# Comparative analysis of carbon sequestration capacity of selected exotic trees for reforestation program Ogun State

Eguakun F.S[1] and Adesoye, P.O.[2]

[1.] Department of Forestry and Wildlife Management, University of Port Harcourt
[2.] Department of Forestry School of Agriculture, University of Venda Thohoyandou, South Africa
Funmilayo.popo-ola@uniport.edu.ng, petadesoye@yahoo.com

**Abstract:** The amount of carbon in the atmosphere is alarming; storing this atmospheric carbon (C) in terrestrial biosphere like forest is one of the options, which have been proposed to compensate greenhouse gas (GHG) emissions. Trees are believed to be a major potential carbon sink if judiciously managed and carbon source if otherwise. Thus, the importance of reforestation as a land-use system is receiving wider recognition not only in terms of forest sustainability but also in issues related to climate change. The objective of this paper was to compare the Carbon sequestration capacity of selected exotic tree species used for reforestation program and to develop prediction models for these species. Although there were no significant difference among the carbon sequestered by the species, *Tectona grandis* sequestered more carbon compared to the other species tested. From the model trials used in the study, polynomial models were selected as the best predictive models for the species.

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**Key words**: Carbon sequestration, Reforestation, Models, Species, Wood density

## 1. Introduction

Anthropogenic activities has lead to increased concentration of greenhouse gases especially carbon and as such lead to the search for ways of sequestering carbon, varieties of strategies are therefore needed to reduce $CO_2$ emissions and remove carbon from the atmosphere in order to mitigate the potential effects of global warming and climate change. The impact of increasing carbon dioxide ($CO_2$) in the atmosphere is becoming a global concern. Research as shown that forest ecosystems play an important role in climate change because they can be both sources and sinks of $CO_2$ (Trexler and Haugen, 1994). Although forests plays a significant role in the global carbon cycle, having absorbed approximately one third of anthropogenic emissions of carbon dioxide ($CO_2$) to the atmosphere (Percy *et al.,* 2003), human activities in the forest have also been a source of carbon emission to the atmosphere, with deforestation (primarily in the tropics) contributing about one fifth of the annual anthropogenic emissions. Goers *et al.* (2012) stated that forests occupy about four billion hectares of the Earth's land area, or roughly 30% of its land base. However, worldwide forest cover today is only a fraction of its historical extent, with some research estimating that 47% of original forest cover has been lost (WRI, 2009). The drastic loss of forest estate has significant impact on its carbon storage capacity. Nikolic *et al*. (2008) emphasized that land-use change through deforestation and degradation of natural forests diminishes overall carbon storage capacities in vegetation and in soils. Generally, forest resources depletion and its current trends have serious implications, not only for resource base but also on the livelihood of humanity.

Growing trees to sequester carbon is a relative inexpensive means of combating climate change (Bruce *et al*., 1999). Increased establishment of tree plantations on cleared land in the tropics has long been suggested as a way of reducing the rate of increase in atmospheric $CO_2$. Reforestation is an important technique for climate change mitigation (Sulistyawati *et al*., 2007). During forest growth, atmospheric carbon is taken up by plants and incorporated into their biomass and the soils and it resides on the ecosystem for a period of time. In this manner, reforestation is a means for carbon sequestration. The 'service' provided by forest to sequester carbon has increasingly been appreciated and its value can now be sold through various carbon trading mechanisms. A tool is required to facilitate assessment of the potential of carbon sequestration on various reforestation settings. Such information is very valuable for practitioners and policy makers when formulating reforestation strategy. The amount of $CO_2$ sequestration depends on forest type, forest status, dominant tree species and forest stand age.

When selecting tree species for large plantation programs, reforestation projects should consider not only the survival and growth of trees, but the quality and utilization potential of the promising tree species (Laurila, 1995). It is therefore imperative to analysis the capacity of commonly used exotic tree species for reforestation to sequester carbon. Hence the aim of this study is to compare commonly planted exotic species used in reforestation project in Omo Forest Reserve for their carbon sequestration capacity and to develop models for predicting carbon sequestered by the species.

