Research Journal of Agriculture and Forestry Sciences ISSN 2320– 6063
Vol. **8(3),** 32-40, July **(2020)** *Res. J. Agriculture and Forestry Sci.*

Growth characteristics and trends of *Hevea brasiliensis* Muell. Arg. plantations in rainforest ecosystem of Edo State, Nigeria

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Available online at: www.isca.in, www.isca.me
Received 23th March 2020, revised 10th May 2020, accepted 30th June 2020

Abstract

The climate change problem is compounded by the tree-deficit situation in the world due to deforestation, forest degradation and other land-use changes. The objective of this study was to examine growth characteristics of Hevea brasiliensis plantations of different ages. Using simple random sampling method, five age series were selected for enumeration. Four temporary sample plots of 20mx20m were randomly selected per hectare, resulting to a total of 20 sampling plots for this study. Within each sample plot; diameter at breast height (dbh), and total height of all individual trees were measured; while diameters at the top, middle and base of two mean trees were measured. Simple linear regression equations were fitted to the growth data to test the relationships between pairs of growth parameters. The results showed that stand mean Dbh ranged from 7.7cm to 31.2cm, stand basal area ranged from 1.8 m^2/ha to 26.1m^2/h, while stand volume ranged from 10.6m^3/ha to 282.7m^3/ha. Hevea brasiliensis trees in this study showed evidence of fast growth rate. The mean stand growth parameters (Dbh, basal area, height and volume) showed strong and positive linear relationships with stand age. For individual trees, volume was linearly related to Dbh (R^2=0.78) and exponentially related to total height (R^2=0.92). Effective management and sustainable development of H. brasiliensis plantations are strongly recommended for higher yields and environmental benefits in Nigeria.

Keywords: Growth characteristics, *Hevea brasiliensis* plantations, the environment.

Introduction

Climate change and its adverse effects on the ecosystem have been reported[1-3]. The problem is worsened by the tree-deficit situation in the globe due to deforestation and forest degradation caused by unsustainable removal of timber; and the conversion of both primary and secondary forests to farmland, pasture lands and other forms of land-uses; especially in tropical and subtropical developing countries, including Nigeria[4]. The ecosystem services and environmental significance of *Hevea brasiliensis* (rubber) plantations as forest resource has been demonstrated, and the application of rubber trees in climate change mitigation has also been reported[5-7]. In Nigeria, the level of establishment, management and development of this resource is very low. *Hevea brasiliensis* plantations in Nigeria were established for latex production with little emphasis on its growth characteristics and management practices for biomass production. Rubber plantations have been classified as forest tree crop by the FAO and can be harnessed for both economic and environmental benefits[8]. Properly managed rubber plantations are renewable forest resources with high capacity for sequestrating atmospheric carbon-dioxide due to its fast growth rate[6].

Hevea brasiliensis is a fast growing forest tree species belonging to the botanical family of Euphorbiaceae, and to the genus *Hevea*. Depending on initial planting spacing, plantation of the species in Malaysia attained mean diameter and total height of 15.1-20.0 cm and 14.9-22.1 m, respectively after 9 years of growth[9]. *Hevea brasiliensis* is found at the middle of the forest canopy in its natural habitat in the tropical forest region. The species is the major source of natural rubber world-wide. Plantations of *H. brasiliensis* are in southern Nigeria, where mean annual rainfall range is 1800–2000mm, which is typical of tropical rainforest[10,11].

Growth refers to increase in size with time, while increment is a quantitative expression of increase in size as a result of growth over a given interval of time. There is a relationship between size and age of a tree such that growth parameters of trees have some forms of relationships with age. Such relationships enable prediction of future growth and size increment. In this regard, size-age relationship is sigmoidal, with linear and in some cases, curvilinear relationship[12]. Linear and curvilinear relationships in forest growth and yield estimation are very important; for instance, linear size/age relationship enables future growths (e.g. of DBH, height, basal area, and volume) to be predicted. With curvilinear or nearly-curvilinear relationships such as basal area (G)/age graph, projection of basal area may be possible[12]. The objective of this study was to examine the growth characteristics of *H. brasiliensis* plantations of different ages and to estimate growth and yield of the plantations in the study area.

Methodology

The study area: This study was conducted at the *Hevae brasiliensis* plantations of Rubber Research Institute of Nigeria, Benin City. This study area is situated in the humid tropical rainforest region of Nigeria and lies within Latitudes 6°00' - 6°15' N and Longitudes 5°30' - 5°45' E. The study area is plain land without undulations. The rainfall pattern is bimodal with peaks in July and September and a short rainfall break in August. Mean annual rainfall, relative humidity and temperature are 2000 mm, 65±5%, and 23^0C–26^0C respectively, while the soils are mainly ultisols with 4.0–5.5 pH range[13].

Data Collection: Table-1 shows the five age series and the extent of stands of *H. brasiliensis* that were selected for this study. From each age series, 1ha block was selected and subdivided into 20mx20m temporary sample plots. Four sample plots were then randomly selected for detailed enumeration; this brought the total number of sample plots in this study to 20.

Table-1: *Hevea brasiliensis* stands of different ages from which data were collected.

