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Forecasting carbon sequestered in leaf litter of *Tectona grandis* species using tree growth variables

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ABSTRACT

Forests have several pools that acts as carbon sink to atmospheric carbon which is released by anthropogenic causes. Leaf litter is one of those very important pools whose role in nutrient cycling and carbon sequestration cannot be overemphasized. This study was conducted to develop equations for carbon stored in leaf litter of *Tectona grandis* using tree growth characteristics as explanatory variables. Data was collected from four 20 m × 20 m sample plots which were randomly selected. Within each plots, four litter traps were set to collect leaf litter on a weekly basis. The collected litter was further taken to the laboratory for carbon analysis. The tree growth variables measured in the plots were processed into suitable form for statistical analyses using descriptive statistics in form of tables, charts and graphs and inferential statistics using correlation and regression analysis. Different equation were developed and tried with different tree growth characteristics with a view to select the best equation among the simulated ones. The equation with a highest coefficient of determination (R^2) and lowest standard error of estimate (SEE) was selected as the best fit. The average leaf litters produced per day ranged from 2.26g/m^2 to 7.67g/m^2, the maximum and minimum values of carbon stored in the studied species was 63%, 59% respectively. All the tried equations were significant and fit the data set well. The result showed that the logarithm equation has the highest R^2 and lowest SEE values and was therefore selected as the best model. Result from the validated models showed that all tried equations except the exponential equation were good for prediction. Conclusively, the ability of the forest to sequester carbon is a function of the biomass production which is linked to the litter fall produced by the system. Since litter fall represent a major flux for the transfer of carbon and other nutrients between the vegetation and soil, it should therefore not be altered in order not to have an effect on below ground processes. Even though the scope of this study only covers a very small area and sample

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of the Nigeria forest, it is still very important for prediction of leaf litter carbon and hence, served as a tool for sustainable forest management.

***Keywords*:** Carbon, Correlate, Equations, Forest, Litter, Sequestration, Significant, *Tectona grandis*

1. INTRODUCTION

Anthropogenic activities has led to increased concentration of greenhouse gases especially carbon and these has led to the search for ways to reduce CO_2 emissions and carbon sequestration from the atmosphere in order to mitigate the potential effects of global warming and climate change (Eguakun and Adesoye, 2016). Carbon (C) is the building blocks of all living organism because it makes up the skeleton of macromolecules that create the storage matrix for N and other nutrients and gives structure to all living organisms (Berg and McClaugherty, 2008). Atmospheric carbon in form of carbon dioxide (CO_2) is fixed by plants through the process of photosynthesis. Pan *et al*., (2011) stated that recent estimates of net annual carbon storage show forests as an important carbon sink, sequestering more carbon from the atmosphere than they are emitting.

Litter fall is one of the various carbon pools that exist in a forest ecosystem. It represents a major pathway for the transfer of carbon and nutrients between the vegetation and soil and as such, any alteration in litter fall will have an effect on below ground processes (Sayer *et. al*., 2011). Carbon stored in litter fall plays as an important part of whole carbon pools of forest ecosystems just like other pools. Due to the role carbon plays in greenhouse gases, different programs which are believed to be an incentive to promote forest conservation has been formed (Moutinho *et al.,* 2005). These programs have focused mainly on above ground biomass C despite the enormous contribution of litter fall in C sequestration.

Soils and litter fall are known to contain more C than the vegetation and atmosphere combined (Lal, 2004). However, information on carbon stored in leaf litter fall is rather poor or very scanty in Nigeria. Hence this study was focused on estimating and forecasting carbon stored in leaf litter fall using tree growth characteristics as the explanatory variable,

