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# Stand growth, Biomass and Carbon sequestration potentials of *Parkia biglobosa* (jacq.) Bench plantation in South-Western Nigeria

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**ABSTRACT:** This study assessed tree growth variables, above (AGB), below ground biomass (BGB) and total carbon content (TC) sequestered by *Parkia biglobosa* (Jacq.) Bench. Plantation in Wasangare, Oyo State using non-destructive ground base survey. Tree growth data (Diameter at breast height, Dbh and Tree height, Th) were collected using lacer ace hypsometer and diameter girth tape from 20 temporary sampling plots of size 25 m X 25 m established through systematic transect lines. Diameter size classes (DSC) for the plantation was examined, carbon stock for each DSC was also determine while basal area ($m^2 ha^{-1}$), volume ($m^3 ha^{-1}$), Biomass ($Mg\ ha^{-1}$) and Carbon ($Mg\ ha^{-1}$) were also estimated. Results showed mean Dbh of 18.7 $\pm$ 0.25 cm with 8.14 $\pm$ 0.10 m, 0.033 $\pm$ 0.00 $m^2 ha^{-1}$ and 0.320 $\pm$ 0.01 $m^3 ha^{-1}$ for tree height, basal area and volume respectively. AGB and BGB were 10.877 $\pm$ 0.39 $Mgha^{-1}$ and 2.175 $\pm$ 0.08 $Mgha^{-1}$ respectively while TC was 6.527 $\pm$ 0.24 $Mgha^{-1}$. The percentage carbon stock proportion for each DSC revealed class size 25-29-9 cm (19.02%) as the highest while the least proportion was observed in less than 5 cm class with 0.04% of carbon. The DSC showed majority of the tree Dbh in lower Dbh classes with fewer trees in higher classes forming almost a normal bell shape. The study provides information that can help the management in planning silvicultural activities and selective removal from the stand (harvesting schedule). Tree Dbh, height, basal area, volume and biomass are the determinant characteristics for forest carbon assessment. In conclusion, the plantation actively sequesters carbon showing potentials for indigenous trees in climate change mitigation.

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Climate change is one of the biggest problems facing humanity today. As a result, research scientists, policymakers and other stakeholders have given climate change mitigation serious consideration (Xul *et al*., 2018). Also, it has been acknowledged that the primary method of reducing the effects of climate change is through effective forest management. Forest ecosystems are critical to the biosphere's functioning and conservation, as well as are the basics of many plants and animals (Onilude *et al*. 2020). The lack of timely and accurate information on stand conditions is one of the key obstacles and difficulties in understanding the functioning of Nigerian forest ecosystems (Onilude *et al*. 2020). Forest managers, on the other hand, can only assure sustainable management of their forest stands if reliable and

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timely information on the growing stock is available (Ige 2017). 96% of all tree species on Earth are found in tropical forests, which highlights the importance of forests in sequestering carbon (Ajayi and Adie 2018). Climate change and global warming are majorly caused by anthropogenic activities such as greenhouse gas (GHG) emissions, land-use and land-cover change which are now considered major environmental concerns (Sharma *et al*. 2020). However, answers to this concerns have been focused on two paths: (1) reducing the quantity of GHGs particularly carbon dioxide ($CO_2$), and (2) determining the amount of carbon sink by forests, soils, and the ocean. Although carbon can be stored in several pools with trees and soils considered as the principal pools (Bhatta *et al*. 2018).

Forests are essential terrestrial carbon sinks because they store a large amount of carbon in vegetation and soil and interact with atmospheric processes through the absorption and respiration of $CO_2$ (Xu *et al*., 2013, Li *et al*., 2015). Currently, forest resources, particularly tropical forests, are experiencing increasing pressure due to the growing population and land-use conversion resulting in deforestation and degradation (FAO, 2010). Hence, the mounting rate of tropical deforestation makes the search for alternative natural resources critical. Several approaches for assessing biomass and carbon stock in forests have been demonstrated. Some approaches estimate total biomass whilst others estimate above-ground biomass and below ground biomass separately. Understanding standing carbon stocks in natural forests or plantations is critical for forest management aimed at minimizing climate change, biodiversity loss, and settling conflicts over multiple land-uses (Olayode *et al*. 2015). Therefore, assessment of carbon stored as biomass in forest ecosystems are gaining importance in global climate change research (Nonini and Fiala 2019).

