ISSN 2449-8955
European Journal of Biological Research
Research Article

# Growth space requirements models for *Prosopis africana* (Guill & Perr) Taub tree species in Makurdi, Nigeria

**J. H. Dau, I. Chenge**

Department of Forest Production and Products, College of Forestry and Fisheries, University of Agriculture Makurdi, Nigeria
*Corresponding author: J. H. Dau; Phone: 08068347777; 08029153959; E-mail: daujaphson@gmail.com

**Received:** 21 June 2016; **Revised submission:** 31 July 2016; **Accepted:** 27 August 2016

**DOI:** http://dx.doi.org/10.5281/zenodo.61034

## ABSTRACT

All parts of *Prosopis africana* (Guill & Perr) Taub are used by rural communities in Nigeria, and this exposes it to degradation and a regeneration problems. There is lack of information on inventory on natural forest estates for management and decision-making. This species is facing a regeneration problem and overexploitation. The aim of this study was to developed model that can predict the growth space requirements for *P. africana* plantation establishment. Growing space was associated with crown size; seven crown and stem diameter relation models were tested on data recorded from *P. africana* trees in Makurdi-Nigeria; simple random sampling technique was used to collect data. The linear model (crown-stem diameter relation) provided the best model fitted with $R^2$ values of 0.778 with adjusted $R^2$ 0.777. For optimum planting, fast growth and high production/yield the tree species would require a planting spacing of 4 x 4 meters; for example, that a dominant free-growing tree of diameter 52.90 cm would required 0.008 hectare of growing space with a stocking of 125 tree per hectare for *P. africana*. Stand density converges around 0.000016 $m^2$. The baseline information provided by this study could serve as a guide for optimum planting distances and tree stocking in large scale plantations of *P. africana* species in Nigeria and international, this to avoid extinction of the economic tree.

**Keywords:** Crown diameter; Bole diameter; Growth space; Models; Predict/estimate; Indigenous species.

## 1. INTRODUCTION

*Prosopis africana* (Guill. and Perr.) Taub is the only known species of its genus found in Africa; the species occurring from Senegal to Ethiopia in the zone between the Sahel and savanna forests. The tree plant belongs to the family *Fabaceae*, sub-family *Mimosoideae*. The common names include, Iron wood, *Ubwa* (Ibo), *Kiriya* (Hausa), *Okpehe* (Idoma) [1].

Abah et al. [2], reported that almost all parts of the tree are used for medicinal and economic purposes by rural communities. *P. africana* is a particularly vulnerable species because all parts of the tree are used by rural communities [3]. Its wood is dense and highly resistant, so it is used for making construction poles and planks, and mortars and pestles. The wood has a high calorific value [4, 5]; the tree species is highly valued for charcoal by blacksmiths. The leaves, roots and especially the bark are used in traditional medicine. The leaves and pods are used for fodder and the seeds for food [6]. Sustainable management would require ensuring natural regeneration of the species, and promoting their domestication to reduce the pressure on natural populations [3].

Crown width (diameter) and bole diameter at breast height are important tree characteristics; therefore any attempt that can improve the accuracy of measuring, predicting and analyzing these parameters should be taken into consideration [7]. The strong correlation between crown and bole diameter is particularly useful for predicting and estimating growth space, stand density and limiting stocking relationships [8-11]. It is also very relevant in studies of the growth of stands, and the 'packing' or density of trees in a stand [11]. The growth of a tree mostly is determine by the tree crown characteristics, i.e. tree crown size can determine tree growth and survival; tree height and crown dimension determine length of its clear bole, which is important in merchandizing of the tree into various wood products [12].

Koziowski et al. [13], reported that the crown of a tree refers to the totality of the tree above ground, including stems, leaves and reproductive structures; a tree's crown is that section(s) of a tree bearing live branches and foliage [14, 15]. Measurements of crowns are important in quantifying and qualifying plant health, growth stage and efficiency. Crown shape therefore represents the physical space a tree utilizes for growth as modified by the physical environment.

