	9.9 (31)	16.6 (52)	22.3 (70)
Dbh (cbh) max (cm)	21.7 (68)	29.0 (91)	36.9 (116)
Dbh (cbh) mean (cm)	12.5 (39)	23.4 (74)	29.1 (91)
Basal area ($m^2 \cdot ha^{-1}$)	10.42	30.75	36.51
H min (m)	9.20	16.50	21.80
H max (m)	17.10	21.50	24.50
H mean (m)	12.58	18.95	23.26
Annual increment dbh (cbh) ($cm \cdot year^{-1}$)	4.2 (13.1)	3.3 (10.4)	2.6 (8.2)
Annual increment on H ($m \cdot year^{-1}$)	4.19	2.71	2.11

Table 2. Biomass (kg) measured for the 24 felled trees.

Stand age (years)	cbh (cm)	dbh (cm)	H (m)	Trunk (kg)	Branches (kg)	Leaves (kg)	Total (kg)
3	66	21	17.1	172.42	32.42	29.96	234.80
	65	21	16.3	126.28	25.83	25.23	177.34
	47	15	14.1	57.80	10.52	11.32	79.64
	51	16	15.2	65.57	17.13	12.77	95.47
	31	10	10.7	25.26	9.65	4.63	39.54
	40	13	14.6	51.97	19.30	7.02	78.29
	36	11	11.2	29.00	16.47	10.92	56.39
	37	12	9.5	30.50	26.84	10.92	68.26
	39	12	11.4	34.00	14.03	9.12	57.15
	37	12	10.4	32.00	16.47	9.52	57.99
	37	12	10.4	27.00	11.59	8.99	47.58
	50	16	10.53	40.32	23.76	39.64	103.72
	52	17	12.1	56.91	46.44	59.64	162.99
7	84	27	20.6	180.68	52.05	32.16	264.89
	70	22	18.7	150.56	23.38	16.44	190.38
	82	26	19.1	199.13	62.68	37.31	299.12
	83	26	21.5	203.50	50.75	29.30	283.56
	87	28	17.3	249.16	53.86	24.21	327.23
	86	27	16.5	210.79	53.60	19.04	283.43
11	105	33	23.8	442.46	67.42	58.26	568.14
	103	33	24.5	378.35	48.35	30.05	456.75
	93	30	23.5	338.53	38.08	18.58	395.19
	91	29	21.8	348.24	61.58	44.23	454.05
	100	32	22.7	377.38	74.71	37.24	489.32

(19%) and the lowest in the 11-year stand (8%). The distribution of branches biomass in the different stand age classes was similar to that of leaves. It was more important in the 3-year stand (21%) and lower in the 11-year stand (12%).

4.3. Allometric Equations

For the estimation of the total biomass and also of the compartments trunk, branches and leaves, this study made it possible to develop allometric equations. The best equation for estimating total biomass was total $B = \exp\left(-1.073 + 2.081 \times \ln(D)\right)$ with $Adj \cdot r^2$ = 0.97 and AIC = −89 which equivalent to $B = \exp\left(-3.455 + 2.081 \times \ln(C)\right)$ if circumference was used as input variable (**Table 3**). For trunk biomass, model II had the same value of $Adj \cdot r^2$ = 0.98 with model III and the lowest AIC = −92. However, validation with

