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COMPARATIVE ASSESSMENT OF CARBON STORAGE IN BIOMASS AND SOIL ORGANIC CARBON IN TEAK PLANTATION OF DIFFERENT AGES IN YEWA NORTH, OGUN STATE, NIGERIA

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ABSTRACT

Tree act as a sink for CO2 by fixing carbon during photosynthesis and is a vital tool to alleviate climate change through CO2 absorption from the atmosphere. This study was conducted to assess carbon storage in tree biomass and soil carbon stock in Teak (*Tectona grandis*) plantations of different age series (5, 9 and 12 years). Data were collected on diameter at breast height (DBH) and total height (TH) of all the trees in a sample plot of 1000 m2 in each plantation of age series. Carbon stored was evaluated based on tree growth variables, soil parameters and above ground biomass. Topsoil and subsoil (0-15 and 15-30 cm) samples collected from three sites were analyzed for organic carbon (OC) following standard methods. Mean diameter at breast height were 67.11, 45.42, and 21.35 cm ha-1 and the mean volumes were 0.39, 0.16 and 0.02 m3ha-1 for 12, 9 and 5 years old were significant different ($p<0.05$). The highest value of total soil organic carbon (TSOC) was 8464.65 t.ha-1 for the 12year-old followed by 4430.25 t.ha-1 for 9 years old stand and 3004.95 t.ha-1 for 5years old were significant different ($p<0.05$) respectively. The total soil organic carbon per hectare were higher for the older than the younger *Tectona grandis* stand (8464.65 t.ha-1, 4430.25 t.ha-1 and 3004.95 t.ha-1) were significant different ($p<0.05$). Total carbon storage by soil and in biomass (CSB) was 15899.85 and 49.31 tons.ha-1 and total carbon accumulated by the plantation under investigation was in the order of 12 years old > 9 years old > 5 years old, respectively. The results of this study confirm that teak has good potentials to offer carbon sequestration through its soil and accumulate large amount of biomass carbon. The plantation ownership should be guided properly on the management activities such as thinning, pruning and weeding operation as well as indiscriminate removal of individual caused by anthropogenic activities should be avoided.

Keywords: Carbon stock, Teak plantation, aboveground carbon, Bulk density, Soil organic carbon and soil depth

INTRODUCTION

A forest stand's carbon storage capacity is determined by its age and biomass (Alexandrov, 2007). Estimates of productivity are essential for assessing the potential of forest ecosystems and their ability to sequester carbon. The production of biomass is an important factor considered in all planting programmes and has been used in estimating forest carbon stock and productivity. The amount of biomass produced by forest trees reflects its potential capacity to assimilate solar energy under some set of environmental conditions (Ige, 2018). Forest soils are formed as a result of a long-term mutual relationship between the forest stand and the soil. The content of soil organic carbon (SOC) depends on the balance between the rate of influx of fresh debris and its depletion by decomposition of organic matter. In forest soils, large proportion of organic matter is accumulated in the surface organic (O) horizon as well as in the mineral topsoil (A) horizon (Polish Soil Classification, 2011). To mitigate global climate change due to greenhouse gas emission, reduction of emissions through minimizing tropical deforestation or increasing the natural carbon sequestration potential of degraded forests through forest regeneration and afforestation programme cannot be over emphasize. Carbon stored in biomass and soil carbon are two major carbon pools, considering total carbon sequestration potential of forests (IPCC, 2006). Previous studies indicate that forest development is closely related with carbon stock over the entire life cycle of the ecosystems while the rate of tree growth varied with age of stands (Law et al., 2003; Taylor, Wang and Chen, 2007). Consequently one of the most important aspects in managing carbon stock is stand age. (Law et al., 2003; Martin et al., 2005; Fonseca, Rey Benayas and Alice, 2011; Seedre et al., 2015). Understanding the standing carbon store in forest trees is critical knowledge for forest management aimed at minimizing climate change, biodiversity loss, and addressing land-use conflicts. Carbon dioxide is stored in soil and trees as organic matter, and continuously cycled between forests and the atmosphere through the breakdown of dead organic matter (Alexandrov, 2007). Trees act as a sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass (Nowak et al., 2013). This carbon is sequestered in living plants and on death, gets transformed to carbon which is stored in the soil (Kaul et al., 2010 and Sang et al., 2013). A young forest sequesters large amounts of carbon while an old forest acts more as a reservoir while adding less carbon annually. Besides, old forest can hold large amounts of carbon as biomass for a long time (Luyssaert et al., 2008). The capacity to sequester carbon varies with species, site, spacing, climate, and age (Vucetichet et al., 2000; Pussinenet et al., 2002; Terakunpisutet et al., 2007; Kaulet et al., 2010).

