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Prediction Equations for Estimating Growth Space for *Parkia biglobosa* (Jacq) Benth in the Guinea Savanna Ecozone of Nigeria

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Abstract *Parkia biglobosa* (Jacq) Benth has great importance to the people of rural and urban communities in the guinea savanna of Nigeria, and this exposes it to high exploitation and is facing regeneration problem. There is lack of information on growth spacing of *P. biglobosa for* plantation establishment and sustainable management. This have led to the species declining in the natural forest areas and the loss of biological values (genetic hereditary). A total of nine blocks as sample plots sizes 100 x 100 meters each was randomly laid. Simple random sampling design was used to collect data on tree heights, diameter at breast height (dbh), diameter at the base, middle, top (using diameter tape) and crown diameter. The data collected were tested on seven equations on crown and stem diameter relationship. The linear equation (equation 3) was the best model fitted with R^2 value of 0.854 species. Based on the results, a dominant free-growing tree species with diameter 50.5cm would require 0.009 hectare of growing space with a limiting stocking of the stand in terms of total occupancy by tree crowns of 110 trees per hectare. Stand basal area (density) converges around 0.000038 m^2. For optimum planting spacing in term of fast growth and high production/yield, *P. biglobosa* would require a planting spacing of 4 x 4 meters for non-wood forest products while for timber purpose, thinning can be applies to create more spacing until merchantable size of timber is achieved. The species requires a definite amount of growth space and this study could serve as a guide for optimum planting distance and tree density when establishing plantations of the economic species.

Keywords: *Crown- diameter, Stem-diameter, Growth space, Sustainable forest, Parkia biglobosa*

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1. Introduction

Parkia biglobosa (Jacq.) Benth belongs to the family Leguminosae and the subfamily Mimosoideae. Common names are African Locust Bean, fern leaf, arbre à farine, monkey cutlass tree, two-ball nitta-tree. In French West Africa it is commonly known as *néré, netto, ulele, séou*, and *ouli*. In Ghana, the tree is called *dua*. *P. biglobosa* is found in a wide range of environments in Africa including Nigeria. It is a dicotyledonous angiosperm [1]. It is a deciduous perennial plant that grows up to between 7 and 20 meters high, in some cases up to 30 meters [2]. The tree is a fire-resistant, characterized by a thick dark grey-brown bark; the pods of the tree, commonly referred to as locust beans, are pink in the beginning and turn dark brown when fully mature. They are 30-40cm long on average, with some reaching about 45cm in length. Each pod can contain up to 30 seeds.

P. biglobosa is one of the trees protected in farmers' fields and near households because it has several uses, including fodder, food, medicine, green manure, fuel wood, timber and economic purposes [3]. The yellow pulp, which contains the seeds, is naturally sweet and is processed into a valuable carbohydrate food known as *sikomu* and *daddawa* among the Yoruba and Hausa people of Nigeria, respectively [4].

The species numbers are threatened as natural resources are depleted and people are suffering from their poor economic situation. Currently, farmers do not actively plant *P. biglobosa* trees; therefore, regeneration must be carried out by natural means. Livestock, fire, and humans are all factors that limit the success of natural regeneration. The continuous removal of this tree species could affect the rural dwellers directly or indirectly because of the species economic and ecological values.

Growth space knowledge has been employed in growth equation studies on its measure as the ground area available to individual tree and also as an indication of competition [5,6]. Therefore, growth space simply refers to the adequate resources required within a given area or unit of land for the germination, emergence, growth and development of tree species. An inadequacy of any of these resources needed by individual tree in a stand may limit the growing space and hence affect tree growth [5].

Information concerning the planting spacing and stand density has great effect on tree variables and enhance high growth and yield of tree species. Jerome *et al* [7], reported that the effects of growth spacing on tree variables such as:

Height Growth: The height growth of many hardwood species is significantly less at low densities than at moderate or high levels. Very dense natural stands of some hardwood species display greatly reduced height growth, and some spacing studies with fast-growing conifers wood species have shown significantly greater height for 10 x 10 feet (3.08 x 3.08 meter) spacing than 6 x 6 feet (1.85 x 1.85 meter) plantings.

