PRINT ISSN 1119-8362
Electronic ISSN 1119-8362

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://ww.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 24 (10) 1767-1773 October 2020

Comparative Evaluation of Growth Performance and Soil Quality of Two Age-Sequences of *Gmelina arborea* Plantation in University of Port Harcourt, Nigeria

***AKHABUE, EF; CHIMA, UD; EGUAKUN, FS**

Department of Forestry and Wildlife Management, University of Port Harcourt, Port Harcourt, Nigeria
**Corresponding Author Email: akhasfaith@gmail.com; Tel: 07034911305*

ABSTRACT: This study was conducted in 2019 to compare the growth performance and soil quality of two age-sequences of *Gmelina arborea* plantation within the premises of the University of Port Harcourt, Nigeria. Data were collected from two stands of *G. arborea* established in 2011 and 2015. Growth performance was evaluated based on tree growth variables and above-ground carbon stored. Tree growth variables estimated were total height (TH), diameter at breast height (DBH), crown height (CH), crown diameter (CD) and merchantable height (MH). Topsoil (0 – 30 cm) samples collected from the two sites were analyzed for particle size distribution, organic carbon (OC), total nitrogen (TN), available phosphorus (Av.P), exchangeable bases (Mg, Ca, K and Na), exchangeable acidity ($Al^{+}H^{+}$), effective cation exchange capacity (ECEC), base saturation (BS), pH, Manganese (Mn), Iron (Fe), Copper (Cu) and Zinc (Zn). The above-ground biomass (AGB) and carbon stock (CS) were also determined. T-test was used to test for significant difference in the measured parameters between the two age-sequences of *G. arborea*. Higher values for TH, DBH, CS and MH were recorded for the older stand although the differences between the two age-sequences were not significantly different ($p \geq 0.05$). The AGB and CS per hectare were higher for the older than the younger *G. arborea* stand (302.27 m^3ha^{-1} and 151.52 m^3ha^{-1}, respectively). Higher values for silt, clay, Ca, Mg, $Al^{+}H^{+}$, ECEC, BS, Mn, Fe and Zn were also recorded for the older stand. However, the observed differences were only significant ($p < 0.05$) for clay, pH, Av.P, Mn and Fe. The study revealed that although soil properties, tree growth as well as carbon sequestration capacity of *G. arborea* stand improved/increased with age, the differences were mainly not statistically significant ($p \geq 0.05$) between the two (eight and four years) age-sequences.

DOI: https://dx.doi.org/10.4314/jasem.v24i10.9

Copyright: *Copyright* © 2020 Akhabue *et al.* This is an open access article distributed under the Creative Commons Attribution License (CCL), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Dates: Received: 15 August 2020; Revised: 22 September 2020; Accepted: 19 October 2020

Keywords: *Gmelina arborea*, age sequence, soil quality, carbon sequestration

The role of tropical tree plantations in carbon sequestration through the capture and storage of carbon in wood and soil, has been underscored. In addition, by producing biomass needed by local communities, they reduce the pressure on natural forests (Swamy *et al*., 2003). Plantations are also vital features of the carbon cycle since they can be manipulated by humans as a carbon storehouse and reduce the effects of deforestation (Houghton *et al.,* 1983). The increasing levels of CO_2 in the atmosphere and its potential to alter global climate is an important concern today. This situation has resulted in varying environmental issues. In order to mitigate this problem, IPCC (1996) advocated an increase in the size of carbon pools through large scale tree planting. The productivity of trees is greatly influenced by nutrient availability and cycling. Understanding how nutrients are stored and distributed will help in applying strategies in nutrient management for increasing biomass production (Swamy *et al*., 2003). Trees generally influence the nutrient quality and cycling through the addition of litter and root exudates into the soil. Reforestation and afforestation programmes aimed at restoring degraded land and establishing new plantations are usually carried out with fast-growing species like *Gmelina arborea* (Swamy *et al*., 2003)*. G. arborea* is widely cultivated in West Africa majorly for pulp and paper industries due to its great productivity and fast growth with eight to nine years rotation age (Greaves, 1981; Twimasi, 1991; Yani *et al*., 2011). *G. arborea* is a deciduous tree species belonging to the verbenaceae family. It is grown in plantations as an exotic species in Nigeria, Ghana and Sierra-Leone; and serves as an important raw materials for the pulp and paper industries (Akindele, 1989). The species is native of India and Burma where it reaches its best development but its natural distribution extends from Himalayan in Pakistan to Nepal, Cambodia, Vietnam and southern provinces of China (Onyekwelu and Stimm, 2002). It tolerates a wide range of conditions with annual rainfall from 750 to 500 mm, mean annual temperature of 21-28 °C and deep, well drained, base-rich soil with pH between 5.0 and 8.0 (Onyekwelu, 2002). Gmelina is short-lived with a life span of 30-50 years but grows fast during the first 5-6 years and achieves a high