Bole diameter at breast height (Dbh at 1.3 m above the ground) is an important tree characteristic; and a more easily measured tree variable than crown diameter, often used as a substitute for a tree's crown diameter; tree crown diameters (horizontal diameter, radius) are well correlated with a tree's diameter. The crown diameter and bole diameter relationship is specifically useful for estimating crown competition index, stand density and stocking relationships, and tree growth [8, 16].

Despite the current economic, environmental, medicinal and social values of *P. africana* to rural communities; at the moment, no adequate information on growth space of the species is available for plantations establishment. The aim of this study was to develop models for growth space requirements for *P. africana* in Nigeria for establishment and proper management of plantations for timber and non-timber forest products. The study would attempt to find ways of improving production per unit area through stand density control. It would also provide baseline information and a guide for optimum planting distance and tree stocking per hectare basis which would help to control competition and enhance growth for sustainable management of *P. africana* plantations.

## 2. MATERIALS AND METHODS

### 2.1. The study area

The study was carried out on *Prosopis africana* in Makurdi, Nigeria which lies between longitude 8° 21' to 9° E and latitude 7° 21' and 8° N in Benue State, within the southern guinea savanna ecological zone [17-19]. One important feature is the presence of the River Benue which divides the town into the northern and southern parts. The climate of the area is tropical sub-humid climate 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 [20]. The climate is characterized by distinct rainy and dry seasons. The mean annual rainfall is 1200 to 1500 mm. The vegetation of the area has been described as southern guinea savanna [21]. The major occupations of the people include; farming, civil service, trading and hunting; the major tribes are Tivs, Idoma and Igede.

### 2.2. Data collection (measurement procedures)

*Prosopis africana* was selected based on its economic values to Makurdi community. Data from *P. africana trees* were collected in North-core, University of Agriculture Makurdi. Simple random technique was used to locate nine sample plots sized 100 x 100 m each within the study area. Complete enumeration of trees greater than 10 cm diameter at breast height (dbh) was assessed and the measurements of the parameters of interest were taken; bare areas were excluded. The data collected on every sampled tree includes: crown diameter by using 30-meter measuring tape; diameter at breast height (dbh), base, middle and top (with the help of portable ladder). 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*.

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 [22, 23]. 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 - metre ranging pole was used to align vertically to the edge of the crown [8, 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 [22]. Average crown diameter (Cd) was calculated by summing up the four radii and divided by 2, thus;

$Cd = \sum ri / 2$

Equation [1]

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

## 2.3. Data analyses

### *2.3.1. Basal area estimation*

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

$B.A = \pi D^2 / 4$

Equation [2]

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

### *2.3.2. Crown-diameter*

The data collected from the field 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:

- $Cd = b_o + b_1\, dbh + ei$
  Equation (3a) [15]
- $Cd = b_o + b_1\, dbh^2 + ei$
  Equation (3b) [22]
- $Cd = b_o + b_1\, dbh + b_2 \ln dbh + ei$
  Equation (3c)
- $Cd = b_o + b_1 \ln dbh + ei$
  Equation (3d) [23]
- $\mathrm{Ln}Cd = b_o + b_1\, dbh^2 + b_2\, \mathrm{Ln}dbh^2 + ei$
  Equation (3e) [22]
- $\mathrm{Ln}Cd = b_o + b_1 \ln dbh + ei$
  Equation (3f)
- $\mathrm{Ln}Cd = b_o + b_1 dbh^2 + b_2\, \mathrm{Ln}dbh + ei$
  Equation (3g) [23]

Where: Cd = crown diameter; dbh = diameter at breast height; $b_0$ = intercep$_{t;}$ $b_1$ and $b_2$ = regression coefficient.

### *2.3.3. 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):

$A = (\pi\, Cd^2 / 4) / 10{,}000$

Equation (4)

Where: A = growing space/area; Cd = crown diameter; π = 3.142

N = 1/A i.e. $[1/ (Cd^2/ 4) / 10{,}000]$

Equation (5) [24, 25]

Where: N = Stock; A = growing space.

