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ASSESSEMENT OF BIOMASS CONTENTSAND CARBON STOCK OF PLANTATION-GROWN NEEM SPECIE (*Azadirachta indica*) IN YOLA, NIGERIA

[1]Saka M. G., [2]Osho, J. S. A. and [3]Isa, H. D.

[1]Department of Forestry and Wildlife Management, Modibbo Adama University of Technology, Yola, Nigeria.
E-mail address: *sakmof@yahoo,com;* Phone Number: +2348039150569

[2]Department of Social and Environmental Forestry,University of Ibadan, Ibadan, Nigeria.
E-mail address: *jsaosho@yahoo.com;* Phone Number: +2348034009559

[3]Department of Forestry, Adamawa State Ministry of Environment, Yola, Adamawa State, Nigeria.
E-mail address: *harunaisadumne@gmail.com*; Phone Number: +2348101254041

ABSTRACT

The biomass contents and carbon stock of 22 years old plantation-grown neem (Azadirachta indica) species was assessed in Modibbo Adama University of Technology, Yola, Nigeria. Two-stage nested design was employed for data collection. Two plots of 100 x 100 m was randomly laid in the plantation, 4 sub-plot of 20 x 20 m were nested in each corner of the super plots. The total numbers of trees in each of .the sub-plot were enumerated and recorded, while, the diameter at breast height (≥ 10 cm) and the total height of the trees were measured. For biomass estimation, two trees were harvested at stump height in each of the sub-plots, and were separated into components: bole, branch and the foliage. The tree bole was sectioned into 2 m long billets, and a sample of 2-cm thick disk was extracted from top, middle and bottom of the 2 m sectioned bole. Green and oven-dry mass of the stem, branches and leaves were weighed to determine their moisture content (in percentage). Biomass contents were obtained as a product of tree volume, wood density and biomass expansion factor, while, the carbon stock was obtained by multiplying the biomass by constant (0.45). Results showed that the tree boles had the highest average biomass content of 22.30 kg, while the tree branch and the foliage had an average biomass of 2.53 and 0.008 kg respectively. There was no significant relationship (p > 0.05) between the estimated biomass and carbon stored by Azadirachta indica among the components assessed. The study has shown that the biomass content in the bole of A. indica is higher than those in the branch and leaf, while the stored carbon content is higher in the branch than the bole and the leaf components.

Keywords: Forest ecosystems, destructive, nested, Biomass, carbon stock.

INTRODUCTION

Forest plantation has been gaining importance due to their role in mitigating atmospheric carbon dioxide in the nation's context of climate change (Hughton, 2005). As carbon dioxide (CO_2) drastically enhances greenhouse effect and global warming, which in turn trigger climate change, forest proves to be promising means of combating this undesirable phenomenon by their unique ability to store large volumes of carbon in their biomass (Hughton 2005). Reduction of forest areas has a great impact on the amount of carbon dioxide stored in the atmosphere (Sivaram *et al.*, 2016), because forest is the great essential source of the world producing oxygen and storing carbon dioxide. Importantly, the carbon dioxide is an influential gas leading to climate change. Estimating the aboveground biomass content is necessary for considering total carbon content stored in forest ecosystem. Biomass density of each area in the tropical forest widely varies according to weather, soil, topography, and forest utilization.

However, a rapid rise in the rate of deforestation especially in the tropics increases the amount of CO_2 in the atmosphere, posing a possible peril to the atmosphere due to rise in temperature leading to climate change (Lewis, 2009). In this era, plantation forestry has turned out to be a preferential option for carbon sequestration and storage. Besides timber production, forest plantation also helps to deliver a range of environmental benefits. These include salinity amelioration by reversing rise of saline water table; reducing green house effects; reducing soil erosion and providing shelter belt for crops and pastures (Peter and Stanley, 2003). Biomass estimation is important for national development planning as well as for scientific study of ecosystem productivity and carbon budget (Zianis *et al*., 2004). Recently biomass is being increasingly used to help quantifying the pool and fluxes of greenhouse gases (GHGs) from terrestrial biosphere associated with land used and land cover changes (Cains *et al*., 2003).The importance of terrestrial vegetation and soil as significant sink (house) of atmospheric CO_2 and its other derivatives has been highlighted by (Mani and Parthasarathy, 2007). Vegetation especially, forest store carbon in the biomass through photosynthetic process thereby sequestering Co_2 that would otherwise be present in the atmosphere.

