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ABOVE GROUND BIOMASS AND CARBON STOCK OF *Nauclea diderrichii* (De Wild. & T. Durand) Merill PLANTATION IN OMO FOREST RESERVE, NIGERIA

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ABSTRACTS

Allometric equations are useful tools in estimating the biomass and carbon stock of forests without actual destruction of the tree species. Therefore, this study focused on using allometric equations to estimate above ground biomass and carbon stock of *Nauclea diderrichii* in Omo forest reserve. Three age series selected (47, 44 and 43 Years old) and ten (20m x 20m) temporary sample plots were laid in each plantation to give a total of 30 plots in all. Six candidate alometric equations were selected to estimate the above ground biomass of the tree species. Models developed were assessed and ranked based on high coefficient of determination, significant F-ratio ($P<0.05$) and least Root Mean Square Error. A total of 900 trees were encountered for 47Years, 875 in 44 Years and 825 in 43 Years old stands. The dominant diameter at breast height (dbh (cm) in each of the stands were: 24.51, 39.78 and 43.28 for 47, 44 and 43 years old stands respectively. The dominant heights for each of the three stands were: 17.2m, 18.4m and 23.10m for 47, 44 and 43 years old stands respectively. The mean above ground biomass for the stands were 1372.25kg/m^3, 1196.01kg/m^3 and 1213.04kg/m^3 for 47, 44 and 43 years old stands respectively and the highest carbon stock was recorded for 47 years old stands and the least carbon stock was found in 44 years old stands. Above ground biomass equation - $Y = e^{(1.09+ (-0.04)\ln D)}$ ($R^2 = 93.51\%$), gave the best fit and the estimate of the biomass was significant. A very high significant relationship exists between the dbh and basal area (0.97) hence, as the dbh increases the basal area increases likewise between above ground biomass and volume (1.00). The results of this study also show that most of the trees in the plantation have low slenderness coefficient (i.e. SLC< 70). The developed allometric models for the *Nauclea diderrichii* plantation has provided useful basis to improve the prediction of aboveground biomass and carbon stock.

Key words*:* Aboveground Biomass, Carbon stock, Allometric equations, *Nauclea diderrichii*

Introduction

*Nauclea diderrichii*i s a tropical African hardwood species belonging to the family Rubiaceae. The species is widely distributed across tropical Africa, from Liberia eastward through the Congo Basin to Uganda and Angola. It is a moderately fast-growing species, with fairly high density timber and durable wood. The tree grows up to about 60 m in height, with straight, cylindrical bole clear to 30 - 40 m, and trunk diameter ranging from 1.0 - 2.5 m. Its natural habitat is subtropical or tropical moist lowland forests. As a sun-loving species, the plant regenerates abundantly in gaps and openings and is often almost gregarious in the transition zone between freshwater swamps and lowland forests (Hawthorne, 1995). *Nauclea diderrichii*, is a commercial timber of West Africa. The wood is yellow and darkens slightly when exposed to light. It is semi-heavy and of medium hardness; its shrinkage and nervosity are average. Because of its good mechanical properties and natural durability, which can be enhanced by preservative treatment, it is sought after as a timber for outdoor uses (harbor works, railway sleepers), buildings (carpentry, floors, facings, indoor and outdoor woodwork) and for cabinetmaking. The wood is also suitable for fence posts and bridges as it is moderately termite-resistant and resistant to fungi and marine borers. In Ghana, its most popular use is for mortars, but it is also used to make telegraph poles, pit props and mine-shaft guides, furniture and drums. A bark decoction is prescribed for anaemia, stomach-ache and indigestion, as part of an infusion for treating jaundice, bark infusion to treat gonorrhea; a decoction of leaves is used as a wash for measles (Orwa *et al*., 2009).

Tree biomass is a function of wood volume (obtained from the diameter and height), architecture and wood density (dry weight per unit volume of fresh wood). Density varies according to species (Sterck *et al*., 2001, Swaine and Whitmore, 1988), tree age (Fujimoto *et al*., 2006), life-history strategy (King *et al*., 2005) and environmental factors such as topography and slope aspect (Hultine *et al*., 2005). Tree biomass can be quantified by either destructive harvest (direct method) or use of allometric equations (indirect method) that are ultimately based on harvested trees (Chave *et al*., 2005). Allometric models relate tree dry mass (obtained by the direct method) to measurable variables such as diameter at breast height (dbh), total tree height, and wood density (Abdala *et al*., 1998, Delitti *et al*., 2006).

