Evaluative analysis of regression models for carbon sequestration determination in *Gmelina arborea* stands in Omo Forest Reserve, Ogun State

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Abstract: Carbon sequestration is the process of removing carbon dioxide (CO_2) from the atmosphere and 'storing' it in plants that use sunlight to turn CO_2 into biomass and oxygen. The integration of carbon sequestered by forest ecosystems into forest management planning models has become increasingly more important, particularly in the areas of climate change, land use, and sustainable forest management. The objective of the study was to develop and evaluate carbon sequestration prediction models for *Gmelina arborea*. Based on the data set from the temporary sample plots, several regression models including semi logarithm, double logarithm, power, polynomials and combined variable models were tested. These models were evaluated in terms of coefficient of determination (R^2), standard error of the estimate (SEE) and Akiakes Information Criteria (AIC). The significance of the estimated parameters was also verified. Plot of residuals against estimated carbon sequestered were observed. Polynomial models were observed to be more consistent in their predictive ability; and were therefore recommended for predicting carbon sequestered in the stand.
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1. Introduction

Global warming is the increase in the average temperature of the earth's surface resulting from the rise in the concentration of greenhouse gases (GHGs) like carbon dioxide CO_2, methane (CH_4), nitrous oxide (N_20), and chlorofluorocarbons. Urban developmental activities are increasing the concentration of GHGs, especially CO_2 which in turns increases atmospheric temperature through the trapping of certain wavelengths of heat radiation in the atmosphere. Increasingly convincing evidences show that the Earth is getting warmer and in the future warming could have serious effects on human (Mann *et al*., 1998). Forests are critical to mitigating the effects of global climate change because of their ability to absorb carbon dioxide from the atmosphere continuously and they are considered large store house of carbon (Goers *et al*., 2012).

Berg and McClaugherty (2008), stated that Carbon makes up the skeleton of macromolecules that create the storage matrix for nitrogen (N) and other nutrients hence it is essential for life. Trees absorb carbon from the atmosphere and store it in its tissues as they grow and increases in biomass (Mathews *et. al*., 2000). This process of removing carbon dioxide (CO_2) from the atmosphere and 'storing' it in plants that use sunlight to turn CO_2 into biomass and oxygen is termed carbon sequestration (Tagupa *et al.*, 2010). About one-half the weight of dry wood is carbon and that carbon is stored or sequestered as long as the wood is in existence. As the amount of tree biomass increases (within a forest or in forest products) the increase in atmospheric CO_2 is mitigated.

When forests are cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide. This act is considered the largest source of greenhouse gas emissions in most tropical countries. In 2005, FAO reported that deforestation accounts for nearly 70% of total emissions in Africa. Nikolic et al. (2008) stated that land-use change through deforestation and degradation of natural forests diminishes overall carbon storage capacities in vegetation and in soils. Moreover, clearing tropical forests also destroys globally important carbon sinks that are currently sequestering CO_2 from the atmosphere and are critical to future climate stabilization (Stephens *et al* 2007). Despite the importance of avoiding deforestation and associated emissions, developing countries have had few economic or policy incentives to reduce emissions from land use change (Santilli *et al* 2005).

Issues of climate change and loss of biodiversity are increasingly prompting nations to focus on accounting for and managing greenhouse gas emissions (Korner *et al.*, 2005). Several studies have found that growing trees to sequester carbon could provide relatively low-cost net emission reductions for a number of countries (Newell and Stavi, 2000).

According to Tan *et al*., (2007), there is considerable interest today in estimating the carbon sequestration capacity of forests for both practical forestry issues and scientific purposes. However, the quantification of carbon pools of a forest suffers from a number of methodological problems. Accurate carbon estimation requires locally applicable carbon sequestration equations.. It is therefore necessary to develop and evaluate carbon sequestration models for Gmelina stands in Omo Forest Reserve. Such models will enhance not only the silvicultural management of the stands, but also the accurate prediction of the carbon sequestration capacity of the stands.