Tropical forests are an important component of global carbon stocks. They contribute an estimated 428 Pg (1Pg = 1015 g) of carbon globally, divided approximately evenly between vegetation and soils (Watson 2000). This total is approximately one fifth of the global carbon stock, and the vegetation component is one half of the above-ground carbon stored in vegetation of all biomes. However, there is a great deal of uncertainty in these numbers (Watson, 2000). While some of this uncertainty is due to the unknown amount of de- forestation and degradation in tropical forests, another large component is due to the uncertainties involved in estimating standing biomass in the field (Houghton, 2005). This uncertainty is compounded when a few sampled areas is used to predict biomass over large tracts of forest (Hunter *et al*., 2013).

The tree biomass from forest ecosystems plays a key role in the sustainable management of natural resources and also for the contribution of forest in the global carbon cycle (Brown 2002). The effect of climate change, which causes global warming needs to be addressed, and this can be achieved by knowing the total amount of carbon being stored or emitted from the earth. Although, biomass studies are very costly, time consuming if destructives methods was adopted, but the knowledge to be gained may help to reduce the uncertainty associated with carbon accounting at regional and national level (Vahedi *et al.*, 2014).

Research has shown that management of a forest greatly influence the transfer of carbon between the terrestrial forest ecosystem and the atmosphere. Hence, estimating the forest carbon stocks is mainly important to assess the magnitude of carbon exchange between the forest ecosystem and the atmosphere. This study therefore, assessed the estimation of aboveground biomass content and carbon stock content in a plantation-grown *A indica* species in Yola. The stocking density and best prediction equation for biomass content was also explored.

MATERIALS AND METHODS

Study Site

The study was carried out in the Department of Forestry *Azadirachta indica* (Neem) plantation, Modibbo Adama University of Technology, Yola. It is located within Latitude 9^{0} 35” to 10^{0} 25” N and Longitude 12^{0} 55” to 14^{0} 55”E (Figure. 1). The soils of the study area range from sandy loam underlined by salty clay, to sandy loam. Soil pH is acidic (6.5 - 6.9). Total nitrogen and phosphorus is low. Generally the area is semi-arid and of low fertility (Musa, 2006). Rainfall starts in April and becomes more intense in August and September and periods of no rainfall exist between January and March. Temperature varies between 26.9 °Cand 27.8 °C mean annually while the minimum temperature can be as low as 18 °C between December and January and maximum temperature about 40 °C, depending on the season of the year. The relative humidity of the study area varies between 30 – 80 % depending on the particular period of the year (Adebayo and Tukur, 1999).

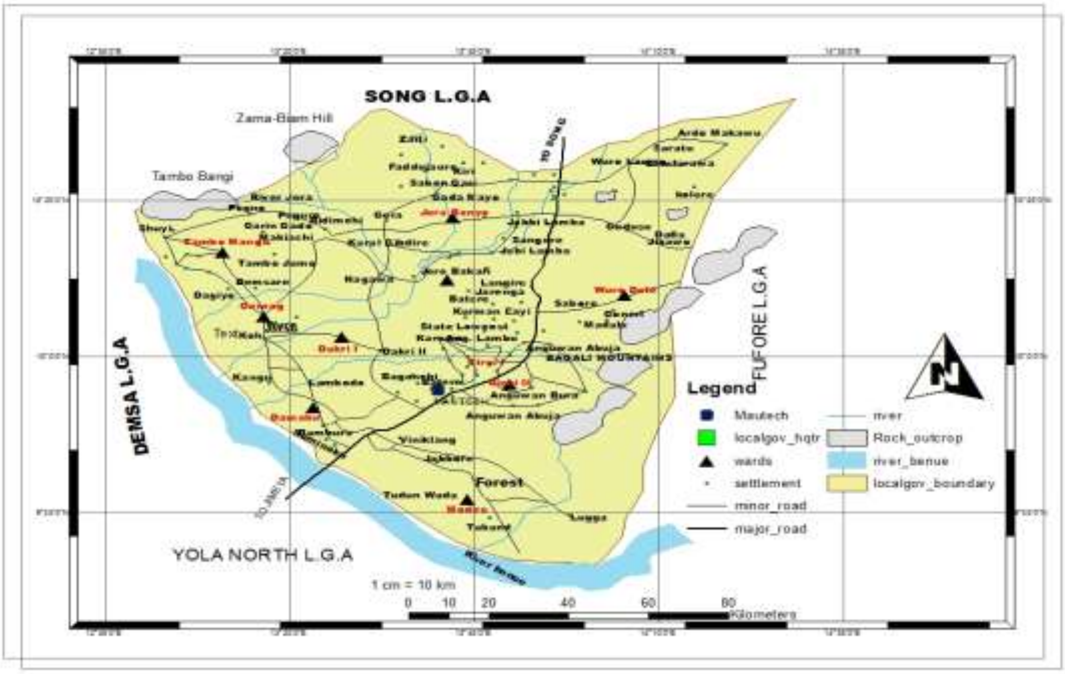


Figure 1: Map of *Azadirachta indica* (Neem) plantation, Modibbo Adama University of Technology, Yola.