Teak (*Tectona grandis Linn. f.*) is a huge deciduous tree with a smooth cylindrical bole that grows to about 25 meters in height. Forest plantations can have an important role in removing CO_2 from the atmosphere. Teak is one of the world's high-quality timbers and hence in great demand in specific markets of luxury applications including furniture, ship building and decorative components. Soil organic carbon (SOC) is an integral part of soil organic matter which can be used to predict amount of soil organic matter. The litter fall from tree plantations could increase soil organic carbon (Yang et al., 2005; Njar et al., 2011; Lu et al., 2013). It is very necessary to measure the amount of soil organic C in these species and be able to estimate their content at specific ages. Enhanced CO_2 sequestration in the soil, as stable soil organic matter, is a more long-term option than CO_2 sequestration in standing biomass. Thus, this study was carried out to: (i) estimate biomass potential of Teak plantations of different age series and (ii) estimate the carbon content from tree biomass accumulation (iii) determine the SOC under the plantation of different ages (5, 9 and 12 years) and examine amount of soil organic carbon in response to age of the plantation to increase soil CO_2 sequestration towards exploiting carbon storage to improved assessments of local and regional carbon stock which is vital to speak to the problems of climate change alleviation through CO_2 absorption from the atmosphere.

MATERIALS AND METHODS

Geographic description of the study area

The study area comprised of teak plantation of three age sequences (5, 9 and 12 years old) forest. The plantations were of different size area (greater or equal to 3 ha) but managed under silvicultural norms of teak plantation. It is located in 3 places in the outskirts of Ayetoro town, Yewa North local government of Ogun State, Southwestern Nigeria (Figure 1). Ayetoro lies on latitude 6020'15'' to 801'30'' N and 2040'30'' to 401'30'' E in a deciduous- derived savannah zone of Ogun State. The climate is sub-humid tropical with a longtime average annual rainfall of 1,909.30mm. Ayetoro is about 35 km north-west of Abeokuta, a town in south-west part of Nigeria and the capital of Ogun State. Ayetoro is the administrative seat/ headquarters of Yewa (formally known as Egbado) North Local Government Area. The soils are developed over a deeply weathered layer of sedimentary rocks consisting of false bedded sandstones which underlies the area.