In other vein, information about aboveground biomass (AGB) is necessary for estimating and forecasting ecosystem productivity, carbon budgets, nutrient allocation, and fuel accumulation (Brown *et al.*, 1999; Kurz and Apps, 1999; Price *et al.*, 1999; Zheng *et. al.*, 2004). Being able to accurately estimate biomass is therefore important to assess the role of forests in the global carbon (C) cycle, particularly when defining its contribution toward sequestering carbon (Brown, 2002). Biomass is also considered a useful indicator of structural and functional attributes of forest ecosystems across a wide range of environmental conditions (Brown *et al.*, 1999).

Forests play an important role in global carbon cycling, since they are large pools of carbon as well as potential carbon sinks and sources to the atmosphere. Accurate estimation of forest biomass is required for greenhouse gas inventories and terrestrial carbon accounting. The needs for reporting carbon stocks and stock changes for the Kyoto Protocol have placed additional demands for accurate surveying methods that are verifiable, specific in time and space, and that cover large areas at acceptable cost (IPCC, 2003; Krankina *et al*., 2004; Patenaude *et al*., 2005). Thus, the objective of this study is to estimate above ground biomass and carbon stock in *Nauclea diderrichii* plantation in area J4 section of Omo forest reserve, Nigeria.

METHODOLOGY

The study area

This study was carried out in Ogun state Forestry Plantation Project, Area J4, Omo forest reserve, Ogun state (Fig 1). It is located between latitudes 6^0 35' to 7^0 05' N and longitudes 4^0 19' to 4^0 10' E. The reserve shares a common boundary in its Northern part with two other forest reserves – Ago Owu and Shasha in Osun state. It also has a common Eastern boundary with Oluwa Forest Reserve in Ondo state (Karimu, 1999). The reserve falls within the tropical wet-and-dry climate characterized by two rainfall peaks separated by a relatively less humid period usually in the month of August. The mean annual rainfall is about 1750mm and the mean relative humidity is 80%, sunshine duration during the rainy season varies between 8-10 hours.