Stand Age	4	6	13	15	22
Hectares	16	4	9	8	40

The measurements made within each sample plot were diameter at breast height (Dbh), measured at 1.3m from ground level for individual trees [14]. Mean plot Dbh was then computed, and two trees having their Dbh nearest to the mean plot Dbh were selected for further measurements. Measurements of tree total height, and diameters at the top, middle and base were made on the two mean trees. Measurement of Dbh was made using girth-diameter tape while measurements of total height, diameters at the base, middle and top were carried out with the aid of a Spiegel Relascope[15]. Plantation age, extent of each plantation and management histories were obtained from plantation records.

Method of Data Analysis: ***Estimation of Basal Area:*** Equation-1 was used for estimating the basal area (m^2) for each individual tree:

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

Where: π = Pie (3.142), D = diameter at breast height (cm).

Basal area per plot was determined as the sum of the basal areas of all the trees per plot (equation 2):

$$BA_{plot} = \sum_{i=1}^{n} BA \quad (2)$$

Basal area per hectare: Per hectare basal area (BA/ha) for each plantation was obtained by first computing the mean plot basal area (i.e. mean of the four sample plots per plantation) and secondly by multiplying the mean plot basal area 25, being the number of 20mx20m sample plots in one hectare (Equation 3).

$$BA/ha = 25 * \overline{BA}_{plot} \quad (3)$$

Where $\overline{BA}_{plot}$ = mean basal area per plot

Estimation of Volume: The volumes of two mean trees per plot were calculated using equation 4, which is the Newton's equation for estimating volumes of trees[16].

$$V = \left(\frac{h}{6}\right)(A_b + 4A_m + A_t) = \left(\frac{\pi h}{24}\right)(D_b^2 + 4D_m^2 + D_t^2) \quad (4)$$

Where: D_b, D_m and D_t are diameters (cm) at the base, middle and top of the mean trees, respectively; V = volume of tree (m^3); h = total height (m); while A_b, A_m, and A_t are cross-sectional areas (m^2) at the base, middle and top of the tree, respectively.

Mean volume of trees per plot was estimated using equation (5):

$$V_t = \left(\frac{1}{2}\right)(V_1 + V_2) \quad (5)$$

Where: V_t = mean volume of trees in a plot; V_1 = volume of mean tree 1; V_2 = volume of mean tree 2; Trees 1 and 2 are the two mean trees in each sample plot.

Total volume of trees in a sample plot was determined by multiplying the mean volume of trees in the sample plot by the corresponding number of trees in that sample plot (Equation 6).

$$V_T = \left(\frac{1}{2}\right)[V_1 + V_2] * n \quad (6)$$

Where: V_T = total tree volume per plot; n = the number of trees in the plot.

To calculate volume of trees per hectare, the mean plot volume per hectare was multiplied by 25, which is the number of 20 m x 2 0m sample plots in one hectare (Equation 7):

$$Volume/ha = \left(\frac{1}{4}\right)(V_{T1} + V_{T2} + V_{T3} + V_{T4}) * 25 \quad (7)$$

Growth Trend: Growth data were analysed with the view of examining the relationships between various individual tree growth parameters of the rubber trees plantations under study. The relationship between pairs of growth parameters was evaluated through regression equations. The growth parameters are mean height, mean Dbh, basal area and volume per hectare. Simple linear regression equation was fitted to the data. The regression equation is presented as follows:

$$Y = b_0 + b_1 X \quad (8)$$

The following pairs of characters were evaluated: volume (Y) with each of height (X), Dbh (Y) and age (X); height (Y) with each of Dbh (X) of individual trees and age (X); Dbh (Y) with age (X) as well as B (Y) with age (X).

Results and discussion

Growth Characteristics: There was steady increase in stand Dbh, height, basal area and volume with increasing age of plantations (Table-2). This suggests that the growth of the rubber trees still in active stage, and it is an indication of the ability of the trees to trap and sequester more carbon-dioxide (CO_2), with age. In the case of density, the highest stand density was obtained at age 6 years (406 trees), followed by age 15 years (388 trees), age 13 years (356 trees), age 4 years (350 trees) and age 22 years (318 trees). The oldest stand (22 years) had the lowest stand density of 318 trees per ha; reduction in tree density with age is evidence of natural loss/mortality of trees in rubber plantations. Generally, there was no clearly defined trend of stand density with plantation age (Table-2). Stand density in our study is lower than what was reported by Naji *et al*. for *H. brasiliensis* plantations in Malaysia where density ranged from 500 to 2000 trees per hectare, depending on initial planting spacing[9]. Also, Brahma et al. reported higher stand density (576-784 tree per ha) than our study[17]. The low stand density in this study could be attributed to poor management practices, wide initial planting spacing, tree mortality and the fact that tapping of latex from the rubber trees have been going on in some of the plantations for years. As in Malaysia, it has become expedient to expand the management objective of *H. brasiliensis* plantations in Nigeria to cover latex and timber production, and to undertake studies to determine the appropriate planting spacing that will yield optimum latex and timber.