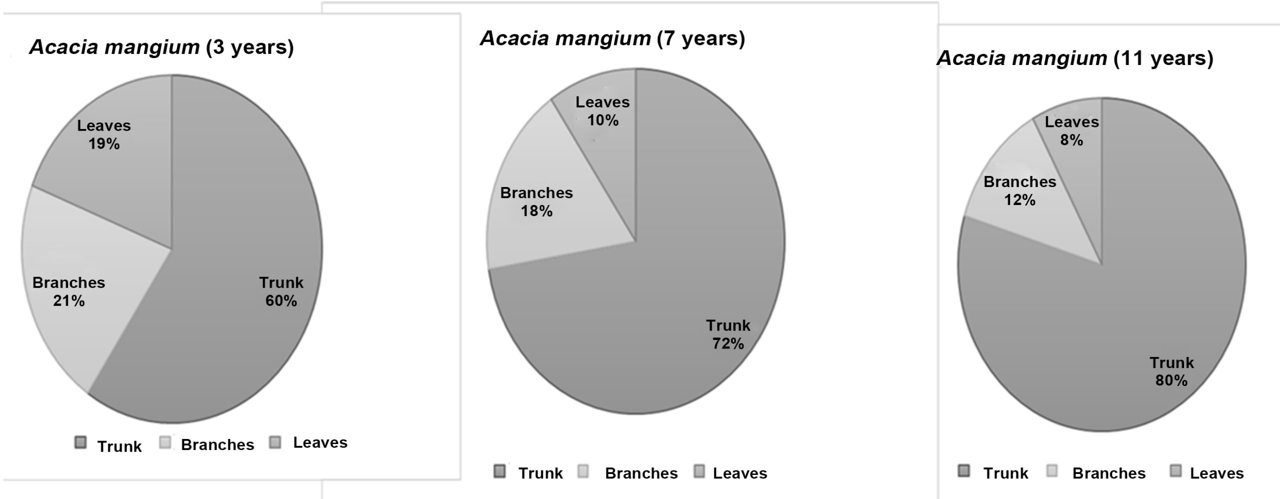

Figure 4. Biomass (%) in the various tree compartments.

Table 3. Results of regression analysis with models I. II. and III., *a*, *b*, *c* adjusted parameters of the model, *D* diameter at breast height, *C* circumference at breast height, H total height and B biomass. The best fit parameters are reported for each model. *N*: number of trees measured. *CF*: correction factor. *AdjR*^{2}: Adjusted square regression coefficient. *RSE*: Residual standard error and *AIC*: Akaike information criterion.

Tree compartments	Model	Model Parameters							
		a	*b*	*c*	*N*	*CF*	*Adj r*^{2}	*RSE*	*AIC*
TOTAL	I) $\ln(B) = a + b\ln(D)*$	−1.083	2.081		24	0.010	0.97	0.144	−89
	II) $\ln(B) = a + b\ln(D^2H)$	−1.476	0.756		24	0.015	0.96	0.173	−80
	III) $\ln(B) = a + b(D) + c\ln(H)$	−1.039	2.132	−0.072	24	0.011	0.97	0.147	−86
	I) $\ln(B) = a + b\ln(C)*$	−3.465	2.081		24	0.010	0.97	0.144	−89
	II) $\ln(B) = a + b\ln(C^2H)$	−3.206	0.756		24	0.015	0.96	0.173	−80
	III) $\ln(B) = a + b(D) + c\ln(H)$	−3.480	2.132	−0.072	24	0.011	0.97	0.147	−86
TRUNK	I.	−2.591	2.443		24	0.017	0.97	0.182	−78
	II.	−3.155	0.899		24	0.009	0.98	0.136	−92
	III.*	−3.238	1.681	1.056	24	0.010	0.98	0.138	−89
	I.	−5.387	2.443		24	0.017	0.97	0.182	−78
	II.	−5.215	0.899		24	0.009	0.98	0.136	−92
	III.*	−5.163	1.681	1.056	24	0.010	0.98	0.138	−89
BRANCHES	I.	−0.763	1.403		24	0.049	0.76	0.314	−52
	II.*	−0.924	0.498		24	0.059	0.71	0.344	−47
	III.	−0.033	2.262	−1.190	24	0.042	0.80	0.290	−53
	I.	−2.369	1.403		24	0.049	0.76	0.314	−52
	II.*	−2.064	0.498		24	0.059	0.71	0.344	−47
	III.	−2.622	2.262	−1.190	24	0.042	0.80	0.290	−53
LEAVES	I.*	−0.987	1.339		24	0.105	0.57	0.459	−33
	II.	−1.064	0.465		24	0.120	0.51	0.489	−30
	III.	0.231	2.772	−1.986	24	0.083	0.66	0.408	−37
	I.*	−2.520	1.339		24	0.105	0.57	0.459	−33
	II.	−2.131	0.465		24	0.120	0.51	0.489	−30
	III.	−2.943	2.772	−1.986	24	0.083	0.66	0.408	−37

