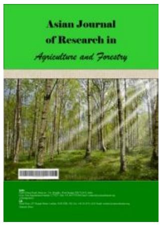

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Growth and Volume Estimates of Teak (*Tectona grandis* Linn F.) in Kanya Forest Plantation, Kebbi State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author AD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SBS and RBM managed the analyses of the study. Authors MAG and AIZ were part of reconnaissance survey, data collection and screening. Author BA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study was conducted in order to estimate growth and volume production of Teak (*Tectona grandis)* in Kanya Forest Plantation, Nigeria. The plantation was divided in to six strata-based age classes (A=38, B=37, C=36, D=35, E=34, F=28, years). Five plots were randomly selected from each stratum. Trees within each plot were enumerated and measured. Variables measured include total height, diameter at the base, middle, top, and diameter at the breast height were taken from 30 temporary sampled plots of 25x25 m approximately from the center, 180 dominant trees were selected from 712 trees. Descriptive statistic was used to summarize the results while inferential statistic (correlation) was used to establish relationship growth and yield variables. Basal area and

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volume of sampled trees were computed using Excel as well as scatter plots, correlation analysis was achieved using SPSS statistical package version 20. The results of growth and yield values obtained from the dominant trees are (B=249.312 m^3/ha, D=196.128 m^3/ha, F=134.976 m^3/ha, C=119.328 m^3/ha, E=100.320 m^3/ ha and A=86.976 m^3/ha). The results showed that B was (37 years) the best and A (38 years) was the poorest. The results of correlation showed positive relationships with most of the tree growth and yield characteristics but negative relationships exist between age and some parameters that is to say as the age increases those parameters are decreasing.

Keywords: Volume; site index; site productivity; Basal area; DBH.

1. INTRODUCTION

Forest stand productivity is largely defined as site quality which expresses the growth potential of the species, and it is influenced mainly by forest soils [1,2]. According to Skovvsgaard and Vanclay [3] Forest Site productivity is a quantitative estimate of the potentials of a given site to produce wood/timber or biomass for a particular species. For instance, site index (SI) or height of the specific population of the dominant and co-dominant trees at reference age is a widely accepted measure of site productivity in forestry [4]. In forestry, site productivity emphasizes the timber or biomass production capability as a major site indicator for site regardless of its ecosystem concept. The concept of site classification has long and rich history in agriculture and forestry. Alternative approaches have been developed for productivity site, depending on the intended purpose. For instance, plant communities or even attribute of single plants have been used as relative indicators of productivity potentials of an ecosystem sometimes refers to as “phytometers”. Site index is an important proxy of site quality and has been used in many conceptual and simulation models of ecosystem dynamics.

Continuous depletion of forest resources in Nigeria is on the increase as a result of high demand of wood and wood products, this result in a situation where the resources can no longer meet current demands and the future needs of the teaming population. Consequently, there has been a shift from tropical natural forest management to management of plantation of mainly exotic species in Nigeria [5]. Sustainable forest management require information on the growing stock, such information serves as a guide to the forest managers for evaluating and allocating forest area for exploitation. In timber production, estimations of the growing stock are often expressed in terms of volume, which can be estimated from easily measurable dimensions of the tree [6,7]. In current forest research, the requirement to encompass this new paradigm involves an increasing need for precise estimate of forest structure and biomass, potential productivity or forest growth [8] and modeling on different scales from stand to landscape level. In this regard, a deep knowledge of forest productivity of the state is essential to develop forestry and land use plan and policies [9]. The main objective of this study estimates the volume production of Teak in Kanya Forest Plantation and specifically to determine basal area, volume growth in relation to specific sites and to establish relationships between tree measurable parameters and stand age.

Teak *(Tectona grandis* Lf.) occurs naturally only in India, Myanmar, the Loa's People's Democratic Republic and Thailand. It is, however, naturalized in Java and Indonesia [10]. It is also planted throughout tropical Asia, many parts of tropical Africa, and some parts of Latin America [10,11]. Nigeria was the first country outside Asia where teak was introduced between 1889 and 1902 [12,13,10,5]. The first teak seed was imported into Nigeria from India while subsequent ones came from Myanmar. The first 750 ha of teak plantation was established in 1890 at the Olokemeji forest reserve in the then Western Nigeria, now part of Ogun State 273 [5,13,10]. There were about 651 ha of teak trees at premier teak plantation site in Nigeria, the Olokemeji forest reserve, alone in 1997 [13]. By the year 2000, there were about 132,500ha in tropical Africa [11].