Hevea brasiliensis trees in this study, showed evidence of fast growth rate when compared with the growth rates of *Gmelina arborea* and *Tectona grandis* which are the common fast-growing tree species for forest plantations in Nigeria. For example, mean Dbh and height of a 13-year *H. brasiliensis* plantation in this study were: 19.7cm and 13.2m, respectively (Table-2), which are comparable to those of a 14-year *Tectona grandis* plantation (mean dbh: 18.25cm and mean height: 14.31 m[18]). Also, the mean total height and mean Dbh of the 22-year old *H. brasiliensis* plantation in this study were: 20.5m and 31.2 cm, respectively (Table-2), which compare with those of 21-year *G. arborea* plantation, which were reported to be 22.9 m and 30.2 cm, respectively[19]. Naji et al.[9] reported mean dbh range of 15.1cm to 20.0cm for a 9 year old *H. brasiliensis* plantation in Malaysia, which compares favourable with the mean dbh (19.7cm) for 13 years plantation of the species in our study. However, the mean height (14.9m to 22.1m) for the 9 years plantation in Naji et al. study is higher than our results[9]. The 15 years *H. brasiliensis* plantation in India has lower dbh and height growth compared with the 15 years plantation in this study[17]. The basal area per hectare and volume per hectare of the 15-year old *H. brasiliensis* plantation in this study were 20.41 m^2/ha and 142.02 m^3/ha respectively, which are lower in comparison with the 27.81 m^2/ha and 259.06 m^3/ha respectively for a 14-year old *Tectona grandis* plantations[18,19]. This is probably because density of trees is higher in the *Tectona grandis* plantations compared with *Hevea brasiliensis* plantations. Latex-Timber clones (RRIM 2023 – 2026 series) have been developed in Malaysia with 0.8 –1.87 cubic meter of wood per rubber tree, significantly higher compared to 0.68 – 1.33 cubic meter from earlier clones[20]. At 450 trees/ha, wood volume per hectare will be higher than estimates for *T. grandis*. There are therefore prospects of genetic improvement of the Nigerian *Hevea* population for improvement in tree volume.

Table-2: Summary of *Hevea brasiliensis* tree/stand growth and yield characteristics

Age	Density	DBH (cm)			Mean Ht	Basal Area	Volume
	($no.ha^{-1}$)	Min.	Mean	Max	(m)	(m^2ha^{-1})	(m^3ha^{-1})
4	350	3.8	7.7	12.4	6.0	1.80	10.56
6	406	4.1	10.5	14.0	8.1	3.35	27.60
13	356	8.6	19.7	31.2	13.2	11.62	78.77
15	388	11.1	28.4	40.2	16.8	20.41	142.02
22	318	19.0	31.2	50.0	20.5	26.06	282.70

Relationships between Stand Growth Parameters: There were strong and positive linear relationships between pairs of stand growth parameters evaluated in this study, with coefficient of determination (R^2) ranging from 0.7668 in height versus Dbh to 0.949 in Dbh versus stand age (Figures-1-7). These are indications of high correlation between the pairs of growth parameters for *H. brasiliensis* plantations. The relationships between mean stand growth parameters (Dbh, basal area, height and volume) revealed strong linear relationship with age; thus indicating that growth and yield of the species increased with stand age. The strong linear relationships suggest that the growth of the plantation is still active and has not culminated, which may offer insight into management of the species for timber. The observed active growth of the species at 22 years (i.e. the oldest age in this study) suggest that its rotation age for timber production would be higher than 22 years. This is because at this age (i.e. 22 years) the species would not have attained its maximum production potential and harvesting the trees at this age would lead to massive export of site nutrients, which would not guarantee sustainable management[21,22]. Determining the appropriate age for *H. brasiliensis* timber plantations in Nigeria is important as the country is currently considering managing current and future plantations of the species not only for latex production but also for timber production.

The R^2 range of 0.7668 and 0.949 which indicated that between 76.68% and 94.9% of the variations in the dependent variables in this study are accounted for by the corresponding independent variable. Thus, the independent variables are good predictors of the dependent variables. Diameter and height measurements are needed for calculation of tree volume which is a key parameter in biomass and carbon content estimations. Accordingly, the linear relationships: height-Dbh and volume-Dbh (Figure-1 and 2) were significant. For instance, in forest inventories; total heights of trees can be estimated from tree Dbh as diameter is easier to measure than height of trees[23, 24]. More so; volume, as a factor of carbon capture, can be estimated using volume-Dbh equations[23].