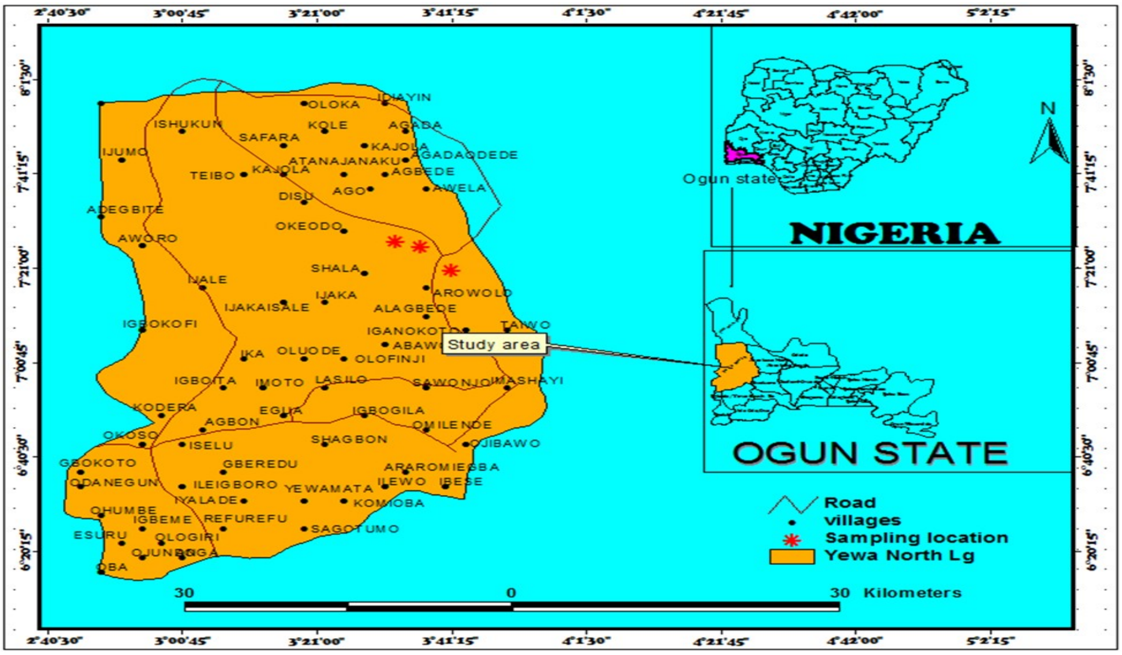

Fig. 1: Map of the Yewa North Local Government showing study area

Biomass assessment of Teak stand

Forest inventory-based approach was adopted to estimate biomass in the study areas. The data used in this study were collected from 3 temporary sample plots established in the *Tectona grandis* (Teak) stand (5, 9 and 12-year old) at different locations at Ayetoro, in Yewa North local government of Ogun State, South-Western Nigeria. A quadrat of 100 m × 100 m (1ha plot size) was laid out in each plantation as sample plot. The diameter at breast height (dbh: diameter of the bole 1.3m from the ground) and the corresponding total height (THt) of all trees in each plot were measured using diameter tape and hypsometer, respectively. A total of 1381 trees were sampled from all the age series that constituted the plantation used for the analysis. This included a total of 600 trees ha-1 that was sampled in the 5year-old stand; 597 trees/ha in the 9 year-old stands and 184 trees ha-1 in the 12 year-old stand. Wood density factor of the tree species (550 kg.m-3) was obtained from literatures (Nigerian Standard Code of Practice, 1973; Dinwoodie, 1981; Brown, 1997).

Tree growth attributes

Total height of trees in the sampled plots of each age sequence was measured using a hypsometer. The DBH was calculated by measuring the tree girth at a height of 1.3 m from the base of each tree with a measuring tape. The diameter was thereafter estimated using the formula:

$$Dbh = C/\pi \text{ .... } 1$$

where c= circumference and π = 3.142. Circumference (Girth) of the tree was measured using a measuring tape.

Above-Ground Biomass (AGB) and Carbon Stock

Basal area estimation

The Basal Area (BA) of individual trees was estimated using the formula of Husch et al., (2003):

$$BA= \pi\ (Dbh)^2)/4 \text{..............} 2$$

Stem volume estimation

The method proposed by von Wulffing (1932) charts was adopted as:

$$\text{Volume}= (BA \times Ht)\ f \text{..........} 3$$

Where: V = volume (m3), Dbh= diameter at breast (cm), and H= total height (m) and BA= Basal Area (m2), and f=tree shape factor (0.7) where AGB= above ground biomass (kg).

Biomass and Carbon Stock Estimation

AGB was calculated using the formula:

$$AGB = \text{Volume} \times \text{Wood density} \text{.........} 4$$

Specific wood density of Tectona grandis was 0.55 g.cm^{-3} (Chave, et al., 2009; Zanne et al., 2009).

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

$$\text{Carbon stock} = AGB \times CF \text{ ....} 4$$

The default value for the CF was 0.50 as it was noted that 50 % of the tree biomass forms the carbon stock (Ravindranath et al., 1997; IPCC (2006), Hetland et al., 2016; Jew et al., 2016).

Soil organic carbon stock (SOC) estimation

Soil sampling

Three teak plantations of different age groups (5, 9 and 12 years old) were chosen as sampling site. Soils were sampled at predetermined coordinates at two depths: 0-15 cm and 15 cm-30 cm using a soil auger. Two sets of soil samples were taken at each sample site and depth. The first series of samples were dried in the shade, crushed and passed through a 2 mm-sieve for organic carbon (C) determination. Twenty corer samples were collected at each of 0-15 and 15-30 cm depth per teak plantation. The core samples at each depth were thoroughly homogenized to form two composite samples in each plantation. A total of 60 soil samples were taken for soil organic carbon determination.

The second series of samples were taken using a cylinder dimensions to calculate the bulk density (Blake and Hartge, 1986). Undisturbed soil cores were collected using a sampling tube with a diameter of 3.5 cm and a length of 7.5 cm. Soil samples were brought to the soil laboratory, for oven drying to constant weight for 24 hours at ± 105°C.

Soil Bulk Density

The sample dry weight was divided by the volume of the cylinder. Thereafter, the bulk density values were used to transform the Carbon (C) values obtained in percentages to absolute SOC values (t. ha−1 C).

Soil bulk density was determined following formula of Pearson et al. (2005), while the soil organic carbon was determined according to Walkley–Black method (Black et al., 1934).

$$\varrho b = Wav,dry/v \text{ ....}5$$

Where, ϱb is bulk density of the soil sample per quadrate ($g.cm^{-3}$), Wav, dry is average air dried weight of soil sample per the quadrate, V is volume of the soil sample in the core sampler auger in cm^3

Soil Organic Carbon Stocks

The amount of soil organic carbon that is stored in a given soil profile is SOC stock expressed in tons per hectare. SOC $_{stock}$ (SOC_{stock};t C ha^{-1}) is a function of the soil's carbon concentration (SOC_{conc}; mg g^{-1}), the bulk density ($BD_{<2mm;}$ g cm^{-3}) of the fine soil fraction (< 2 mm) and the investigated soil depth (d; cm) (Ellert *et al.,* 2008; Rodeghiero *et al.,* 2009; Poeplau and Don, 2013 and Guidi *et al.,* 2014).

