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 2013. 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). Tops (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 (AlH^+), 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 ≥ 0.05). The AGB and CS per hectare were higher for the older than the younger *G. arborea* stand (302.27 t ha^{-1} and 151.52 t ha^{-1}, respectively). Higher values for silt, clay, Ca, Mg, AlH^+, 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 ≥ 0.05) between the two (eight and four years) age-sequences.

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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 CO₂ 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 (Onyekwelw 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 (Onyekwelw, 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

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biomass at an early age (Nwoboshi, 1985a). In tropical and sub-tropical regions nearly 418,050 ha are occupied by *G. arborea* plantation (FAO, 2000). An estimated yield in excess of 30 m³ 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 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 in 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 Kjedah 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 = \( \frac{r}{\pi} \) 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:

\[ AGB = \text{Volume} \times \text{Density}. \]

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:

\[ V = DBH^2 \times H. \]

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.

Carbon stock = \(\text{AGB} \times \text{CF}\)

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).

| Variables | Ga 2011 | Ga 2015 | \(p\)-Value (two-tailed) |
|-----------|---------|---------|-------------------------|
| VOL (m³)  | 0.32±0.07 | 0.19±0.05 | 0.21 \(\geq 0.05\) |
| AGB (ton) | 0.15±0.04 | 0.09±0.02  | 0.20 \(\geq 0.05\) |
| CS (ton)  | 0.08±0.02  | 0.05±0.01 | 0.20 \(\geq 0.05\) |

\(\text{Ga 2011} = \text{Gmelina arborea planted in 2011}, \text{Ga 2015} = \text{Gmelina arborea planted in 2015}, \text{VOL} = \text{volume}, \text{AGB} = \text{above-ground biomass}, \text{CS} = \text{carbon stock.}\)

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.

| Variables | Ga 2011 | Ga 2015 |
|-----------|---------|---------|
| VOL (t/ha) | 630.3 | 246.38 |
| AGB (t/ha) | 302.27 | 117.93 |
| CS (t/ha) | 151.52 | 59.2 |

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 |

\(\text{Ga 2011} = \text{Gmelina arborea planted in 2011}, \text{Ga 2015} = \text{Gmelina arborea planted in 2015}, \text{TH} = \text{total height}, \text{DBH} = \text{diameter at breast height}, \text{CH} = \text{crown height}, \text{CD} = \text{crown diameter}, \text{MH} = \text{merchantable height.}\)

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.
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*                 |

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^3+ 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^3+ (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               |

* = significant difference at p < 0.05
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 ≥ 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.

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