**Corresponding Author Email: akhasfaith@gmail.com; Tel: 07034911305*

biomass at an early age (Nwoboshi, 1985a). In tropical and subtropical regions nearly 418,050 ha are occupied by *G. arborea* plantation (FAO, 2000). An estimated yield in excess of 30 m^3 timber ha^{-1} $year^{-1}$ can be achieved in fertile soil of rainforest in Nigeria (Yani, *et al*., 2011). Onyekwelu (2001), estimated Gmelina plantations in Nigeria to be at about 122,000 ha. Although the species is widely used in land restoration projects, there is paucity of information on changes in growth, soil nutrient and carbon storage capacity as the tree grows. Plantation trees grow rapidly and therefore nutrients demand is high especially at the early stage of development. The nutrient demand also varies with the age of the stand as reported by Farley and Kelly (2004). In addition, the usefulness of comparing stands of various ages to adjacent natural forest for understanding how nutrient status changes as plantation matures have been observed by Davis and Lang (1991) and Farley and Kelly (2004). This study therefore evaluated the impact of stand age on tree growth rate, soil quality and carbon storage using two age-sequences (4 and 8 years) of *Gmelina arborea* plantation.

MATERIALS AND METHODS

Study area: This research was conducted at the Arboretum of Forestry and Wildlife Management Department, University of Port Harcourt, Nigeria. The University is situated on a 400-hectare land in Obio/Akpor Local Government Area - Latitude 4.90794 and 4.90809 N and longitude 6.92413 and 6.92432 E (Chima *et al.*, 2016). The location is characterized with the dry and wet seasons with a nearly all-year-round rainfall distribution (Aiyeloja *et al*., 2014). The arboretum covers a total area of 15,996.90 m² with several tree stands of various species including *Gmelina arborea, Tectona grandis, Khaya grandifoliola, Nuclea diderrichii, Irvingia gabonensis, Entandrophragma cylindricum, Terminalia ivorensis, Ricinodendron heudelotti*, *Treculia africana, Garcinia kola, Persea americana* and *Anona muricata*.

Site selection and sampling: Within the study area, two stands of *Gmelina arborea* established in 2011 and 2015 were purposively chosen. An area of 16.489 m x 8 m was mapped out from each of the age-sequences for data collection. Total enumeration of trees was carried out in each stand. Soil samples were also collected from each stand for laboratory analysis.

Collection of soil samples and soil analysis: Soil samples were collected from a depth of 0-30 cm from nine randomly selected points around the core area of each age-sequence of the *G. arborea* stand using an auger. The rationale behind excluding areas close to the boundaries of the two age-sequences in soil sampling was to avoid edge effect. The soil samples were bulked in triplicates for each age-sequence and taken to the laboratory for analysis using standard laboratory procedures described in Agbenin (1995). The particle size distribution was determined using the hydrometer method; the exchangeable bases were determined using ammonium acetate extraction method; exchangeable acidity was determined by the titrimetric method; available phosphorus was determined by the molybdate blue (Bray No. 2 extraction) method, total nitrogen was determined by Kjedahl method; soil pH was measured in 1:1 soil: water ratio; organic carbon was determined by Walkley Black wet oxidation method and organic matter derived there from by multiplying with 1.72 (Agbenin, 1995). The micronutrients (manganese, iron, copper and zinc) were determined using 0.1N extraction method; ECEC was determined by the summation method while base saturation (%) was computed using the formula: BS (%) = [(exchangeable cations – exchangeable acidity)/exchangeable cations] x 100.