2. METHODOLOGY

2. 1. Study Area

This study was carried out in the Arboretum, University of Port Harcourt, and Rivers State, Nigeria. The University of Port Harcourt is located on a land area of about 400 hectares in Obio/Akpor Local Government Area of Rivers State (Latitude 4.90794 and 4.90809 N and longitude 6.92413 and 6.92432 E). The area is characterized by two seasons, the dry season and wet season with a rainfall distribution that is nearly all year round (Aiyeloja *et al.*, 2014). The arboretum is located at the North Eastern area of Abuja campus of the University, and covers a total land area of about 4226.25815 m^2 containing several tree species including *Gmelina arborea, Tectona grandis, Khaya grandifoliola, Nauclea diderrichii, and Irvingia gabonensis.*

2. 2. Data Collection

Data was collected from temporary sample plots due to the fact that permanent sample plots are not available in the study area. Four (4) Plots of 20m × 20m (0.04ha) in size were randomly located in the *Tectona grandis* plantation. All the trees in the selected plots were enumerated and the number of trees in the selected plot was identified.

2. 3. Measurement of Tree Variables

Within each sample plot, the following tree variables were measured for all trees:

i. Total height
ii. Clear Bole height
iii. Crown length
iv. Crown diameter
v. Diameter outside bark at breast height (DBH, 1.3m above the ground)

Haga altimeter and distance tape was used for the height measurements while diameter tape was used to measure diameter outside bark at breast height.

2. 4. Collection of Litter Sample

Within each plots four (4) litter traps at 8m apart were set at random to collect litter on a weekly basis. The collected litter was pooled for each plot at the sampling time. The collected litter was put on a zip-lock bag and taken to the laboratory for analysis on the weight of litter as well as carbon content determination.

2. 5. Data analysis

The data collected from tree measurement were processed into suitable form for statistical analysis. Data processing includes stem volume estimation, basal area estimation, crown variable estimation and carbon stored in leaf litter.

2. 6. Stem volume estimation

The stem volume for each tree in each sample plot was estimated using the Huber's formula as presented by Husch *et al.*, (1982)

$$V = g_m x L - - - - - - - - Equation 1$$

where: V = Stem volume (m^3), g_m = cross sectional areas at the middle of the tree (m^2), L = length or height of the solid.

2. 7. Basal area estimation

The basal area for each tree in each sample plot was estimated using the formula

$$BA = \frac{\pi D^2}{4} - - - - - - - - Equation 2$$

where: BA = Basal area, D = diameter at breast height (m)

2. 8. Crown variables estimation

Crown projection area for each tree in the plots was estimated using the formula

$$CPA = \frac{\pi(CD^2)}{4} ------ Equation\,3$$

where: CPA = crown projection area and CD = crown diameter.

Crown ratio will also be computed for each tree using the formula

$$CR = \frac{CL}{H} ------ Equation\,4$$

where: CR = crown ratio, CL = crown height and H = total height.

2. 9. Determination of total carbon

Two (2)g of each sample was weighed into a crucible and the crucible was placed in a furnace at 500 °C for 2 hours. The furnace was allowed to cool and the sample was weighed to determine the final weight of the sample. The loss in weight was determined and the percentage organic matter calculated.

% organic matter = loss in weight / weight of sample used × 100 ------ Equation 5

2. 10. Statistical analysis

Descriptive (tables and graph) and inferential statistic was used in this study. Regression analysis option was used to develop suitable leaf litter carbon stored models. Product moment correlation analysis was used to evaluate association between measurable tree characteristics and carbon stored in leaf litter in the study site.

2. 11. Forecasting equation description

Linear function, power function, combined variable model, polynomial models, etc., was used in developing the carbon stored in the leaf litter of the study site species.