## 2. Materials and Methods

### 2.1 Study Area

The study was carried out Omo Forest Reserve (J4). It is situated between latitude 6°35$^1$ and 7°05$^1$N and longitudes 4°19$^1$ and 4°40$^I$E. 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).

### 2.2 Data

Data used for this study was collected from fifteen (15) randomly selected temporary sample plots of size 20×20 m within 3 selected exotic tree species (*Gmelina arborea, Tectona grandis* and *Pinus carribaea*) of the same age (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).

### 2.3 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.

$$C = V * D * \%\ CC \tag{1}$$

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

### 2.4 Stem volume estimation

Stem volume was computed as

$$V = \frac{h}{6}\left(A_b + 4A_m + A_t\right) \tag{2}$$

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$^2$)

### 2.5 Model description

Semi logarithm model, Double logarithm model, Power model, combined variable model, polynomial models was used in developing the carbon sequestration capacity models for the stands.

Semi logarithm model

$$LnC = b_0 + b_1 X_1 \tag{3}$$

Double logarithm model

$$LnC = b_0 + b_1 LnX_1 + b_2 LnX_2 + b_3 LnX_3 \tag{4}$$

Power model,

$$LnC = b_0 X^{b_1} \tag{5}$$

Combined variable model

$$LnC = b_0 + b_1 X_1^{\,2} X_2 \tag{6}$$

Polynomial model

$$LnC = b_0 + b_1 X_1 + b_2 X_2^{\,2} + b_3 X_3^{\,3} \tag{7}$$

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

### 2.6 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$^2$)

$$R^2 = 1 - \left(\frac{RSS}{TSS}\right) \tag{8}$$

Where R$^2$ = Coefficient of determination
RSS = Residual Sum of Square
TSS = Total Sum of Square

2. Standard Error of Estimate (SEE)

$$SEE = \sqrt{MSE} \tag{9}$$

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)

$$AIC = N * Ln\left(\frac{SS}{N}\right) + 2K \tag{10}$$

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.

### 2.7 Data Analysis

Analysis of variance in Completely Randomized Block Design (CRD) was used to compare the amount of carbon sequestered by the species. Regression analysis was used in developing prediction models and t- statistics was used in evaluating the predictive ability of the selected models.

## 3. Results and discussion

The 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

| Variable | Statistic | Gmelina | Pine | Teak |
|---|---|---|---|---|
| DBH (m) | Average | 0.854 | 0.801 | 0.654 |
| | Min | 0.383 | 0.4 | 0.36 |
| | Max | 1.460 | 1.43 | 1.2 |
| | Standard dev | 0.330 | 0.288 | 0.212 |
| MTH (m) | Average | 15.667 | 17.567 | 14.933 |
| | Min | 12 | 12 | 13 |
| | Max | 20 | 25 | 19 |
| | Standard dev | 2.106 | 3.256 | 1.639 |
| BA ($m^2$) | Average | 0.656 | 0.567 | 0.370 |
| | Min | 0.115 | 0.126 | 0.102 |
| | Max | 1.674 | 1.606 | 1.131 |
| | Standard dev | 0.465 | 0.403 | 0.245 |
| SV ($m^3$) | Average | 7.331 | 6.418 | 3.784 |
| | Min | 0.733 | 0.877 | 0.726 |
| | Max | 18.950 | 17.674 | 12.308 |
| | Standard dev | 5.653 | 5.069 | 2.603 |
| Density (Kg/$m^3$) | Average | 388.42 | 487.39 | 512.41 |
| | Min | 293.34 | 383.87 | 3.83.48 |
| | Max | 488.03 | 777.85 | 642.03 |
| | Standard dev | 44.68 | 88.819 | 54.129 |
| Carbon (Kg) | Average | 981.39 | 994.41 | 1350.70 |
| | Min | 82.53 | 135.00 | 201.83 |
| | Max | 1965.11 | 3016.14 | 3138.81 |
| | Standard dev | 691.13 | 999.069 | 676.172 |

DBH- Diameter at Breast Height, MTH- Merchantable height, BA- Basal area, SV- Stem volume

Gmelina, Pine and Teak sequestered an average of 981.39kg, 994.41kg and 1350.70kg carbon respectively. Though there were no statistical significant differences (table 2) among the species but there were appreciable differences in the mean carbon sequestered by the species (Fig 2). The high amount of carbon sequestered by teak may be as a result of the genetic makeup of the species which has influenced its density.