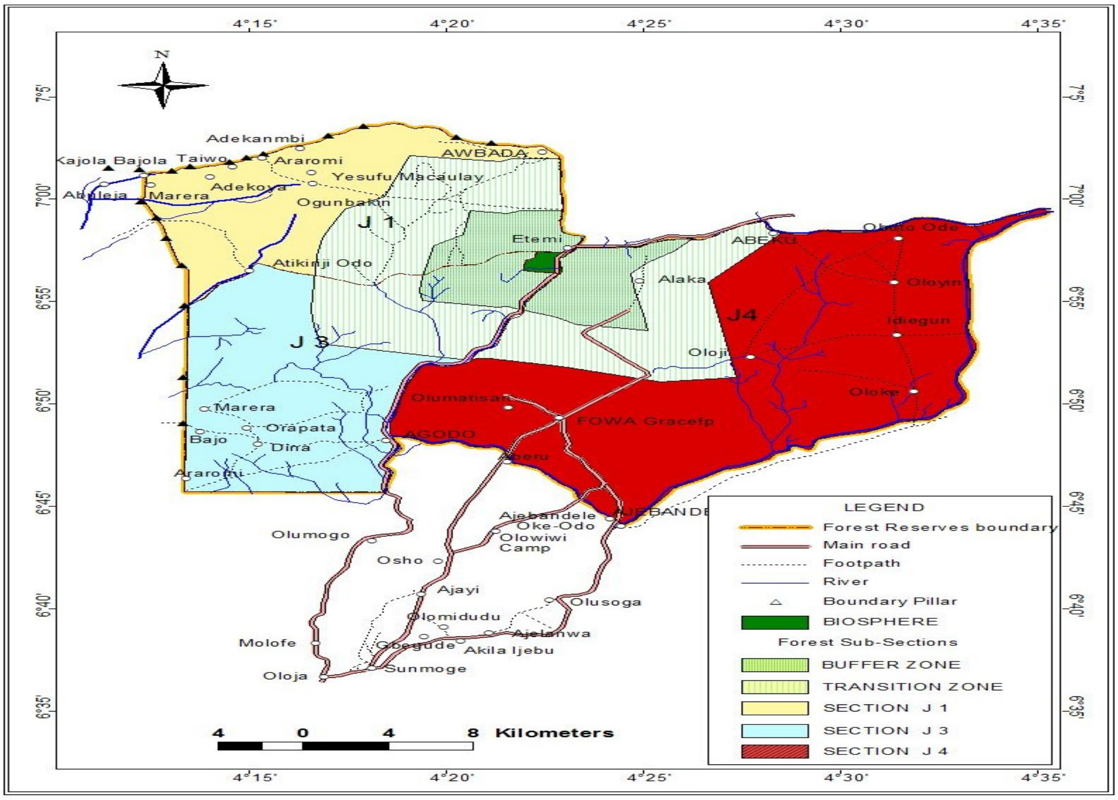

Fig 1: Map of Omo Forest Reserve showing the study area (Area J4)

Data collection

Three stand age series of *Nauclea diderrichii* were selected (47, 44 and 43 Years old) (in the study area. Ten (20m x 20m) temporary sample plots were laid in each stand at 10m intervals to give a total of 30 plots in all. The diameters at breast height (dbh), base (Db), middle (Dm) and top (Dt) and the total height (THt) of all trees in each plots were measured using spigel relascope. Wood density of this species (450kg/m^2) was obtained from literatures (i.e. Nigerian Standard Code of Practice, 1973 and Dinwoodie, 1981).

Data Analysis

Basal area estimation

The Basal Area (BA) of individual trees were estimated using the formula of Husch *et al*, (2003):

$$BA = \frac{\pi}{4} D^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where BA = Basal area (m^2), D = dbh (cm) and Π = 3.142 (constant)

Stem volume estimation

The volume of individual trees was estimated using Newton's equation developed for stem volume estimation (Husch *et al*, 2003):

$$V = \frac{h}{6}(Ab + 4Am + At) \quad \ldots\ldots 2$$

Slenderness coefficient (TSC)

$$TSC = \frac{THt}{dbh} \quad \ldots\ldots 3$$

According to Navratil *et al.*, (1994), slenderness coefficient values were classified into three categories.

TSC values > 99…………… High slenderness coefficient
70 < TSC values > 99……….Moderate slenderness coefficient
TSC values < 70 …………….Low slenderness coefficient

Where V = Stem volume (m^3), H = stem height (m), Db = Diameter at the base, Dm = Diameter at the middle, Dt = Diameter at the top and Π = 3.142 (constant)

Biomass and Carbon Stock Estimation

For estimating the aboveground biomass of the trees, six Allometric Equations were adopted and according to IPCC (2006), the equation Y = AGB x 0.5 was used in estimating the carbon stock.

Allometric Equations Adopted

Six models were selected for this study (eqn 4 – 9). These models were chosen base on their flexibility and suitability in the study area as recommended by some literatures such as Chave *et al.*, (2005), Cole and Ewel (2006), etc.

WITH an independent VARIABLE - DBH

- $Y = e^{(a + b_1 lnD + b_2 lnD^2 - b_3 lnD^3)}$ ………………………………………… 4
- $Y = e^{(a + b_1 lnD)}$ …………………………………………………………….. 5

- $Y = a + b_1D + b_2D^2$ 6

WITH 2 independent VARIABLES – DBH & WOOD DENSITY OR DBH & HEIGHT

- $Y = p * e^{(a + b_1 lnD + b_2 lnD^2 - b_3 lnD^3)}$ 7
- $Y = e^{(a + b_1 \ln D^2 * H))}$ 8

WITH 3 independent VARIABLES - DBH, WOOD DENSITY & HEIGHT

- $Y = p * e^{(a + b_1 \ln (p * D^2 * H))}$ 9

Where: b_1, b_2, b_3 and a represents the regression coefficients and regression constant respectively. D', 'p', 'H' and 'Y' are dbh, wood density (450kg/m^2), total height and carbon stock respectively.