Simple Linear model,

$$C = b_0 + b_1 X_1 ---- Equation\,6$$

Multiple Linear models,

$$C = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 ---- Equation\,7$$

Exponential model,

$$C = e^{b_0 + b1} X_1 \quad -------------------- Equation\ 8$$

Double logarithm models,

$\log C =$ $\log C = b_0 + b_1 \log X_1$ - - *Equation* 9

Semi-logarithm models,

$C = b_0 + b_1 \log X_1$ - - *Equation 10*

where: C = Carbon stored in leaf litter
X = Tree growth variables such as Dbh, height, crown diameter, crown length, volume, stand density, Basal area, etc. a, b = Regression parameters

2. 12. Equation evaluation

The equation formulated was evaluated with a view of selecting the best estimator for carbon store. The evaluation was based on the following criteria:

1. Coefficient of determination (R^2)

$$R^2 = 1 - \left(\frac{RSS}{TSS}\right) ------ Equation 11$$

where: R2 = Coefficient of determination
RSS = Residual Sum of Square
TSS = Total Sum of Square

2. Standard Error of Estimate (SEE)

$$SEE = \sqrt{MSE} ------ Equation 12$$

where: SEE = Standard Error of Estimate
MSE = Mean Square Error

3. Significance of regression coefficient

An equation with higher R^2, least SEE and significant overall regression as well as significant regression coefficient was selected as the suitable equation for carbon stored in the leaf litter.

2. 13. Equation validation

All suitable equations were validated with the aim of observing how reliable they are for prediction purposes. One third (1/3) of the data set was set aside for validation. The selected equation was used to forecast carbon stored values for the plantation. The values were compared with the observed value and the differences was expressed as residual (bias). Student t-test procedure was used to compare predicted values with observed values.

For a model to be valid, it indicated that the observed and predicted values are not significantly different at 0.05 level of significant.

3. RESULTS

3. 1. Descriptive statistics

Result from Table 1 shows the characteristics of the data used for developing models. The maximum and minimum value for diameter at breast height (DBH) in the selected species was 0.72m and 0.04m respectively. Height (HT) has a maximum measure of 14.50m, minimum of 4.00m. The maximum and minimum value for carbon (C) is 63.00%, 59.00% and the dry weight of leaf litter (L) is 2.26 and 7.67 respectively.

Table 1. Summary of the Descriptive statistics of the measured variables

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
DB(cm)	21.0000	86.0000	41.273034	11.3558692
CD (cm)	135.0000	640.0000	321.789326	94.0156060
HT (m)	4.0000	14.5000	9.523034	2.0744281
DBH (m)	.0430	.7193	.100299	.0537621
BA (m^2)	.0015	.4064	.010200	.0302154
VOL (m^3)	.0058	3.8201	.102570	.2870626
LITTER($g/m^2/day$)	2.26	7.67	5.14	1.25
CPA (m^2)	1.4316	32.1741	8.824122	5.3791054
C (%)	59.0000	63.0000	61.258427	1.4807853

DB = Diameter at tree base, CD = Crown diameter, BA = Basal area, VOL = Volume, CPA = Crown projection area, HT = Height of the tree, C = Carbon stored in leaf litter and LITTER = Dry weight of leaf litter produced.

3. 2. Correlation Analysis

The correlation matrix presented in Table 2 reveals that there was a high positive correlation (0.572) between dry weight of litter produced and carbon. Among the tree growth variables measured and estimated, height showed a weak positive correlation (0.155) with dry weight of litter produced while there was no significant correlation with the rest variables (Table 2).

Table 2. Correlation matrix of dry weight of litter produced and growth variables

	LIT	C	DB	CD	HT	DBH	BA	VOL	CPA
LIT	1								
C	.572**	1							
DB	.077	-.020	1						
CD	-.047	-.038	.755**	1					
HT	.155*	.002	.756**	.496**	1				
DBH	-.060	-.123	.439**	.376**	.378**	1			
BA	-.090	-.121	.102	.098	.104	.932**	1		
VOL	-.087	-.128	.154*	.136	.159*	.948**	.997**	1	
CPA	-.063	-.049	.750**	.982**	.470**	.367**	.094	.135	1

*, **significant value at 0.05, C = Carbon stored in leaf litter, DB = Diameter at tree base, CD = Crown diameter, DBH = Diameter at breast height, BA = Tree basal area, VOL = Volume, CPA = Crown projection area, LIT = Dry weight of litter produced, HT = Height

3. 3. Equation development

Different equations were tried for forecasting carbon stored in leaf litter of *Tectona grandis* with a view to select the best equation among the simulated equations. All the equations tried were significant, hence the equation with the highest coefficient of determination (R^2) and lowest standard error of estimate (SEE) was selected as the best equation. The dry weight of litter produced was a unique independent variable that gave the best fit in all the equation (Table 3, 4, 5, 6 and 7). Residual plots were also displayed for the selected equations (Figure 1, 2, 3, 4 & 5).