Sampling Technique

A two-stage nested sampling design was employed in this study, Two super plot of 100 x 100 m, was randomly laid in the plantation, while in the second stage (4 sub-plots) of 20 x 20 m in size was systematically laid at each corner (embedded) of the super plot.

Data Collection

In each sub-plot, the total numbers of trees was enumerated, and the diameter at breast height (dbh) of each tree in the plot was measured at 1.3 m on the uphill side of the tree, using diameter tape. Tree height was measured, using, Christen's hypsometer. Destructive method was employed for this study. In each sub-plot, two trees were harvested at stump height; these were separated into three components viz: the trunk (bole), branch and foliage. The tree bole was sectioned into 2 m length, and a sample of 2 cm disk was extracted from top, middle and bottom of the tree bole (Peichl and Arain, 2006; Zhu *et al.*, 2010). Samples of the branch and foliage, as well as the tree disk were weighed fresh in the field to obtain the wet mass of each component before being taken to the laboratory for oven-drying.

Laboratory Procedures

All the sampled components were oven-dried at 105 °C to constant mass. The dry mass was determined with an electronic balance in the laboratory and was used to estimate the moisture content, the basic wood density was estimated by finding the ratio of dry and green weight ratio, (Equation 1.) while, the aboveground biomass was obtained from the product of wood density and the tree volume (Equation 2). Biomass expansion factor (BEF) was also estimated as the ratio of dry weight to the tree stock volume (Equation 3), while, the quantity of carbon stock stored was expressed as 50 % of the aboveground biomass density (Akindele 2016).

$$MC = \frac{WW - DW}{WW} X\ 100 - - - - - - - - - - - - - - - (1)$$

$$WD = \frac{DW}{WW} - (2)$$

$$BM = WD\ X\ TV - - - - - - - - - - - - - - - - - - - (3)$$

where:
M.C = Moisture Content (%)
WW = Wet weight (Kg)
DW = Oven dry weight (Kg)
WD = Wood density (Kg/m^3)
TV = Tree Volume (m^3)
BM = Biomass

Data Analysis

The output of the collected data from tree measurement and laboratory procedures was processed into a suitable form, using the following statistical tools (Equation 4 - 6)

i. One way analysis of variance (CRD – Completely Randomized Design):

$$Y_{ij} = \mu + t_i + \varepsilon_{ij} - - - - - - - - - - - - - - - - (4)$$

where:

Y_{ij} = Individual observation

μ = General Mean

t_i = Biomass component

ε_{ij} = Error term

ii. Pearson Correlation coefficient:

$$r = \frac{\Sigma XY - \frac{(\Sigma X)(\Sigma Y)}{N}}{\sqrt{\left(\Sigma X^2 - \frac{(\Sigma X)^2}{N}\right)\left(\Sigma Y^2 - \frac{(\Sigma Y)^2}{N}\right)}} - - - - - - - - - (5)$$

Y = Dependent variable (Biomass)
X's = Independent variable (DBH, TH, BA)

iii. Regression equation:

$$Y = \alpha + \beta X - - - - - - - - - - - - - - - - - (6)$$

Y = Biomass; α = Constant; β = Slope

X = Tree Variable (Height, Diameter).

The bias and model efficiency was estimated, using equation (7) and (8) respectively.

$$Bias = \frac{\Sigma(\hat{y}_i - y_i)}{n} - - - - - - - - - - - - - (7)$$

$$ME = 1 - \frac{\Sigma(y_i - \hat{y}_i)^2}{\Sigma(y_i - \bar{y}_i)^2} - - - - - - - - - - - - - (8)$$

where:

n = Number of observation;
= Average Measured biomass;
$\hat{y}_i$ = Predicted biomass;