### *2.3.4. Stand density/basal area per hectare*

$S.D = \pi D^2 / 40{,}000$

Equation (6) [23]

Where: Stand density; D = diameter at breast height; π = 3.142.

### *2.3.5. Criteria for models selection and ranking*

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 [26]. 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 [27, 28].

## 3. RESULTS AND DISCUSSION

The results revealed the status/trend of *P. africana* trees in the study area; most of the trees are small in sizes with few larger trees of the species (see Figure 1, 2 and Table 10. The results of crown diameter and bole diameter distributions on *Prosopis africana* tree from the study area are shown on Figure 1; it ranged from 15.00-55.1 (cm) for bole diameter and 3.00-11.00 (m) crown diameter.

In all the data sets from the tree species (Figure 1 and 2), there was more concentration of stem diameter at the upper diameter class (10.00-40.00 cm) than in the lower diameter class distribution (41.00-50.1 cm). This showed that as the species was growing and increasing in stem diameter, there was declining in the population of the tree species; this may be as results of high mortality or exploitation on the tree species. The results on the crown diameter class can be used as an important visual indicator of tree and forest trend (healthy or unhealthy) in the study area. Tree's crown is a major part of tree that trapped light use for food production; 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 and condition of *Prosopis africana* trees in the area. The figures explained the crown condition of the study area which happened to be healthy and free from high competition. This may be as a results of low population (declining in population due to deforestation without reforestation) of the tree species (open grown trees) or the soil condition of the area. The result is in accord with [29] and [30], who stated 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.

Table 1 shows the result of the descriptive statistics (i.e. 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 tree species. The coefficient of variation of the variables (crown diameter and bole diameter) was 28.4% in bole diameter (Dbh); the entire trees bole diameter was found to have very poor coefficient of variation 28.4% (Table 1), this may be as a result of different/uneven ages (natural forest) associating with the tree species in the study area. Crown diameter has the variable mean of 6.20m with 3.0 meters as minimum and 10.80 meters as the maximum crown diameter. Basal area has the mean of 0.0807 ($m^2$) with the minimum of 0.0234 ($m^2$) and maximum of 0.3197($m^2$).

Table 2 summarized the regression parameter for the tree species. Coefficients of determination ($R^2$) ranged from 0.780 to 0.729 (*Prosopis africana*). RMSE was used to compare untransformed models while *F.I* was used to compare the transformed models as showed on the Table.

Table 2 shows results on linear, power, natural log regressions for the tree species. The coefficients of determination differ among the models; this may be attributed to the fact that almost all the sample trees were small in sized with relatively small crown diameters (see Figures 1 and 2).