*: selected equation.

original data showed that model III estimated the total and mean with an error of −3.81%, (model II: −4.22%, model I: −4.15%) and selected as the best fit. Therefore, the best equation to estimate the trunk biomass was $B = \exp\left(-3.228 + 1.681 \times \ln\left(D\right) + 1.056 \times \ln\left(H\right)\right)$ which corresponded to $B = \exp\left(-5.153 + 1.681 \times \ln\left(C\right) + 1.056 \times \ln\left(H\right)\right)$ if circumference was used as input variable. For branch biomass, the highest $Adj \cdot r^2$ and lowest *AIC* was obtained with model III; however, validation with original data showed that equation II estimated the total and the mean with an error of −2.46% (model I: −3.02%; model III: −2.98%) and was selected. Therefore, the best equation for estimating branch biomass was $B = \exp\left(-0.865 + 0.498 \times \ln\left(D^2 \times H\right)\right)$ which corresponded to $B = \exp\left(-2.005 + 0.498 \times \ln\left(C^2 \times H\right)\right)$ if circumference was used as input variable. For leaf biomass, model III had the highest $Adj \cdot r^2$ and lowest *AIC*, followed by model I. However, validation with original data showed that model I was the best equation with an error of −2.14% (model II: −2.78%; model III: −2.33%). Therefore, the best equation for estimating leaf biomass was $B = \exp\left(-0.882 + 1.339 \times \ln\left(D\right)\right)$ which corresponded to $B = \exp\left(-2.415 + 1.339 \times \ln\left(C\right)\right)$ if circumference was used as input variable. These equations were used to determine carbon stocks per hectare in the study stands.

4.4. Carbon Stock, Carbon Sequestration and BEF

The aboveground biomass stored in average tree increased with the age varying from 66 kg in 3-year stand to 241 kg in 7-year stand and 380 kg for 11-year stand. It was the same case for biomass stored in the leaves (10 kg in 3-year stand to 30 kg in 11-year stand), branches (15 kg in 3-year stand to 49 kg in 11-year stand) and trunk (40 kg in 3-year stand to 313 kg in 11-year stand) (**Table 4**). The corresponding total aboveground carbon stored was 28 $tC \cdot ha^{-1}$ in 3-year stand; 86 $tC \cdot ha^{-1}$ in 7-year stand and 105 $tC \cdot ha^{-1}$ to 11 years. The equivalent carbon dioxide sequestration was higher for 7-year stand with 45 teqCO2 $ha^{-1} \cdot year^{-1}$ and lower in 3-year stand with 34 $teqCO_2 \cdot ha^{-1} \cdot year^{-1}$. The biomass expansion factor (BEF) decreased with stand age and was 1.66 in 3-year stand, 1.37 in 7-year stand and 1.21 in 11-year stand (**Table 4**).

5. Discussion

The diameter structure of the different stands showed a normal distribution of the stems with a maximum frequency of 40% in the class of 12 - 16 cm in 3-year stand, 32% in the class 20 - 24 cm in 7-year stand and 41% in class 28 - 32 cm in 11-year stand. This diameter structure is typical of even forest stands with high regeneration capacity (Rollet, 1974). This diameter distribution structure was consistent with the study of Deb et al. (2014) that found normal distribution in a *Shorea robusta* plantation in Bangladesh. It was also consistent with the study of Ribeiro et al. (2014) which found the same structure in a plantation of *Eremanthus erythropappus*. The mean diameter of *Acacia mangium* 3-year, 7-year and 11-year stands of this study were 12.53 cm, 23.41 cm and 29.1 cm respectively.

Table 4. Biomass stock and carbon sequestration capacity.