Diameter Growth: spacing experiments have consistently increases in breast height diameter (dbh) growth with decreasing stand density. Stands with wider spacing in time, have larger average diameters than similar stands with closer spacing. Inter-tree competition affects diameter growth at low stand densities, particularly in the case of fast-growing, shade-intolerant species; as a result, very low densities are required to produce maximum diameter growth throughout the life of an even-aged stand [7]. At any given age, there is a lower limit of stand density below which no further increase in diameter growth will result from continued density reduction. At density levels below this lower limit, the trees are growing free of inter-tree competition and usually referred to as open-grown-trees. Other vegetation present on the site may also affect diameter growth even though tree density is below this competition limit.

Crown diameter: the major functions of the crown include light energy assimilation, carbon dioxide absorption and release of oxygen via photosynthesis, energy release by respiration and movement of water to the atmosphere by transpiration. These functions are performed by the leaves, branches of the crown provide mechanical support to distribute the leaves efficiently and serve as conduits for resources (water, nutrients, photosynthates). Photosynthesis occurs in tree crowns and photosynthates (the products of photosynthesis) are moved through the crown branches from the leaves to the other parts of the tree. A tree's crown therefore represents the above-ground spatial requirements needed for a tree to survive, grow, and reproduce [7,8].

The aim of this study was to develop prediction equations for estimation of growth space for *P. biglobosa* (Jaqc) Benth plantations in guinea savanna ecozone of Nigeria, for the purpose of timber and non-timber forest products. The prediction of growth space for sustainable management of *P. biglobosa* in the study area, require biological plausible equation(s) to estimate stand density and stocking of the tree species. Therefore, this study would be of great importance to forests managers for optimum planting distance to ensure sustainable species management.

2. Materials and Method

2.1. Study Area

The study was carried out on *P. biglobosa (Jacq) Benth* at the University of Agriculture Makurdi, guinea ecology zone of Nigeria. University of Agriculture Makurdi lies between longitude 8° 21' and 9° E and latitude 7° 21' and 8° N in Benue State, within the southern guinea savanna ecological zone. The climate of the area is tropical sub-humid with high temperatures and high humidity; the average maximum and minimum daily temperature of 35 °C and 21 °C in wet season, and 37°C and 16°C in dry season. Benue state has boundaries to the south with Enugu and Cross River states, to the east with Taraba state, north with Nasarawa state and west with Kogi state. The climate is characterized by distinct rainy and dry seasons. The mean annual rainfall value is between 1200mm to 1500mm. The vegetation of the area has been described as Southern guinea savanna (UAM Physical Planning Manual, 1989). The major occupations of the people include; farming, civil service, trading and hunting; and the major tribes found are *Tiv*, *Idoma* and *Igede*.