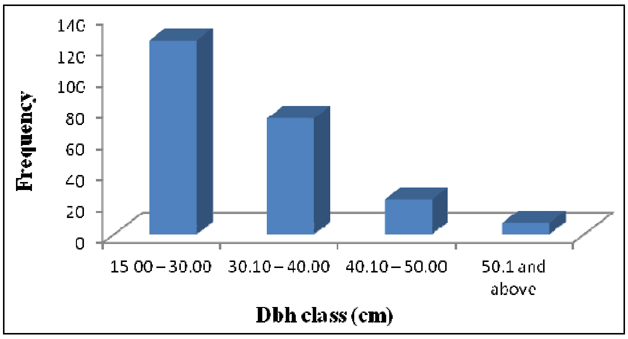


**Figure 1.** Dbh class distributions on *Prosopis africana* (Guill & Perr.) tree in Makurdi, Nigeria.

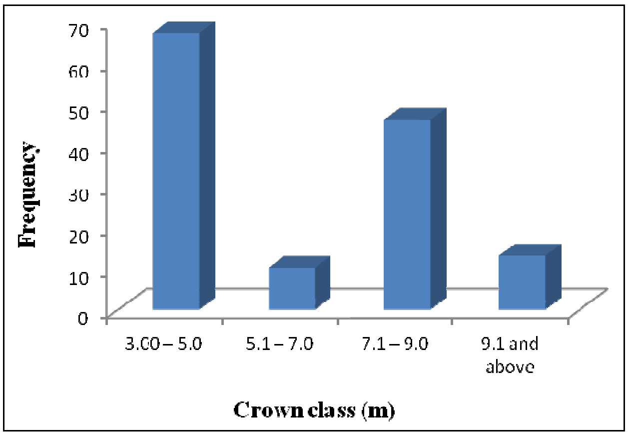


**Figure 2.** Crown diameter distributions on *P. africana* tree species in Makurdi, Nigeria.

**Table 1.** Descriptive Statistics on *P. africana* (Guill & Perr.) Taub in Makurdi, Nigeria.

| N | Variables | Mean | SE | S. Dev. | C. V% | Min. | Max. |
|---|---|---|---|---|---|---|---|
| 227 | DBH | 83.00 | 0.58 | 8.80 | 28.4 | 17.27 | 63.80 |
| | CD | 6.20 | 0.11 | 1.61 | 26.1 | 3.00 | 10.80 |
| | B.A | 0.0807 | 0.0034 | 0.0506 | 62.8 | 0.0234 | 0.3197 |

*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 parameters for the *P. africana* in Makurdi, Nigeria.

| Model No. | Model type and model coefficients | $R^2$ | Adj. $R^2$ | RMSE | F-ratio | FI |
|---|---|---|---|---|---|---|
| [3a] | $Cd = 0.873 + 0.174\,dbh$ | 0.778 | 0.777 | 0.7648 | 787.558 | - |
| [3b] | $Cd = 3.654 + 0.003 dbh^2$ | 0.773 | 0.772 | 0.7736 | 764.696 | - |
| [3c] | $Cd = 6.042 + 0.41\,\text{dbh} - 2.128 \ln dbh$ | 0.780 | 0.779 | 0.7619 | 398.209 | - |
| [3d] | $Cd = -12.054 + 5.392 \ln dbh$ | 0.746 | 0.745 | 0.8176 | 441.910 | - |
| [3e] | $\text{Ln}Cd = 0.584 + 0.010\,dbh^2 + 0.078\,\text{Ln}dbh^2$ | 0.735 | 0.733 | 0.1331 | 310.823 | 0.0609 |
| [3f] | $\text{Ln}Cd = -1.079 + 0.848 \ln dbh$ | 0.729 | 0.728 | 0.1342 | 606.647 | 0.0612 |
| [3g] | $\text{Ln}Cd = -4.30 + 0.00\text{dbh}^2 + 0.624\,\text{Ln}dbh$ | 0.734 | 0.732 | 0.1333 | 309.703 | 0.0610 |

*db = Diameter at breast height(cm); $R^2$=Coefficient of Determination; RMSE= residual mean square error; F.I=furnival index.*

**Table 3.** Estimated crown diameter (cd), Growing space (S), Stocking (N) and Stand density (D) from the modeling (model 4) for the three study species in University of Agriculture Makurdi-Nigeria.

| Species | Dbh (cm) | Cd (m) | Cd/dbh | S (ha) | $Nha^{-1}$ (1/S) | D ($m^2ha^{-1}$) |
|---|---|---|---|---|---|---|
| ***Prosopis africana*** | 16.70 | 3.10 | 0.186 | 0.0013 | 746 | $2.191^{06}$ |
| **(Guill & Perr.)** | 20.00 | 3.90 | 0.195 | 0.0017 | 601 | $3.142^{06}$ |
| | 25.90 | 5.30 | 0.205 | 0.0023 | 429 | $5.269^{06}$ |
| | 35.90 | 7.40 | 0.206 | 0.0037 | 269 | $1.012^{05}$ |
| | 40.70 | 7.89 | 0.194 | 0.0045 | 223 | $1.301^{05}$ |
| | 45.60 | 8.80 | 0.193 | 0.0054 | 186 | $1.633^{05}$ |
| | 52.90 | 9.70 | 0.183 | 0.0068 | 147 | $2.198^{05}$ |
| | 60.77 | 11.20 | 0.184 | 0.0086 | 117 | $2.901^{05}$ |
| | 66.30 | 12.34 | 0.186 | 0.0099 | 101 | $3.453^{05}$ |
| | 70.00 | 12.50 | 0.179 | 0.0109 | 92 | $3.849^{05}$ |