*Measurement of tree growth attributes***:** Total height of trees present in the sampled plots of each age-sequence was measured using a clinometer. The DBH was calculated by measuring the tree girth at a height 1.3 m from the tree base with a measuring tape. The diameter was then estimated using the formula: $DBH = \frac{c}{\pi}$, where c= circumference and $\pi = 3.142$. Crown height was estimated by deducting the height of the tree from the ground to the crown-point from total height of the tree. Crown diameter was measured by getting the average of the distance between the tips of the crown from north to south and from east to west using a measuring tape. Merchantable height was measured using a clinometer by taking the measurement from the base of the bole up to the point merchantable for timber.

Computation of Above-Ground Biomass (AGB) and Carbon Stock: AGB was calculated using the formula:

$$\text{AGB} = \text{Volume x Density}.$$

Specific wood density of *G. arborea* was gotten from the Global Wood Density Database (Chave, *et al*., 2009; Zanne *et al*., 2009) while stem volume was calculated using the formula:

$$V = DBH^2 \; x \; H.$$

Where: V = volume, DBH= diameter at breast, and H= total height.

The above-ground carbon stock for each plantation was evaluated by multiplying the above-ground biomass with the carbon fraction (CF) as shown below.

$$\text{Carbon stock} = AGB \ x \ CF$$

The default value for the CF is 0.50 as it is noted that 50 percent of tree biomass forms the carbon stock (Ravindranath *et al*., 1997; Hetland *et al*., 2016; Jew *et al*., 2016).

Data Analysis: T-test was used for comparison to determine if the evaluated soil and tree attributes varied significantly ($p < 0.05$) between the two age-sequences of *Gmelina arborea* plantation.

RESULTS AND DISCUSSION

Growth characteristics for the two age-sequences of Gmelina arborea: Table 1 shows the means, standard deviations and *p-values* for growth characteristics of the two age-sequences of *G. arborea* plantation. The *p-value* indicates no significant difference ($p \geq 0.05$) between the two age-sequences (4 and 8 years) for the growth parameters measured. This implies that no much growth difference is observed between the four years old and eight years old Gmelina stands. This may be as a result of the slow growth that occurs after the first 5-6 years of establishment, as it is noted that the species grows fast during the first 5-6 years of planting (Nwoboshi, 1985a).

Table 1: Growth characteristics of *Gmelina arborea* stands

Growth Characteristics	Ga 2011	Ga 2015	*P-Value* (two-tailed)
TH (m)	12.58±1.17	10.38±0.42	0.15
DBH (m)	0.13±0.01	0.11±0.01	0.29
CH (m)	7.00±0.85	7.63±0.42	0.58
CD (m)	5.12±0.33	4.28±0.26	0.08
MH (m)	7.87±0.74	6.93±0.38	0.34

Ga 2011 = Gmelina arborea planted in 2011, Ga 2015 = Gmelina arborea planted in 2015, TH = total height, DBH= diameter at breast height, CH= crown height, CD= crown diameter, MH= merchantable height.

However, it was observed that the average value for the total height, DBH, crown diameter and merchantable height was higher for the older Gmelina stand which means that the tree growth variables increased with stand age. Adekunle *et al*., (2011) in their study also reported an increase in tree growth with increase in tree age.