Table 3. Comparison of carbon stored in leaf litter equations using simple linear equations

MODEL	ESTIMATE	R^2	SEE
$C = b_0 + b_1 L$	$B_0 = 58.00$ $B_1 = 0.276$	0.328	1.217
$C = b_0 + b_1 DBH$	$B_0 = 61.60$ $B_1 = - 3.38$	0.015	1.4737
$C = b_0 + b_1 VOL$	$B_0 = 61.326$ $B_1 = - 658$	0.016	1.4728

$C = b_0 + b_1$ BA	B_0 = 61.319 B_1 = - 5.952	0.015	1.4739
$C = b_0 + b_1$ CPA	B_0 = 61.377 B_1 = - 013	0.002	1.4832
$C = b_0 + b_1$ CD	B_0 = 61.450 B_1 = -001	0.001	1.4839

L = Dry weight of leaf litter, R^2 = Coefficient of determination, SEE = Standard error of estimate, CPA = Crown projection area, CD = Crown diameter, BA= Basal area, VOL = Volume

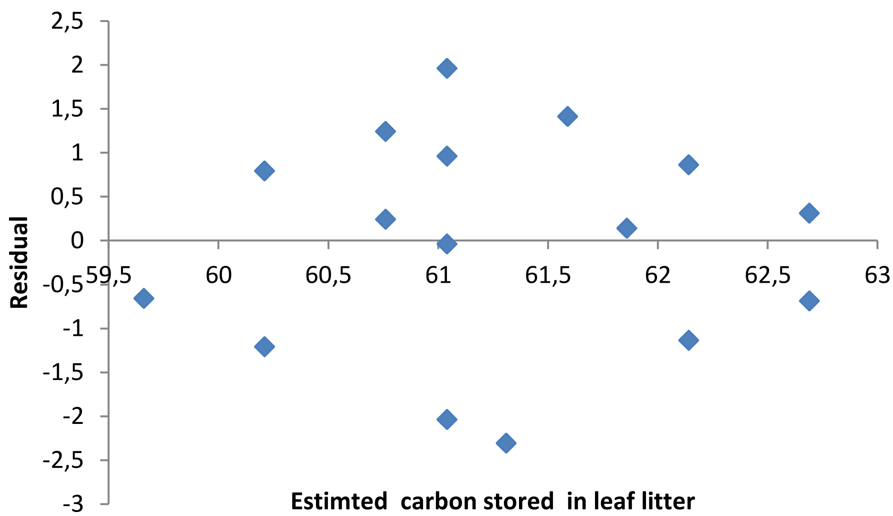

Figure 1. Residual plot of the selected simple linear equation

Table 4. Comparison of the leaf litter carbon store using multiple linear equations

MODEL	ESTIMATE	R^2	SEE
$C = b_0 + b_1 L + b_2 BA$	B_0 = 58.067 B_1 = 0.273 B_2 = -3.462	0.333	1.2165
$C = b_0 + b_1 BA + b_2 VOL$	B_0 = 61.351 B_1 = 44.311 B_2 = - 5.307	0.022	1.4731
$C = b_0 + b_1 VOL + b_2 L$	B_0 = 58.076 B_1 = - 0.404 B_2 = 0.272	0.334	1.2155

L = Dry weight of leaf litter, R^2 = Coefficient of determination, SEE = Standard error of estimate, BA = Basal area, VOL = Volume

