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ABOVE GROUND BIOMASS AND CARBON STOCK ESTIMATION OF *Gmelina arborea* (Roxb.) STANDS IN OMO FOREST RESERVE, NIGERIA

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ABSTRACTS

Above ground biomass and carbon stock were estimated for Gmelina arborea plantations (34, 32, 30, 26, 24, 22, 20, 18 and 16 years old) in Area J4 of Omo Forest Reserve, Nigeria. A total of 45 plots (20 x 20m) were laid (5 plots in each age series) and growth data were collected from a total of 8816 trees. Two trees from each plot were randomly selected and wood core samples were collected and analyzed for wood density. Volume over bark (VoB), total above ground biomass (TAB) and carbon stock (CS) were estimated. The results were subjected to descriptive statistics. The result reveals number of tree stands per hectare ranges from 875 to 1000 while basal area and VoB had respective values which ranges from 33.31±0.034 to 413.78±0.074 m^2/ha and 297.14±0.044 to 6375.21±0.121 m^3/ha. The mean TAB ranges from 5246.93t/ha (34 years old) to 266.80t/ha (18 years old). In the same trend, the mean CS estimated was highest in 34 years old stands (2623.46t/ha) while the least was observed in 18 years old stands (133.40t/ha). The result shows that there is a significant relationship between the dbh and TAB (0.955) hence, as the dbh increases the TAB increases. This is the same for dbh and CS (0.955). Gmelina has a high biomass yield per hectare, even at young age. The high stem biomass also indicates that a high proportion of Gmelina wood is merchantable for timber. Conceptually trees are considered to be a terrestrial carbon sink. Therefore, managed forests can, theoretically, sequester carbon both in situ (biomass and soil) and ex situ (products).

Keywords: Above ground biomass, carbon stock, *Gmelina arborea*, growth and management

INTRODUCTION

The effect of greenhouse gases especially Carbon dioxide (CO_2), on the warming of the atmosphere and the earth is of great importance. For this reason, studies are being conducted on certain measures such as limiting emissions in order to reduce the amount of CO_2 in the atmosphere. Forest ecosystems have a significant potential in this respect. Carbon can be stored in the biomass, soil, litter, and coarse woody debris pools in forest ecosystems. As a carbon sink, forests annually absorb million tons of carbon dioxide rendering the atmosphere clean and habitable for human race (FAO, 2011). As a complex living unit, they enhance floral and faunal diversity and the associated food web necessary in balancing the intricate global ecosystems. It provides wood, food, medicine, and other minor and major products. Forests also store, filter, and release huge amounts of superior quality of water for households, farms, hydroelectric power plants, water districts, various industries, and other consuming entities. 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 allometric equations (indirect method) that are ultimately based on harvested trees (Brown 1997, Chave *et al*. 2005).

However, the undue pressure imposed on forests by the growing number of people has relentlessly damaged such ecosystems. Population pressure is also gradually depriving people of the environmental services that they used to enjoy every day. The substantial increase in the demand for timber and timber products has depleted the world's forest (FAO, 2011) including that of Nigeria. Plantation forests have often been considered as a "quick fix" solution to the perennial problems of over exploitation of the natural forest resources. Plantation forestry in Nigeria started in the early 1900s (Ajayi, 2013). Large-scale plantation forestry in Nigeria was preceded by many successful species and provenance trials, mainly of exotic species. FAO (2011) reported that the annual planting rate is about 58,000 ha in which *Gmelina arborea* is one of the trees typically planted in this regard.

Gmelina arborea is a fast-growing deciduous tree occurring naturally in India, Thailand, Cambodia and southern provinces of China but planted extensively in Nigeria, Sierra Leone and Malaysia (Ajayi, 2013). It is commonly planted as avenue trees, in gardens and also in villages along agricultural land, on village community lands and on wastelands. It is light demanding, tolerant of excessive drought but moderately frost hardy and has good capacity to recover in case of frost injury (Duke 1983). In Nigeria, large investments in *Gmelina arborea* plantations have been made particularly to provide raw materials for pulp and paper mills (Ajayi *et al*, 2004).