Description	Stand age		
	3 years	7 years	11years
Trunk Biomass of Average Tree (kg)	39.52	175.83	312.67
Branches Biomass of Average Tree (kg)	15.07	38.05	48.77
Leaves Biomass of Average Tree (kg)	9.89	24.80	30.18
Total biomass of Average Tree (kg)	65.78	241.49	379.75
Biomass Expansion Factor	1.66	1.37	1.21
Carbon Stock (tC·ha^{-1})	27.79	86.33	105.00
Carbon Stock (tCO_2eq·ha^{-1})	101.71	315.97	384.50
Carbon Sequestration Capacity (tCO_2eq·ha^{-1}·year^{-1})	33.90	45.14	34.94

The mean total height (m) varied between 12.58 m and 23.26 m. It was also the case with the stands basal area which grew with age from 10.42 m^2·ha^{-1} for 3-year stand to 36.51 m^2·ha^{-1} for 11-year stand. This growth in mean diameter, mean height and basal area with age was close to the results of other studies in forest plantations (Dupuy & N'Guessan, 1990; Lehtonen et al., 2004).

Stand Densities ranged from 845, 715 and 553 stems·ha^{-1} respectively for 3-year, 7-year and 11-year forest. These values were lower compared to the growth model prediction of *Acacia mangium* (Dupuy & N'Guessan, 1990) with stand density varying from 1350 stems·ha^{-1} in 3-year stand to 970 stems·ha^{-1} in 9 year stand. The difference could be due to the fact these values are results of model prediction and not direct measurements; also human activities such as tree harvest for fire wood, logging, bush fires and other factors such as natural disturbance (e.g. Chablis) and intraspecific competition (light, water and nutrient availability) can also explain this difference with the model (Oliver & Larson, 1996; Guillaume, 2006).

The biomass stored in the trunk (up to 22 cm circumference or 7 cm diameter) represented 60%, 72% and 80% of the total biomass in 3-year, 7-year and 11-year stands respectively. For leaves, the highest biomass (19%) was stored in the *Acacia mangium* of 3-year stand. This proportion decreased with age to reach 8% in the 11-year stand. The proportions of biomass stored in the trunk were consistent with the study of Heriansyah et al. (2007) in *Acacia mangium* stands of 3 to 10 years in West Java in Indonesia which showed that the biomass stored in the trunk was between 63 and 71% of the total biomass. At the branch level, the highest proportion representing 21% of total biomass was observed in the *Acacia mangium* stand of 3 years. This proportion decreases with age, reaching 12% in 11-year stand. These results were close to those of the 7-year stand of *Acacia mangium* provenance trials in Ibi carbon sink project in Democratic Republic of Congo (Yusufu, 2014). The study of Henry et al. (2010) in a dense moist forest of Ghana showed a significant difference with this study in leaf biomass that represented the smallest proportion with about 1% of the total aboveground biomass. In three native mixed species stand of a Hyrcanian forest in Iran, constituted by *Fraxinus excelsior*, *Pterocarya fraxinifolia*, *Populus caspica*, *Quercus castaneifolia* and *Ficus carica,* the crown biomass (branches and leaves) varied between 20%, 21% and 25% (Vahedi et al., 2016) which was close to this study ranging between 20%, 28% and 40% in 11-year, 7-year and 3-year stands respectively.

Data collected from 24 trees in 3 stands of *Acacia mangium* allowed developing allometric equations using two independent variables the diameter or circumference at 1.30 m aboveground, and the total height. To measure the goodness of each of the models the residual standard error (*RSE*) and Akaike Information Criteria (AIC) was assessed and the error made on the estimation of total and mean biomass used to validate the final selection. For total biomass, Model I selected with only diameter (circumference) measured perfectly the total and mean biomass and had also the lowest *AIC* and highest Adj·r^2. This showed that the total height did not influence significantly the total biomass as the total height is a function of *D* (Chave et al., 2005; Fayolle et al., 2013). The best equation for estimating trunk biomass was obtained with model III (*RSE* = 0.138, *AIC* = −89, error = −2.98% on total or mean) and for branches model II (*RSE* = 0.314, *AIC* = −52, error = −2.46% on total or mean) showing that the total biomass was needed for precise estimate of these compartments. As with total biomass, the best fit for leaf biomass was model I (error −2.14%) which is not influenced by the total height.