*Volume, Above Ground Biomass and Carbon stock for the two age-sequences of G. arborea***:** The means, standard deviations and *p-values* for volume, above ground biomass and carbon stock for the two stands are presented in Table 2. The *p-values* indicate no significant difference ($p \geq 0.05$) between the two stands. Higher values were recorded for the older stand in all the parameters evaluated. The production of biomass is an important factor considered in all planting programmes. Tree biomass is important in estimating forest carbon stock and productivity. The amount of biomass produced by a forest shows its capacity to assimilate solar energy under some set of environmental conditions (Ige, 2018). In this study the older stand was observed to have accumulated more biomass than the younger. The older stand was observed to have sequestered over twice the amount of carbon (per hectare) sequestered by the younger one. Several studies (e.g. Brown and Lugo 1985; Terakunpisut *et al.,* 2007; Meta *et al*., 2015) have equally shown that the age of forest influence the potential to sequester carbon.

Table 2: Volume, AGB and Carbon stock of *Gmelina arborea* stands

Variables	Ga 2011	Ga 2015	*P-Value* (two-tailed)
VOL (m^3)	0.32±0.07	0.19±0.05	0.21
AGB (ton)	0.15±0.04	0.09±0.02	0.20
CS (ton)	0.08±0.02	0.05±0.01	0.20

Ga 2011 = Gmelina arborea planted in 2011, Ga 2015 = Gmelina arborea planted in 2015, VOL= volume, AGB= above-ground biomass, CS= carbon stock.

Total Volume, Density, AGB and Carbon stock of stands per hectare for the two age-sequences of Gmelina arborea: Table 3 shows Total Volume, Density, AGB and Carbon stock per hectare of the two age-sequences of *G. arborea* plantation. All variables were observed to be over 100% higher in the older stand (8 years old) than the younger one (4 years old). Biomass accumulation is directly connected to forest's potential to store carbon. A forest has the capacity to store and retain huge quantity of carbon over a time frame (Sedjo, 2001) and the major activity which adds to carbon input in an ecosystem is photosynthesis (Schulze, 2006)**.** This result is comparable to what has been reported by various authors. For instance, Ige (2018) recorded 2623.46t/ha in a 34 years old stand and 133.40t/ha in an 18 years old stand. In Ghana, 56t/ha was reported by Nwoboshi, (1985b) while in Nigeria, 272t/ha was reported by Nwoboshi (1994). Ige (2018) stated that stands with better growth characteristics will have a much higher above-ground biomass accumulation and carbon stock since biomass is directly related to growth.

Table 3: Total Volume, Density, AGB and Carbon stock of stands per hectare

Variables	Ga 2011	Ga 2015
VOL(m^3ha^{-1})	630.3	246.38
AGB($t.ha^{-1}$)	302.27	117.93
CS($t.ha^{-1}$)	151.52	59.2

Ga 2011 = Gmelina arborea planted in 2011, Ga 2015 = Gmelina arborea planted in 2015, VOL= volume, AGB= above-ground biomass, CS= carbon stock.

Particle size distribution of *Gmelina arborea* stands for the two age-sequences of *Gmelina arborea:* Table 4 shows the soil particle size distribution of the two stands. Only the clay component showed significant difference ($p < 0.05$) between the two age-sequences. Sand was higher in the younger stand with higher values for silt and clay recorded in the older stand. The soil is an important part of terrestrial ecosystems with vital roles such as provision of base and physical support for effective plant growth, supply of nutrients and minerals for growth and biomass production, biodiversity conservation and provision of ecosystem services for mankind and home for microorganisms (Ren *et al*., 2012; Edmondson *et al*., 2003). *G. arborea* is known to be a good soil modifier for stabilization of soil nutrients (Mishra *et al.,* 2003). In this study, a general increase was observed in the silt and clay content with increase in stand age while there was decrease in percentage sand content. However, no significant difference was observed between the two age-sequences except in percentage clay. Oseni *et al*. (2007) in their study stated that sandy soil is known to usually dominate artificial forest soils. However, the observed lower percentage sand in the older stand may have been as a result of more deposition, accumulation and decay of leaf litter over time in the older stand.