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; UNEP, 1999). Thus, the objective of this study is to estimate above ground biomass and carbon stock in *Gmelina arborea* plantation in Omo forest reserve, Ogun state, Nigeria.

MATERIALS AND METHODS

Study data

This study was carried out in Plantation section (Area J4) of Omo Forest Reserve (Fig 1). It is situated between latitudes 6^o 45′ and 7^o 15′N and longitudes 4^o 8′ and 4^o 40′E. The reserve shares its northern boundary with Shasha and Ago Owu Forest Reserves in Osun State and Oluwa forest reserve in Ondo State. The reserve had a total area of approximately 130,500ha with 6,500ha of enclaves. Major communities present in the reserve include: Aberu, Abititun, Olooji, Osoko, Ajebamidele, Abakurudu, Olomogo, Etemi and Abeku.The topography of the reserve is generally gently undulating with average elevation of 12m above sea level (Akindele and Abayomi, 1993). The main study area is generally low-lying. It is neither lower than 20m nor higher than 61m, maintaining a landform which can be regarded as flat to undulating (Chijioke, 1988). The general geology of the reserve is undifferentiated Basement Complex with outcrops of older granites in some places (FRIN, 2011). The soils in the area are typical of the variety of soils normally found in intensively weathered areas of the basement complex formations on the West Coast of African. The reserve has a typical humid tropical climate with an annual rainfall of about 1426mm which is common with more than 65% occurring between the months of April and October. A mean annual temperature of 26.5^oC has been reported for the reserve, while a minimum of 19.5^oC and maximum of 32.5^oC was reported for rainy season and dry seasons respectively (Ogun State Forestry Plantation Project, (OSFPP), 2015). The rainy season starts from the month of March and ends in November. In some years, there is a short dry period from mid July to the first or second week of August. The dry season occurs between December and January with occasional rain during the period.

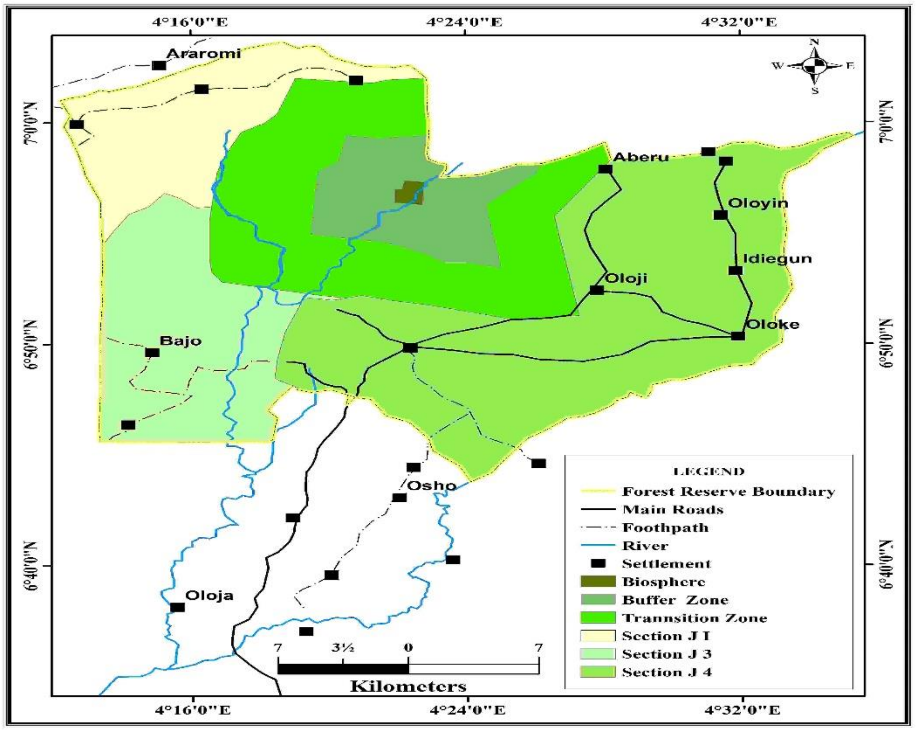

Figure 1: Map of Omo Forest Reserve showing the study area (Area J4)

Data collection

Nine stand age series of *Gmelina arborea* were selected (34, 32, 30, 26, 24, 22, 20, 18 and 16 years old). Five (20m x 20m) plots were laid in each stand at 20m intervals to give a total of 45 plots in all. The diameters at breast height (dbh), base (Db), middle (Dm) and top (Dt) and the total height (THt) of all tree in each plots were measured. Wood density values were obtained from core samples randomly collected from two trees in each plot using standard laboratory procedure.