ME = Model efficiency

RESULTS

Stocking Density of Neem (*Azadirachta indica*) Specie in the Study Area

A total of 395 trees were measured in the 22 years old *Azadirachta indica* plantation for this study. Presented in (Table 1) are the values obtained from the measured variable in the 8 plot of 20 x 20 m laid within the two super plots. The results revealed that the diameter at breast height (dbh) and the tree total height (TH) of the specie ranges from 9.4 – 12.0 cm and 5.4 – 7.9m respectively, while, the plot basal area and plot volumes ranges between 0.359 – 0. 618 m^2 and 1.950 and 3.971m^3. In term of stoking density, a total number of 9,875 trees were recorded per hectare, while, the basal area and the volume of the tree per hectare were 100.00 m^2 and 636 m^3 respectively. The results indicated that the trees are yet to reach diameter girth limit (30 cm) for timber, but can be thinned for telegraph or electrical pole, to create room for girth development. Also presented in Figure 2 was the distribution of the number of trees per hectare into diameter classes, a high peakedness and negatively skewed distribution of the number of trees per hectare was observed at dbh class of 9-12 cm interval, which indicated that majority of the trees in the study areas lies towards the lower diameter class, while fewer trees were towards the larger dbh classes.

Table1. Stand Density of Neem (*Azadiracta indica*) species in the Study Area

PLOT No	No. of Trees Per Plot	DBH (cm)	TH (m)	Plot BA(m^2)	Plot Volume (m^3)	No of Trees Per Ha.	BA (m^2/Ha)	Volume (m^3/Ha.)
1.	55	10.2	7.9	0.504868	3.9632	1,375	12.62	99.080
2.	42	10.0	6.4	0.377732	2.3986	1,050	9.44	59.965
3.	56	10.2	6.5	0.499235	3.2350	1,400	12.48	80.875
4.	47	9.4	5.4	0.359106	1.9499	1,175	8.97	48.747
5.	43	9.9	6.1	0.505315	3.0824	1,075	12.63	77.060
6.	48	11.8	6.4	0.546953	3.4731	1,200	13.67	86.827
7.	52	12.0	5.4	0.617553	3.3533	1,300	15.44	83.832
8.	52	11.9	6.6	0.606198	3.9706	1,300	15.15	99.265
Total	395	96.5	50.7	5.0265	25.4261	9,875	100.00	636.000