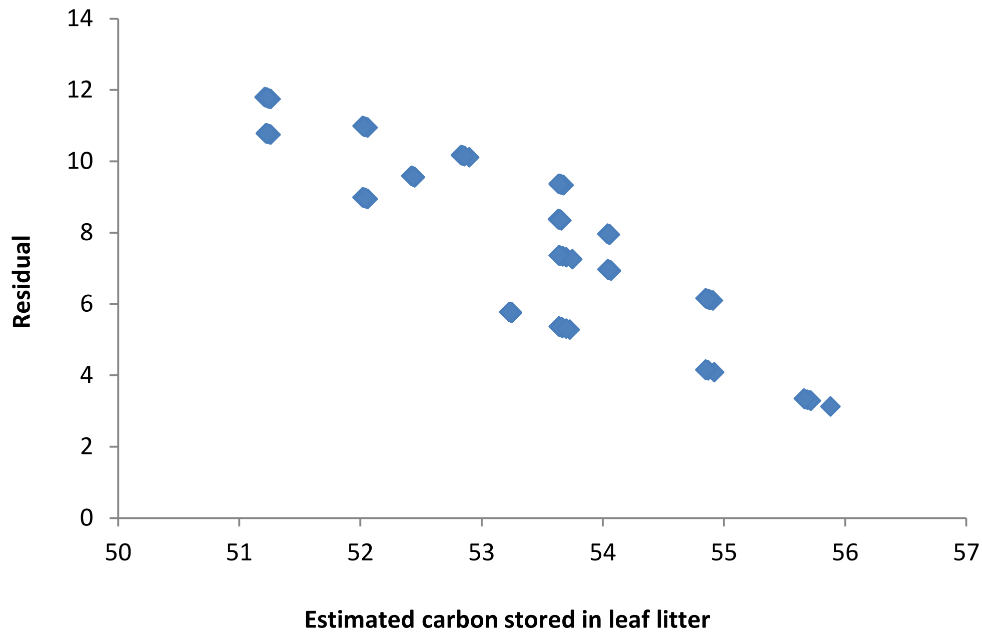

Figure 2. Residual plot of the selected multiple linear equations

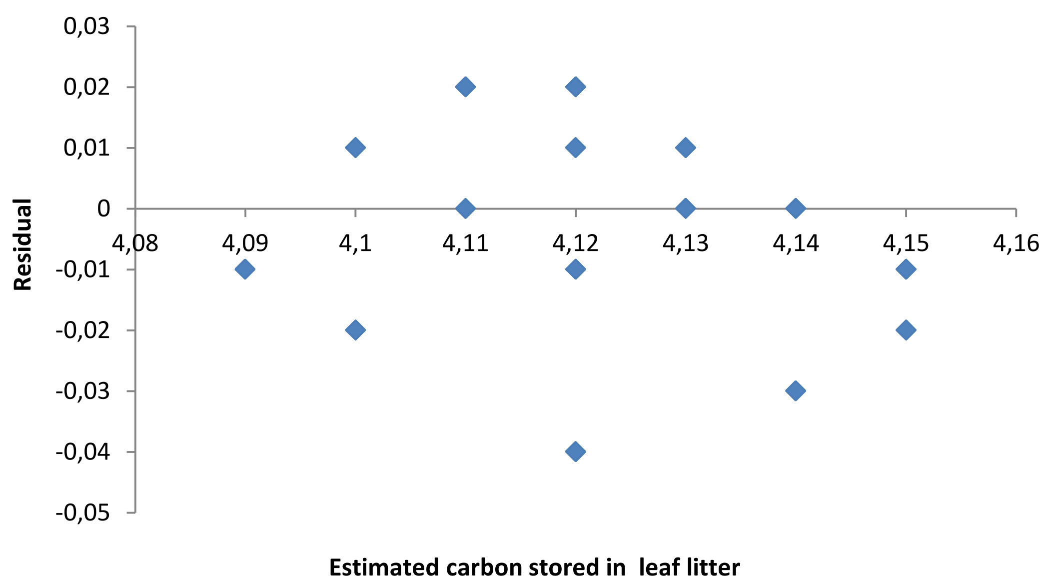

Figure 3. Residual plot of the selected exponential non-linear equation

Table 5. Comparison of carbon stored in leaf litter equations using exponential equations