Estimation of Variables

Basal area estimation

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

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

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

Volume over bark estimation

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

$$V = \pi H \left[\frac{Db^2 + 4Dm^2 + Dt^2}{24} \right] \;\ldots\ldots\ldots\ldots 2$$

Where V = Volume over bark (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, the following procedures were adopted (IPCC, 2006)

1. Calculate the biomass density of the inventoried volume:

Aboveground biomass density (t/ha) = VOB x WD x BEF ……3

where:

VOB= Volume over bark (m^3/ha)

WD= volume-weighted average wood density (oven dry biomass per m^3 green volume)

BEF= biomass expansion factor (ratio of aboveground oven-dry biomass of trees to oven-dry biomass of inventoried volume)

2. The volume-weighted average wood density is calculated as:

WD = [((V1/Vt)*WD1) + ((V2/Vt)*WD2) + ….. + ((V10/Vt)*WD10)] ………………… 4
where:
V1, V2,…..V10 = Volume of individual selected trees in each plot per age series 1, 2, …… to the 10^{th} tree per age series
Vt= Total Volume for trees in an age series

WD1, WD2,……WD10 = Wood density of tree 1, 2, …… to the 10^{th} tree per age series
3. Calculate the biomass expansion factor (BEF) according to IPCC (2006) as:
BEF = exp(3.213 –0.506*ln(BV) **for BV < 190 t/ha**
BEF = 1.74 **for BV > 190 t/ha**
where:

BV = Biomass of inventoried volume in t/ha, calculated as the product of VOB/ha (m^3/ha) and wood density (t/m3)

3. Calculate the Carbon stock

Carbon stock = TAGB x 0.5

Where: TAGB = Total above ground biomass and 0.5 = the average Carbon fraction (IPCC, 2006).

Data analysis
Result of the growth variables were subjected to descriptive statistics and correlation analysis and the result presented in form of tables and charts.

RESULTS
Table 1 provided important whole stand variables estimated for *G. arborea* in the study area. The number of trees stands per hectare ranges from 875 to 1000. Mean tree dbh and tree height ranges from 21.50±0.011 to 70.61±0.054 cm and 16.08±0.040 to 24.98±0.060 m respectively. Mean basal area and volume over bark had respective values which ranges from 33.31±0.034 to 413.78±0.074 m^2/ha and 297.14±0.044 to 6375.21±0.121 m^3/ha. These ranges indicate that *Gmelina* trees in this study area are growing well.

Table 1: Summary of whole stand growth variables

Age (yrs)	No of stem/ha	Mean Dbh (cm)	Mean Stem height (m)	Mean BA (m^2/ha)	Mean V (m^3/ha)
34	1000	70.61±0.054	24.10±0.007	413.78±0.074	6375.21±0.121
32	925	67.36±0.031	24.98±0.060	335.81±0.063	4403.12±0.088
30	1000	64.51±0.024	22.73±0.048	333.29±0.070	5030.71±0.069
26	975	61.51±0.035	21.57±0.032	263.38±0.060	3224.52±0.116
24	975	58.46±0.028	21.52±0.040	296.05±0.050	3622.05±0.096
22	950	41.64±0.030	22.06±0.021	138.19±0.042	1791.86±0.054
20	975	22.71±0.041	17.72±0.057	41.21±0.067	349.08±0.044
18	875	22.88±0.011	16.60±0.036	33.31±0.034	297.14±0.044
16	900	21.50±0.011	16.08±0.040	38.40±0.036	387.22±0.049

±Standard error

Table 2: Summary of Estimated Aboveground Biomass (t/ha) and Carbon Stock (t/ha)