Key: DBH = Diameter at Breast Height; BA = Basal Area; TH = Tree Height

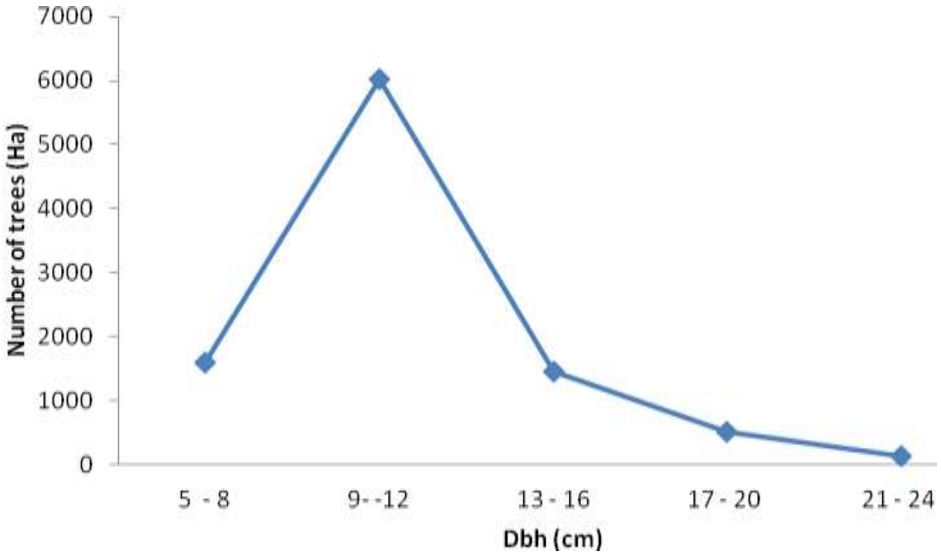


Figure 2: Diameter Distribution of Number of Trees per Hectare

Estimation of the Aboveground Biomass and Carbon content in the Study Area

The mean, maximum and minimum estimated above ground biomass (AGB) and the carbon content of *A.indica* is presented in Table 2. It was revealed that the bole component of the studied species (Neem) had the highest mean biomass content of 22.304 kg ha^{-1}(±3.853), this was followed by the branch component with mean of 2.536 kg ha^{-1} (± 1.107) while, the least biomass of 0.08 kg ha^{-1} (± 4.503) was recorded for the. leaf (foliage) component. Presented in Figure 3 is the Bar chart indicating the variation in biomass and carbon contents of *A. indica* . These show that the trunk (bole) component of *A indica* contains larger amount of aboveground biomass contents than the branch and leaf section of the tree. To check for significance difference among the AGB of the tree components examined, analysis of variance was conducted, and it was revealed that, there was a significant difference ($p < 0.05$) among the three components examined, this indicated that the biomass content in the tree bole, branch and the leaves differs (Table 3). The result on the estimated carbon stock of *A indica* specie also revealed the highest mean biomass of 10.483 kg ha^{-1} in the bole component, while an average biomass of 1.192 and 0.004 kg ha^{-1} was estimated for the tree branch and leaf respectively (Table 2). Analysis of variance conducted shows significance difference ($P < 0.05$) among the three components (Table 3).

Table 2:Summary Statistics of the Estimated Aboveground Biomass and Carbon Stock in *Azadirachta indica* Plantation.

Variable	Mean	Maximum	Minimum	Standard Deviation	Standard Error
Biomass (Kg/ha)					
Bole	22.304^{a}	45.903	8.820	10.910	± 3.853
Branch	2.536^{b}	9.805	0.168	2.133	± 1.107
Leaf	0.008^{b}	41.66	0.004	12.73	± 4.503
Total					
Carbon Stock (Kg/ha)					
Bole	10.483^{a}	21.574	4.145	5.127	± 1.813
Branch	1.192^{b}	4.609	0.079	1.473	± 0.521
Leaf	0.004^{b}	0.006	0.002	0.002	± 0.001
Total					

Means following with the same alphabet are not significantly different (p < 0.05)

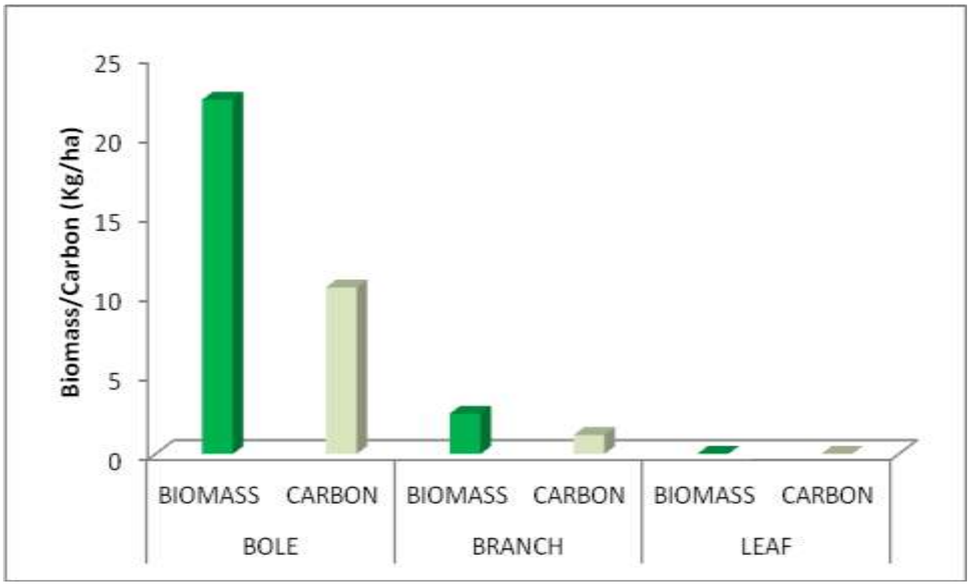


Figure 3. Bar Charts showing estimated percentages of Biomass and Carbon content in *A. indica* Plantation.

Table 3: Analysis of Variance for Aboveground Biomass and Carbon Stock

Source of Variation	Sum of Square	Degree of Freedom	Mean Square	Computed F-Value	Probability Value	Critical F-Value
Aboveground Biomass						
Biomass Components	2384.69	2	1192.345	27.76017	1.26954E-06	3.4668*
Error	901.9846	21	42.95165			
Total	3286.675	23				
Carbon Stock						
Carbon stock	526.7781	2	263.389	27.76017	1.27E-06	3.4668*
Error	199.2484	21	9.488019			
Total	726.0265	23				

*Significant ($P < 0.05$)

Correlation of the Aboveground Biomass (AGB) with the Tree Variables

The degree of association existing between the estimated aboveground biomass and the tree variables was also evaluated. Pearson's correlation coefficient (Table 4.) conducted shows that there was a high significant positive correlation (0.77) between aboveground biomass and tree height. Also, there was a moderate and low negative correlation of (-0.53) and (0.30) with the dbh and basal area respectively. Although, there was a strong relationship between the dbh and the basal area of the studied species, while, low negative correlation (- 0.06) existed between the tree dbh and total tree height.