Conversion factor between the units is 100.

$$SOC_{stock}\ (t.ha^{-1}) = SOC_{conc} \times BD_{<2mm} \times d \times 100 \text{ ....}6$$

Where, SOC =Soil organic carbon (t/ha), SOC_{conc} (% OC) =Organic carbon concentration of the quadrate (%) expressed in decimal, BD=Bulk density of the quadrate (g cm^{-3}), D =Depth of the soil sample (cm).

Total Carbon Stock Estimate

The total carbon storage from various carbon pools was calculated using the equation given by Subedi *et al.,* (2010).

$$TC = AGC + SOC \text{.........}7$$

where TC is total carbon, AGC is aboveground carbon and SOC is soil organic carbon.

Data Computations and Statistical Analysis

The data collected were organized and screened for analysis.

Descriptive statistic was used to summarize the results while inferential statistic (correlation) was used to establish relationships between growth and yield variables. Basal area and volume of sampled trees were computed using Excel. Correlation was performed in order to detect the relationships between soil carbon and other soil parameters using SPSS statistical package version 20.

RESULTS AND DISCUSSION

Stand Density and Basal Area Estimation

A total of 1381 trees were sampled from all the age series that constituted the sample plot. The stand density for 5 years old, 9 years old and 12 years old was 600, 597 and 184 trees.ha^{-1}, respectively (Table 1). The 5 year- old trees accounted for about 43% and were the highest number of trees/ha; followed by 9 year- old trees that also accounted for the same percentage while the 12 year- old trees accounted for about 13% of the total population in the sampled plots and was the lowest. Conversely, the 9 year-old trees had the largest basal area (10.69 m^{2}ha^{-1}), followed by 12 year old trees (7.09 m^{2}ha^{-1}) while the 5 year old trees had the smallest (2.50 m^{2}ha^{-1}). In contrast to the initial stocking of the plantation (1100 trees.ha^{-1}; 3×3 m^2 spacing) as expected, the number of trees reduced considerably in all the age series, especially in the 12 year old plantation, due to thinning activities and this influenced its basal area. However there was a weak negative correlation between stand density and basal area estimation on the plantation ($r= -0.89$, $p<0.05$). There was also a weak negative correlation between age series and stand density ($r= - 0.82$, $p<0.05$). Stand density estimation after years of plantation shows the level of survival of planted stocks. The findings of this study generally show a plantation with low stand density and small basal area compared with those reported by other studies (Ige and Akinyemi, 2015; Mwangi, 2015 and Amusa and Adedapo, 2021). This may indicate a low level of survival of stocks after plantation. As observed by Nwoboshi (1982), as the forest stand develops and individual trees grow larger, the number of trees/unit area decreases. This is because an increase in individual tree size places more demands on site resources and growing space, and when the resources are no longer sufficient to support additional growth, self-thinning is initiated and the number of trees unit^{-1} area decreases consequently (Amusa and Adedapo, 2021).

Diameter and height Class distribution

The Dbh ranged from 16.4 cm ha^{-1} to 121 cm ha^{-1} in the 12 year-old stand, while it ranged from 5.15 cm ha^{-1} to 88 cm ha^{-1} in the 9 year-old stand and 1.86 cm ha^{-1} to 48.7 cm ha^{-1} in the 5 year-old stand respectively (Table 1). A similar trend was also observed for the stand height. Consequently, the growth rate of the trees varied with their age series across the teak plantation; the observed differences were significantly different at $p<0.005$. Ola-Adams (1990) reported that at different plantation spacings (from 1.37 m × 1.37 m to 3.96 m × 3.96 m), the proportion of survival, Dbh, and basal area were directly proportional to plantation spacing. Therefore, at a plant spacing of 3.0 m × 3.0 m, the low stand density and small base area observed could be ascribed to insufficient silvicultural management (beating up and selective thinning) in the studied area.

The highest number of trees of about 74% per hectare belonged to the lowest diameter class (10-20 cm and 20-30 cm) in the 5year-old stand (Figure 2) while the highest number of trees of about 82% per hectare was in the middle diameter class (30-40 cm and 50-

60 cm) in the 9 year-old stand. The highest number of trees of about 93% per hectare occurred in the middle to high diameter class (50-60 cm, 70-80 cm and 90-100 cm) of distribution.