Teak is almost found in all northern states with the exception of few, such as Sokoto Maiduguri and Yobe etc,.With about 70,000 ha, Nigeria has the largest (52.7%) teak plantation in Africa Common local uses of teak timber include furniture making, joinery and general carpentry works, floor parquet production, flush door manufacturing, as poles for electricity transmission and land telephone lines, as struts in buildings, and as beams in bridge construction [14,15,16].

2. MATERIALS AND METHODS

2.1 The Study Area

The study was conducted in Kanya Forest Plantation in Danko Wasagu Local Government, Kebbi State is located on Latitude 11.339°N to 11.348° and Longitude 5.606°E to 5.641°E, occupying about 4,208 km^2. It is bordered in the South by Sakaba Local Government, in the West by Zuru Local Government both in Kebbi State and in the North by Bukkuyum Local Government Area of Zamfara State. Danko Wasagu has an estimated population of about 265,271 people [17]. The vegetation falls under Northern Guinea Savannah. The topography is said to be flat or low land with fertile soil covered by sandy soils, sometime coarse in texture with fadama and alluvial plain suitable for agricultural activities. The weather is marked by single rainy season and long dry season; the average rainfall is 720 mm, the rainy season is about four to five months, the mean temperature ranges from 31°C and 38°C. From the month of November to February cold weather is usually experienced due to the dry harmattan wind and from March to May, the weather is generally hot and wet as in the tropics [18].

2.2 Sampling Procedure

The area was stratified in to different age classes based on the years of establishment (1979, 1980, 1981, 1982, 1983, and 1989) on which five temporary sample plots of 25 x 25 m (0.0625ha) were marked at random from each age block close to the center. Measurements were taken on all trees within the selected plots. Stand age was obtained from plantation records.

2.3 Data Collection

The data obtained include:

Counting and recording of individual trees per plot, Measuring the total height of six dominant trees in all selected plots using Haga Altimeter (this represented the 100 largest trees per ha), Diameter at breast height (DBH) of