Understanding the growth characteristics of the indigenous tree species like *Parkia biglobosa* (Jacq.) Bench and an estimate of the biomass and carbon contained in a plantation reflects the potential of *P. biglobosa*, an indigenous species towards climate change mitigation (Ghimire *et al*. 2018; Sharma *et al*. 2020). Nonetheless, the growth information on the *P. biglobosa* (Jacq.) Bench plantation as well as biomass and carbon content of the Savannah zone of the state is inadequate and even limited. Thus, in order to overcome these research gaps, it is important to understand the growth characteristics of the plantation and estimate the tree biomass and carbon stock.

*Parkia biglobosa* (Jacq.) Bench is typically found in West African Savannah villages. It belongs to Fabaceae family and can reach heights of 7 to 20 meters, and can also be found up to 30 meters (Ntui *et al*. 2012). The tree species is also known as locust beans, or "Daddawa," "Ogiri," or "Iru" in Hausa, Igbo, and Yoruba, respectively. It can be used for a variety of functions such as fodder, food, medicinal, lumber, and socio-economic purposes (Ntui *et al*. 2012). Hence, the objective of this paper was to evaluate Stand growth, Biomass and Carbon sequestration potentials of *Parkia biglobosa* (jacq.) Bench plantation in South-Western Nigeria.

## MATERIAL AND METHODS

*Study site:* The research was carried out at the *P. biglobosa* (Jacq.) Bench plantation in Wasangare village, which is located in Oyo state's Savannah belt. It is located at latitudes 8.8558ºN and 8.8573ºN, and longitudes 3.42353ºN and 3.42519ºE. (Fig. 1). Guinea savannah and rain forest have been the major vegetation pattern in the state located in north and south respectively. The climate is tropical, with two peak wet seasons in the south and one peak wet season in the north. The average annual temperature is 21°C, while yearly rainfall and the average daily temperature ranges from 1000mm to 1500mm and 25ºC to 35ºC respectively. (Adeola *et al*. 2012).

*Sampling Design and Data collection:* A systematic line transect was used for this study. A total of 20 temporary sampling plots of size 25 m × 25 m spaced at 20 m to each other and laid alternatively to each other were obtained from four transect lines of 205 m each at 150 m from each other. An edge effect of 20 m was established before laying the plots (Figure 2). In each of the established temporary sample plots, measurement and information on all trees irrespective of their diameters and height were collected for each *P. biglobosa* (Jacq.) Bench tree. With this, information on all diameter sizes of woody plants in the plantation were captured. Dbh and tree height were measured to the nearest 0.1 cm and 0.1 m with diameter tape and a lacer ace hypsometer respectively. The Basal Area (BA) and Volume (Vol) of all the individual trees were obtained as presented in table 1.

The estimation of above ground biomass (AGB) was done through Chave *et al*. (2014) allometric model developed for the tropical forest as adopted by Sharma *et al*. (2020) in his study of *Pinus roxburghii* in Central Nepal (Table 1). Wood Densities done by Reyes *et al*. (1992) for tropical tree species was taken as the dry wood density of the Parkia tree species. According to Ajayi and Adie (2018), 50% of the tree total volume constitutes the carbon content of any woody biomass. As a result, the carbon weight in the tree was determined by multiplying the dry weight of the tree by 50%. Thus, equation 4 was adopted in the determining the amount of carbon sequestered (Sharma *et al*., 2020). Moreso, the carbon stock for all the diameter classes was also determined with the view to understand the distribution pattern of the carbon available within the Dbh classes.