The candidate models were subjected to statistical test to select the best predictive models. The best fit model was selected based on some model statistics criterion such as high coefficient of determination (R^2), low root mean square error, mean of residual, coefficient of variation and must be significant. The best fit model was validated using student T-test.

RESULTS

A total of 900 trees/ha were encountered in the 1971 stand, 875 trees/ha in 44 years old and 825 trees/ha in 43 years old stands. Table 1 shows the summary of the stands' growth variables. The maximum dbh in 47 years old stands was 63.34cm, in 44 years old stand it was 64.29cm and in 43 years old stand it was 81.16cm. This trend was also observed for the stand mean height. It was observed that between 44 and 43 years old stands, the growth rate of the trees was high as reflected in their dbh and height (44 years - max. dbh = 64.29cm, 43 years - max. dbh = 81.16cm and 44 yeras max. height=24.70cm, 43 years max. height=29.60cm). The dominant dbh in the 47 years old plantation was 24.51cm, it was 39.78cm for the 44 years old stand and 43.28cm for the 43 years old stand. The dominant height was found to be 17.20m, 18.40m and 23.10m in 47, 44 and 43 years old stands respectively.

The slenderness coefficient (i.e. the ratio of total height and diameter) values were classified into three categories according to Navratil *et al* (1994). The result of this study shows that most of the tree in the plantations have low slenderness coefficient (i.e SLC < 70). This implies that most of the trees are not prone to wind throw. Therefore, they have good standing and vigor (Navratil *et al.*, 1994).

Figure 2 shows the DBH distribution for the stand. Diameter class 20-29cm had the highest number of individuals (78) for 47 years old stand and 30-39cm (72) for 43 years old stand. For the 47 and 44 years old stand, the same number of individuals was recorded in diameter class 30-39cm (63). The least number of individual was recorded for the class 60 and above for all the stands: 3, 7 and 5 for 47, 44 and 43 years old stands respectively. Figure 3 shows the height class distribution. Height class 16-20m had the highest number of individuals (102) for 44 years old stand, 47 years old stand (94) for the same height class, 21-25m (83) for 43 years old stand. The least number of individual was recorded for height class < 5m for all the stands; 2, 1 and 4 for 47, 44 and 43 years old stands respectively. Height class >25 had 10/ha individual for 43 years old stand which was the only year it occurred in this height class.

The results of the aboveground biomass and carbon stock estimates are presented in Table 2. The mean aboveground biomass for 47, 44 and 43 years old stands are 1372.25kg/m^3, 1196.01kg/m^3 and 1213.04kg/m^3 respectively and the mean carbon stock for 47, 44 and 43 years old stands are 686.12kg, 598.00kg and 606.52kg respectively. The carbon stock was recorded highest (686.12kg) for 47 years old stand and the least carbon stock was found in 44 years old stand (598kg).

The aboveground biomass and carbon stock estimates are significantly different in 44 years old stand, however there was no significant difference between the mean value at 44 and 43 years old stand (Tables 3 and 4). Table 5 shows the models used for the biomass estimation. Model 2 gave the best fit and estimate of the biomass (93.51%), followed by model 3 (88.54%), model 5 (0.83%) being the poorest according to the statistical criteria for assessment.

Table 6 shows the correlation matrix for the stands. The result shows that there is a significant relationship between the dbh and basal area (0.9777) hence, as the dbh increases the BA increases. This is the same for dbh and volume (r = 0.97). The SLC (Slenderness Coefficient) has negative relationship with the dbh (-0.523) and basal area (-0.524). AGB (aboveground biomass) has a significant relationship with the volume at (1.00) but there was no significant relationship between AGB and dbh, basal area and height). Figure 4 is the graph showing the relationship between carbon stock (kg) and the natural logarithm of dbh while figure 5 shows the residual plot of estimated carbon stock.