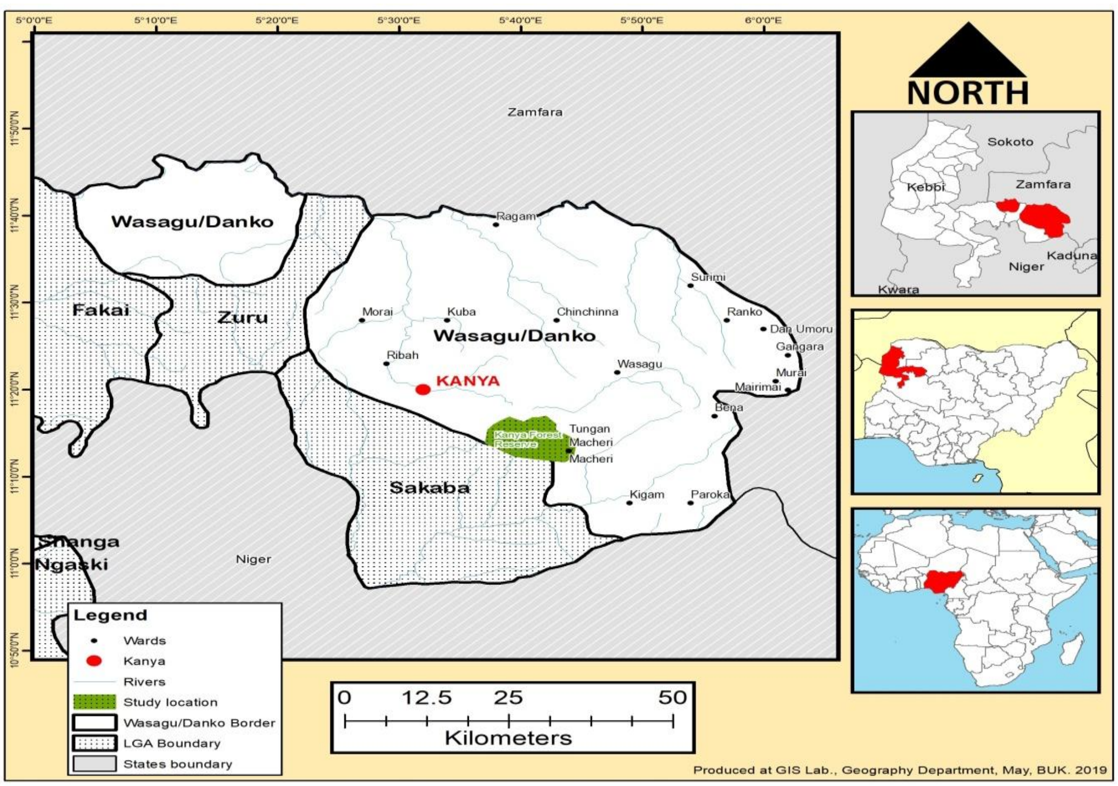

Fig. 1. Map of Kanya forest plantation

all individual trees was measured at 1.3 m above ground level. Flexible measuring tape was used to determine the circumference of the boles, Diameters at three different points (Base, middle, Top) were determined with the aid of Spiegel Relascope.

2.4 Data Computations and 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 as well as scatter plots, correlation analysis was achieved using SPSS statistical package version 20.

2.5 Basal area Computation

The basal area for each sampled tree was determined using the formula suggested by Husch et al. [6]

$$BA = \frac{\pi D^2}{4} \quad (1)$$

Where: BA = Basal area in m^2, D = Diameter at breast height (m), π= Pi (3.142)

Basal area per plot was obtained by adding the basal area of all individual trees within the plot. Basal area per hectare for each age series was determined by first summing the basal areas of the 30 sample plots selected from the age series and finding their mean, then multiplying the mean basal area per plot by the number of sample plots per hectare which is 16.

2.6 Volume Estimation

The stem volume of each mean tree was estimated using the Newton's formula [6]. The formula is expressed as:

$$V = \pi h \left(\frac{D_b^2 + 4D_m^2 + D_t^2}{24}\right) \quad (2)$$

Where: V = Stem volume in (m^3), D_b = Diameter (m) at the base of the tree, D_m = Diameter (m) at the middle of the tree, D_t = Diameter (m) at the top of the tree, h = Total height of the tree (m).

3. RESULTS

3.1 Growth and Yield Variables

The data collected include all the individual trees (712) measured from 30 plots selected at random. The parameters computed are summarized and presented in Table 1. In the summary, the mean, minimum, maximum values together with standard error and standard deviation are also presented in order to see the data distribution pattern.

The summaries of growth and yield characteristics of 180 sampled dominant trees are presented in Tables 2 and 3. Mean, minimum and maximum values of Dbh, height, BA and volume are recorded for all the age series. The standard error of the mean was also attached to all the mean values in order to see the variability distribution of the sampled data from the population.

3.2 Basal Area and Volume Accumulation at Different Dbh Size Classes

Basal area and volume production at different Dbh classes are presented in Table 4. The lowest and highest basal area were 0.73 m^2 and 174.77 m^2 which was recorded from Dbh class 41-45 cm and 46-50 cm, respectively. The lowest and highest volume recorded were 4.46 m^3 and 509.821 m^3 from Dbh class (41-45 cm and 45-50 cm) respectively.

3.3 Basal Area and Volume by Height Classes

Basal area and volume growth based on the height classes are presented in Table 5. The lowest and highest BA values were 26.54 m^2 and 174.77 m^2, the lowest and highest volume were 111.310 m^3 and 509.82 m^3 recorded from 13-16 m and 25-28 m classes, respectively.

3.4 Relationship between Variables

Table 6 shows correlation coefficients between tree variables and age of the plantation in which the relationships between measured variable/parameters were positive and significant, while the relationship between the age and some variables showed the negative relationship with exception of basal area and volume which showed positive correlation.

Table 1. Growth and yield characteristics/variables why is the base less central?

Variables	Min	Max	Mean	SEM	SD
Db(cm)	7.1	55.7	27.9	0.24	6.44
Dbh(cm)	6.6	48.1	22.9	0.19	5.19
Dm(cm)	5.5	45.0	20.6	0.19	5.08
Dt(cm)	5.0	35.0	14.9	0.18	4.72
H(m)	4.85	28.25	12.96	0.23	3.89
BA(m^2)	0.01	0.94	0.25	0.01	0.17
V(m^3)	0.060	5.190	0.716	0.024	0.651

Note: Db = Diameter at the base; Dbh = Diameter at the breast height; Dm = Diameter at the middle; Dt = Diameter at the top; H = Height; BA = Basal area and V = Volume; Min = Minimum; Max = Maximum; SEM = standard error of mean and SD = Standard deviation

Table 2. Summary statistics of dominant trees (Sampled trees)