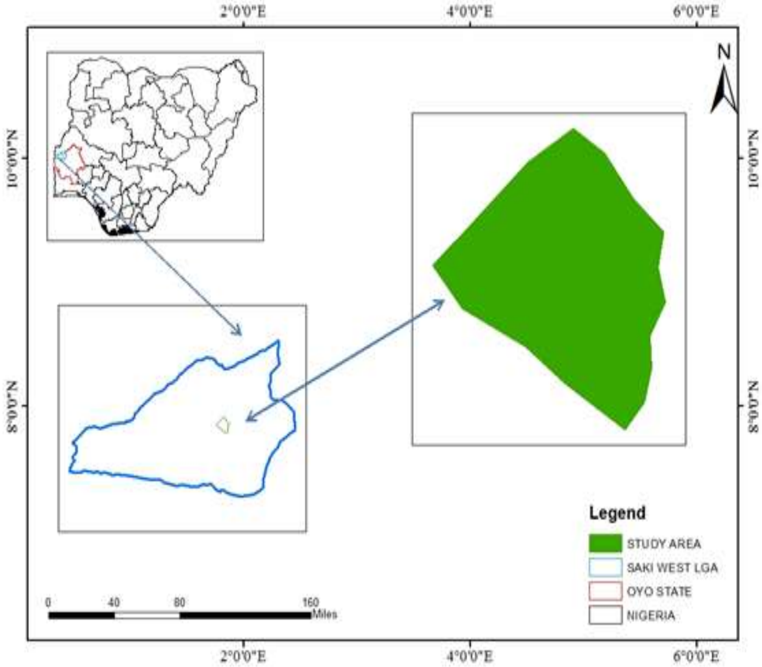


**Fig 1**: Map of Nigeria showing Oyo State, Saki West LGA and the *P. biglobosa* (Jacq. Bench.) Plantation in Wasangare.

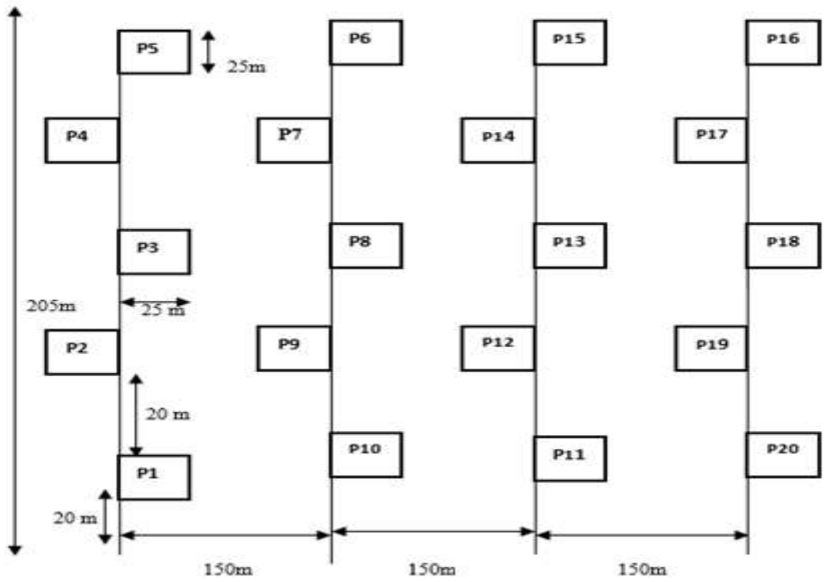


**Fig 2**: Ground layout of the transect lines used for the plot sampling

**Table 1:** Estimation of Variables

| Eq. | Variables | Formula | References |
|---|---|---|---|
| 1 | Basal area (BA) | $\frac{\pi D^2}{4}$ | Husch *et al.* (2003) |
| 2 | Volume (Vol) | $\pi H \frac{[Db^2 + 4Dm^2 + Dt^2]}{24}$ | Husch *et al.* (2003) |
| 3 | Above Ground Biomass (AGB) | AGB (kg) = $0.0509 \times \rho D^2 H$ | Chave *et al.* (2014), Sharma *et al.* (2020) |
| 4 | Carbon sequestered | $C_s = W X 0.5$ | Sharma *et al.* (2020) |

***Note**: Eq. is equations, ρ is wood density (kg $cm^{-3}$), D is diameter at breast height of the tree (cm), and H is the height of the tree (m), BA = Basal area ($m^2$), V = Volume over bark ($m^3$), Db = Diameter at the base, Dm = Diameter at the middle, Dt = Diameter at the top and π = 3.142 (constant), $C_s$ = sequestered carbon (tons/ha), W = above ground dry biomass (tons/ha)*