Table 4: Pearson's Correlation of the Aboveground biomass with biometric variables

Variable	Biomass	DBH	BA	TH
Biomass	1			
DBH	-.531	1		
BA	-.298	.863**	1	
TH	.772*	-.058	.099	1

**. Correlation is significant at the 0.05 level: **. Correlation is significant at the 0.01 level.*

Key: *DBH = Diameter at Breast Height; BA = Basal Area; TH = Tree Height*

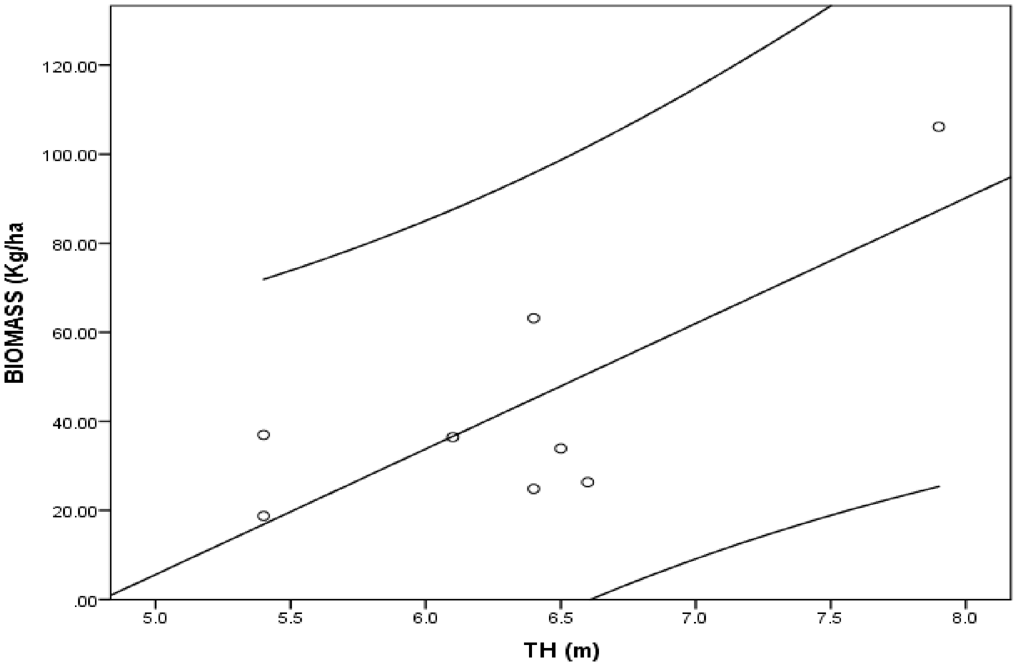
Prediction Equation for Biomass Content of *A indica* Specie in the Study Area: Transformed and untransformed explanatory variables were used to predict the aboveground biomass of *Azadirachta indica* in the study area. After several iterations, models (Table 5) with high coefficient of determination (R^2) or lower standard error of estimate (SEE) were selected. These models were further subjected to screening and the best model (Model 1) among the five candidate models, which uses the tree diameter (D) and the square of the tree height (H) as the explanatory variables was chosen due to its high R^2 value (87.2%) and low standard error of estimate (0.2012). The bias and the model efficiency was estimated as -1.72 and 0.46 respectively.

Table 5: Predicted Equations for *Azadirachta Indica* Plantation

Model	Equation	R^2 Value	SEE	Bias	ME
1.	$L n (B) = 4.734 – 0.277D + 0.003H^2$	87.2	0.2012	-1.72	0.46
2.	$Ln (B) = -2.702 + 0.413H + 32.744D^{-1}$	87.2	0.2013		
3.	$Log (B) = 1.513 – 0.122D^2H +41.127D^{-1}$	86.7	0.0889		
4.	$B = -45.176 + 10.655H$	59.5	7.4871		
5.	$B = 52.272 – 0.260 D^2$	29.4	9.8914		

B = Aboveground Biomass; D = Diameter; H = Tree Height; Ln = Natural logarithm

Key: SEE = Standard Error of Estimate; ME = Model Efficiency



. **Figure 4: Graph showing relationship of the Tree Height with the Aboveground Biomass.**

DISCUSSION

Stocking Density of Neem (*Azadirachta indica*) Specie in the Study Area

Quantification of tree biomass is a time-consuming activity, especially the measurement of certain biomass components, such as the bole, foliage and branches. The higher value of stem per hectare obtained from this study is in accordance with Gillespie *et al*., (2000) and Saka, (2015), who reported a higher value of stock density in their works, carried out on species diversity composition in central America and growth and yield study on eucalyptus species in Nigeria respectively. The negatively skewed diameter distribution exhibited at diameter class of 9 – 12 cm is an indication that majority of the trees in the study site is of pole sizes, but, if management objectives is for timber purpose (30 cm dbh), a routine thinning should be carried out to give room for tree girth expansion.