Age (yrs)	Mean Wood density (g/cm^3)	Biomass (t/ha)	Biomass Expansion Factor	TAGB (t/ha)	Carbon stock (t/ha)
34	0.473	3015.47	1.74	5246.93	2623.46
32	0.472	2078.27	1.74	3616.19	1808.10
30	0.472	2374.50	1.74	4131.62	2065.81
26	0.461	1486.50	1.74	2586.52	1293.26
24	0.461	1669.77	1.74	2905.39	1452.70
22	0.459	822.46	1.74	1431.09	715.54
20	0.457	159.53	1.91	304.70	152.35
18	0.410	121.83	2.19	266.80	133.40
16	0.410	158.76	1.91	303.23	151.62

The mean aboveground biomass ranges from 5246.93t/ha (34 years old) to 266.80t/ha (18 years old) as presented in Table 2. In the same trend, the mean carbon stock estimated was highest in 34 years old stands (2623.46t/ha) while the least was observed in 18 years old stands (133.40t/ha). This showed that the older trees stored more carbon than the younger ones in this study. This could be attributed to the fact that the total above ground biomass was volume-weighted. This was further revealed in Table 3 as high correlation coefficients were obtained between total above ground biomass and all the growth variables assessed and estimated including stand age. Hence, stands with better growth features will have higher above ground biomass accumulation and resultant carbon stock. The relationship between total above ground and dbh (fig 2) further reveals a unique relationship that existed between them. The high stem biomass in *Gmelina* attests to its suitability for timber and the commercial viability of its wood since the stem yields most of the commercially useable timber. *Gmelina* has a high biomass yield per hectare, even at young age (Table 2).

Table 3 shows the correlation matrix. Generally, there were significant and positive relationship between all the variables considered in this study. The result shows that there is a significant relationship between the dbh and total above ground biomass (0.955) hence, as the dbh increases the total above ground biomass increases. This is the same for dbh and carbon stock (0.955).

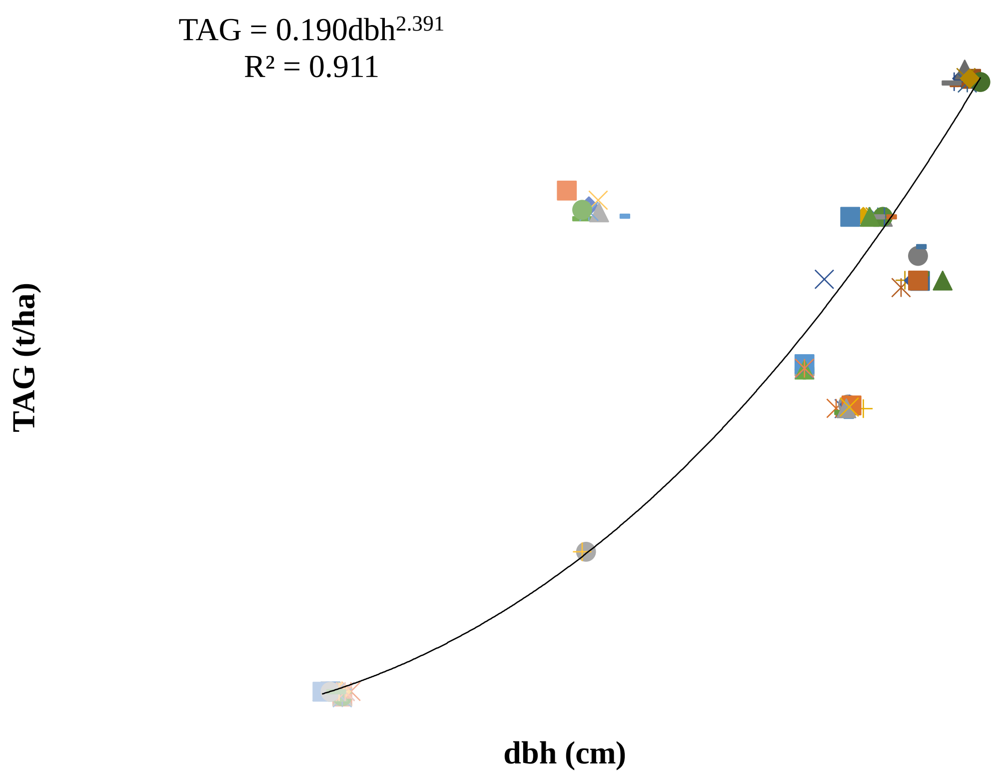

Figure 2: Relationship between total above ground biomass (t/ha) and diameter at breast height