2. Material and Methods

Study Area

The study was carried out Omo Forest Reserve (J4). It is situated between latitude 6^o35^1 and 7^o05^1N and longitudes 4^o19^1 and 4^o40^IE. The Reserve shares its northern boundary with Osun and Ago Owu Forest Reserves in Osun state and Oluwa Forest Reserve in Ondo state. The Omo and Oni Rivers mark the southern boundary. The Oni River continues futher north to form eastern boundary, while the western boundary is formed by surveyed paths and demarcated cut lines. The Reserve had a total area of approximately 130,550ha with 65km of enclaves. Communities present include Aberu, Abititun, Oloji, Osoko, Ajebandele, Abakurudu, Tisaba, Olomogo, Etemi, Abeku. The topography of the reserve is generally undulating with average elevation of 125m above sea level (Akindele and Abayomi, 1993).

Data

Data used for this study was collected from fifteen (15) randomly selected temporary sample plots of size 20×20 m within 3 age series (18, 20 and 24years) in the study area. Within each sample plot, the following tree growth variables were measured for all trees: total height (m), bole height (m), merchantable height (m), crown length (m), diameter (cm) outside bark at breast height (i.e. dbh measured at 1.3 m above the ground level), diameter (cm) outside bark at top, middle and base, crown diameter (cm).

Carbon sequestration estimation

Haglof increment borer was used to collect core sample from DBH of selected trees. The samples were oven dried at 70 degree centigrade for 48hrs and its dried weights were determined using a triple beam balance. The density of the core sample was estimated as the ratio of dry weight to fresh volume. The percentage carbon content of the core was also determined and hence the amount of carbon sequestered estimated.

$$C = V * D * \% \; CC ------(1)$$

Where C = Amount of C sequester
V = merchantable volume
D = wood density
CC = carbon content %

Computation of derived variables

The following variables were derived from measured tree growth variables.

1. Basal area computed as

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

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

2. Crown projection area and crown ratio computed as

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

$$CR = \frac{CL}{H} ----------------(4)$$

Where CPA= Crown Projection Area, CR = crown ratio, CL = crown height and
H = total height.

3. Tree slenderness Coefficient

$$TSC = \frac{THT}{DBH} ---------(5)$$

Stem volume computed as

$$V = \frac{h}{6}\left(A_b + 4A_m + A_t\right) ----(6)$$

Where V = Stem volume (m^3), h = Merchantable height (m), A_b, A_m, A_t,= cross sectional areas at the base, middle and top of the tree respectively (m^2).

Model description

Regression models were developed for Gmelina trees relating carbon sequestered with DBH for each tree. Semi logarithm model, Double logarithm model, Power model, combined variable model, polynomial models e.t.c. was used in developing the carbon sequestration capacity of Gmelina arborea stands in Omo Forest Reserve. SemiLogarithm model,

$$LnC = b_0 + b_1X_1 ----(7)$$

Doublelog

$$LnC = b_0 + b_1LnX_1 + b_2LnX_2 + b_3LnX_3 --(8)$$

Power,

$$LnC = b_0X^{b_1} ------(9)$$

Combinedvariable,

$$LnC = b_0 + b_1X_1^2X_2 ------(10)$$

Polynomial

$$LnC = b_0 + b_1X_1 + b_2X_2^2 + b_3X_3^3 ----(11)$$

Where C = Carbon sequestration capacity

X = Tree growth variables such as Dbh, height, crown diameter, crown length, volume, age, stand density, Basal area e.t.c

a, b = Regression parameters

Model evaluation

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

1. Coefficient of determination (R^2)

$$R^2 = 1 - \left(\frac{RSS}{TSS}\right) ------(12)$$

Where R2 = Coefficient of determination

RSS = Residual Sum of Square

TSS = Total Sum of Square

2. Standard Error of Estimate (SEE)

$$SEE = \sqrt{MSE} ------(13)$$

Where SEE = Standard Error of Estimate

MSE = Mean Square Error

3. Significance of the overall regression equation (F-ratio)
4. Significance of regression coefficient
5. Akiakes Information Criteria (AIC)

$$AIC = N * Ln\left(\frac{SS}{N}\right) + 2K ------(14)$$

Where AIC = Akiakes Information Criteria

N = Number of data points

SS = Sum of Squares Error

K = Number of Parameter plus 1

A model with higher R^2, least SEE, least AIC and significant overall regression as well as significant regression coefficient was selected as the suitable model for carbon sequestration.

3. Results

Data summary

The model fitting data set covered a wide range. The mean, maximum, minimum and standard deviation of the main measured variables and other derived variables are presented in Table 1 below.