Table 1: Growth, biomass and carbon storage of *Tectona grandis* of different age classes

		Tree age (years)		
Variables	**Parameters**	**5**	**9**	**12**
Dbh (cm ha^{-1})	Mean	21.35	45.42	67.11
	Max	48.70	88.00	121.00
	Min	1.86	5.15	16.40
	S.D	8.37	13.82	18.34
Height (m ha^{-1})	Mean	6.90	11.91	13.60
	Max	12.20	18.81	19.30
	Min	1.00	4.27	2.90
	S.D	2.10	2.13	3.17
B.A (m^2 ha^{-1})	Mean	0.00	0.02	0.04
	Max	0.02	0.06	0.12
	Min	0.00	0.00	0.00
	S.D	0.00	0.01	0.02
	Total	2.50	10.69	7.09
Volume (m^{3}ha^{-1})	Mean	0.02	0.16	0.39
	Max	0.16	0.64	1.11
	Min	0.00	0.00	0.01
	S.D	0.02	0.11	0.24
	Total	13.90	94.13	71.26
Density (N ha^{-1})	Population	600	597	184
Area (m^2)	Dimension	100	100	100
AGB (kg ha^{-1})	Mean	12.74	86.87	213.01
	Max	88.71	353.36	609.98
	Min	0.06	1.03	3.30
	S.D	12.03	62.75	130.87
	Total	7643.12	51773.04	39193.86
Carbon stock (t ha^{-1})	Mean	0.01	0.04	0.11
	Max	0.04	0.18	0.30
	Min	0.00	0.00	0.002
	S.D	0.01	0.03	0.07
	Total	3.82	25.89	19.60

Max: Maximum; Min: Minimum; SD: Standard Deviation; BA: Basal Area; AGB: Above

Ground Biomass; Dbh: Diameter at breast height

In the 5- year old stands, the highest number of trees (64% per hectare) was found in the lower height class (4-6 m and 6-8 m) (Figure 3) but was about 86% per hectare found in the middle height class (8-10 m, 10-12 m and 12-14 m) in the 9-year old stands and about 90% per hectare in the middle to high height class (8-10 m, 10-12 m, 12-14 m, 14-16 m and 16-18 m) of distribution. Appreciable number of trees per hectare belonged to the height class ranges between 4-6 m, 10-12 m and 16-18 m, respectively.

Thus, the distribution varied appreciably in both the diameter and height within the age series, indicating the structure of the forest. This is the index for assessing stand structure, volume production, and stability in the forest (Gorgoso-Varela & Rojo-Alboreca, 2014). The results obtained indicated that the plantation has traits of an older forest. Furthermore, the high percentage number of trees (47%) per hectare found in the diameter class of 50-60 cm in the 9- year old stand made it to be dominant class diameter. However the dominant height was found in the class 6-8 m and 10-12 m of 5-years and 9-years old, respectively. This indicates that growth variables of plantation increases with increase in age. Our findings contrast the findings of Akindele (1991), who assessed the site quality of Teak stands in the dry high forest area of southwestern Nigeria and reported a dominant height of 16.1 m for 9-year-old teak stands.

Furthermore, Haninec *et al.* (2017) reported an average Dbh and total height of 15.2 – 20.1 cm and 17.7 – 19.5 m, respectively, in a much younger teak plantation aged 1 – 5-years old in Nicaragua under a plantation spacing of 1×1 m. The differences recorded in this study may be attributed to variations in the climatic conditions, site, and management between the study areas.