Table 1: Summary of tree Growth Variables for Nauclea in the study area

Variables	Parameters	47 years old	44 years old	43 years old
DBH (cm/ha)	Mean	29.00	33.57	34.90
	Maximum	63.34	64.29	81.16
	Minimum	10.00	10.00	10.00
	Dominant	24.51	39.78	43.28
	Standard Error	0.73	0.936	0.815
Height (m/ha)	Mean	15.83	17.06	19.08
	Maximum	24.70	24.20	29.60
	Minimum	10.00	10.00	10.00
	Dominant	17.20	18.40	23.10
	Standard Error	0.28	0.267	0.366
BA (m^2/ha)	Mean	0.075	0.099	0.110
	Maximum	0.315	0.325	0.517
	Minimum	0.005	0.001	0.007
	Dominant	0.047	0.124	0.147
	Standard Error	0.004	0.006	0.005
Volume(m^3/ha)	Mean	2.658	2.696	3.049
	Maximum	5.554	5.900	7.814
	Minimum	0.487	1.030	1.065
	Dominant	3.278	3.315	3.952
	Standard Error	0.061	0.074	0.063
SLC	Mean	53.17	60.215	63.407
	Maximum	127.394	141.390	502.72
	Minimum	29.278	21.750	18.815
	Dominant	62.84	62.84	62.84
	Standard Error	1.280	2.898	1.361
No of trees/ha	Mean	36	35	33
	Total	900	875	825

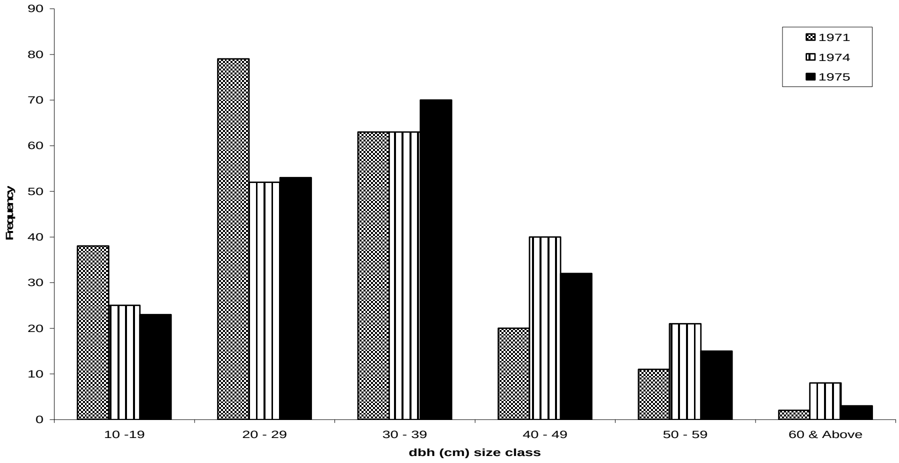

Fig 2: Diameter Class Distribution

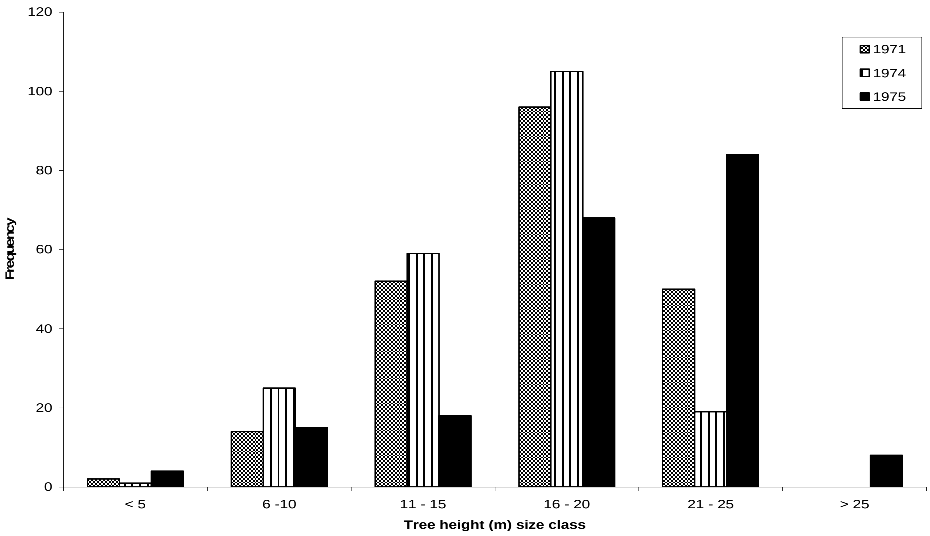

Fig 3: Height Class Distribution

Table 2: Summary of Estimated Aboveground Biomass (Kg/m^3) and Carbon Stock (Kg)