*Data Analysis:* Descriptive and Inferential statistics were adopted for this study. The descriptive statistics was used to estimate means, range, total and standard error for the tree growth variables, tree biomass as well as the carbon stock. Inferential statistics like correlation analysis was performed to determine the type of relationship between the tree biomass and carbon stock, stand density, tree height, tree Dbh, basal area, volume and crown dimension. A significant correlation was obtained when significance level was set at $\alpha_{0.05}$. However, prior to correlation analysis, the growth data was subjected to test of normality to ascertain if the data were normally distributed (Shapiro-Wilk test, $P < 0.05$). The result of the test revealed that none of the tree growth variables was normally distributed. However, on subjecting the data to several transformation methods, the natural logarithm method was found to confer the best normalcy to the data. The growth variables were then correlated using Pearson correlation (a parametric test).

## RESULTS AND DISCUSSION

*The plantation density and growth structure:* Growth characteristics and frequency distribution of *Parkia biglobosa* (Jacq.) Bench trees in the study area is presented in Table 2 and 3 respectively. A total of 75 trees per hectare of *P. biglobosa* (Jacq.) Bench were enumerated in the study area. The diameter at breast height ranges from 2cm to 61.7 cm with mean value of 18.7±0.25 cm. The tree height ranges from 1.8 m to 21 m with mean value of 8.14±0.10 m. Basal area and the volume range from 0.0003 $m^2$ to 0.2990 $m^2$ and 0.0008 $m^3$ to 3.2529 $m^3$ respectively with mean values of 0.033±0.00 $m^2$ and 0.320±0.01 $m^3$ respectively. The frequency distribution for the trees in different Dbh classes revealed the highest and lowest number of trees were observed in the 10 – 14.9 and above 55 classes respectively (Table 3).

**Table 2:** Growth characteristics (Mean) of the tree species in the study area

| Variables | Mean ± SE | Min | Max |
|---|---|---|---|
| Dbh (cm) | 18.7 ± 0.25 | 2 | 61.7 |
| BA ($m^2$/ha) | 0.033 ± 0.00 | 0.0003 | 0.2990 |
| THT (m) | 8.14 ± 0.10 | 1.8 | 21 |
| Vol ($m^3$/ha) | 0.320 ± 0.01 | 0.0008 | 3.2529 |
| CR (%) | 45.77 ± 0.56 | 5.22 | 100.0 |

*Note: diameter at breast height (cm), BA-Basal Area ($m^2$ $ha^{-1}$), THT- Tree height (m), Vol- Volume ($m^3$ $ha^{-1}$), CR-crown ratio (%)*

The tree species in the study area can be regarded as "under-girth sized trees" according to Adekunle (2006) who reported 48cm as the minimum merchantable tree size as contained in the logging policy of Southwestern Nigeria. Also, basal area regarded as the measure of stand density was observed to be low. When basal area is very low, the stand is under-used and may result in trees that are prone to wind-throw damage but when it is high, individual tree growth maybe stunted as a result of competition for available resources and also, become more susceptible to pest attack and damage (Adio *et al*., 2019). Studies on structure of a forest are instrumental and important in the management and sustainability of the forest. This is due to their importance in the conservation of plant species and the overall management of forest ecosystems (Adio *et al*., 2019). Despite the reduction in the size of the total plantation area and wanton disturbance occurring on *Parkia biglobosa* plantation, the forest can still compare favorably with other community forest reserves in the country (Adio *et al*., 2019) and outside the country (Mohandass and Davidar, 2009; Addo-Fordjour *et al*., 2009). The density per hectare of *P. biglobosa* presented for this study was much higher than that of 48 trees/ha reported by Addo-Fordjour *et al*. (2009) in a moist semi-deciduous forest in Ghana and that of 86 trees/ha reported by Mohandass and Davidar, (2009) in a tropical montane evergreen forest in India. Although the result of the study differs from that of Aigbe *et al*. (2014) and Adekunle *et al*. (2013) who reported 323 trees/ha in Afi river forest reserve in Nigeria and 387 stems per hectare in strict nature reserve, Akure, Nigeria respectively. In addition, the density of this study was within the range of values reported (62–247 species per hectare) as an evidence of mature tropical forest in Southeast Asia by Losose and Leigh (2004).