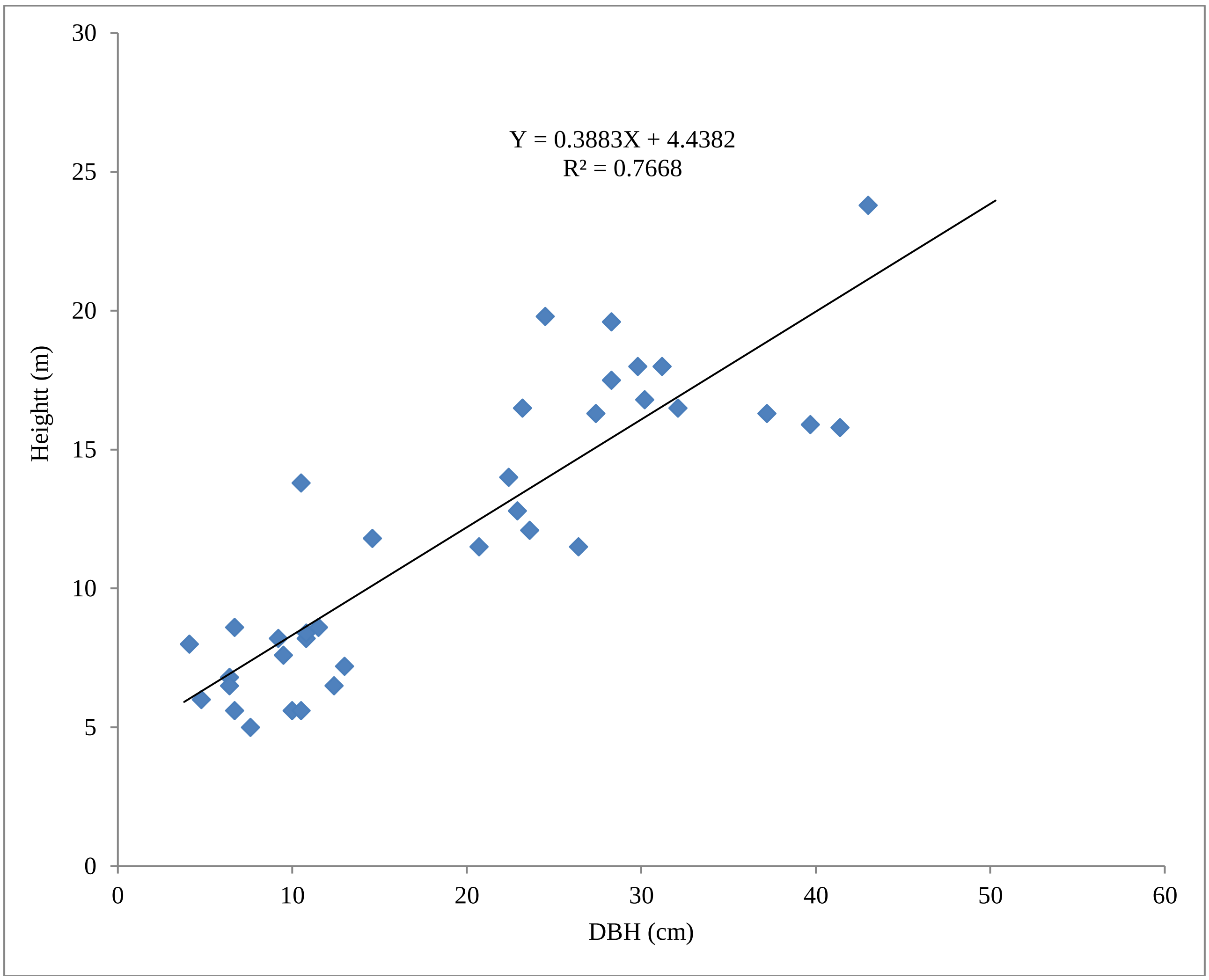

Figure-1: Height-Dbh relationship for individual *Hevea brasiliensis* trees.