Parameters	Above Ground Biomass (kg/m^3)			Carbon Stock (kg)		
	1971 (47 Years)	1974 (44 Years)	1975 (43 Year	1971 (47 Years)	1974 (44 Years)	1975 (43 Year
Mean	1372.25	1196.01	1213.04	686.12	598.00	606.52
Maximum	2655.15	3516.32	2499.47	1327.58	1758.16	1249.73
Minimum	479.18	219.08	463.48	239.59	109.54	231.74
Standard Error	27.603	33.098	28.355	13.801	16.549	14.177

Table 3: ANOVA for Aboveground Biomass

SV	Sum of Squares	df	Mean Square	F-cal	F-tab
Plantation age	3981053.735	2	1990526.868	10.843*	2.996
Error	113079393.211	616	183570.444		
Total	117060446.946	618			

*significantly different at 5% probability level

Table 4: Mean Separation for Aboveground Biomass (kg/m^3)

Age (years)	Mean
44	1196.01^b
43	1213.04^b
47	1372.25^a

Means with the same superscript alphabets are not significantly different at 5% probability level

Table 5: Biomass Model and the Statistical criteria for assessment

Model	**Parameters**				**P-level**	**RMSE**	**R^2 (%)**	**Mean of residual**	**Std.dev. of residual**	**Sum of square of residual**	**Coeff of variation of residual**	**Ranking**
	a	**b_1**	**b_2**	**b_3**								
$Y = e^{(a + b_1 \ln D + b_2 \ln D^2 - b_3 \ln D^3)}$	3.42	1.03	-1.11	0.67	1.32×10^{-20}*	159.09	36.08	2.72×10^{-13}	158.69	4910285.15	5.83×10^{14}	4
$Y = e^{(a + b_1 \ln D)}$	1.09	-0.04			3.7×10^{-117}*	50.70	93.51	7.03×10^{-13}	50.57	498723.48	7.20×10^{13}	1
$Y = a + b_1 D + b_2 D^2$	0.37	3.18	0.11		3.46×10^{-93}*	67.38	88.54	2.02×10^{-13}	67.20	880675.53	3.32×10^{14}	2
$Y = p * e^{(a + b_1 \ln D + b_2 \ln D^2 - b_3 \ln D^3)}$	4.15	1.20	0.62	0.21	1.32×10^{-20}*	159.09	36.08	2.76×10^{-13}	158.69	4910285.15	5.75×10^{14}	5
$Y = e^{(a + b_1 \ln D^2 * H)}$	3.40	1.06			0.2039*	198.17	0.83	1.77×10^{-13}	197.66	7618399.23	1.12×10^{15}	6
$Y = p * e^{(a + b_1 \ln(p * D^2 * H))}$	0.05	1.00			1.62×10^{-53}*	107.83	70.64	3.17×10^{-13}	107.56	2255833.27	3.39×10^{14}	3

*Significant at 5% probability level

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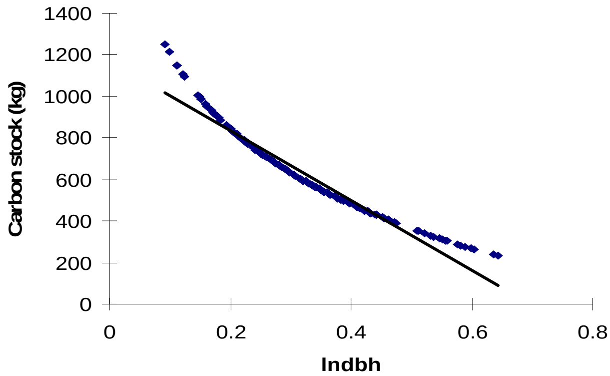