Table 4: Particle size distribution of *Gmelina arborea* stands

Particle size distribution	Ga 2011	Ga 2015	*P-Value* (two-tailed)
Sand (%)	75.2±1.15	80.53±1.76	0.06
Silt (%)	16.13±0.67	13.87±1.76	0.25
Clay (%)	8.67±0.67	5.6±0.00	0.01*

*Ga 2011 = Gmelina arborea planted in 2011, Ga 2015 = Gmelina arborea planted in 2015. *= significant difference at p < 0.05*

Soil chemical properties of Gmelina arborea stands for the two age-sequences of Gmelina arborea: Table 5 shows the soil chemical properties of the two age-sequences of *G. arborea* plantation. Soil pH, available phosphorus, manganese and iron were significantly different between the two age-sequences. Potassium, sodium, total organic carbon, soil organic matter, available phosphorus and copper were higher in the younger stand while manganese, iron, zinc, pH, calcium, magnesium, ECEC, and base saturation were higher in the older stand. Soil pH has a great influence on soil ion exchange equilibrium due to its effects on weathering, organic matter mineralization and nutrient mobilization (Adekunle *et al.,* 2011). On the other hand soil pH is affected by the concentration of the exchangeable acids and bases in the soil, as the pH level reduces with an increase in Al^{+}+H^{+} and a decrease in Ca, Mg and K (Brady and Weil, 2002). A relationship exists between the availability of nutrient elements and soil pH. Nwoboshi (2000) reported an increase in nutrients at pH range of 6.5-7.5. The soils under both stands were observed to be acidic. Although the values obtained do not fall within the range of pH for effective growth of the species (5.0 and 8.0) as reported by Hossain (1999), a significant difference was observed between the two stands. This significant difference is indicative of a possible increase in the pH of the topsoil under the stands as they increase in age and as more leaf litter accumulate and decay. A general increase was observed in most of the soil chemical properties with increase in stand age although the increment was not statistically different in many of the evaluated parameters. This implies that the difference in stand development (4 years) between the two age-sequences has no significant effect on their soils yet. Turner and Kelly (1985) observed that most significant changes in nutrient status of the soil are likely to take place between the ages of 10 - 20 years. This observation lends credence to reports on improvement in soil properties with increase in stand age (Chijioke, 1980; Negi *et al.* 1990; Kadeba 1991; Mishra *et al.,* 2003; Swamy *et al.,* 2004). The decrease in soil organic matter and organic carbon with an increase in age may be due to rapid decomposition and use by the growing trees and other associated and prevailing factors. Oseni *et al.* (2007) reported that other factors such as parent material, clay content, temperature, and rainfall distribution usually have modifying influence on soil organic matter content. There is usually little nutrient recycling during the first few years of plantation establishment due to crown development, few leaves and branches which results in reduced litter fall and as such little nutrient is returned to the soil (Evans, 1999). Lower nutrient input and higher nutrient demands needed for the development of young stands have also been reported as reasons for low nutrient concentration in the stands of young plantations (Singh and Sharma, 2007). For maximum productivity of soils in forest plantations, the input rate of nutrient must equal or exceed any losses that occur through tree uptake, leaching, erosion, fire or harvesting (Cahyono *et al.,* 2004).

Table 5: Soil chemical properties of *Gmelina arborea* stands

Soil chemical properties	Ga 2011	Ga 2015	*P-Value* (2-tailed)
pH	4.64±0.05	4.21±0.05	0.00*
Ca (cmol/kg)	1.09±0.23	0.44±0.12	0.07
Mg (cmol/kg)	0.88±0.55	0.30±0.10	0.36
K (cmol/kg)	0.10±0.01	0.13±0.01	0.05
Na (cmol/kg)	0.21±0.02	0.33±0.05	0.08
$Al^{+}H^{+}$ (cmol/kg)	0.13±0.01	0.12±0.01	0.56
ECEC (cmol/kg)	2.41±0.79	1.33±0.26	0.26
B. Sat (%)	93.64±1.57	90.02±1.91	0.22
TN (%)	0.09±0.02	0.09±0.01	0.78