Age (years)	Plots	Trees	Dbh (cm)			Height(m)		
			Min	Max	Mean*	Min	Max	Mean*
38	5	6	12.51	36.98	23.77±0.29	9.85	15.25	15.61±0.44
37	5	6	20.53	27.05	25.10±0.75	11.30	19.60	15.19±0.51
36	5	6	19.26	37.91	26.62±0.93	10.70	20.00	15.58±0.42
35	5	6	16.23	37.91	30.07±1.39	11.55	19.60	22.61±0.46
34	5	6	19.89	48.09	24.91±0.89	18.80	28.25	15.07±0.39
28	5	6	16.87	39.15	25.59±0.41	12.90	19.80	16.06±0.29

**Mean± standard error*

Table 3. Summary of yield characteristics of dominant trees (Sites trees)

AC	P	Trees	Basal area (m^2)				Volume (m^3)			
			Min	Max	Mean	Mean BA/ha	Min	Max	Mean	Mean volume/ha
A	5	6	0.01	0.11	0.04±0.01	4.29	0.240	0.980	0.906±0.04	86.976
B	5	6	0.03	0.16	0.50±0.03	18.03	0.610	4.310	2.597±0.20	249.312
C	5	6	0.29	1.11	0.11±0.04	10.34	1.260	5.630	1.243±0.18	119.328
D	5	6	0.02	1.11	0.08±0.01	7.20	0.480	5.470	2.043±0.18	196.128
E	5	6	0.03	0.18	0.05±0.01	4.70	1.150	5.300	1.045±0.08	100.320
F	5	6	0.02	0.12	0.14±0.02	13.14	0.580	2.290	1.406±0.08	134.976

**Mean± standard error*

Table 4. Basal area and volume accumulation at different Dbh size classes

Dbh class (cm)	Basal area (m^2)	Volume (m^3)
05-09	4.01	6.941
10-15	42.08	91.290
16-20	65.46	180.803
21-25	44.64	152.952
26-30	6.51	28.244
31-35	8.30	32.371
36-40	2.79	12.442
41-45	0.73	4.460
46-50	174.77	509.821

Volume distribution in the reserve is said to be more concentrated in trees with Dbh ranging from 12-32 cm with the highest volume accumulation recorded between 0.100-1.200 m^3. The trees are said to be sparsely distributed when recording increase in Dbh i.e from 32-50 cm, volume production above 32cm ranges from 1.2-5.0 (Fig 2). Fig. 3 presents volume distribution in the reserve based on height and was more concentrated in trees with height

Table 5. Basal area and volume at different height classes

Height Classes(m)	Basal Area(m^2)	Volume (m^3)
05-08	68.81	150.140
09-12	58.08	185.272
13-16	26.54	111,310
17-20	36.81	133.331
21-24	27.30	113.023
25-28	174.77	509.821

Table 6. Correlation matrix for growth and yield variable of trees in the study area

	H(m)	DB(cm)	DBH(cm)	DM(cm)	DT(m)	BA(m²)	VOL.(m³)	Age
H(m)	1	0.457**	0.556**	0.606**	0.591**	0.181**	0.529**	-0.188**
DB(cm)	0.457**	1	0.817**	0.734**	0.549**	0.301**	0.520**	-0.150**
DBH(cm)	0.556**	0.817**	1	0.853**	0.683**	0.432**	0.601**	-0.096*
DM(cm)	0.606**	0.734**	0.853**	1	0.765**	0.384**	0.618**	-0.204**
DT(m)	0.591**	0.549**	0.683**	0.765**	1	0.671**	0.790**	-0.167**
BA(m²)	0.181**	0.301**	0.432**	0.384**	0.671**	1	0.846**	0.141**
VOL.(m³)	0.529**	0.520**	0.601**	0.618**	0.790**	0.846**	1	0.018**
AGE	-0.188**	-0.150**	-0.096*	-0.204**	-0.167**	0.141**	0.018**	1