The above table was derived from the crown-diameter and stem-diameter regressions, and was computed as follows: *Cd*= 0.873+ 0.174 *dbh* (*Prosopis africana*); Growing space (S) = $Cd^2 \pi /40\,000$ and limiting stocking (N) = 1/ S.

The results significantly explained the variation in crown diameter and correlated well with tree diameter (model 3a). The data behaved accordingly with increasing crown diameter and tree diameter size. The Furnival indexes [33] (RMSE) of the estimates of crown-diameter were low enough to make models 3e, 3f and 3g sufficiently reliable for predicting crown-diameter from bole-diameter but the F-ratios and $R^2$ are very low with negative coefficients (see Table 2). Thus, the coefficients of the regression were positive and significant different in models 3a and 3b; $R^2$, RMSE and F-ratio were better in model 3a. A comparison of the residual plots (i.e. normal probability plots, histogram and scatter plots) from the results tended to favour models 3e, which was fairly fitted and better than the other models.

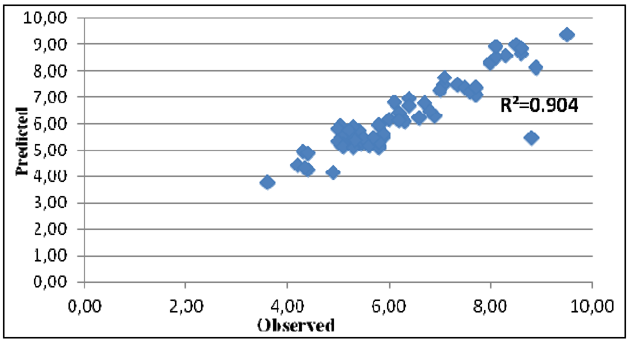


**Figure 3.** Relationship between predicted and observed values for *Prosopis africana* tree species in Makurdi.

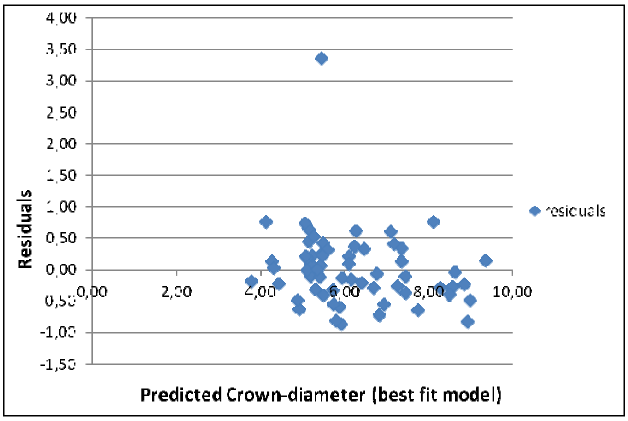


**Figure 4.** Scatter plot of residuals and predicted crown-diameter for *Prosopis africana* (Guill & Perr.) tree species in Makurdi-Nigeria.

The results on linear and power regressions (i.e. models 3a and 3b) are in accord with Foli et al. [22] and Lockhart et al. [15], stated that crown-diameter and bole-diameter relationship is sigmoid for forest grown trees. Crown expansion would be slow relative to early diameter growth as trees are crowded in dense young stands; as trees begin to express dominance, stem diameter growth increases almost linearly as crown expansion increases. When the tree reaches maturity, crown expansion essentially ceases while diameter continues to increase as photosynthesis are increasingly used for tree maintenance and support [15].