MODELS	ESTIMATE	R^2	SEE
$C = e^{b0+\ b1}\ L$	$B_0 = 4.061$ $B_1 = 0.005$	0.327	0.02000
$C = e^{b0+\ b1}\ DBH$	$B_0 = 4.120$ $B_1 = -\ 0.056$	0.015	0.02419
$C = e^{b0+\ b1}\ VOL$	$B_0 = 4.116$ $B_1 = -\ 0.011$	0.016	0.02418

L = Dry weight of leaf litter produced, R^2 = Coefficient of determination, SEE = Standard error of estimate, DBH = Diameter at breast height, VOL = Volume

Table 6. Comparison of carbon stored in leaf litter equations using double logarithm equations

MODEL	ESTIMATE	R^2	SEE
$Log\ C = b_0 + b_1 \log L$	$B_0 = 3.989$ $B_1 = 0.052$	0.342	0.01978
$Log\ C = b_0 + b_1 \log VOL$	$B_0 = 4.108$ $B_1 = -\ 0.002$	0.006	0.02430
$Log\ C = b_0 + b_1 \log DBH$	$B_0 = 4.100$ $B_1 = -\ 0.006$	0.007	0.02429

L = Dry weight of leaf litter produced, R^2 = Coefficient of determination, SEE = Standard error of estimate, DBH = Diameter at breast height, VOL = Volume

Table 7. Comparison of leaf litter carbon store using semi-logarithm linear equation

MODELS	ESTIMATE	R^2	SEE
$C = b_0 + b_1 \log DBH$	$B_0 = 60.340$ $B_1 = -\ 0.389$	0.007	1.47986
$C = b_0 + b_1 \log L$	$B_0 = 53.592$ $B_1 = 3.148$	0.342	1.20423
$C = b_0 + b_1 \log VOL$	$B_0 = 60.865$ $B_1 = -\ 0.0143$	0.006	1.48033

Log L = Logarithm of dry weight of leaf litter produced, R^2 = Coefficient of determination, SEE = Standard error of estimate, Log DBH = Logarithm of diameter at breast height, Log VOL = Logarithm of volume