**Table 3:** Frequency distribution of *Parkia biglobosa* (Jacq.) Bench trees in the study

| Dbh Class | Frequency |
|---|---|
| less than 5 | 27 |
| 5 - 9.9 | 117 |
| 10 - 14.9 | 303 |
| 15 - 19.9 | 290 |
| 20 - 24.9 | 206 |
| 25 - 29.9 | 118 |
| 30 - 34.9 | 66 |
| 35 - 39.9 | 46 |
| 40 - 44.9 | 13 |
| 45 - 49.9 | 6 |
| 50 - 54.9 | 3 |
| 55 above | 1 |

*Diameter size classes (DSC):* The diameter size class distribution pattern for the study site is presented in figure 3. Diameter size classes distribution pattern is considered an important feature in understanding changes occurring in a forest stand, and in appreciating differences in the structural pattern (structural heterogeneity) and species size composition (Akinyemi and Oke 2014; Adio *et al*. 2019; Sharma *et al*. 2020). The majority of the trees in the plantation forest was characterised by trees whose diameter was mostly between 10 – 14.9 cm, about 25.3% of the total trees sampled; in 15 – 19.9 cm Dbh class, about 24.2% of the total tree sampled; and 20 – 24.9 cm (17.2%) Dbh classes with a fewer number of trees found in higher diameter classes e.g. 45 – 49.9 cm (0.5%), 50 - 54.9 cm (0.3%) and above 55 cm (0.1%) (Fig. 3). The plantation forest has trees with mean Dbh and height of 18.7±0.25 cm (min - max: 2 - 61.7) and 8.14±0.10 m (min - max: 1.8-21) respectively (Table 2). This is also in the range of growth variables reported by Adio *et al*. (2019) in their study of Tumbuyan forest in Kwara State. This similarity might be due to the fact that the stands are located in the same ecological zone (Savannah zone). The Dbh minimum value of 2cm observed might have been as a result of the saplings growing on the forest floor. This however, is an indication of the maturity of the forest. The mean Dbh and height for the study were lower compare to the report of Sharma *et al*. (2020) in their study of plantation forest of *Pinus roxburghii* Sarg. in Nepal. This difference might be due to differences in tree species and ecological characteristics. Furthermore, the mean basal area (0.033±0.00 $m^2ha^{-1}$) revealed that the forest was characterised by small diameter stems and actually recovering from disturbance. The small basal area generally observed is an evidence of the disturbance and degradation going on in the *P. biglobosa* Plantation forest at Wasangare. The statistics for the diameter size classes revealed that the plantation forest is disturbed and the disturbed portions are in their early successional stages. Despite the disturbance, the stands were actively growing.