Table 3: Correlation matrix

	Age (yrs)	*stem/ha*	*Dbh (cm)*	*height (m)*	*BA (m^2/ha)*	*V (m^3/ha)*	*density (g/cm^3)*	*Biomass (t/ha)*	*TAGB (t/ha)*	*Carbon stock (t/ha)*
Age (yrs)	1									
stem/ha	0.620	1.000								
Dbh (cm)	0.935	0.634	1.000							
height (m)	0.927	0.584	0.937	1.000						
BA (m2/ha)	0.948	0.653	0.986	0.912	1.000					
V (m3/ha)	0.958	0.667	0.959	0.891	0.989	1.000				
density (g/cm3)	0.836	0.834	0.818	0.883	0.800	0.780	1.000			
Biomass (t/ha)	0.960	0.666	0.956	0.891	0.987	1.000	0.780	1.000		
TAGB (t/ha)	0.960	0.663	0.955	0.889	0.986	1.000	0.777	1.000	1	
Carbon stock (t/ha)	0.960	0.663	0.955	0.889	0.986	1.000	0.777	1.000	1	1

DISCUSSION

The high density of trees in the stands could be attributed to the fact that the stands have not been thinned. Due to lack of adequate silvicultural operations, trees exhibited relative degree of forking below breast height, thus multiple stems occurred. The occurrence of multiple stems is among the problems associated with the poor natural form of *Gmelina arborea* (Dupuy and Mille, 1993). The general growth trends shown in these ranges correspond to the common trend often reported in tropical plantation growth studies (Abayomi, 1986; Adesoye, 2002 and Onyekwelu *et al*., 2006). According to Jagdish (2012), biomass production is an important consideration in all tropical tree planting programmes and the tree biomass plays a key role in sustainable management and in estimating forest carbon stocks and fluxes of several biogeochemical elements, the amount of energy stored in biomass, and other conventional goods and services. The biomass production by a plant community is the reflection of its capacity to assimilate solar energy under some set of environmental conditions. Different plant communities have different rate of biomass production, based on their efficiency**.** There is considerable interest in estimating the biomass of trees and forests for both practical forestry issues and scientific purposes. The high stem biomass observed in this study indicates that a high proportion of *Gmelina* wood is merchantable for timber production. It has been shown that high stand density generally results in more stem biomass and less branch and leaf biomass for a tree of given dimensions (Naidu *et al.*, 1998). Thus, it appears that management of *Gmelina* plantations for timber should start with high initial stand density (Onyekwelu, 2004). This result is comparable to what has been reported for the species by various authors. In Ghana, 56t/ha was reported while in Nigeria, 272t/ha was reported (Nwoboshi, 1985; Nwoboshi, 1994). Biomass yield of 127t/ha has been recorded in 7 years old plantations of species in the Philippines (Kawahara *et al.*, 1981). The high above ground biomass production in this study could partly be explained by the fast growth rate of the species as well as the high stand density in the study area. Furthermore, site conditions in the study area are such that supports an optimum growth for *Gmelina*. It therefore appears that the high nutrient requirement by *Gmelina* (Chijioke, 1980) is adequately met by the soils of the study area. Conceptually trees are considered to be a terrestrial carbon sink (Houghton *et al.*, 1998). Therefore, managed forests can, theoretically, sequester carbon both *in situ* (biomass and soil) and *ex situ* (products).

CONCLUSION

Trees play a vital role in mitigating the diverse effects of environmental degradation and increasing concentration of carbon dioxide in the atmosphere and also its consequences on climate change. Tree promotes sequestration of carbon into soil and plant biomass. Therefore, the result of this study revealed that *Gmelina arborea* has a great potential in promoting carbon sequestration especially when they are left to grow older. Favourable growth conditions have high capability of increasing the biomass accumulation of this species. Hence, it is recommended that sustainable management of this plantation should be paramount in ensuring cleaner environment and mitigating the effect of climate change in Nigeria.

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