Table 2: Comparison of carbon sequestered among the different species

| Species | Carbon sequestered |
|---|---|
| Gmelina | 981.36 ± 152.75a |
| Pine | 994.41 ± 188.29a |
| Teak | 1350.7 ± 180.58a |

Means with the same alphabet are not significantly different.

An interesting observation in this study was that species differences in the study area did not influence the amount of carbon sequestered. This observation is in line with De Gier (2003). Chojnacky (2003) also observed overlapping curves among many tree species of U.S.A. This finding is extremely important because one equation can serve for all tree species of the forest, and it can avoid another error, namely wrong species identification, a frequently encountered problem in many countries (De Gier, 2003).

### 3.2 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 ($R^2$) 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 are presented in Table 3, 4 and 5.

One unique independent variable that features in all the models is DBH. 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 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 for all the species. 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.

Table 3: Individual tree carbon sequestration models for Gmelina species

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

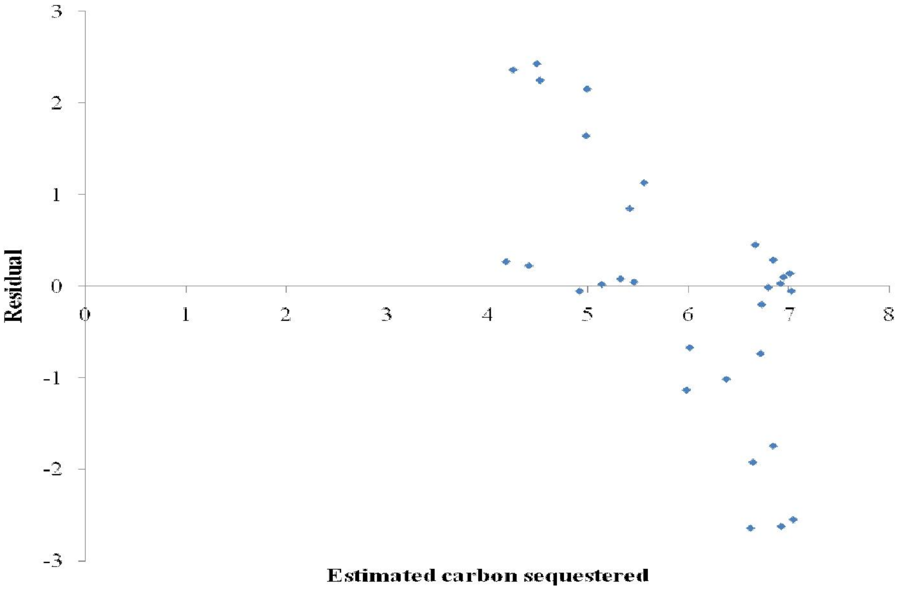

Fig 1: Relationship between residual and estimated Carbon sequestered using the selected individual tree model on the Gmelina data set