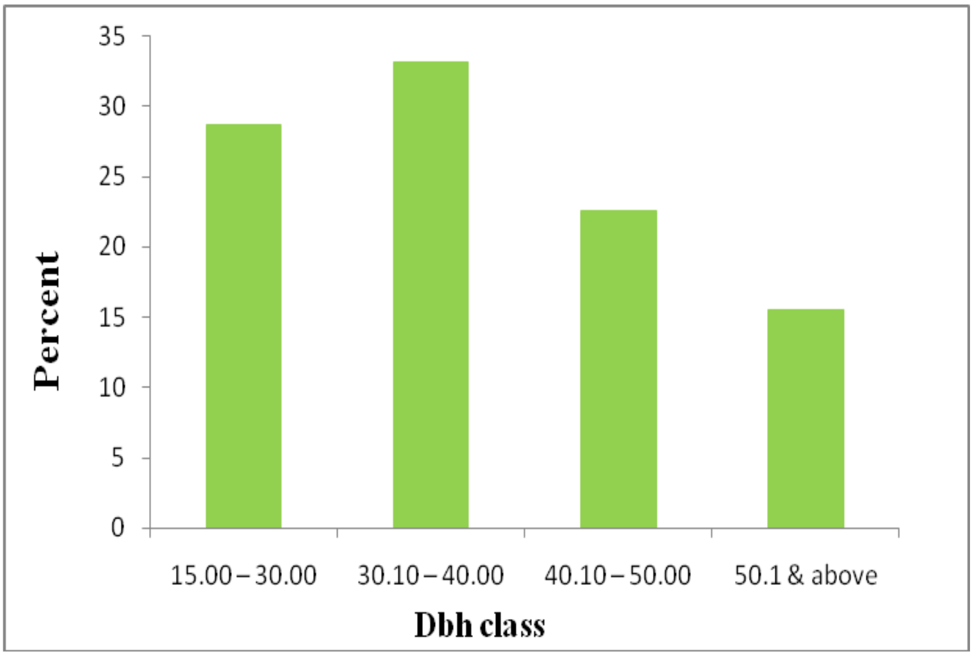

Figure 1a. Stem Diameter Distributions of *P. biglobosa (Jacq) Benth*

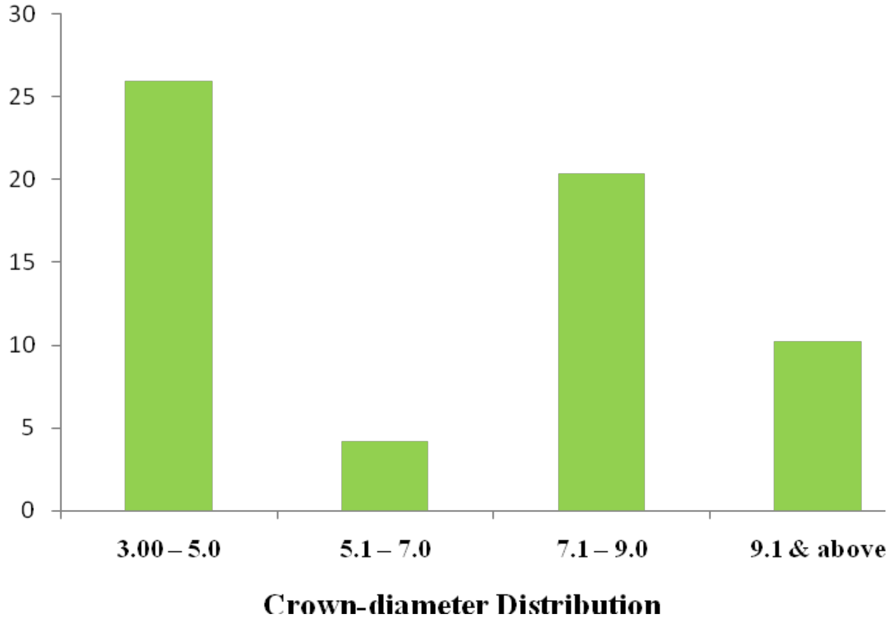

Figure 1b. Crown-diameter Distributions of *P. biglobosa (Jacq) Benth*

2.2. Measurement Procedures

P. biglobosa was selected based on its economic values to the people of the guinea savanna ecozone of Nigeria. Simple random design was used to laid down sample plots. Trees ≥10 cm-diameter at breast height (dbh) were sampled. A complete enumeration of trees in the sampled plots size 100m x 100 m each was carried out and the measurements of the parameters of interest were taken. The data collected on every sampled tree including: crown diameter by using 30-meter measuring tape; diameter at breast height (dbh), diameter at base, middle and top. Diameter of the sampled trees was determined with the use of diameter tape on winding the tape around the tree at point of measurement (1.3 m) above the ground on the uphill side of the tree. Total height was measured by the used of *Haga altimeter* [9].