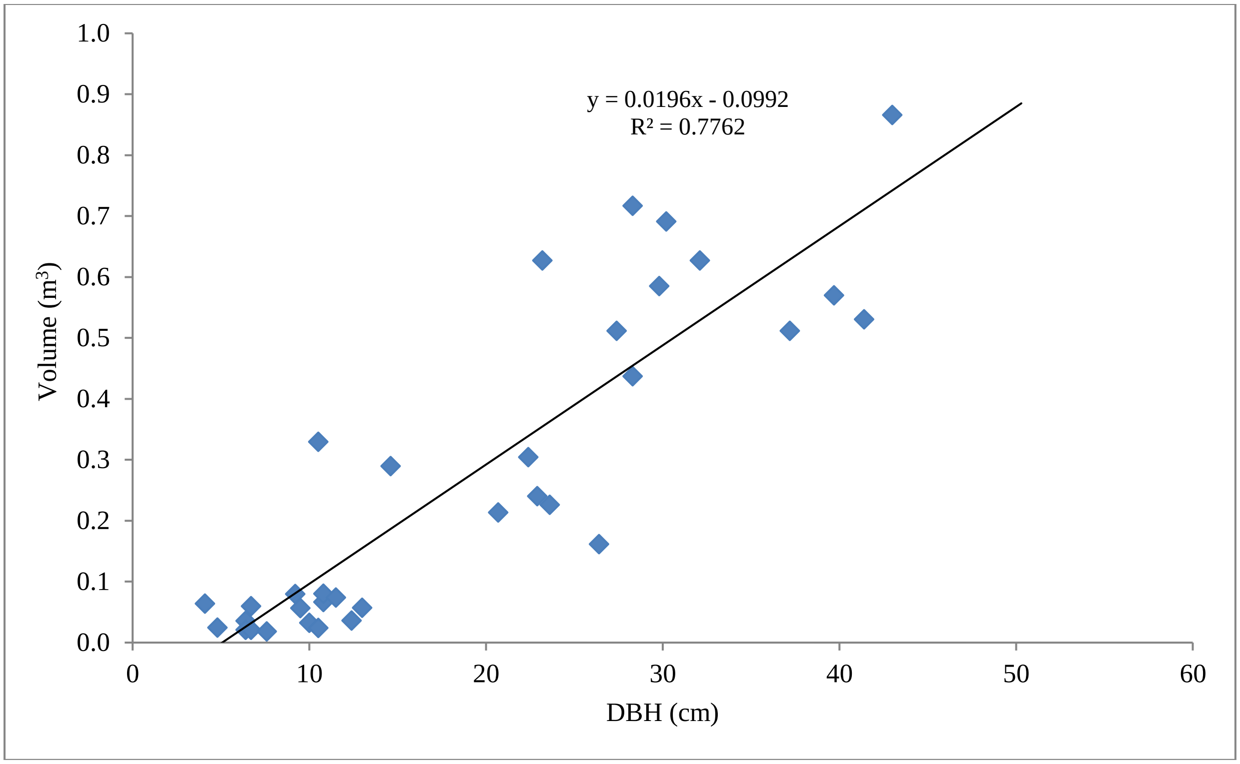

Figure-2: Volume-Dbh relationship for individual *Hevea brasiliensis* trees.

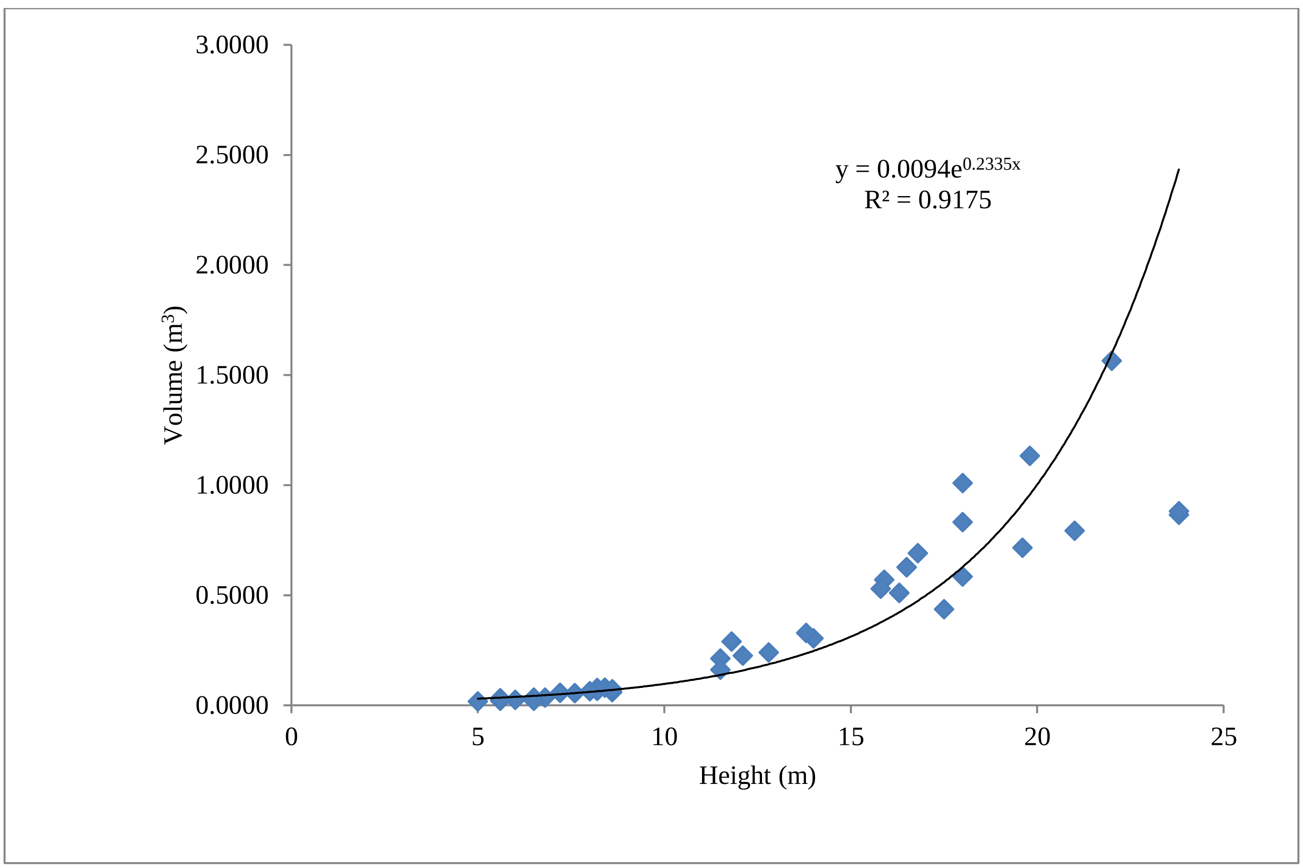

Figure-3: Exponential relationship between volume and height of individual trees.