Table 4: Individual tree carbon sequestration models for pine species

| Model | Parameter Estimate | R$^2$ | SEE | AIC |
|---|---|---|---|---|
| **Power**<br>$LnC = b_0 DBH^{b_1}$ | $b_0 = 7.431$<br>$b_1 = 0.369$ | 0.873 | 0.366 | -54.394 |
| **Semi logarithm**<br>$LnC = b_0 + b_1 DBH + b_2 THT$ | $b_0 = 3.115$<br>$b_1 = 2.927$<br>$b_2 = 0.979$ | 0.861 | 0.39 | -49.770 |
| **Double logarithm**<br>$LnC = b_0 + b_1 LnDBH + b_2 LnTHT$ | $b_0 = 4.455$<br>$b_1 = 2.473$<br>$b_2 = 0.979$ | 0.919 | 0.298 | -65.346 |
| **Combined variable**<br>$LnC = b_0 + b_1 DBH^2 THT$ | $b_0 = 5.614$<br>$b_1 = 0.07$ | 0.731 | 0.532 | -32.702 |
| **Polynomial**<br>$LnC = b_0 + b_1 DBH + b_2 DBH^2 + b_3 DBH^3$ | $b_0 = 4.430$<br>$b_1 = 2.234$<br>$b_2 = -0.561$<br>$b_3 = 0.043$ | 0.924 | 0.293 | -65.494 |

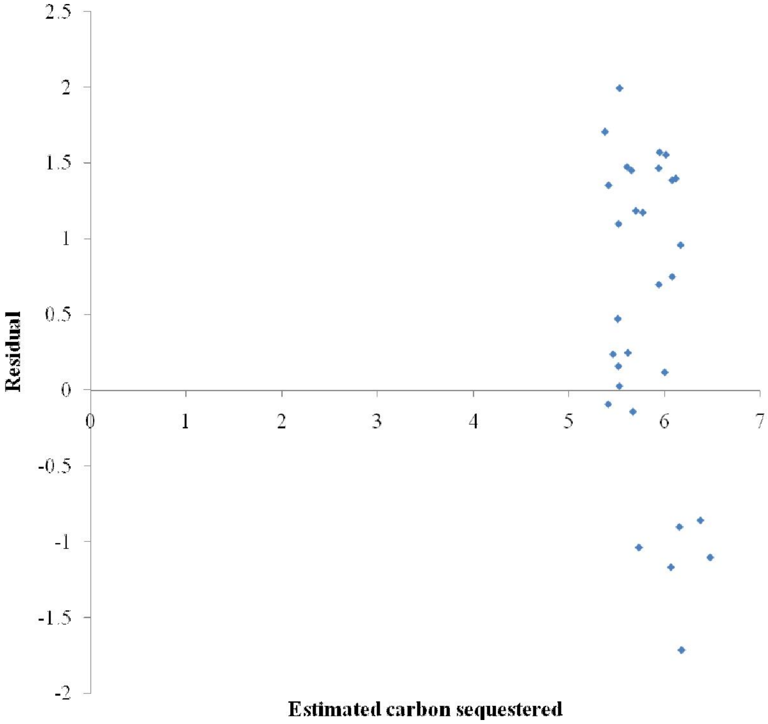

Fig 2: Relationship between residual and estimated Carbon sequestered using the selected individual tree model on the Pine data set

Table 5: Individual tree carbon sequestration models for teak

| Model | Parameter Estimate | $R^2$ | SEE | AIC |
|---|---|---|---|---|
| **Power**<br>$LnC = b_0 DBH^{b_1}$ | $b_0 = 7.687$<br>$b_1 = 0.312$ | 0.922 | 0.190 | -86.262 |
| **Semi logarithm**<br>$LnC = b_0 + b_1 DBH + b_2 THT$ | $b_0 = 4.198$<br>$b_1 = 3.021$<br>$b_2 = 0.024$ | 0.895 | 0.228 | -77.797 |
| **Double logarithm**<br>$LnC = b_0 + b_1 LnDBH + b_2 LnTHT$ | $b_0 = 7.213$<br>$b_1 = 2.099$<br>$b_2 = 0.146$ | 0.928 | 0.189 | -88.682 |
| **Combined variable**<br>$LnC = b_0 + b_1 DBH^2 THT$ | $b_0 = 5.753$<br>$b_1 = 0.092$ | 0.819 | 0.293 | 64.009 |
| **Polynomial**<br>$LnC = b_0 + b_1 DBH + b_2 DBH^2 + b_3 DBH^3$ | $b_0 = 2.139$<br>$b_1 = 12.512$<br>$b_2 = -10.487$<br>$b_3 = 3.448$ | 0.930 | 0.180 | -87.421 |