Crown-diameter measurement was based on the assumption that the vertical projection of a tree crown is circular; four radii were measured (using 30-meter measuring tape) and in the direction forming equal angles [6]. Along each radius of the tree crown, the diameter tape was held horizontally and extended until each person was vertically under the tip of the longest branch on both sides; a 3.00 - meter ranging pole was used to align vertically to the edge of the crown [9]. The diameter tape was turned by 90^o and measurements were carried out repeatedly along the thinnest part of the tree crown and recorded [5]. Average crown diameter (Cd) was calculated by summing up the four radii and dividing by 2, thus;

$$\mathrm{Cd} = \sum \mathrm{ri} / 2 \quad [10] \qquad (1)$$

Where Cd = average crown diameter; ri = projected crown radii measured on four axes

2.3. Data Analyses

Basal area estimation

The diameter at breast height (dbh) was used to compute basal area using the formula:

$$\mathrm{B.A} = \pi \mathrm{D}^2 / 4 \quad [9] \qquad (2)$$

Where: BA = Basal area (hectare); D = Diameter at breast height (m) and $\pi = 3.142$.

Crown-diameter

Data on crown diameter and stems diameter were fitted to the following model forms for predicting crown diameter suggested by different authors with the aim of choosing the model form that showed the best ability to stabilize the variance in the data:

$$Cd = \mathrm{b_o} + b_1 dbh + ei \quad [11] \qquad (3)$$

$$Cd = \mathrm{b_o} + b_1 dbh^2 + ei \quad [5] \qquad (4)$$

$$Cd = b_o + b_1 dbh + \mathrm{b_2} \ln dbh + ei \quad [9] \qquad (5)$$

$$Cd = \mathrm{b_o} + b_1 \ln dbh + ei \quad [6] \qquad (6)$$

$$\mathrm{Ln}Cd = b_o + b_1 dbh^2 + \mathrm{b_2 Ln} dbh^2 + ei \quad [5] \qquad (7)$$

$$\mathrm{Ln}Cd = b_o + b_1 \ln dbh + ei \quad [9] \qquad (8)$$

$$\mathrm{Ln}Cd = b_o + b_1 dbh^2 + \mathrm{b_2 Ln} dbh + ei \quad [6] \qquad (9)$$

Where: Cd = crown diameter; dbh = diameter at breast height; b_0 = intercept; b_1 and b_2 = regression coefficient

Crown area (growth space)

Using the calculated crown diameter (Cd), the crown area (A) was estimated and expressed in hectare basis (conversion of crow diameter in meters to area in hectares):

$$\mathrm{A} = \left(\pi \mathrm{Cd}^2 / 4\right) / 10{,}000 \quad [5] \qquad (10)$$

Where: A = growing space/area; **Cd** = crown diameter; $\pi = 3.142$.

$$\mathrm{N} = 1 / \mathrm{A\ i.e.} \left[1 / \left(\mathrm{Cd}^2 / 4\right) / 10{,}000\right] \quad [12,13] \qquad (11)$$

Where: N = stock; A = growing space

Stand density/ basal area per hectare

$$S.D = \pi D^2 / 40,000 \ [6] \quad (12)$$

Where: SD= stand density; D= diameter; $\pi = 3.142$.

Criteria for models selection

The models were fitted and assessed. The assessment was based on all the following criteria: the significance of regression equation (F-ratio), coefficient of determination (R^2), root mean square error (RMSE) and normal probability plots of residuals [14]. The best model was selected based on a ranking procedure, for each model ranking was based on the above mentioned criteria. The model with the highest F-ratio/R^2 was assigned a rank of one while model with the lowest F-ratio/R^2 was assigned a rank of seven; the model with best fitted residual/normal probability plots and lowest RMSE was assigned a rank of one. Then the rank for R^2, RMSE, F-ratio, residual and normal probability plots were combined, and were then summed to determine the most appropriate model [15,16]. T-test was used to test for significant difference at $p \leq 0.05$. Thirty percent (30%) of data from the tree species were used (independent of those used to develop the model) for the purpose of validation.