Table 1: Characterization of the individual tree variables used for the development of the Carbon sequestration model

Statistic	DBH (m)	MTH (m)	BA (m^2)	TSC	SV (m^3)	Density (Kg/m^3)	Carbon (Kg)
Average	0.85	15.67	0.66	28.16	7.33	388.42	871.49
Min	0.38	12.00	0.12	7.61	0.73	293.34	82.53
Max	1.46	20.00	1.67	61.02	18.95	488.03	1965.11
Standard dev	0.33	2.11	0.47	8.89	5.65	44.68	691.13

The range of growth variable in the data set reflects the age, stand condition and site productivity of the stand used in the study (table 1). Effort was directed towards obtaining carbon sequestration prediction models. Before the models were developed, correlation analysis was carried out to give an insight of the association between carbon sequestered and the growth variables. It was observed from the correlation matrix presented in Table 2 that carbon sequestration increases with increasing tree size (height, DBH) but decreases with increasing slenderness coefficient. Among the measured tree growth variables, diameter at breast height was highly significantly correlated with the amount of carbon sequestered by the trees. Measurements of diameter at breast height (DBH) alone or in combination with tree height can be converted to estimates of forest carbon stocks using allometric relationships. The negative correlation of carbon sequestration with tree slenderness coefficient indicates that trees that are tall and slender sequester less carbon. Wood density was positively related to carbon sequestered by the stand which is similar to previous work (Baker *et al.*, 2004), forest biomass increased with community wood density.

Stegen *et al.*, (2009), observed a linear positive correlation between forest biomass, stand wood density and total basal area in his findings. Similar trend was observed in this study. This makes intuitive sense: basal area is intimately linked to standing biomass so that an increase in basal area with wood density leads to an increase in biomass. Bunker *et al.* (2005) found a positive correlation between forest biomass and wood density for Barro Colorado Island via simulation analyses, and subsequently proposed plantations of high wood density species as a management strategy to increase carbon storage.

Model fitting and evaluation

Model fitting and evaluation are important parts of model building. Fitting of carbon sequestration models were based on the total data set. A number of different models were examined for predicting carbon sequestration. In this study coefficient of determination (R^2), Akiakes Information Criteria (AIC) and standard error of estimate (SEE) were computed in order to evaluate the fitted models. In addition, residual plots were carried out to check the error assumption. The significance of the parameter estimates was also observed. The selected versions of the models, their parameter estimates and fit statistics are presented in Table 3. Scatter plots in Fig. 4 indicate a nonlinear relationship between carbon sequestered and DBH. However, in order to facilitate comparison to linear models in other papers (Nelson et al., 1999), DBH and carbon estimates given by all selected models were ln-transformed, and linear regressions were fit to the ln-transformed data.

Table 2: Correlation matrix for individual measured tree growth variables

	THT	*CL*	*CD*	*DBH*	*BA*	*TSC*	*V*	*CPA*	*D*	*C*
THT	1									
CL	0.50*	1								
CD	0.48	0.50*	1							
DBH	0.72*	0.45	0.58*	1						
BA	0.66*	0.42	0.56*	0.99*	1					
TSC	-0.63*	-0.40	-0.59*	-0.97*	-0.93*	1				
V	0.72*	0.38	0.57*	0.98*	0.97*	-0.93*	1			
CPA	0.45	0.49	0.99*	0.61*	0.58*	-0.62*	0.59*	1		
D	0.38	0.09	0.33	0.44	0.39	-0.48	0.43	0.37	1	
C	0.71*	0.35	0.53*	0.95*	0.94*	-0.92*	0.98*	0.56*	0.53*	1

*Significant at 0.05 level of significance, THT- Total height, CL- Crown length, CD- Crown diameter, DBH- Diameter at breast height, BA- Basal area, TSC- Tree slenderness coefficient, V- Volume, CPA- Crown projection area, D- Density, C- Carbon sequestered