The aboveground biomass of carbon stored was 27.8 tC·ha^{-1} in 3-year, 86.3 tC·ha^{-1} in 7-year and 105.0 tC·ha^{-1} in 11-year stands respectively. These values were close to those obtained by Yusufu (2014) in the 46 provenances trial of *Acacia mangium* in the Democratic Republic of Congo. Bakayoko et al. (2007) study in an Australian Acacia experimental plantation of 14 and 15 year old in Côte d'Ivoire found aboveground biomass varying from 35.7 tC·ha^{-1} to 121.3 tC·ha^{-1} which was close to the results of this study.

The *BEF* of this study converted the trunk biomass to the total biomass (trunk, branches and leaves). In case the volume of the trunk is the data available, the wood density is needed to convert this volume data to trunk biomass (biomass = volume × wood density) before applying the BEF to obtain the total biomass. The *BEF* was 1.66 in 3-year, 1.37 in 7-year and 1.21 in 11-year stands respectively. Henry et al. (2010) found *BEF* ranging between 1.13 and 2.20 while Mavouroulou (2012) obtained *BEF* ranging between 1.04 and 3.88. For tropical forests, IPCC (2003) suggests using locally developed *BEF* for reliable estimates or 3.4 *BEF* in case there is no value in the study area.

6. Conclusion

This study allowed determining the diameter structure of *Acacia mangium* stands of 3-year, 7-year and 11-year stands respectively obtained from natural regeneration. Destructive data from 24 trees allowed developing allometric equations for the estimation of total aboveground biomass and the biomass of trunk, branches and leaves. Three models were tested and the residual standard error (*RSE*), $Adj \cdot r^2$ and *AIC* were used to determine the goodness of fit and the error of total or mean biomass used to confirm and make the final selection of the best allometric equation. The total height did not influence the estimate of total aboveground biomass and the biomass of leaves. However for precise estimate of leaves and branches, total height needed to be added in the model and independent variable. The allometric developed were used to estimate carbon stock, the CO_2eq and the carbon sequestration capacity of the three forest stand of *Acacia magium* studied. For each stand, the BEF was also developed to convert the trunk data available for example from forest inventory data into total aboveground biomass.

The results of this study contribute to improve the estimation of the aboveground biomass of even stands resulting from natural regeneration. However, this research did not include the root biomass and recommends further studies providing precise information on this important compartment for the estimation of carbon stocks.

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References

Adou, K. (1986). *Caractéristiques de la station CTFT de l'Anguédédou*. Abidjan: Rapport technique CTFT, 7 p.

Bakayoko, O. (2009). *Contribution à la lutte contre les réchauffements climatiques: étude des caractéristiques sylvicoles et des capacités de stockage de carbone de quatre peuplements expérimentaux des Acacias australiens dans le sud de la Côte d'Ivoire*. PhD Dissertation, Abidjan: Université de Cocody.

Bakayoko, O., Assa, A. M., Coulibaly, B., & Traoré, D. (2007). Carbon Storage in Biomass and Soils of Four Australian Acacia stands of Anguededou Station (South-East of Côte d'Ivoire. *European Journal of Scientific Research, 19*, 25-37.

Bakayoko, O., Coulibaly, B., N'Guessan, K. A., & Assa, A. M. (2012). Carbon Storage in *Nauclea didderichii* and *Triplochiton scleroxylon* stands in Côte d'Ivoire. *American Journal of Scientific Research, 75*, 133-142.

Benbrahim, K. F., Berrada, H., Ghachtouli, E. N., & Ismaili, M. (2014). Les *acacias*: *acacias*: des plantes fixatrices d'azote promette uses pour le développement durable des zones arides et semi-arides. *IJIAS, 8*, 46-58.

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J. P., Nelson, B. W., Ogawa, H., Puig, H., Riera, B., & Yamakura, T. (2005). Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests. *Oecologia, 145*, 87-99. https://doi.org/10.1007/s00442-005-0100-x

CTFT (1989). *Mémento du Forestier* (3rd ed.) Paris: Ministère Français de la Coopération et du Développement.