TOC (%)	1.14±0.21	1.22±0.14	0.76
SOM (%)	1.96±0.37	2.09±0.24	0.77
Ava. P (mg/kg)	9.65±2.57	31.73±5.76	0.02*
Mn (mg/kg)	33.98±7.94	6.40±0.68	0.03*
Fe (mg/kg)	9.32±1.80	1.98±1.24	0.03*
Cu (mg/kg)	0.56±0.11	0.68±0.11	0.46
Zn (mg/kg)	1.77±0.28	1.28±0.47	0.42

*Ga 2011 = Gmelina arborea planted in 2011, Ga 2015 = Gmelina arborea planted in 2015. *= significant difference at p<0.05. Ca = calcium, Mg = magnesium, K= potassium, Na= sodium, Al^+H^+ = exchangeable acidity, ECEC = effective cation exchange capacity, Mn = manganese, Fe= iron, Cu = copper, Zn = zinc. Ava. P=* Available Phosphorus, SOM = Soil Organic Matter, TOC = Total Organic Carbon, TN = Total Nitrogen, B. Sat = Base Saturation

*Conclusion***:** The study revealed that although soil properties, tree growth as well as carbon sequestration capacity of *G. arborea* stand improved/increased with age, the differences were mainly not statistically significant ($p \geq 0.05$) between the two (four and eight years) age-sequences. This implies that the difference in the ages of the two *G. arborea* stand did not impact significantly on the evaluated tree and soil attributes at their present stages (4 and 8 years) of development. However, further studies are required to ascertain if there could be significant variations in the evaluated parameters as the stands get older.

REFERENCES

Adekunle, VAJ; Alo, AA; Adekayode, FO (2011). Yields and nutrient pools in soils cultivated with *Tectona grandis* and *Gmelina arborea* in Nigerian rainforest ecosystem. *J. Saudi Soc. Agric. Sci.* 10: 127-135.

Agbenin, JO (1995). Laboratory Manual for Soil and Plant Analysis: Selected methods and data analysis. Faculty of Agriculture/Institute of Agricultural Research, A.B.U. Zaria, 7-71.

Aiyeloja, AA; Adedeji, GA; Larinde, SL (2014). Influence of seasons on honeybee wooden hives attack by termites in Port Harcourt, Nigeria. *Inter. J. Bio. Vet. Agric. Food Eng.* 8(8):734-737.

Akindele, SO (1989). Teak yield in the dry low land rain forest area of Nigeria. *J. Trop. For. Sci.* 2(1):32-36.

Brady, NC; Weil, RR (2008). The soils around us. The Nature and Properties of Soils, 14th ed Pearson Prentice Hall, New Jersey and Ohio, p.1-31.

Brown, S; Lugo, AE (1985). Biomass of tropical tree plantations and its implications for the global carbon budget. *Canadian J. For. Res.* 16(1986): 390-394.

Cahyono A; Oka, K; Satoshi, K; Kikuo, H; Hiroto, T; Suryo, H; Haryono, S; Mohamad, N; Wahyu, W; Maurit, SS; Khomsatun; Suhartono, W (2004). Sustainable site productivity and nutrient management in a short rotation plantation of *Gmelina arborea* in East Kalimantan, Indonesia. *New Forest*. 28: 277-285.

Chave, J; Coomes, DA; Jansen, S; Lewis, SL; Swenson, NG; Zanne, AE (2009). Towards a worldwide wood economics spectrum. *Ecology Letters.* 12(4): 351-366

Chima, UD; Akhabue, FE; Gideon, IK (2016). Rhizosphere soil properties and growth attributes of four tree species in a four-year arboretum at the University of Port Harcourt, Nigeria. *Nig. J. Agric. Food Environ.* 12(2): 74-80.

Chijioke, EO (1980). Impart on soils of fast growing species in lowland humid tropics. FAO Forestry Paper No. 21. FAO, Rome, p.111.