***Correlation is significant at the 0.01 level (2-tailed) *Correlation is significant at the 0.05 level (2-taile)*

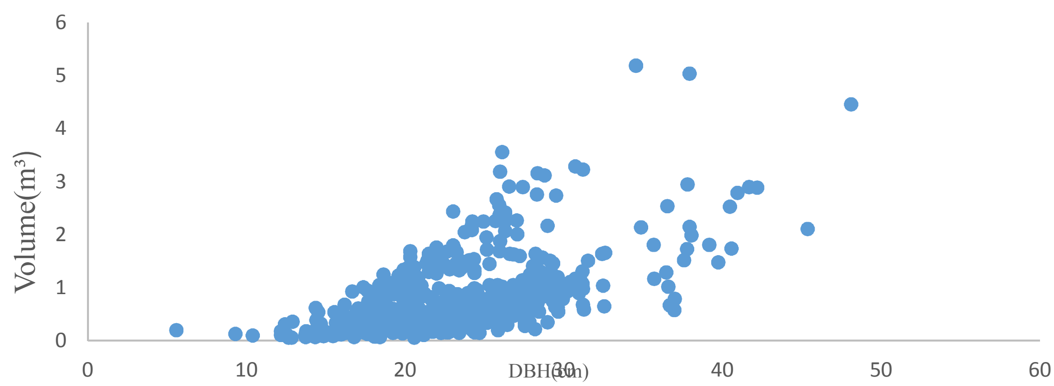

Fig. 2. Volume accumulation of measured trees at different Dbh

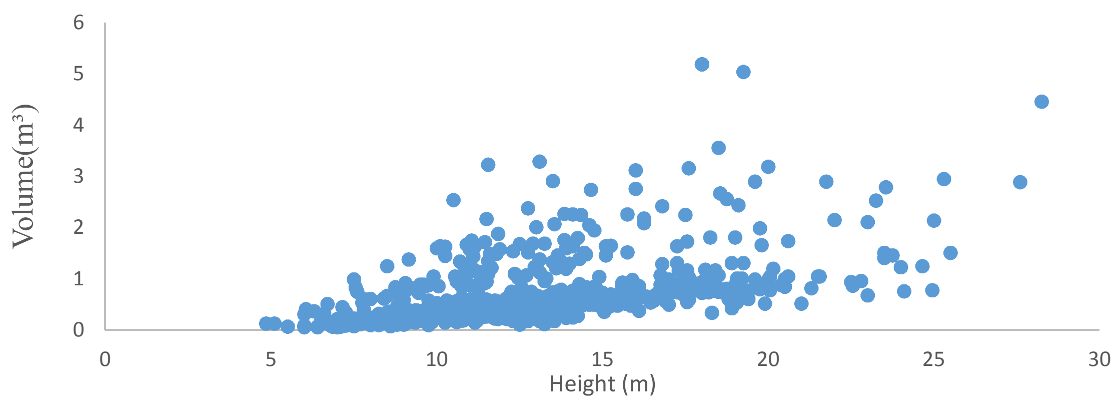

Fig. 3. Volume accumulation of measures trees at different height

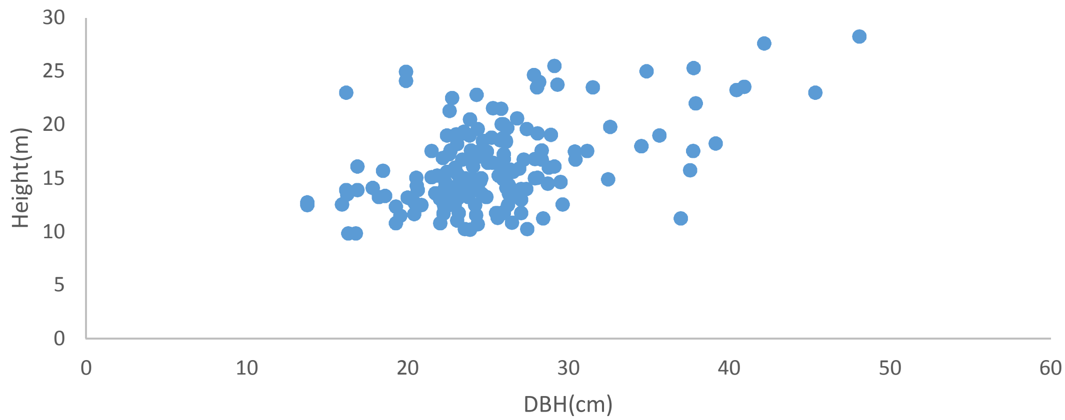

Fig. 4. Dominant height of 180 sampled trees based on Dbh

ranging from 5.2-20.5 m with the highest volume accumulation recorded between 1.000-2.000 m^3. The trees were sparsely distributed when recoding increase in height i.e. above 20.5 m. Fig. 4 shows dominant height distribution and was more concentrated in trees with Dbh ranging from 15-30 cm and sparsely distributed above 30. Fig. 4 shows dominant height and volume distribution of dominant trees. Volumes of dominant trees were found within 0.100-1.200 m^3 sparsely distributed above 1.200 m^3.