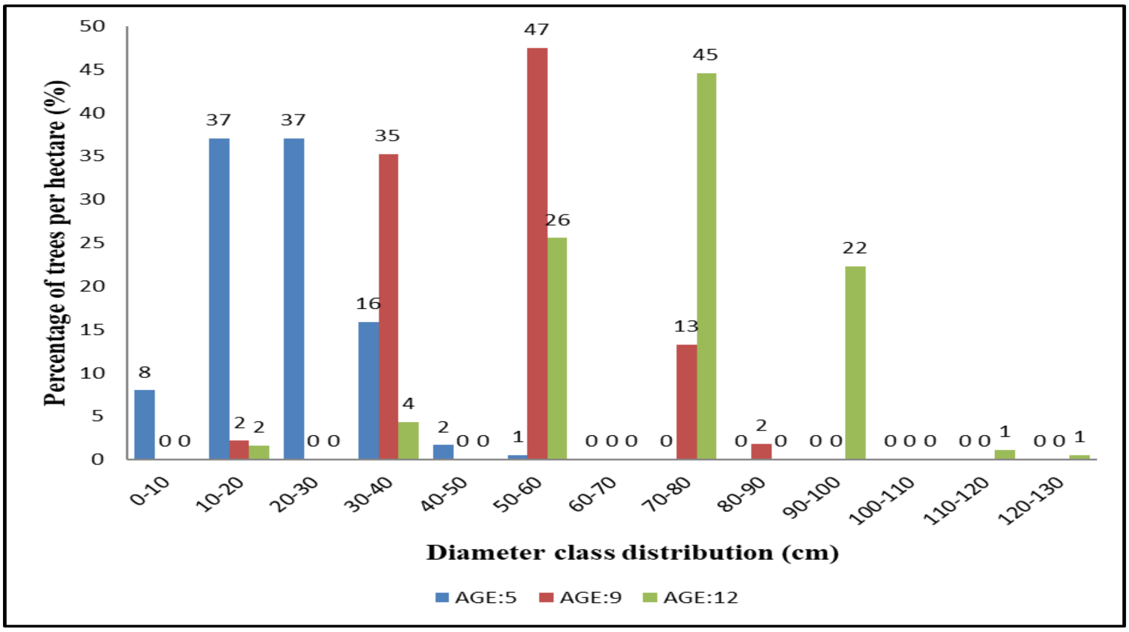

Fig. 2: Tree population in percentages at different age series and their diameter class distribution

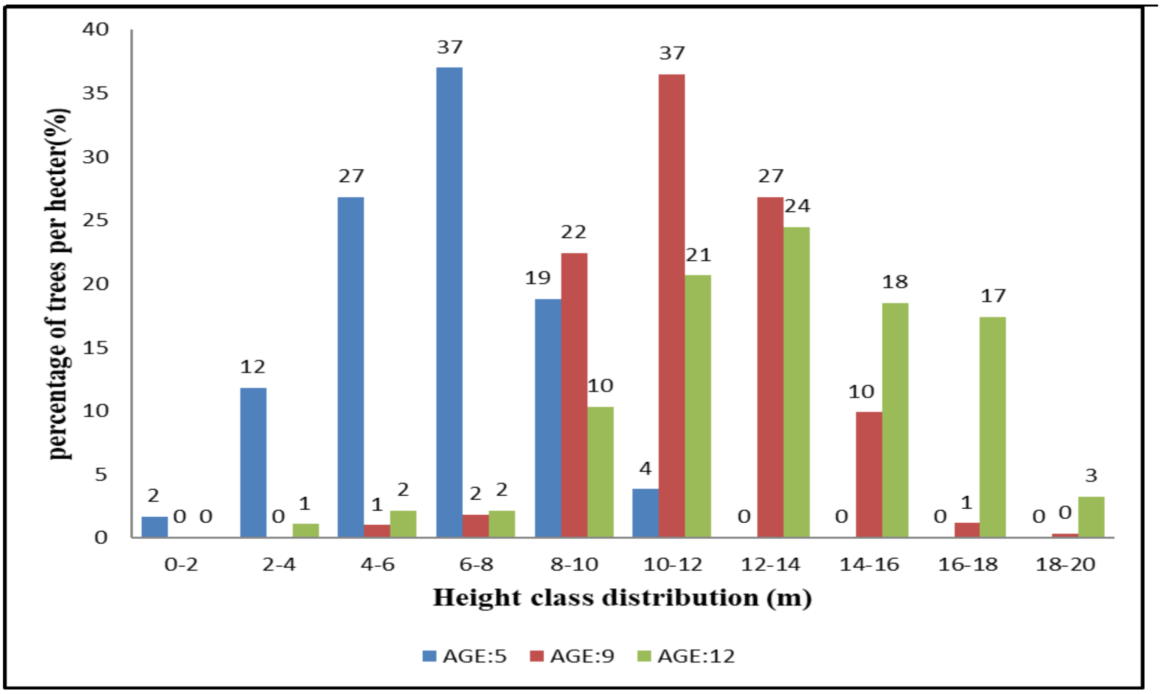

Fig. 3: Population of tree in percentage at different age series and their height class distribution

Stand volume, above ground biomass (AGB) and carbon stock Estimation

The mean volume per hectare was 0.02, 0.16 and 0.39 $m^3 \cdot ha^{-1}$ in the 5, 9 and 12-year old stands, respectively (Table 1). Total volume of wood accumulation was 13.90 (5-year-old stand), 94.13 (9-year-old stand) and 71.26 $m^3.ha^{-1}$ in the 12 year-old stand. The 12-year-old stand had the highest mean volume per hectare while the least mean volume per hectare was found in the 5-year old stand. Conversely, the highest volume of wood accumulation was found in the 9 years-old stand while the least was found on the 5years-old stand. The total estimated volume in the entire plantation was 179.29 $m^3.ha^{-1}$. The differences recorded in the diameter distribution and the stand density in each plantation showed a weak negative correlation (r= - 0.85, $p<0.05$). This affects the volume estimation across the age series. It agrees with the findings of Amusa and Adedapo, 2021) who reported stand density estimation after years of plantation may depict the level of survival of planted stocks.