3. Results and Discussion

The results on crown diameter and stem diameter distributions of the species from the study area ranged from 15.00 to 61 (cm) for stems diameter and 3.00 to 11.00 (m) crown diameter. Most of the tree species in the study area have a stem diameter size between 15.00cm to 40.00 cm while few of the tree species were in the diameter class distribution of 41.00 to 50.1 cm. This could be as a result of high exploitation of the trees; coupling with inability of farmers to actively plant *P. biglobosa*. Livestock, fire and human activities are factors that limit the success of natural regeneration of the species; therefore, regeneration must be carried out by plantations establishment.

The crown diameter sizes of *P. biglobosa* can be used as a vital visual indicator of tree and forest trend (healthy or unhealthy) in the study area. Trees with full and healthy crowns are generally associated with higher growth rates as a result of an increased rate for photosynthesis. When crowns become unhealthy, the rate of photosynthesis is reduced. These results described the current status/trends and condition of *P. biglobosa* in the area as summarized in Figure 1a and Figure 1b. The results show that, the crown condition of the trees was healthy and free from high competition. This may be as the results of free stressors. The result is in accord with Kenk, [17] and Lawrence *et al.*, [18], who reported that crown degradation is typically the result of past and present stressors such as insects, diseases, weather events, drought, senescence, and competition or other stand conditions and when severe enough, may result in tree mortality.

Descriptive statistics (the mean, standard error, standard deviation, co-efficient of variation, minimum and maximum of each growth variable) of data collected on growth variables (characteristics) for the species are shown on Table 1. There was high variation among the tree species as a result of different (uneven) ages and the nature of the forest (disturbed natural forest estate) in the study area. The mean Dbh was recorded to be 37.77 cm with minimum and maximum stem diameter of 15.02 and 87.85 cm, respectively. Crown diameter had the variable mean of 7.55m with 3.85 meters as minimum and 12.45 meters as the maximum crown diameter. Basal area had the mean of 0.237 (m^2) with the minimum of 0.059 (m^2) and maximum of 0.697 (m^2).

Table 2 summarized the regression parameters on *P. biglobosa* tree. Coefficients of determination (R^2) ranged from 0.653 to 0.825. RMSE was used to compare untransformed models while *F.I* was used to compare the transformed models. These criteria for model selection is acceptable for simple models involving one or two functions[25] and having the same response or dependent variable but it is not suitable when they differ. Transformed model can be analyzed based on the value of the Furnival index [19] as it has different and transformed response variable [13]. The index adjusts the standard error of the regression in order to facilitate the comparison.

Table 1. Descriptive Statistics on *Parkia biglobosa* (Jacq) Benth

N	Variables	Mean	SE	S. Dev.	Min.	Max.
322	DBH	37.77	0.76	12.3	15.02	87.85
	CD	7.55	0.11	1.86	2.90	12.45
	B.A	0.237	0.0056	0.0904	0.059	0.697

DBH = Diameter at breast height (cm), CD = Crown diameter (m), BA = Basal area (m^2), VOL. =Volume (m^3). Mean interval= ± standard error.

Table 2. Summary of regression parameter on *P. biglobosa (Jacq) Benth*

Model No.	Model type and model coefficients	R²	Adj. R²	RMSE	F-ratio	FI
[3]	Cd = 2.134 +0.126 dbh	0.854	0.834	0.710	1226.7	-
[4]	Cd = 4.895+ 0.001 dbh^2	0.764	0.763	0.822	851.06	-
[5]	Cd =-1.805+0.91 dbh + 1.459 lndbh	0.825	0.824	0.709	617.83	-
[6]	Cd = -11.93`1+5.242lndbh + ei.	0.815	0.814	0.728	1155	-
[7]	LnCd = 0.123 – 0.00004 dbh^2 +1.35 Lndbh^2	0.655	0.652	0.173	248.67	0.0608
[8]	LnCd = -1.129+0.814lndbh	0.653	0.651	0.173	494.05	0.0608
[9]	LnCd = -1.304+ -1.479dbh^2 +0.869 Lndbh	0.653	0.650	0.173	246.50	0.0608

dbh =Diameter at breast height(cm);=Coefficient of Determination; RMSE= residual mean square error; FI=furnival index.