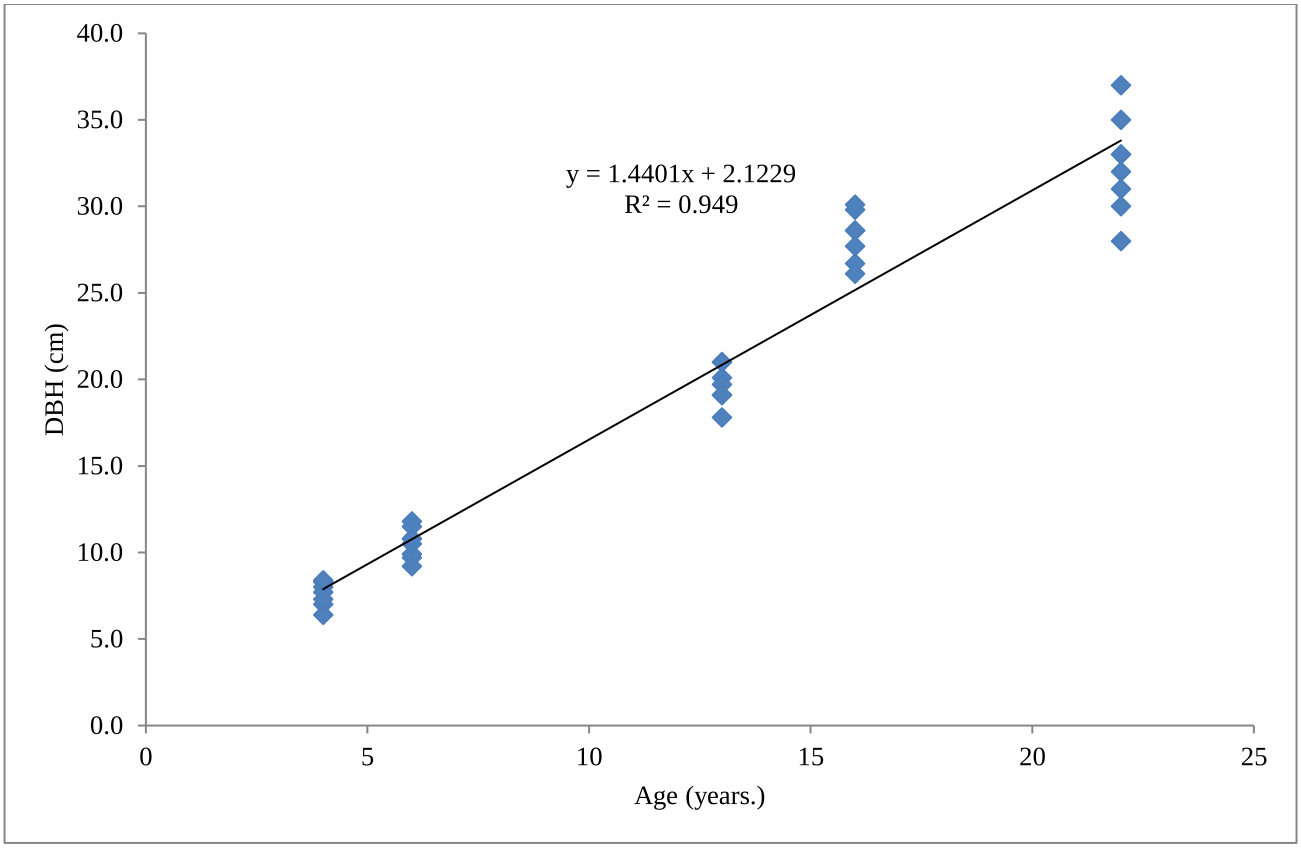

Figure-4: Development of stand Dbh of *Hevea brasiliensis* plantations.