Estimation of the Aboveground Biomass and Carbon content in the Study Area

The forest carbon stocks are widely estimated from the allometric equations for forest biomass. Generally, the carbon concentration of the different parts of a tree is assumed to be 50% of the biomass (Brown, 1996) or 45% of the biomass (Whittaker and Linkens, 1973).The largest amount of dry mater found in the tree trunk of *A. indica* species was similar the trends which has been reported by Kraenzel *et al.,* (2003) and Ganeshaiya *et al.*, (2003) in teak plantations. Also, for the estimated carbon stock, the bole component had the highest mean mass of stored carbon (10.48 Kg ha^{-1}), while the branch and the leaf had 1.19 and 0.004 Kg ha^{-1} respectively. The result obtained in on carbon stock in the Neem species here in Nigeria is in contrary to the result obtained by Carlos *et al.,* (2015) who reported that the highest carbon content was found in the leaf component of *Elias guinensis* in North eastern Brazil. The low amount of biomass content and carbon stock recorded in the Neem plantation may be attributed to the age of the plantation, this result agrees with that of Gower *et al*. (1996) that the aboveground net primary production declines with age, which according to Steppe *et al.*. (2011) is related mainly to changing respiration intensity and carbon gains of trees over their lifespan.

Prediction Equation for *A. indica*

The high positive correlation exhibited between the tree heights and the biomass in this study is similar to the findings of Skovsgaard and Vanclay, (2008) in their work in which a reliable relationship existed between tree height and stand density. However, the relationship between volume and stand height is usually represented by a curve, and these actually depends on stand management. The use of diameter at breast height and the square of the tree height as explanatory variables gave the best prediction equation for the transformed estimated biomass. The report of this study is in consistent with Segura and Kanninen (2005); Carlos *et al*. (2015) and Ostadhashami *et al*. (2014) who used diameter at breast height to predict aboveground biomass in their different countries.

CONCLUSION

The results of this study have shown that there are variations in the amount of biomass content assessed in the *A. indica* plantation. It was found that the tree trunk had the highest biomass content, indicating that, most of the carbons from carbon-dioxide being trapped by the leaves during photosynthesis are stored in the tree trunk. Conclusively, the study has revealed that Neem (*Azadirachta indica*) harbours moderately carbon pool on earth and also acts as a major source of carbon sinks in nature, therefore, stake holders and forest managers should cultivate the habit of conserving the forest for carbon sustainability, posterity and for climate change mitigation.

REFERENCES

Adebayo A. A., and Tukur A L. (1999). Climate 1(sunshine, temperature, evaporation and Relative humidity), Adamawa state in Maps, Adebayo, A.A and Tukur, A.L. (Eds).pp.20-26.

Akindele, S, O. (2016) Pre-Conference Capacity-Building Workshop on “Emerging Issues in Tropical Forest Measurements” held at Delta State University, Abraka, Delta State from 25th – 26thApril, 2016.

Brown, S. (1986). Estimating Biomass and Biomass Change of Tropical Forests: A Primer. Rome: FAO Forestry Paper 134.

Brown, S. (2002). Measuring carbon in forest; Current status and future challenges Environmental pollutant 116: 363 -372. Building workshop Pp 1 – 17.

Cairns, M. Olmsted, A. L., Gradanos, J. and. Agraeg, J. (2003) Composition and above ground tree biomass of dry Semi eve gram forest on Mexico’s Yucatcin Peninsula. *Forest ecology and management*, 186: 125-132.

Carlos, S., Silvio, P., Ana, P.D.C., Aurelio, L. R., Alexandre, B. and Mateus, N. I .S. (2015).