Comparison of the residual plots from all the regression models, the scatter of the data points in the crown diameter and bole diameter relationships gave no evidence of non-linearity, the regressions line in models 4 and 5 for individual species conforming to Dawkins 1963 type 2 behavior i.e. 'straight line with a positive intercept' [15, 23] models 3d and 3g exhibited the type 3 behavior 'namely a straight line with a negative intercept' [22]. He also reported that crown diameter and stem diameter equations should have positive intercepts, which suggests that crown diameter and bole diameter ratio decreases with tree size. Based on models ranking and selection criteria, the regression analysis results (Table 2) showed that crown diameter was better correlated with bole diameter in model 3a in *Prosopis africana*. Thus, model 3a (linear model) was the best model; because the model conformed to assumptions of regression analysis with positive coefficients (Table 2), coupled with its superiority in past research and ease of application [22].

When the selected model (linear model 3a) was validated for significant test at 0.05 level of significant difference using t-tests, p-values revealed no significant difference between the measured crowns diameter (observed) and crown diameter predicted. The Pearson correlation coefficient was 0.90, this showing a strong correlation between the observed and predicted crown diameter values. When the observed data were compared with predicted values using the best models, the T-tests revealed no significant differences ($p = 0.41$ at one-tail and 0.82 two-tail).

According to the results, the best model was the linear model which fitted best; power model was equally good and can sufficiently estimate crown diameter from bole diameter. These results agreed with Mugo et al. [31] based on the data set from the study area i.e. the crown diameter and bole diameter relationship is close to linear. Avsar and Ayyildiz [32], settled on the power model to describe crown diameter and bole diameter relationships. Simple regression model (linear model) was used by Lockhart et al. [15] to determine crow diameter and Dbh relationships for six bottomland hardwoods species on *pittman* island along Mississippi river; these results agreed with their results in the study area. While model 3b (power model) was used by Zuhaidi [23], in modelling crown and stem diameter relationship on plantation-grown of *Dryobalanops aromatica* in *Bukit lagong* forest reserve (Malaysia) which happened to be the best because it explained the variation in crown diameter adequately and had the lowest standard error (RMSE), according to the result obtained, model 3b happened to do better from the other models (*i.e.* model 3c to 3g).

If relationships between crown diameter and bole diameter are known, basal area (B.A), stand density and stocking of trees in the forest estates can be estimated from crown diameters derived from bole diameters; just as a tree's diameter at breast height (dbh) is often used as a substitute for a tree's crown dimensions a trees crown diameter can equally be used as the substitute for dbh [15]. The crown diameter and stem diameter at breast height (dbh) relationship is particularly useful for determining crown competition factors stand density, stocking relationships and tree growth [8, 16].

Growth space requirements for *P. africana* tree was determined based on the findings by Foli et al. [22], who stated that growth space was associating with crown size. Therefore, using the calculated crown diameter (Cd), the crown area (A) for each tree species was estimated and expressed in hectare basis (Table 3); to improve production, fast growth and quality of tree species in the study area, *P. africana* tree in a stand must have unrestricted continuous free-growing space; this requires knowledge of maximum occupancy [stocking] in sites with time. Thus, the results also provide a means of estimating the stocking per hectare (N $ha^{-1}$) required for producing a complete canopy (i.e. to fully occupy the site). This can be expressed as inverse of the growing space (Table 3).