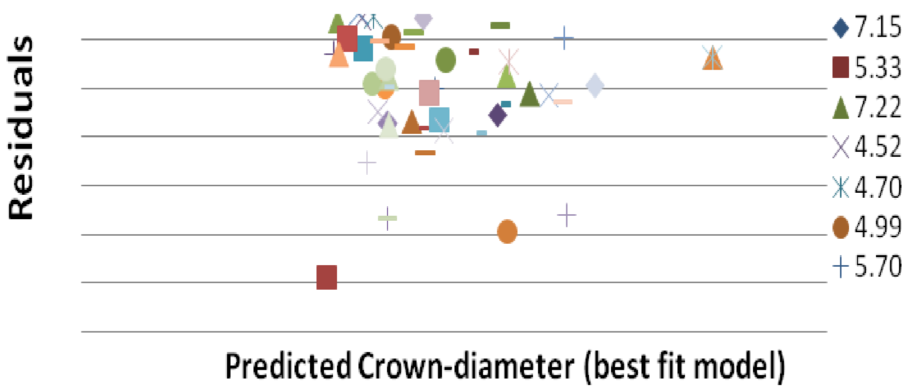

Figure 2. Plot of Residuals vs. Predicted Crown Diameter for *P. biglobosa (Jacq) Benth*

The Relationship between Crown-diameter and Stem-diameter of *P. iglobosa* Species in the Guinea Savanna Ecozone of Nigeria

Table 2 shows crown diameter and stem diameter relationships which include linear, power and natural log regressions for the tree species. The coefficients of determination differ among the models within the species in this study area, this may be attributed to the fact that almost all the sample trees were small in size with small crown diameters (Figure 1a and 1b). The results in Table 2 explained the variation associated with the equations used to predict crown diameter from stem diameter. The relationship strongly correlated with stem diameter (equation 3). The *Furnival* index (RMSE) of the estimates of crown-diameter were low enough to make equations 7,8 and 9 strongly reliable for predicting crown diameter from stem-diameter but the F-ratios and R^2 were so low with negative coefficient in equation 7 (i.e. – 0.00004) and intercepts in equation 8 (i.e. -1.129) and equation 9 (i.e. -1.304 and +0.869). The coefficients of the regression were positive and significantly different in equations 3 and 4. R^2, RMSE and F-ratio were better in equation 3 (Table 2). Comparison of the residual plots from all the regression equations, the scatter of the data points in the crown diameter and stem diameter relationships gave no evidence of non-linearity. The regressions line in equations 3 and 4 conforming to [20] type 2 behavior i.e. 'straight line with a positive intercept' [11]; while equations 5, 6, 7 and 9 exhibited the type 3 behavior 'namely a straight line with a negative intercept' [5]. Also reported that crown diameter and stem diameter equations should have positive intercepts, which suggests that crown diameter and stem diameter ratio decreases with tree size.

Based on the results obtained, linear equation (equation 3) was the best equation among the tested equations. Because it conformed to the assumptions of regression analysis with positive coefficients, couple with its superiority in previous research and ease of application [5]. The linear equation was fitted on independent (reserved) data collected from the field for validation test using t-tests. The p-values i.e. $p = 0.31$ (one-tail) and $p=0.63$ (two-tail) at $p<0.05$ showed no significant difference between the observed (measured crown diameter) and predicted (crown diameter values) with the Pearson correlation coefficients of 0.98. This showed a close correlation between the observed and predicted crown diameter values. The T-tests revealed no significant difference.

Height was not added to the equations because the study was based on ease of application of equation on growth space. Also, it was thought to have little or less improvements to the growth space equation as observed by Samantha *et al.* [21] and Mugo *et al.*, [22]. Tree diameter can be measured easily and at little cost but total tree height, is more difficult and costly to measure due to time required to complete measurements, chance of observer error and visual obstruction [16, 23].