Deb, J. C., Salman, H. R., Halim, A., Chowdhury, Q., & Roy, A. (2014). Characterising the Diameter Distribution of Sal Plantations by Comparing Normal, Lognormal and Weibull Distributions at Tilagarh Eco-Park, Bangladesh. *Southern Forests, 76*, 201-208. https://doi.org/10.2989/20702620.2014.947077

Djomo, A. N., Ibrahima, A., Saborowski, J., & Gravenhorst, G. (2010). Allometric Equations for Biomass Estimations in Cameroon and Pan Moist Tropical Equations Including Biomass Data from Africa. *Forest Ecology and Management, 260*, 1873-1885. https://doi.org/10.1016/j.foreco.2010.08.034

Djomo, A. N., Picard, N., Fayolle, A., Henry, M., Ngomanda, A., Ploton, P., McLellan, J., Saborowski, J., Adamou, I., & Lejeune, P. (2016). Tree Allometry for Estimation of Carbon Stocks in African Tropical Forests. *Forestry, 89*, 446-455. https://doi.org/10.1093/forestry/cpw025

Djomo, N. A., & Chimi, D. C. (2017). Tree Allometric Equations for Estimation of Above, Below and Total Biomass in a Tropical Moist Forest: Case Study with Application to Remote Sensing. *Forest Ecol Manage, 391*, 184-193. https://doi.org/10.1016/j.foreco.2017.02.022

Doumbia, V. (2014). Évaluation des stocks de carbone de jeunes peuplements issus de semis naturels de *Acacia mangium* en zone de forêt dense sempervirente: Cas du site d'Anguédédou. Master's Dissertation, Abidjan: Ecole Supérieure d'Agronomie (ESA), Institut National Polytechnique Félix Houphouët-Boigny.

Dupuy, B., & N'Guessan, A. (1991). Le *Gmelina arborea* en Côte d'Ivoire. Table de production de *Gmelina arborea*. Rapport du projet PSF. Abidjan: CTFT Côte d'Ivoire.

Dupuy, B., & N'Guessan, K. A. (1990). Sylviculture de *Acacia mangium* en basse Côte-d'Ivoire. *Bois et Forets Des Tropiques, 230*, 24-32.

Dupuy, B., & N'Guessan, K. A. (1991). Utilisation des *Acacias* pour régénérer les cocoteraies. *Bois et Forets Des Tropiques, 225*, 15-18.

Ekoungoulou, R., Liu, X., Ifo, S. A., Loumeto, J. J., & Folega, F. (2014). Carbon Stock Estimation in Secondary Forest and Gallery Forest of Congo using Allometric Equations. *IJSTR, 3,* 465-474.

Eldin, M. (1971). Le climat de la Côte d'Ivoire. In J. M. Avenard, M. Eldin et al. (Eds.), *Le milieu naturel de la Côte d'Ivoire* (No. 50, 77-108). Paris: Mémoire ORSTOM.

Fayolle, A., Doucet, J. L., Gillet, J. F., Bourland, N., & Lejeune, P. (2013). Tree Allometry in Central Africa: Testing the Validity of Pantropical Multi-Species Allometric Equations for Estimating Biomass and Carbon Stocks. *Forest Ecology and Management, 305,* 29-37. https://doi.org/10.1016/j.foreco.2013.05.036

Genet, A., Wernsdörfer, H., Mothe, F., Ponette, J. B. Q., Jonard, M., Nys, C., Ranger, A. L. J., Vallet, V., & Saint-André, L. (2011). Des modèles robustes et génériques de biomasse: Biomasse: Exemple du hêtre. *Rev For Fr, 2,* 179-190. https://doi.org/10.4267/2042/45203

Girard, P. (1992). Techniques et matériels de carbonisation: Contrôle de performances. *Bois Et Forets Des Tropiques, 232,* 53-65.

Gnahoua, G. M., & Louppe, D. (2003). *Acacia mangium*. Fiche Technique, Abidjan: CNRA.

Gnahoua, G. M., N'Guessan, K. A., & Ballé, P. (2014). Les jachères de légumineuses arborescentes: Sources potentielles de bois énergie et de service en Côte d'Ivoire. *Journal of Applied Biosciences, 81,* 7290-7297. https://doi.org/10.4314/jab.v81i1.11

Guillaume, C. (2006). *Élaboration d'une typologie forestière adaptée à la forêt boréale irrégulière*. Dissertation, Université Laval, Faculté de foresterie et de géomatique

Guillaumet, J. L., & Adjanohoun, E. (1971). La végétation de la Côte d'Ivoire. In J. M. Avenard, M. Eldin et al. (Eds.), *Le milieu naturel de la Côte d'Ivoire* (No. 50, pp. 166-262). Paris: Mémoire ORSTOM.