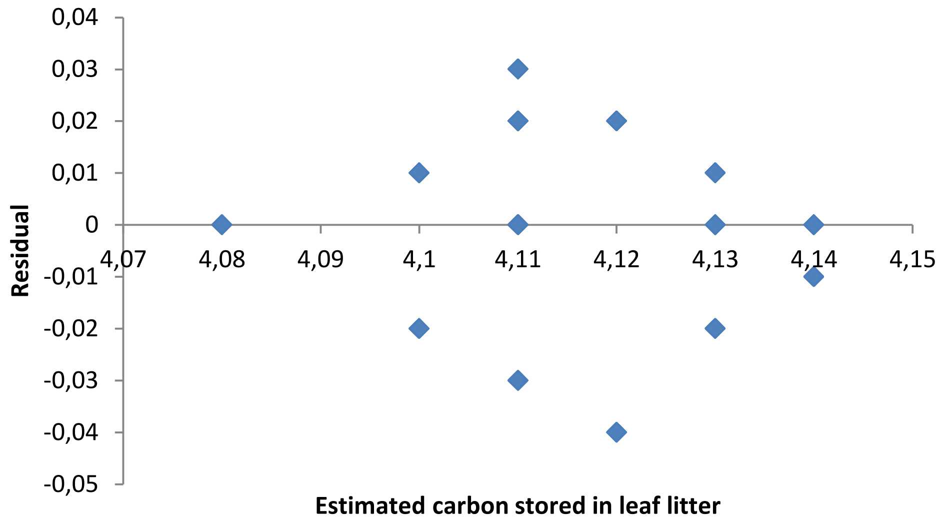

Figure 4. Residual plot of the selected double logarithm equation

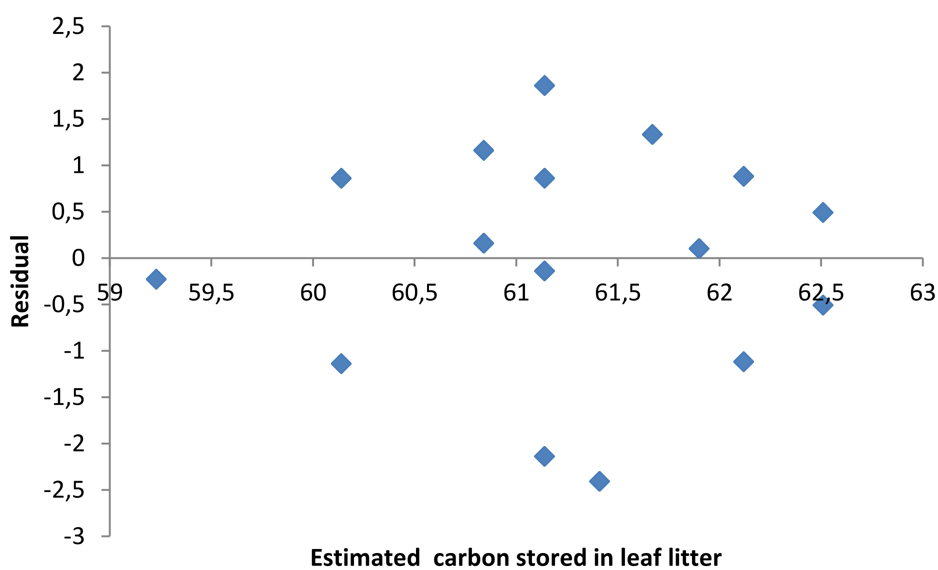

Figure 5. Residual plot of the selected semi-logarithm equation

3. 4. Equation validation

Table 8 below shows the validation of selected models that will be used for prediction of carbon stored values in the studied plantation. In order to determine the predictive ability of the selected models, student t-test was used to test for the significant difference between the observed values with the predicted values. The t-test result of the simple linear, multiple linear, double logarithm, and semi-logarithm shows that there were no significant differences between the observed and predicted values so the model is valid or fit for prediction of the amount of carbon stored in leaf litter of the studied species. But since the t-test result of exponential non-linear model shows significant difference between the observed and expected values, it therefore means the model is not fit for prediction of the amount of carbon stored in leaf litter of the studied species (Table 8).

Table 8. Validation of selected equations

MODEL	MOV	MEV	P VALUE	REMARK
Simple linear	61.25	61.32	0.30	Not significant
Multiple linear	61.25	61.27	0.47	Not significant
Exponential	4.115	4.122	0.0007**	Significant
Double logarithm	4.115	4.116	0.3618	Not significant
Semi-logarithm	61.2584	61.2583	0.499	Not significant

**Significant P-Value (< 0.05), MOV = Mean Observed values, MEV = Mean Expected or predicted values

4. DISCUSSION

4. 1. Litter production and carbon stored

Litter production is a major pathway through which carbon and nutrients are transferred from vegetation to the soil. Litter fall comprises of leaves, twigs, and branches of which leaf litter constitute between 78-92% of total litter fall (Becker *et al.*, 2015) hence this study concentrated on leaf litter. The average leaf litters produced per day in this study ranged from 2.26 g/m^2 to 7.67 g/m^2 and was within the ranges recorded in several studies. For instance the comparative study on mangrove productivity in Mauritius carried out by Mohit and Appadoo (2009) showed that litter fall rates were 4.63 g/m^2/day and 4.74 g/m^2/day at Maconde and Bambous Virieux, respectively. Similarly Abib and Appadoo (2012) stated that stands at Petite Riviere Noire and Trou D'eau Douce has average leaf litter of 4.07 ±0.95 g/m^2 and 3.20 ±0.44 g/ m^2 respectively. Comparing the rate of litter fall obtained in this study with that of other countries (2.4 g/m^2 South Africa (Rajkaran and Adams, 2010), 2.2-2.5 g/ m^2 in Brazil (Saint-Paul and Schneider, 2010) and 0.28 g/m^2 in Mexico (Navarette and Rivera, 2002)], it can be concluded that the teak plantation at the arboretum is very productive.