Davis, MR; Lang, MH (1991). Increased nutrient availability in topsoils under conifers in the South Island high country. *New Zealand J. For. Sci.* 21: 165-179.

Edmondson, JL; O'Sullivan, OS; Inger, R; Potter, J; McHugh, N; Gaston, KJ; Leake, JR (2014). Urban tree effects on soil organic carbon. *PLoS one*. 9(7):e101872.

Evans, J (1999). Plantation Forestry in the Tropics, second ed. Oxford Science Publication, Oxford University Press, New York.

FAO (2000). Global forest products outlook study working paper series. Brown, C. (Ed.), working paper no. GFPOS/WP/03, Forestry policy and planning division, Rome, Italy.

Farley, KA; Kelly, EF (2004). Effects of afforestation of a pa´ramo grassland on soil nutrient status. *For. Ecol. Manage.* 195: 281-290.

Greaves, A (1981). *Gmelina arborea*. *For. Abstr*. 42: 237-258.

Hetland, J; Yowargana, P; Leduc, S; Kraxner, F (2016). Carbon-negative emissions: systemic impacts of biomass conversion: a case study on CO2 capture and storage options. *Inter J. Greenhouse Gas Control.* 49: 330–342.

Hossain, MK (1999). Gmelina arborea: A popular plantation species in the tropics. FACT Sheet. Quick guide multipurpose trees from around the world. FACT 99-05. Forest, Farm and community Tree Network. Winrock international. Available at http://www.winrock.org/fnrm/factnet/factpub/FACTSH/Gmelina%20arborea1.pdf.

Houghton, R.A., Hobbie, J.E., Melillo, J.M., Moore, B., Peterson, B.J., Shaver, G.R. and Woodwell, G.M. (1983). Changes in the carbon content of terrestrial biota and soils between 1860 and 1980: a net release of CO2 to thee atmosphere. *Ecological Monographs.* 53: 235-262.

Ige, PO (2018). Above Ground Biomass and Carbon Stock Estimation of *Gmelina arborea* (Roxb.) Stands in Omo Forest Reserve, Nigeria. *J. Res. For., Wildlife. Environ.* 10(4): 71-80.

IPCC (1996). Impacts, adaptations and mitigation of climate change: scientific technical analysis contributions of working group II to IInd assessment report of Intergovernmental panel on climate change, Watson, R.T., Zingowera, M.C., Moss, R.H. (Eds.) Cambridge University Press, New York, NY, USA, p.880.

Jew, EKK; Dougill, AJ; Sallu, SM; O'Connell, J; Benton, TG. (2016). Miombo woodland under threat: consequences for tree diversity and carbon storage. *For. Ecol. Manage*. 361: 144-153.

Kadeba, O (1991). Above-ground biomass production and nutrient accumulation in an age sequence of *Pinus caribaea* stands. *Forest Ecol. Mgmt*. 41: 237–248.

Meta, FJ; Wanqin, Y; Fuzhong, W; Bo, T; Muhammad, NK; Yeyi, Z (2015). Biomass Stock and Carbon Sequestration in a Chronosequence of *Pinus massoniana* Plantations in the Upper Reaches of the Yangtze River. *Forests.* 6: 3665-3682.

Mishra, A; Sharma, SD; Khan, GH (2003). Improvement in physical and chemical properties of sodic soil by 3, 6- and 9-years old plantation of *Eucalyptus tereticornis* bio rejuvenation of sodic soil. *For. Ecol. Manage*. 184: 115–124.

Negi, JDS; Bahuguna, VK; Sharma, DC (1990). Biomass production and distribution of nutrients in 20 year old teak (*Tectona grandis*) and gamhar (*Gmelina arborea*) plantations at Tripura. *Ind. Forest*. 116: 681-686.

Nwoboshi, LC (1985a). Growth of teak, ten years after thinning. *Nig. J. For.* 15(1): 82.

Nwoboshi, LC (1985b). Biomass and nutrient uptake and distribution in *Gmelina* pulpwood plantation age-series in Nigeria. *J. Trop. For. Res.* 1(1): 53–62.