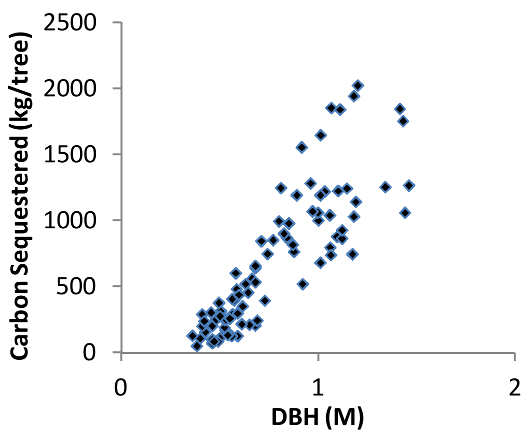

Fig 2: Scatter plot of Carbon sequestered against DBH

One unique independent variable that features in all the models is DBH. Regressions of carbon content on DBH, with ln-transformed data, did an excellent job of predicting the carbon content of individual trees. The work of Losi *et al.*, (2003), also followed the same trend. Realizing that tree DBH and tree height are the most commonly used variables to predict carbon sequestration (Wang, 2006), they were used in all the models formed. All the models show strong fit to the carbon sequestered data.

The selected models generally had a high R^2 values that were above 80% with low values of SEE. The values of R^2 ranged between 0.826 to 0.971 while the SEE values ranged between 0.187 to 0.443. The observed goodness of fit of the models was in agreement with the previous works on the relationship between Above Ground Biomass and DBH or D^2H (De Gier, 2003; Ketterings *et al*., 2001, Wang, 2006). Polynomial models were selected as the best model at the individual tree level. Conventionally second degree polynomials are used for the development of biomass equations (De Gier, 2003). Brown *et al.* (1989) and Parresol (1999) have mentioned that linear models, that may be polynomial or combined variable, can achieve as good fit as any non-linear model. The result obtained from the individual tree data set model is in conformity with work done by De Gier, 2003.

From the scatter plots of residuals against predicted carbon sequestered by sample trees in the selected model shown in the Figure 3 below, it is clear that the estimates by the selected model are closer to the observed estimates. This finding further emphasizes the efficiency or predicting ability of the models.

The polynomial model from the error analysis appeared constant error variance distributed both in the positive and negative region of the x-axis (i.e. the estimated carbon sequestration values). This is desirable for a good model. Based on the evaluation of the error analysis, polynomial models are recommended for predicting carbon sequestered in the stand. They also possess higher R^2 values compared to the other models hence; they are more precise in their predictive ability.

Table 3: Carbon sequestration models

Model	Parameter Estimate	R^2	SEE	AIC
Power $LnC = b_0 DBH^{b_1}$	$b_0 = 6.865$ $b_1 = 0.4$	0.942	0.255	-75.39
Semi logarithm $LnC = b_0 + b_1 DBH + b_2 THT$	$b_0 = 2.10$ $b_1 = 2.547$ $b_2 = 0.094$	0.931	0.284	-68.122
Double logarithm $LnC = b_0 + b_1 LnDBH + b_2 LnTHT$	$b_0 = 4.278$ $b_1 = 2.364$ $b_2 = 0.845$	0.961	0.284	-84.558
Combined variable $LnC = b_0 + b_1 DBH^2 THT$	$b_0 = 5.075$ $b_1 = 0.066$	0.826	0.443	-43.277
Polynomial $LnC = b_0 + b_1 DBH + b_2 DBH^2 + b_3 DBH^3$	$b_0 = 1.356$ $b_1 = 7.961$ $b_2 = -2.551$ $b_3 = -0.151$	0.971	0.187	-94.603

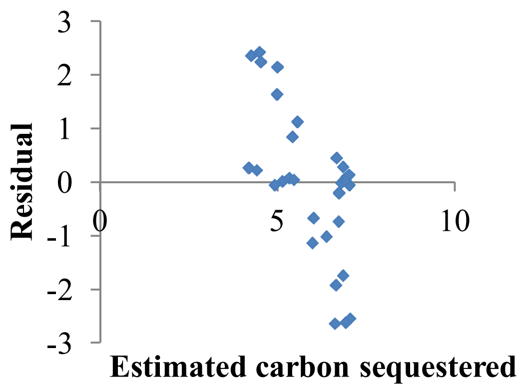

Fig 3: Relationship between residual and estimated Carbon sequestered of selected model

Conclusion

Based on the evaluation of the models examined in this study, the polynomial models are recommended as carbon sequestration models for *Gmelina arborea* stand in Omo Forest Reserve. This model has DBH as its independent variables. It is note worthy that the age range of data used for modelling was small. As more data become available to cover a wider range of ages, the model can further be investigated through validation.

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