Table 3. Predicted Crown Diameter (CD), Growth Spacing (S), Stocking (N) and Stand density (D) from the Linear Equation (Equation 3)

Dbh (cm)	Cd (m)	Cd/dbh	S (ha)	Nha^{-1} (1/S)	D (m^2ha^{-1})
19.6	3.2	0.163	0.0008	1243	8.0^{04}
26.6	4.7	0.177	0.0017	576	1.7^{03}
30.1	5.4	0.179	0.0023	437	2.3^{03}
38.2	6.9	0.181	0.0037	267	3.7^{03}
45.1	8.85	0.196	0.0062	163	6.2^{03}
53.3	10.7	0.201	0.0090	111	9.0^{03}
60.1	12.3	0.205	0.0119	84	1.19^{02}
70.2	12.9	0.184	0.0131	77	1.131^{02}
75.7	13.4	0.177	0.0141	71	1.41^{02}
81.8	13.8	0.169	0.0150	67	1.50^{02}
86.2	14.6	0.169	0.0167	60	1.67^{02}

The above table was derived from the crown-diameter and stem-diameter regressions, and was computed as follows: Cd= 2.134 + 0.126 dbh; Growing space (S) = $Cd^2\pi$ /40 000 and limiting stocking (N) = 1/ S.

Growth space requirements for *P. biglobosa* was determined based on the findings by Foli *et al*., [5], who stated that growth space was associated with crown size. The predicted crown diameter (Cd) and the crown area (A) were estimated and expressed in hectare basis (Table 3). To improve production, fast growth and quality of the tree species, individual tree in a stand must have unrestricted continuous free-growing space. This requires knowledge of maximum stock of site stand with time. Thus, equations 10 and 11 were used to predict the growth space and stand density for the trees species in Guinea savanna ecozone of Nigeria. From the results presented on Table 3 estimated the maximum stocking per hectare (N ha^{-1}) which is needed for producing a complete canopy (i.e. to fully occupy the site). This can be expressed as inverse of the growth space (Table 4).

The results in Table 3 showed that a dominant free-growing tree species of diameter 53.3cm would require a growing space of 0.0090 ha and limiting stocking of the stand in terms of total occupancy by tree crowns of 111 trees per hectare. The crown and stem diameter ratio is a measure of efficiency of a tree to accumulate diameter at breast height per unit of crown area. The higher the ratio, the more efficient a tree species is at accumulating dbh [11]. The results on ratio show that for each meter of crown diameter in *P. biglobosa*, 0.205 cm of stem diameter was accumulated as the highest efficient without serious crown interference or competition. Data in the present study represent a wider range of diameter classes (Figure 1a and Figure 1b).

The rationale for optimum planting during the establishment of economic trees plantation should be generally based on fast growth, economic considerations, reduction of mortality and increased total production per unit area in a given period of time. The significance of stand density stems within maximum stocking, the greater the amount of growing space per tree, the faster the tree will grow. Stands with wider spacing in time, have larger average stem and crown diameter than similar stands with closer spacing; from Table 3 above, the tree species would require low densities for optimum planting, fast growth and high yield for the purpose of timber and non-timber forest products. This agreed with Clutter *et al.,* [24], that very low densities are required to produce maximum diameter growth throughout the life of an even-aged stand.

4. Conclusion and Recommendations

Based on this finding, there was close relationship between crown diameter and bole diameter relationship; this mean that crown diameter can be predicted from the measurement of tree stem diameter. Thus, *P. biglobosa (Jacq) Benth* in the study area would require growth planting spacing of 4 x 4 meters for plantation establishment. For the purpose of timber, fencing pole and electric-pole, thinning should be administered at canopy closure; this would create more spacing for continue growing of the species in an established plantation. The recommended planting spacing would provide optimum planting, fast growth and high production/yield. It could also be used as a tool to control competition in *P. biglobosa* plantations.

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