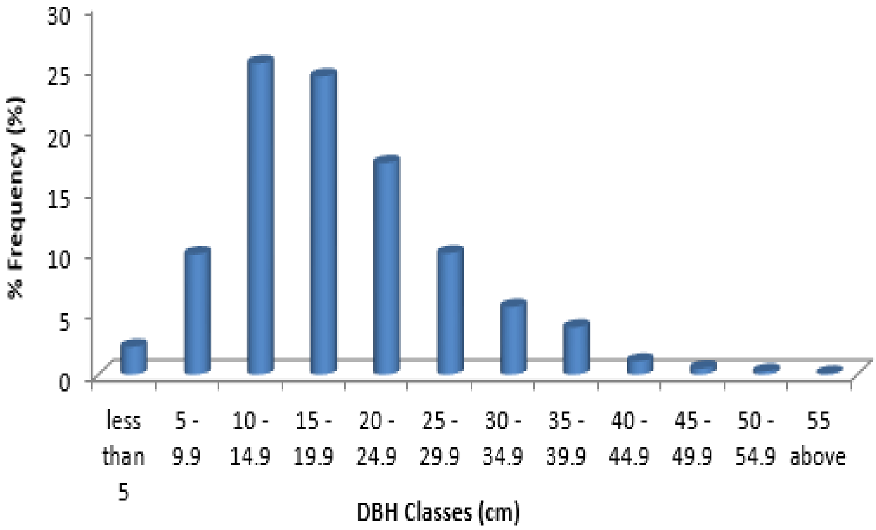


**Fig 3:** Diameter size class distribution pattern of the *P. biglobosa* species

*Correlation Matrix Analysis:* The Correlation analysis result is presented in table 3. The table showed that biomass, carbon, Dbh, BA, Th and the volume were all positively correlated at probability level of 5% (Table 4). Both Dbh and height were also positively correlated with basal area and volume (Table 4). The correlation between biomass and carbon against the tree volume revealed a significant positive correlation (r = 1.00). All the growth characteristics (Dbh, BA, THT, VOL) were all positively correlated with both biomass and carbon (Table 4). However, the tree distribution curve in the forest assumed a bell shaped (fig.3). Similar trends were reported by Bhatta *et al*. (2020) and Sharma *et al*. (2020). In addition, Dbh of the stand had high positive correlations (+0.88) with tree volume, biomass and carbon sequestered while the biomass and carbon showed very high positive correlation (+0.93) with tree basal area and moderate correlation (+0.64) with volume (Table 4). Consistent findings were observed by Thapa-Magar and Shrestha (2015), Shaheen *et al*. (2016) and Sharma *et al*. (2020). Thus, for the estimation of forest carbon, tree Dbh, height, BA, volume and biomass are determinant variables.

**Table 4:** Correlation matrix of the tree growth characteristics, biomass and the carbon stocks of the *P. biglobosa* plantation in Wasangare

| Variables | Dbh | BA | Tht | Vol | B | C |
|---|---|---|---|---|---|---|
| Dbh | 1 | | | | | |
| BA | 0.96* | 1 | | | | |
| Tht | 0.50* | 0.45* | 1 | | | |
| Vol | 0.88* | 0.93* | 0.64* | 1 | | |
| B | 0.88* | 0.93* | 0.64* | 1.00* | 1 | |
| C | 0.88* | 0.93* | 0.64* | 1.00* | 1.00 | 1 |

*Note: *- significant at $P \leq 0.05$, Dbh- diameter at breast height (cm), BA-Basal Area ($m^2$ $ha^{-1}$), Tht- Tree height (m), Vol- Volume ($m^3$ $ha^{-1}$), B- Biomass, C- Carbon*

Estimation of biomass and carbon stock: The aboveground biomass (AGB) observed for the *P.*

*biglobosa* was 10.877±0.39 $Mgha^{-1}$, the belowground biomass (BGB) and total biomass (TB) was 2.175±0.08 $Mgha^{-1}$ and 13.052±0.47 $Mgha^{-1}$ respectively (Table 5). The aboveground carbon (AGC) observed for *P. biglobosa* was 5.439±0.20 $Mgha^{-1}$ while the belowground carbon (BGC) and total carbon (TC) were 1.088±0.04 $Mgha^{-1}$ and 6.527±0.24 $Mgha^{-1}$ respectively (Table 5).

Forest biomass assessment, scientific studies of ecosystem productivity and carbon budget are critical for national development planning. The capacity of a forest stands to sink carbon will have impact on immediate and future global carbon balance. However, this capacity will be determined by how the carbon is sink by the forest and its estimation will still majorly rely on the accuracy of ground-based carbon storage assessment (Ajayi and Adie, 2018). For this study however, the biomass and carbon content in *P. biglobosa* plantation in Wasangare was very low compare to 202 Mg $ha^{-1}$ in tropical Africa (Lewis *et al*., 2013). The low carbon content for the study can be attributed to the low tree density of only 75 individuals $ha^{-1}$ compared to 426 individuals $ha^{-1}$ reported by Lewis *et al*. (2013). Forest biomass assessment, scientific studies of ecosystem productivity and carbon budget are critical for national development planning. The capacity of a forest stands to sink carbon will have impact on immediate and future global carbon balance. However, this capacity will be determined by how the carbon is sink by the forest and its estimation will still majorly rely on the accuracy of ground-based carbon storage assessment (Ajayi and Adie, 2018). For this study however, the biomass and carbon content in *P. biglobosa* plantation in Wasangare was very low compare to 202 Mg $ha^{-1}$ in tropical Africa (Lewis *et al*., 2013). The low carbon content for the study can be attributed to the low tree density of only 75 individuals $ha^{-1}$ compared to 426 individuals $ha^{-1}$ reported by Lewis *et al*. (2013). The biomass and carbon contents reported for this study was however, greater than those reported for *Terminalia superb*a and *Triplochiton scleroxylon* in sub-humid tropical forest in Southwestern Nigeria by Yusuf *et al*. (2019). The difference observed in the contents might be due to difference in ecological conditions, human activities within the forests and management regime.