Quantifying Biomass and Carbon Stocks in Oil palm (*Elais guinensis*) in Northestaren Brazil. *African Journal of Agriculture Research Vol. 10 (43) 4067 – 4075*

Ganeshaiah KN, Barve N, Nath N, Chandrashekhara K, Swamy M. (2003) Carbon allocation in different components of some tree species of India: A new approach for carbon estimation. *Curr Sci* 85: 11- 23

Gillaspie, T. W., Grijalua, A. Farris, C. N. (2000). Diversity, Composition and Structure of Tropical Dry Forest in Central America. *Plant Ecology.*147: 37-47

Gower, S. T., McMurtrie, R. E., Murty, D., (1996). Above- ground net primary production decline with stand age: potential causes. Tree, 11:378–382.

Houghton, R. H. (200)5. Above-ground forest biomass and the global carbon balance. *Global change Biology*. 11: 945-958.

Hunter, M. O. , M. Keller1, D. Victoria, and D. C. Morton (2013). Tree Height and TropicalForest Biomass Estimation. *Biogeosciences*, 10: 8385–8399.

Kraenzel M, Castillo A, Moore T, Potvin C (2003). Carbon storage of harvest-age teak (*Tectona grandis*) plantations, Panama. Forest Ecology Management 173: 213-225.

Lewis S. L, 2009 Increasing carbon storage in intact African tropical forests. Nature 457: 1003–1007.

Musa H, (2006). Characterization and Evaluation of Soil of School of Agriculture and

Agricultural Farm. Unpublished M.Tech. Thesis, Department of Soil Science, Federal University of Technology, Yola, Nigeria.

Ostadhashami, S..Shahraji, T. R., Roehle, H. and Limae S. M. (2014). Estimation of biomass and carbon storage of tree plantation in Northern Iran. Journal of Forest Science 60 (9): 363- 371.

Peichl M. and Arain M.A. (2006). Above- and belowground ecosystem biomass and carbon

pools in an age-sequence of temperate pine plantation forests. *Agricultural and Forest Meteorology*, 140: 51–63.

Peter, R, and Stanley, S. (2003) Measurement and Prediction of Biomass and Carbon Content of *Pinus pinaster* trees in farm Forestry Plantations, South-Western Australia. *Forest Ecology and Management* 175: 103 – 107.

Saka, M. G. (2015). Growth and Yield Models for Sustainable Management of Plantation-Grown Eucalyptus Species in Afaka Forest Reserve, Kaduna State, Nigeria. University of Ibadan Unpublished Ph.D. Thesis. 234p.

Segura, M and Kanninen, M. (2005). Allometric Models for tree volume and total aboveground Biomass in Tropical Humid Forest in Costa Rica. *Biotropica* 37 (1): 2 – 8.

Sivaram,M, Sandep, S. and Matieu, H. (2016). Status of Forest Biomass and Carbon Stock Assessment in South Asia. *Indian Forester* 142 (1): 81 -85

Skovsgaard, J.P.and Vanclay, J.K., (2008). Forest site productivity: Review of the evolution of dendrometric concepts for even-aged stands. *Forestry* 8: 13-31.

Steppe, K., Niinemets, Ü., and Teskey, R. O., (2011). Tree size-and age-related changes in leaf physiology and their influence on carbon gain. In: Size-and age-related changes in tree structure and function. Springer Netherlands, p. 235–253.

Vahedi M, A, Mataji A, Babayi – Kafaki,S, Eshaghi –Rad. J, hodjati, S.M and Djumo, A (2014). Allometric equations for predicting aboveground biomass of beech – hornbeam stands in the Hyrcanian forest of Iran. *Journal of Forest Science*, 60 (6): 236 -247.

Mani, S. And Parthasarathy, N. (2007): Aboveground Estimation in ten Tropical Dry Evergreen Forest Sites of Peninsular, India. *Biomass and Bio-energy* 31: 284 - 290

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. (eds) (2000). Land Use, Land-Use Change and Forestry, IPCC Special Report, Cambridge University Press, Cambridge, 377 pp.

Whittaker RH, Linkens GE (1973) Carbon in the biota. In Woodwell GM, Pecan EV, Carbon in the biosphere, Proceedings of the 24th Brookhaven Symposium in biology. Upton, New York: United States Atomic Energy Commission 281- 302.

Zhu B., Wang X., Fang W., Piao S., Shen H. and Zhao S., Peng C. 2010: Altitudinal changes in carbon storage of temperate forests on Mt Changbai, Northeast China. *Journal of Plant Research*, 123: 439 – 452.

Zianis, D. and Mencuccini, M. (2004).On Simplifying Allometric Analysis of Forest Biomass. *Forest Ecology and Management*. 187: 311 – 332.