The mean AGB for 12, 9 and 5-year-old stands were 213.01 $kg.ha^{-1}$, 86.87 $kg.ha^{-1}$, and 12.74 $kg.ha^{-1}$ respectively and the mean carbon stock for 12, 9 and 5years old stand were 0.11, 0.04, and 0.0064, $t.ha^{-1}$ respectively. The highest total carbon stock estimated was (25.89 $t.ha^{-1}$) in 9-year old stands followed by 19.60 $t.ha^{-1}$ in 12- year old stands and the lowest found in 5-year old stand, (3.82 $t.ha^{-1}$) . The reason for the differences may be due to the number of trees in the 12-year old stands which had greatly affected the total volume estimated in this stand. These results indicate that a teak plantation can accumulate large amount of biomass carbon. In this study, biomass carbon storage of Teak plantation at different locations across age series was between 3.82 and 25.88

tons.ha^{-1} in 5 and 9-year old stands, respectively. Tree biomass constituted a major part of the biomass carbon pool and increased rapidly with plantation age of the above ground biomass (AGB). Similar to trends have been observed in other forest (Cao, *et al.,* 2012; Chen, *et al.,* 2013; and Wang, *et al.,* 2013). This is in agreement with results reported by Ige (2018). However, the average values for the total height and Dbh were higher in the older teak stand; implying that the tree growth variables increased with stand age. The variation in aboveground biomass from site to site in the study areas might be due to different tree growth stages and tree density. The basal area, especially of the biomass of bigger trees has been reported to be the largest component of above ground forest's biomass (Ogawa, 1965). In this study, total estimated carbon in the entire plantation was 49.31 t.ha $^{-1}$. This result is not similar to previous reports, including that of Ige, (2018) who recorded 2623.46 t.ha^{-1} for 34-year old stands.

Relationship between Growth Variables and Age series of trees

Table 2: Correlation Matrix for Growth variables and Age of trees in the Study Area

	AGE	Dbh	Height	BA	Volume	AGB	Cs	Density
AGE	1							
Dbh	0.99*	1						
Height	0.98	0.96	1					
BA	0.98	0.99	0.94	1				
Volume	0.98	0.99	0.92	0.99*	1			
AGB	0.97	0.98	0.91	0.99	0.99*	1		
Carbon storage	0.95	0.96	0.87	0.98	0.99	0.99*	1	
Density	-0.82	-0.85	-0.7	-0.89	-0.91	-0.93	-0.95	1

*Correlation is significant at the 0.05 level (2-tailed); Dbh: Diameter at breast height; BA: Basal Area**;** AGB: Above Ground Biomass**;** CS: Carbon Stocks

Except for density, which had a negative association with all other factors, all the assessed variables had significant positive relationships (Table 2). Positive correlations between tree growth factors such as diameter at the breast height, height, and volume were found in a Pearson correlation analysis of the stand variables across the age series. The age series also had a positive association with the measured variables and significant at 0.05 probability level. These findings are consistent with the findings of other researchers such as Shamki *et al.,* (2011); Oyebade *et al.,* (2014); and Amusa and Adedapo, (2021). Consequently, stands with better growth characteristics will accumulate more above-ground biomass and consequently have a higher carbon stock (Ige, 2018).