**Table 5**: Biomass and carbon contents of *P. biglobosa* plantation in Wasangare, Oyo State

| **Biomass/Carbon stock (Mg $ha^{-1}$)** | **Mean ± S.E** |
|---|---|
| ABG | 10.877 ± 0.39 |
| BGB | 2.175 ± 0.08 |
| TB | **13.052 ± 0.47** |
| AGC | 5.439 ± 0.20 |
| BGC | 1.088 ± 0.04 |
| TC | **6.527 ± 0.24** |

*Note: ABG- Aboveground biomass, BGB – Belowground biomass, TB- Total biomass, AGC- Aboveground carbon content, BGC- Belowground carbon content, TC- Total carbon content*

*Dbh – Carbon stock proportion for the Parkia biglobosa trees:* The percentage carbon content within each Dbh size classes is presented in figure 4 with the shape almost forming a bell shaped pattern (Fig. 4). However, this is due to the high number of Parkia trees present mostly between Dbh classes 15-19.9 cm (13.88%), 20-24.9 cm (18.47%), 25-29.9 cm (19.02%) and 30-34.9 cm (14.0%). Also, Dbh classes with fewer numbers of trees found in higher diameter classes have fewer values of carbon contents. For example, in less than 5 cm class, 0.04% of carbon were found, 0.84% of carbon were discovered in 5-9.9 cm class while 2.05% and 0.58% were found in 50-54.9 cm and above 55 cm classes respectively (Fig. 4).

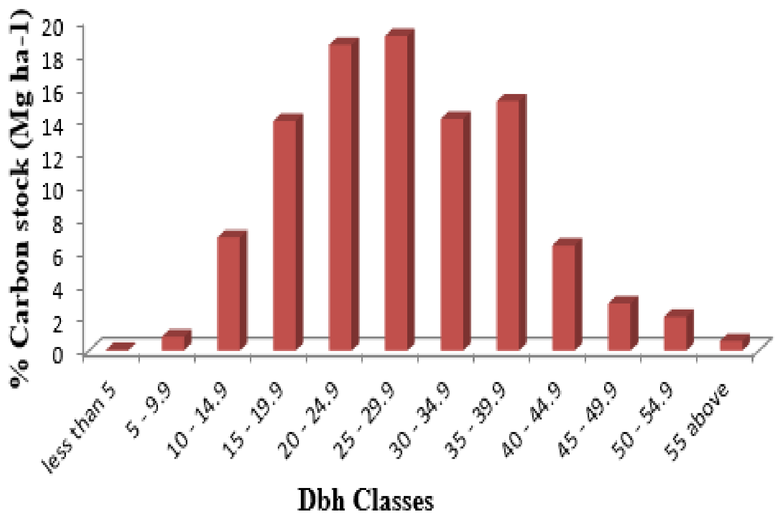


**Fig. 4:** % Carbon stock proportion for each of the Dbh size classes for *P. biglobosa* species

According to Sharma *et al*. (2020), larger diameter trees are important members of a forest as high proportion of carbon is stored. However, for this study frequency of trees present within Dbh size classes is an important factor to be considered in understanding structural pattern of carbon contents with Dbh classes and carbon stock dynamics. This study provides information that can help the management in planning silvicultural activities and selective removal from the stand (harvesting schedule).

*Conclusion:* This study revealed that the tree growth characteristics, biomass and carbon contents of *P. biglobosa* plantation produced lower basal area when compared with other biological hotspots as majority of the tree species registered were in small diameter classes. The tree Dbh, height, basal area, volume and biomass are the determinant characteristics for forest carbon estimation and estimations of these variables are needed to improve the knowledge of carbon budgets. There is the need to restrict human movement and activities in the plantation forest so as to protect the remaining *P. biglobosa* tree species.

*Conflict of Interest:* All authors declare there are no conflict of interest associated with this study.

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