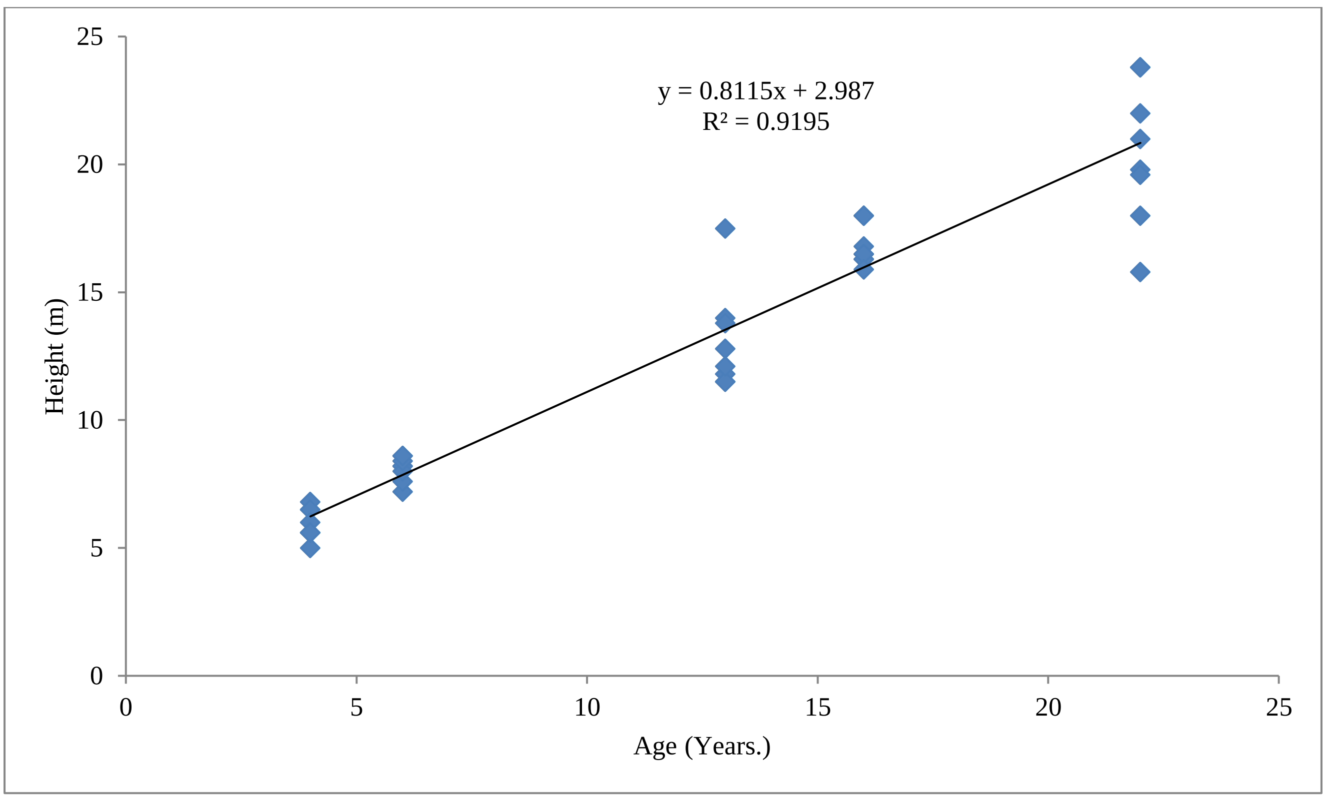

Figure-5: Stand total height development of *Hevea brasiliensis* plantations.