Nwoboshi, LC (1994). Development of *Gmelina arborea* under the Subri Conversion Technique: first three years. *Ghana J. For.* 1: 12-8.

Nwoboshi, LC (2000). The Nutrient Factor in Sustainable Forestry. Ibadan University Press, Ibadan, Nigeria, p.303.

Onyekwelu, JC (2001). Growth Characteristics and Management Scenarios for plantation grown *Gmelina arborea* and *Nauclea diderrichii* in South West Nigeria: Munich Hieronymus Verlag, p.196.

Onyekwelu, JC (2002). Growth characteristics and management scenarios for plantation-grown Gmelina and Nauclea in SW Nigeria. Hieronymus Verlag, Munich, Germany, p.196.

Onyekwelu, JC; Stimm, B (2002). *Gmelina arborea*. In: Enzyklopa¨ dieder Holzgewa¨ chse-28. Erg. Lfg. Ecomed-Verlag, Germany, p.8.

Oseni, OA; Ekperigin, MM; Akindahunsi, AA; Oboh, G (2007). Studies of physicochemical and Microbial Properties of Soils from Rainforest and Plantation in Ondo State, Nigeria. *Afr. J. Agric. Res.* 2(11): 605-609.

Ravindranath, NH; Somashekhar, BS; Gadgil, M (1997). Carbon flow in Indian forests. *Climatic Change.* 35: 297-320.

Ren, Y; Yan, J; Wei, X; Wang, Y; Yang, Y; Hua, L; Xiong, Y; Niu, X; Song, X (2012). Effects of rapid urban sprawl on urban forest carbon stocks: integrating remotely sensed, GIS and forest inventory data. *J. Environ. Manage*. 113: 447–455.

Schulze, ED (2006). Biological control of the terrestrial carbon sink. *Biogeosciences*. 3: 147-166.

Sedjo, RA (2001). Forest Carbon Sequestration: Some Issues for Forest Investments. Discussion Paper 01-34. Resources for the Future 1616 P Street, NW Washington, D.C., p.23.

Singh, B; Sharma, KN (2007). Tree growth and nutrient status of soil in a poplar (Populus deltoides Bartr.)-based agroforestry system in Punjab, India. *Agroforest System*. 70: 125-134.

Swamy, SL; Kushwaha, SK; Puri, S (2004). Tree growth, biomass, allometry and nutrient distribution in *Gmelina arborea* stands grown in red lateritic soils of Central India. *Biomass Bioenergy.* 26: 305-317.

Swamy, SL; Puri, S; Singh, AK (2003). Growth, biomass, carbon storage and nutrient distribution in Gmelina arborea Roxb. stands on red lateritic soils in central India. *Biores. Tech.* 90(2003): 109-126.

Terakunpisut, J; Gajaseni, N; Ruankawe, N (2007). Carbon sequestration potential in aboveground biomass of Tong PhaPhun national forest, Thailand. *Appl. Ecol. Environ. Res*. 5: 93-102.

Turner, J; Kelly, J (1985). Effect of radiata pine on soil chemical characteristics. *For. Eco. Manage.* 11: 257-270.

Twimasi, KA (1991). Strength Characteristics of Packaging Paper Made from Tropic Wood Species. *Tropic.* Sci. 31: 95-100.

Yani, JP; Tella, OI; David, DL; Ali, BD (2011). Site index analysis of an age sequence of *Gmelina arborea* plantation in Jalingo, Taraba state, Nigeria. *J. Agric.Vet.Sci.* 3(2011): 76-84.

Zanne, AE; Lopez-Gonzalez, G; Coomes, DA; Ilic. J; Jansen, S; Lewis, SL; Miller, RB; Swenson, NG; Wiemann, MC; Chave, J (2009). Data from: Towards a worldwide wood economics spectrum. Dryad Digital Repository. https://doi.org/10.5061/dryad.234. Retrieved 25/6/2020.