Henry, M. (2010). *Carbon Stocks and Dynamics in Sub-Saharan Africa*. Dissertation, AgroParisTech, Montpellier: University of Tuscia.

Henry, M., Besnard, A., Asante, W. A., Eshun, J., Adu-Bredu, S., Valentini, R., Bernoux, M., & Saint-Andre, L. (2010). Wood Density, Phytomass Variations within and among Trees, and Allometric Equations in a Tropical of Africa. *Forest Ecology and Management, 260,* 1375-1388. https://doi.org/10.1016/j.foreco.2010.07.040

Henry, M., Picard, N., Trotta, C., Manlay, R. J., Valentini, R., Bernoux, M., & Saint-André, L. (2011). Estimating Tree Biomass of Sub-Saharan African Forests: A Review of Available Allometric Equations. *Silva Fennica, 45,* 477-569. https://doi.org/10.14214/sf.38

Heriansyah, I., Miyakuni, K., Kato, T., Kiyono, Y., & Kanazawa, Y. (2007). Growth Characteristics and Biomass Accumulations of *Acacia mangium* under Different Management Practices in Indonesia. *Journal of Tropical Forest Science, 19,* 226-235.

IPCC (2003). *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Kanagawa: IPCC National Greenhouse Gas Inventories Programme.

IPCC (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the Natinal Greenhouse Gas Inventories Programme.

IPCC (2007). *Climate Change 2007: Synthesis Report*. Intergovernmental Panel on Climate Change.

Krisnawati, H., Kallio, M., & Kanninen, M. (2011). *Acacia mangium Willd: Ecology, Silviculture and Productivity*. Bogor: CIFOR.

Lehtonen, A., Mäkipää, R., Heikkinenb, J., Sievänen, R., & Liskic, J. (2004). Biomass Expansion Factors (BEFs). For Scots Pine, Norway Spruce and Birch According to Stand Age for Boreal Forests. *Forest Ecology and Management, 188,* 211-224. https://doi.org/10.1016/j.foreco.2003.07.008

Lotfi, A. (2008). *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.

Makundi, R. W. (2014). Perspectives de REDD+ dans les plantations forestières africaines. Working Paper Series, *African Forest Forum, 2,* 28.

Mavouroulou, Q. M. (2012). *Développement des équations allométriques afin d'estimer les stocks de carbone séquestrés dans la forêt primaire du Nord-Est du Gabon, Afrique Centrale*. Dissertation, Université des sciences et techniques de Masuku.

N'Guessan, K. A. (1991). *Contribution à l'étude des méthodes de régénération des jachères en Basse Côte d'Ivoire: Le cas de Acacia mangium*. Dissertation, Université Nationale de Côte d'Ivoire

N'Guessan, K. A., & N'Goran, A. (1999). Les brise-vents d'*Acacias* australiens, un système intégré pour l'amélioration durable des terrains agricoles au Sud de la Côte d'Ivoire. In C. Floret, & R. Pontanier (eds.), *Jachères et Systèmes agraires* (pp. 189-194). CORAF/IRD/Union Européenne.

N'Guessan, K. A., & Soro, S. (2006). Production de litière par les jachères naturelles et artificielles au Nord de la Côte d'Ivoire. *Agronomie Africaine, 18,* 231-242.

N'Guessan, K. A., Coulibaly, B., & Coulibaly, K. (2013). *Techniques de création de ressources ligneuses sans replantation*. Rapport scientifique, Abidjan: CNRA.