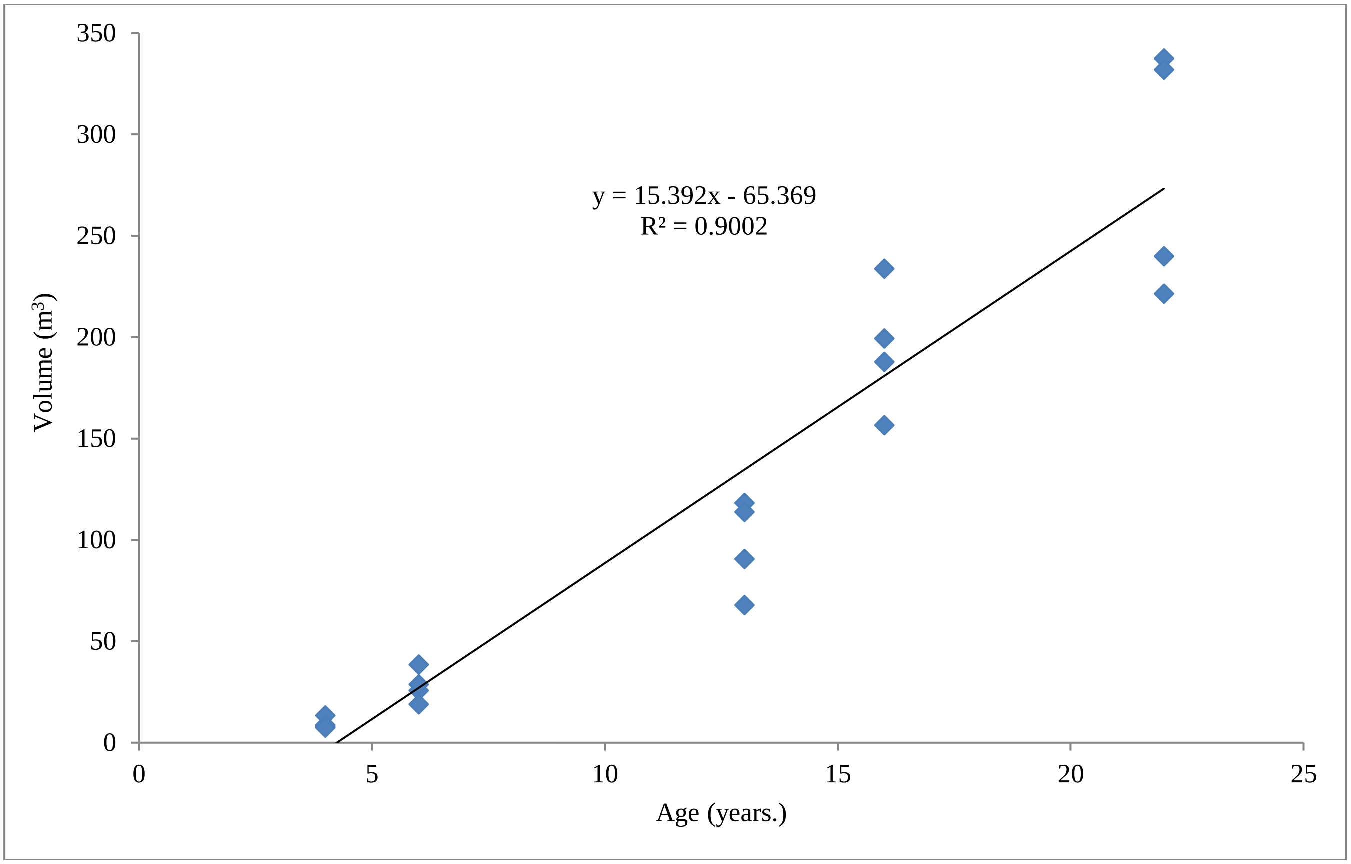

Figure-6: Stand volume development of *Hevea brasiliensis* plantations.

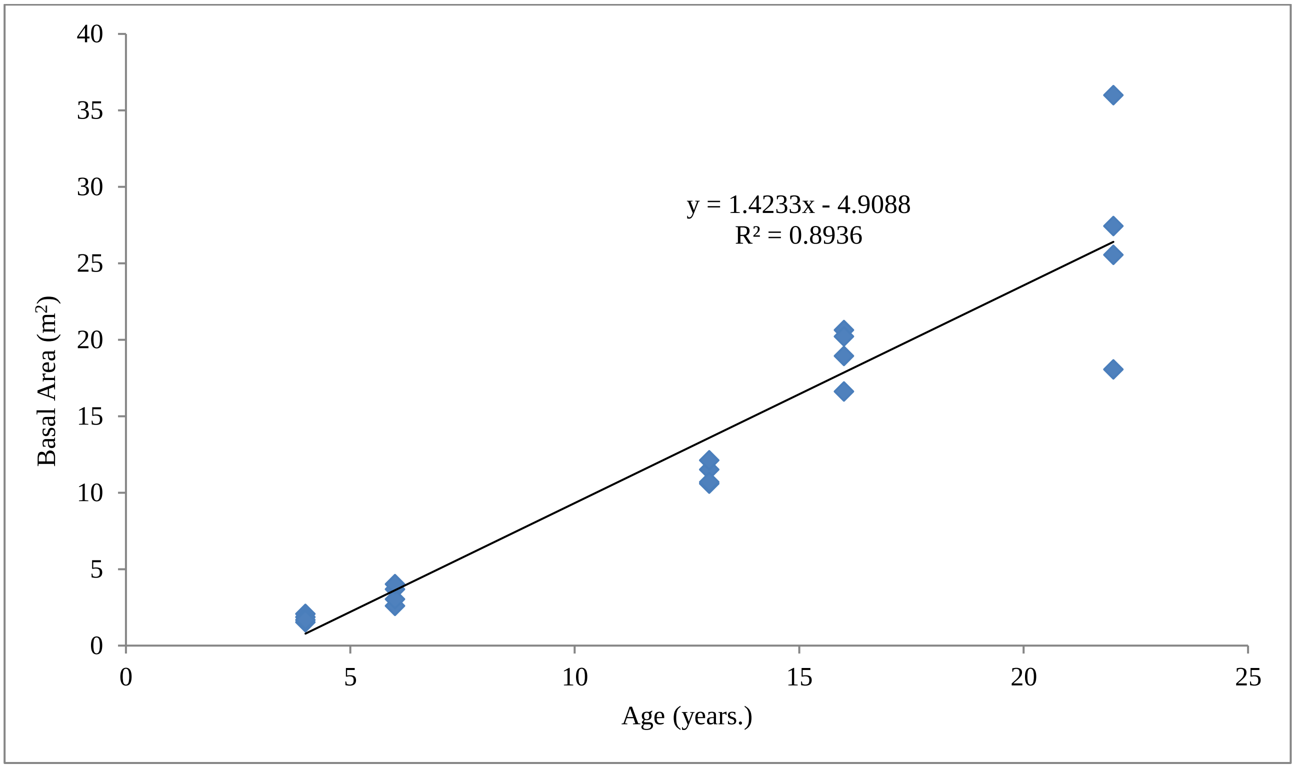

Figure-7: Stand basal area development of *Hevea brasiliensis* plantations**.**

Conclusion

In this study, *Hevea brasiliensis* trees showed evidence of fast growth rate; this implies a potentially higher capacity of the species for sequestrating atmospheric carbon-dioxide. The investigated stand growth parameters (Dbh, total height, basal area and volume) showed strong and positive linear relationship with stand age; which signifies that growth of *H. brasiliensis* (e.g. total height, basal area, and volume) can be predicted with some degree of certainty. Also, at individual tree level; there were linear height-Dbh relationship, linear volume-Dbh relationship, and exponential volume-height relationship. Since forests and trees play important roles in climate regulation mechanism, every forest stand (natural or plantation) is a positive contributor to the global environment. Therefore, effective management and sustainable development of *H. brasiliensis* plantations are strongly recommended for higher yields and environmental benefits in Nigeria. This is more so as the rubber tree is also a source of revenue for resource-poor farmers, even on subsistent bases.

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