Figure 4: Relationship between Carbon Stock and lndbh

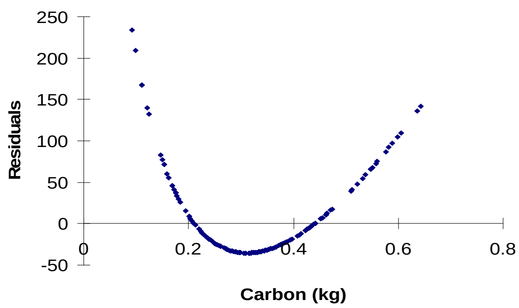

Figure 5: Residual Plot of Estimated Carbon Stock

Table 6: Correlation Matrix

	dbh (cm)	BA (m^2)	Vol (m^3)	H (m)	SLC	AGB (kg/m^3)	C (kg)
dbh (cm)	1						
BA (m^2)	0.977	1					
Vol (m^3)	0.967	0.892	1				
H (m)	0.588	0.514	0.650	1			
SLC	-0.523	-0.524	0.467	0.308	1		
AGB (kg/m^3)	-0.967	-0.892	1.00	-0.650	0.467	1	
C (kg)	-0.967	-0.892	1.00	-0.650	0.467	1	1

DISCUSSION

Allometric modeling has been used since the development of regression analyses in the first half of 20th century (Machado and Figueiredo 2003), only a few allometric models are available to estimate AGB of tropical forests (Cole and Ewel 2006). For tropical forests, most models have been developed using data from equatorial areas (Dawkins 1961, Brown *et al*. 1989, Overman *et al*. 1994, Brown 1997, Araújo *et al*. 1999, Chambers *et al*. 2001, Ketterings *et al*. 2001). This study used different allometric models (Chambers *et al.* 2001, Burger 2005, Tiepolo *et al.* 2002, Chave *et al.* 2005, Scatena *et al.* 1993) to estimate for aboveground biomass using data from *Nauclea diderrichii* plantation in Area J4. The slenderness coefficient values obtained from the analysis data were classified into three categories as suggested by Navratil *et al* (1994) as stated:

SLC values > 99 = High slenderness coefficient, 70 < SLC > 99 = Moderate slenderness coefficient and SLC < 70 = Low slenderness coefficient.

Adjudging the result of this study with above classification, the plantations have low slenderness coefficient (SLC < 70) with the mean values of 53.17, 60.215 and 63.407 respectively for 47, 44 and 43 years old stands. This implies that majority of the trees are not prone to wind throw because, they possess good standing and vigor. The variation in the diameter distribution of the trees was observed to be as a result of factors such as silvicultural treatments, available soil nutrients and above all human activities which are of a larger percentage (Navratil *et al.* 1994).

This study revealed that 47 years old plantation is dominated by trees with dbh (24.51cm), 39.78cm in 44 years old and 43.28 in 43 years old. Likewise for height 17.20m, 18.40m and 23.10m are the dominant tree height in 47, 44 and 43 years old stands respectively. The total number of trees account for 900 trees/ha, 875 trees/ha and 825 trees/ha in 47, 44 and 43 years old stands respectively. In other to select one or other of the existing models to estimate aboveground biomass, the ease with which it is possible to measure the independent variables in the model should be considered. Models that present more accurate estimates is preferred. This study has evaluated the effectiveness of estimating the above ground biomass and carbon stock in *Nauclea diderrichii* plantation using allometric models. The adoption of this method was solely aimed at estimating carbon stock without destructive approach because conservation of biological diversity is a driving force to sustain the environment Variation in the above ground carbon stock among these plantation is as a result of: tree stand density, hence, higher number of trees in a plantation will eventually result to high above ground carbon stock of that plantation. The result of correlation in all the plantation shows that increase in DBH will lead to increase in total height, which will eventually lead to an increase in above ground biomass, and an increase in the total carbon stock as a whole.

CONCLUSION

The developed allometric models for *Nauclea diderrichii* plantation has provided useful basis to improve the prediction of aboveground biomass and carbon stock; this will therefore assist better quantification of the environmental services function of forests in the carbon cycle for policy instruments.

The study concluded that biomass estimation can be obtained using any of the models with varying independent variables however model with only diameter at breast height (DBH) gives the best estimate. Tree sizes in terms of DBH and Total height also has a great influence on the above ground carbon stock of the plantation as it is shown on the result of correlation matrix of the tree variables

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