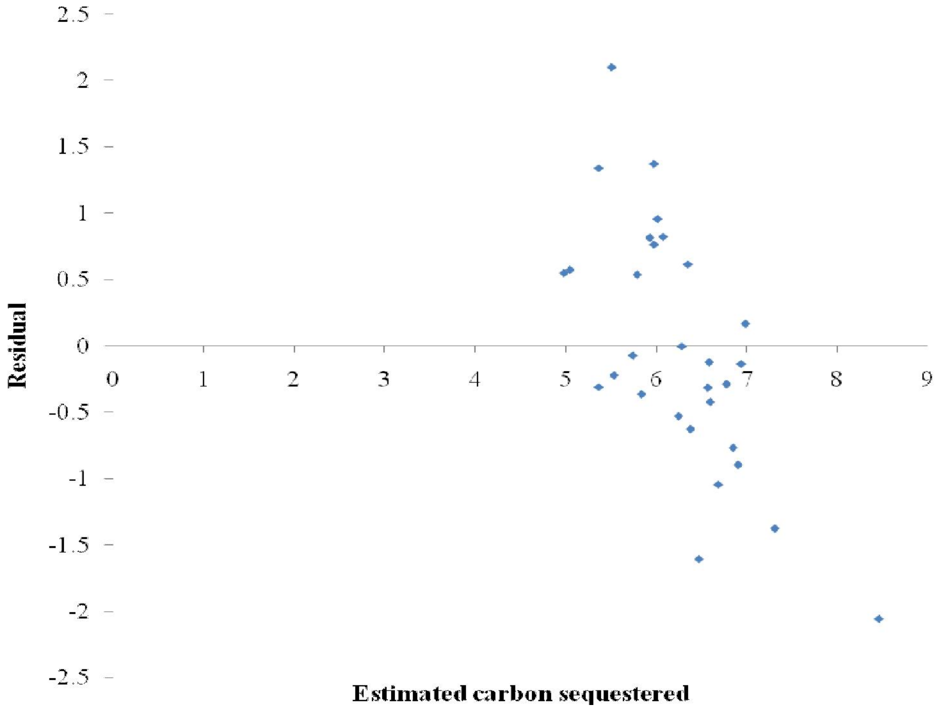

Fig 3: Relationship between residual and estimated Carbon sequestered using the selected individual tree model on the Teak data set

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. Fig 1,2 and 3). 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 6: Validation result for selected models

| Data set | Function | MOV | MPV | t value | p value | Remark |
|---|---|---|---|---|---|---|
| Gmelina spp. | Polynomial | 6.329 | 6.323 | 0.023 | 0.490 | NS |
| Pine spp. | Polynomial | 6.776 | 6.766 | 0.039 | 0.484 | NS |
| Teak spp. | Polynomial | 6.675 | 6.661 | 0.083 | 0.467 | NS |

Where MOV= Mean Observed Value
MPV= Mean Predicted Value
NS = No Significant Differences

Before existing tree based equations can be used in any biomass/ 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. It was observed that there were no significant difference between the observed amount of carbon sequestered and the estimated carbon sequestered using the selected models for all species (table 6). Hence the selected models can be used for prediction of carbon sequestration among trees within the range of data spp used in model development.

## Conclusion

The species exhibits no significant variation in the amount of carbon sequestered. However, appreciable variation exists. *Tectona grandis* sequester the highest amount of carbon. Based on the evaluation of the models examined in this study, the polynomial models are recommended as carbon sequestration models for all the species 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.

**Correspondence to:**
Eguakun Funmilayo Sarah
University of Port Harcourt, Port Harcourt, Rivers State, Nigeria
Telephone: 2348038624661
Email: Funmilayo.popo-ola@uniport.edu.ng

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