Carbon sequestration or storage rate of a forest is influenced by the growing conditions and age or stage of forest development. The average carbon content stored in the leaf litter was 61%. In dry tropical forest in brazil, Pereira *et al*., (2016) observed an average leaf litter carbon content of 44.5%. Chave *et al*., (2010) reported a range of leaf litter carbon of 43.1% – 88.4%. As compared to recent studies the carbon stock in leaf litter of the study site was almost proportional with a little variation.

This indicates that the study site had a good carbon stock potential hence sequestered large amount of CO_2 contributing to the mitigation of global climate change.

4. 2. Correlation of tree growth variables and carbon stored in leaf litter

Forest management decisions are predicated on information about current and future resource conditions. Hence in this study effort was directed towards obtaining leaf litter carbon stored prediction models. Before the models were developed, correlation analysis was carried out to give an insight of the association between leaf litter carbon stored and growth variables.

Leaf litter dry weight and tree height were linearly related to the amount of carbon stored in leaf litter. It was observed from the correlation matrix that carbon stored in litter increases with increase in litter dry weight produced. Kuruppuarachchi and Seneviratne (2013), observed a linear positive correlation between aboveground biomass and litter fall production. This makes intuitive sense: leaf litter content is intimately linked to carbon stored in leaf litter so that an increase in leaf litter production leads to an increase in soil nutrient which in turns leads to increased growth.

4. 3. Leaf litter carbon stored equation

Realizing that tree DBH and tree height are the most commonly used variables to predict above ground biomass and carbon stored (De Gier, 2003; Jenkins *et al*., 2003; Wang, 2006; Zianis and Mencuccini, 2004), six model forms namely simple linear, multiple linear, semi logarithm, double logarithm, exponential functions were used in regression analysis. All the models show strong fit to the leaf litter carbon stored data.

Complicated models, involving more variables that are correlated, were not considered in this study since inclusion of additional variables that are correlated do not necessarily improve the fit of the model significantly, but can create problem with multi-collinearity and can hence reduce the applicability of the developed model (Chojnacky, 2003; Samalca, 2007; Zianis *et al.,* 2005). The logarithm model was found to have the best fit for the data set. The best fit with the logarithm model implies the need for data transformation. This finding further emphasizes the efficiency or predicting ability of the models.

4. 4. Validation of carbon stored equations

Before existing tree based equations can be used in any carbon assessment program, one needs to verify whether they are indeed applicable to the area concerned. De Gier (2003) has observed large differences in biomass estimates while applying different equations from similar climatic zones but at the same time also found the estimates by equations from different climatic zones nearly overlapping. Jenkins *et al.*, (2003) has mentioned sources of errors in forest carbon assessment while using published equations.

The selected models can be used for prediction of carbon stored among trees within the range of data used in model development. Predictions should not be made using the exponential models. In general, growth equations show large differences among geographical areas and land cover types. Hence existing equations should not be used outside their area of origin without validation.

5. CONCLUSION

From the 178 trees measured and 189 leaf litters collected, the average dry weights and carbon stored in leaf litter obtained was 5.14 g/m^2/day and 61% respectively. The high litter productivity in the study site may be an indication for its carbon storage potentials. The ability of the forest to sequester carbon is a function of the biomass production which is linked to the litter fall produced by the system. Since litter fall represent a major flux for the transfer of carbon and other nutrients between the vegetation and soil, it should therefore not be altered in order not to have an effect on the below ground processes. Even though the scope of this study only covers a very small area and sample of the Nigeria forest, it is still very important for prediction of leaf litter carbon store and hence, serves as a tool for sustainable forest management.

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