Table 3 showed that a dominant free-growing tree of diameter 52.9 cm would required a growing space of 0.008 ha and stocking of the stand in terms of total occupancy by tree crowns of 125 trees per hectare. Therefore, to maximize the use of land for timber and non-timber forest products purposes, the selected tree species would require growth planting spacing of 4 x 4 m for plantation establishment in the study area. Thus, for maximum volume for the purpose of timber, fencing pole and electric-pole, thinning should be administer at canopy closure; this is to create more spacing for continue growing until the tree species only react minimal to thinning.
The crown diameter and bole diameter ratio is a measure of the 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 [15]. The results on ratio showed that for each meter of crown diameter in *Prosopis africana*. Data in the present study represent a wide range of diameter classes (see Figure 1). Furthermore, the forest in the present study was subject to periodic harvesting and disturbance, which may have influenced the difference in the stem diameter and crown diameter ratios among the species in the study area. Growth space calculation for the species in this study was based on the assumption that the tree crowns are circular and do not overlap [22].

## 4. CONCLUSION

*Prosopis africana* (Guill & Perr.) Taub tree would require low densities for optimum planting, fast growth and high yield for the purpose of timber and high densities for Non-Timber Forest Products in the study area, because low densities are required to produce maximum diameter growth throughout the life of trees stand which is applicable to the studied tree species as showed by the results obtained from the area.

To maximize the use of land for timber and non-timber forest products purposes, from the result, the selected tree species would require growth planting spacing of 4 x 4 meters for plantation establishment in the study area. Thus, for maximum volume for the purpose of timber, fencing pole and electric-pole, thinning should be administer at canopy closure; this is to create more spacing for continue growing until the tree species only react minimal to thinning. The recommended planting spacing would enhance optimum planting, fast growth, high yield/production and control competition within the tree species for purpose of plantation establishment worldwide.

The forest in the present study was subject to periodic harvesting and disturbance, which may have influenced the difference in the stem diameter and crown diameter ratios among the species in the study area. Therefore, it is recommended that a similar study should be carried out in an undisturbed forest estate using *P. africana* tree species for comparison of the growth space requirements for timber and non-timber forest products purposes (plantations establishment).

## AUTHORS' CONTRIBUTION

JHD: acquisition of data, analysis and interpretation of data, writing manuscript and review of manuscript. IC: development of methodology, conception and design, revision of manuscript and material support. The final manuscript has been read and approved by both authors.

## TRANSPARENCY DECLARATION

The authors declare that there is no conflict of interests.

## ACKNOWLEDGEMENT

Appreciation goes to Prof. Onyekwelu, J.C for technical and material support toward the success of this research work.