Influence of tree plantation age on soil properties

The highest value of 1.33% and 1.85% organic carbon concentration (OC) was recorded in the 12-years old stands, in the top soil and subsoil, respectively (Table 3). The least percentage of 1.64% and 0.59% OC, were got from the top soil and sub soil, respectively, in the 5-year old stands. OC concentration decreased with depth, with the exception in the 12-year old stands. The higher value of SOC concentration in the 12-year old stand can be related to the present canopy closure generating more litter falls which are returned to the soils as organic materials. Lugo et al., 1990 and supported by Singh *et al.,* (2020), surmised that the rate of litter fall and dynamics associated with it, regulate the litter decomposition in soil and assist in organic carbon storage. Furthermore, organic carbon content regulates the soil's fertility and biological activities (Sahu *et al.,* 2016b). High organic content in the organic horizon in 9 year-old stand could be due to the high lignin/ nitrogen ratio in the leaf litter, which results in a slower decomposition rate, leading to higher organic matter accumulation, as compared to the observation in the older stand (Swift *et al.,* 1979). Soil organic carbon (SOC) was generally high in the sub soil than in the top soil (Table 3). In this study, the highest value of bulk density (BD) - 1.92 g.cm^{-3} was observed at the top soil in the 12-year old stands compared to stands of other ages. The BD generally increased with the increasing soil depth, with the exception of 12-year old stands (Table 3); probably due to age of the stand and canopy closure. In addition, there was a presence of cattle track in the site which led to the increase in soil compaction. On the other hand, the presence of organic carbon (or organic matter) in soil makes the soil loose and porous, thereby decreasing soil bulk density (Yihenew and Getachew, 2013); Ouyan *et al.,* 2018; Gebeheyu and Soromessa, (2018) also confirmed this antagonistic relationship between organic and bulk density in forest and agricultural soils. Chaudhari *et al.,* (2013) explained that soil bulk density increases with soil profile depth, due to changes in OC content, porosity, and compaction. In a similar study in teak plantations in Ghana by Amponsah and Meyer (2000), bulk density increased down the soil profile. Soil organic carbon stock has direct implications on atmospheric carbon concentration, as a small fluctuation in soil organic carbon stock may alter the atmospheric carbon. Moreover, they are potent quality, fertility and productivity indicators of soil (Jineneze *et al.,* 2011). The total soil organic carbon stock (TSOC) highest value was recorded in the 12-year old stands followed by 9 and 5-year old stands (8464.65, 4430.25 and 3004.95 t.ha^{-1} C, respectively) and was generally increased with the increasing depth across age series (Table 4) . In this study, SOC and carbon storage by soil and in biomass (CSB) was 15899.85 and 49.31 t.ha^{-1}, respectively. Total carbon accumulated by the plantation under investigation was in the order of 12-year old stand > 9-year old stand > 5-year old stand which reflect clear differences. The variation in carbon stocks may be attributed to age class distribution. Gera (2012), suggested that the variations in the sequestration potential can be attributed to the mean annual increment, which varied with site, age, density, and plantation, as well as the quality of planting stock. The IPCC (2000) reported that, globally, carbon stocks in the soils exceed carbon stocks in vegetation by a factor of about 5.

Table 3: Soil parameters at different depths under Teak plantation across age series

Age of plantation (years)	Soil depth (cm)	Bulk density (g.cm^{-3})	OC (%)	SOC stock (g.cm^{-2})
5	0-15	1.48	0.64	14.21
	15-30	1.79	0.59	15.84
9	0-15	1.54	0.91	21.02
	15-30	1.87	0.83	23.28
12	0-15	1.92	1.33	38.30
	15-30	1.67	1.85	46.34

Table 4: Soil organic carbon stock (t ha^{-1}) at different depth of soil under Teak plantation of different age

Age of plantation (years)	Soil depth (cm)	SOC stock (t.ha^{-1})	Total Soil Organic carbon (t.ha^{-1})	Total Carbon in Biomass (t.ha^{-1})	Total Carbon (AGB +TSOC) (t. ha^{-1})
5	0-15	1420.80	3004.95	3.83	3008.77
	15-30	1584.15			
9	0-15	2102.10	4430.25	25.89	4456.14
	15-30	2328.15			
12	0-15	3830.40	8464.65	19.60	8484.25
	15-30	4634.25			
Total			**15899.85**	**49.31**	

Relationship between Soil chemical parameters across depth and age series of the plantations

Table 5: Correlation Matrix for Soil chemical parameters across depth and Age series

	Tree Age	Soil depth	BD	OC	SOC
Tree Age	1				
Soil depth	0	1			
BD	0.1	0.88**	1		
OC	0.69*	0.579	.68*	1	
SOC	0.71*	0.56	.67*	.99**	1

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).
BD: Bulk Density; OC: Organic Carbon; SOC: Soil Organic Carbon

There is a positive correlation between age, organic content and soil organic carbon at (r: 0.69 & 0.71 at $p<0.05$) as well as bulk density, organic content and soil organic carbon (r: 0.68 & 0.67 at $p<0.05$) respectively (Table 5). Also, there is a strong positive correlation between depth and bulk density at (r: 0.88 at $p<0.01$) as well as organic content in the soil at (r: 0.99 at $p<0.001$)- Table 5.

CONCLUSION

Amount of carbon accumulation by Teak plantations varied with tree age series. The diameter at breast height (Dbh) and the height of the trees contributed to the biomass produced by the trees. There were great differences in the soil organic carbon contents between the older and young plantation across the site. Carbon accumulated by soil is greater than the carbon stored by biomass. Positive correlations exist between tree growth attributes such as diameter at breast height, height, and volume across the age series. Strong positive correlation exist between depth, bulk density, organic content (OC) and soil organic carbon (SOC) significantly at 0.01 probability level and as well as between age, bulk density, OC and SOC significant at 0.05 probability level. Teak has good potentials to offer carbon sequestration through its soil and accumulate large amount of biomass carbon. The ownership of the plantation should be guided properly on the management activities such as thinning, pruning and weeding. Indiscriminate removal of individual caused by anthropogenic activities should be avoided.

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