4. DISCUSSION

4.1 Growth and Yield Characteristics

Summary statistics of 180 sampled trees (dominant Dbh and height) were presented depicting low dbh and height values considering the age of the plantation and were as a result of poor management. Similar research was conducted by Onyekwelu [19], when Developing Site Index Curves for Opepe (*Nauclea didderichii*) Plantation in Southwestern Nigeria who reported slightly higher values of dominant height as well as Dbh, this could be as a result of variation in the ecosystem and the species involved. Akindele [20] also constructed similar site index curve for *Tectona grandis* (Teak) in the Dry High Forest Areas of Southwestern Nigeria. The highest dominant height and dbh reported were less than what was obtained in this study, this could be as a result of variation in age of the plantation and difference in location, Dominant stand height is a good predictor of growth, because size is biologically more significant than chronological age as a causal variable, especially in trees, where meristems are constantly renewed [21].

The mean basal area/ha reported in this study is lower than that obtained by Garcia, Mwangi [22,23], mean volume/ha obtained in this study is said to be higher than what was obtained by [24] this may be as a result of differences in silvicultural practices, location as well as soil factors in the study area. [25] reported high range of basal area than that obtained in this study. The low basal area was as a result of lack of silvicultural management. The findings revealed that the basal area increases with the increase in age except for the aged teak affected by thinning operations. Many researches on Teak volume were reported by different studies at different age classes, for instance at the age of 16 years the volume reported by [26] is far better that the value reported in this study, this variation might have been influenced by climate variability, rainfall as well as soil fertility of the site. [27] reported 40 years old Teak produced volume less than the value obtained in this research. The appropriate method of quantifying volume of a stand is necessary at different age classes and site because volume differ with location, silvicultural activities, site classes and age. Tree volume provides valuable information on supply of both industrial wood and hence identifying sustainable management of forests and woodland ecosystems [28,29]. Dbh classes 40-45 cm, 36-40 and 05-09 recorded lower basal area and volume which could be attributed to fewer number of stems compared to other Dbh classes. In this research, the summation of volume of the second and the third Dbh class was less than that presented by [30] for the same specie which they obtained from similar Dbh class, this might be as a result of climatic variability, site, soil as well as silvicultural operations involved. [31] in Northern Thailand reported similar Dbh class which disagreed with this research.

4.2 Relationships between Growth Variables

Pearson correlation analysis of the stand variables with age revealed that, there was high association between tree characteristics such as diameter at the breast height, height as well as volume. Plantation ages revealed negative relationship with the rest of the variables with the exception of basal area and volume growth which showed positive relationship. There was significant and positive correlation with most of the tree growth and yield characteristics, this coincides with the findings of [32] and [33]. For instance, tree height-DBH, height-volume, DBH-volume and basal area-volume displayed a positive correlation. Also, correlation analysis was observed by [34] in Developing Site Index Equation and Curves for Site Quality Assessment of *Pinus Caribea* Monoculture Plantation in South Western Nigeria. They discovered a high linear relationship between tree age and other growth characteristics such as Dbh, total height, and merchantable height as well as slenderness coefficient, these varies with association displayed by age and other parameters in this research, Dbh, Height, Db, Dm, Dt showed negative relationships and this indicates that as they approached that age (plantation age) these parameters decreases. Appropriate silvicultural treatment such as thinning and pruning be done on regular basis to avoid unnecessary nutrient uptake competition.

5. CONCLUSION

Growth and yield production of *Tectona grandis* was investigated in this research. Basal area of sampled trees are as follows according to magnitude B=18.03 m^2/ha, F=13.14 m^2/ha, C=10.34 m^2/ha, D=7.20 m^2/ha, E=4.72 m^2/ha, A=4.29 m^2/ha with B having the highest and the lowest. The yield values obtained from the dominant trees are (B=249.312 m^3/ha, D=196.128 m^3/ha, F=134.976 m^3/ha, C=119.328 m^3/ha, E=100.320 m^3/ ha and A=86.976 m^3/ha). Conclusively site B was (37 years) as the best site for *Tectona grandis* and A (38 years) was the poorest which is as a result of soil variations within the study site. The results of correlation showed positive relationships with most of the tree growth and yield characteristics but negative relationships exist between age and some parameters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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