Ngomanda, A., Obiang, N. L. E., Lebamba, J., Mavouroulou, Q. M., Gomat, H., Mankou, G. S., Loumeto, J., Iponga, D. M., Ditsouga, F. K., Koumba, R. Z., Bobe, K. H. B., Okouyi, C. M., Nyangadouma, R., Lepengue, N., & Mbatchi, B. (2014). Site-Specific versus Pantropical Allometric Equations: Which Option to Estimate the Biomass of a Moist Central African Forest? *Forest Ecology and Management, 312,* 1-9. https://doi.org/10.1016/j.foreco.2013.10.029

Niklas, K. J. (1993). The Allometry of Plant Reproductive Biomass and Stem Diameter. *American Journal of Botany, 80,* 461-467. https://doi.org/10.2307/2445392

Oliver, C. D., & Larson, B. C. (1996). *Forest Stand Dynamics*. Update. New York, NY: Wiley.

Pardé, J., & Bouchon, J. (1988). *Dendrométrie* (2nd ed.). Nancy: École nationale du Génie rural, des Eaux et des Forêts.

Parresol, B. R. (1999). Assessing Tree and Stand Biomass: A Review with Examples and Critical Comparisons. *Forest Science, 45,* 573-593.

Pega, T. (2008). *Assainissement et gestion de l'environnement à (Adjamé/Williams ville)*. Dissertation, Abidjan: Université d'Abobo-Adjamé.

Peltier, R., & Ballé, P. (1993). De la culture itinérante sur brulis au jardin agroforestier en passant par les jachères enrichies. *Bois Et Forets Des Tropiques, 235,* 54.

Perraud, A. (1971). Les sols. In J. M. Avenard, M. Eldin et al. (Eds.), *Le milieu naturel de la Côte d'Ivoire* (No. 50, pp. 269-390). Paris: Mémoire ORSTOM.

Picard, N., Saint-André, L., & Henry, M. (2012). *Manuel de construction d'équations allométriques pour l'estimation du volume et la biomasse des arbres: De la mesure de terrain à la prédiction*. Rome: Organisation des Nations Unies pour l'alimentation et l'agriculture, et Centre de Coopération Internationale en Recherche Agronomique pour le Développement.

Ribeiro, A., Filho, A. C. F., Scolforo, J. R. S., Netto, S. P., & Machado, S. A. (2014). Structure of the Diameter Distribution of an Experimental Plantation of Candeia (*Eremanthus erythropappus* (DC.). MacLeish. *Ciênc Florest, 24,* 1055-1065. https://doi.org/10.5902/1980509816618

Rollet, B. (1974). *L'architecture des forêts denses humides sempervirentes de plaines*. C.T.F.T, Nogent sur marne.

Rondeux, J. (1993). *La mesure des arbres et des peuplements forestiers*. Belgique: Les presses agronomiques de Gembloux.

Saint-André, L., Gael, S., Henry, M., & Picard, N. (2015). *Ajustement des modèles, principes et cas d'étude*. Conférence Internationale sur le développement des équations allométriques, Abidjan.

Snowdon, P., Raison, J., Grierson, P., Adams, M., Montagu, K., Burrows, W., & Eamus, D. (2002). *Protocol for Sampling Tree and Stand Biomass*. National Carbon Accounting System Technical Report No. 31. Canberra: Australian Greenhouse Office.

SODEFOR (1996). *Aménagement de la forêt classée d'Anguédédou 1996-2005, Abidjan*.

SOFRECO (2009). *West Africa Post Conflict Analysis*. Rapport Final.

UNFCCC (2009). *Methodological Guidance for Activities Relating to Reducing Emissions from Deforestation and Forest Degradation and the Role of Conservation, Sustainable Management of Forests and Enhancement of Forest Carbon Stocks in Developing Countries*. Subsidiary Body for Scientific and Technological Advice, Copenhagen.

Vahedi, A. A., Bijani-Nejad, A. R., & Djomo, N. A. (2016). Horizontal and Vertical Distribution of Carbon Stock in Natural Stands of Hyrcanian Lowland Forests: A Case Study, Nour Forest Park, Iran. *Journal of Forest Research, 62,* 501-510.

Werf, G. R. (2009). Emissions from Forest Loss. *Nature Geoscience, 2,* 737-738. https://doi.org/10.1038/ngeo671

Yusufu, E. K. (2014). *Carbone stocké dans un essai de provenances de Acacia mangium à Ibi Village sur le plateau des Batéké en République Démocratique du Congo.* Dissertation, Université de Laval.