## REFERENCES

1. Agboola DA. *Prosopis africana* (Mimosaceae): stem, roots, and seeds in the economy of the savanna areas of Nigeria. J Econ Bot. 2004; 58, Suppl.: S34-S42.
2. Abah JO, Agunu A, Ibrahim G, Halilu ME, Abubakar MS. Development of quality standards of *Prosopis africana* (Guill. & Perr.) Taub. stem bark. J Biol Agric Healthcare. 2015; 6: 10-17.
3. Laouali A, Boubé M, Tougiani A, Ali M. Analysis of the structure and diversity of *Prosopis africana* (G. et Perr.) Taub. tree stands in the southeastern Niger. J Plant Stud. 2016; 5(1): 58-67.
4. Sotelo Montes C, Weber JC. Genetic variation in wood density and correlations with tree growth in *Prosopis africana* from Burkina Faso and Niger. Ann For Sci. 2009; 66: 713.
5. Sotelo Montes C, Silva DA, Garcia RA, Muñiz GIB, Weber JC. Calorific value of *Prosopis africana* and *Balanites aegyptiaca* wood: relationships with tree growth, wood density and rainfall gradients in the West African Sahel. Biomass Bioenergy. 2011; 35: 346-353.
6. Laouali A, Dan Guimbo I, Larwanou M, Inoussa MM, Mahamane A. Utilisation de *Prosopis africana* (G. et Perr.) Taub. dans le sud du département d'Aguié au Niger: les différentes formes et leur importance. Int J Biol Chem Sci. 2014; 8(3): 1065-1074.
7. Elmugheira MI, Elmamoun HO. Diameter at breast height-crown width prediction models for *Anogeissus leiocarpus* (DC.) Guill &Perr and *Combretum hartmannianum* Schweinf. J For Prod Indus. 2014; 3(4): 191-197.
8. Goelz JCG. Open-grown crown radius of eleven bottomland hardwood species: prediction and use in assessing stocking. South J Appl Forestry. 1996; 20: 156-161.
9. Kigomo BN. Crown and bole diameter relationship in *Brachyleana huillensis* and its application to silvicultural interventions. E Afr Agric Forest J. 1991; 57(1): 67-73.
10. Kigomo BN. Morphological and growth characte-ristics in *Brachyleana huillensis* (Muhugu); some management considerations. Kenya J Sci (Series B). 1998; 11(1-2): 11-20.
11. Hemery GE, Savill PS, Pryor SN. Applications of the crown diameter stem diameter relationship for different species of broadleaved trees. Forest Ecol Manag. 2005; 215(3): 285-294.
12. Smith DM. the practice of silviculture. $8^{th}$ edn. Wiley, New York, 1986.
13. Koziowski T, Kramer P, Pallardy S. The physiological ecology of woody plants. 1991.
14. Helms JA. (ed.) The dictionary of forestry. Society of American Foresters, Bethesda, MD. 210, 1998.
15. Lockhart BR, Weih CR, Smith MK. Crown radius and diameter at breast height relationships for six bottomland hardwood species. J Arkansas Acad Sci. 2005; 59: 110-115.
16. Cole WG, Lorimer CG. Predicting tree growth from crown variables in managed northern hardwood stands. J Forest Ecol Manag. 1994; 67: 159-175.
17. Agera SIN, Agbidye FS, Amonum JI. A survey of wood protection chemicals, tree kllers and sprayers in agrochemical stores within Makurdi metropolis, Benue state, Nigeria. J Res For Wildlife Environ. 2011; 3(2): 107-118.
18. Ajaero C. A brand new image for Benue. Newswatch Mag., 2007.
19. National Population Commission. Population of local government in Benue state. Federal government of Nigeria gazette, 2006.
20. Seibert U. Languages of Benue state in Nigeria. MSc. thesis. Department of Languages and Linguistics, University of Jos, 2007.
21. University of Agriculture Makurdi Physical Planning Manual, 1989.
22. Foli EG, Alder D, Miller HG, Swaine MD. Modeling growing space requirements for some tropical forest tree species. Forest Ecol Manag. 2003; 173: 79-88.

23. Zuhaidi YA. Local growth model in modeling the crown diameter of plantation-grown *Dryobalanops aromatic.* J Trop For Sci. 2009; 21(1): 66-71.
24. Kunluvainen T. Relationship between crown projected area and components of above-ground biomass in Norway spruce stands; empirical results and their interpretation. Forest Ecol Manag. 1991; 40; 243-260.
25. Phillip MS. Measuring trees and forests. CAB International, Wallingford, 1994.
26. Onyekwelu JC. Site index curves for site quality assessment of *Nauclea diderich* monoculture plantations in Omo forest reserve, Nigeria. J Trop For Sci. 2005; 17(4): 532-542.
27. Kozak A, Smith JHG. Standards for evaluating taper estimating system. For Chron. 1993; 69(4): 438-444.
28. Mohamed OA, Ahmed E. Height diameter relationship model for *Acacia nilotica* in riverine forests - Blue Nile. J For Prod Indust. 2014; 3(1): 50-55.
29. Kenk G. Growth in “declining” forests of Baden-Wurttemberg (Southwestern Germany). In: Huettl RF, Mueller-Dombois D, eds. Forest decline in the Atlantic and Pacific region. New York: Springer-Verlag, 1993: 202-215.
30. Lawrence R, Moltzan B, Moser WK. Oak decline and the future of Missouri’s forests. Missouri Conservat. 2002; 63(7): 11-18.
31. Mugo JM, Njunge JT, Malimbwi RE, Kigomo BN, Mwasi BN, Muchiri MN. Models for predicting stem diameter from crown diameter of open grown trees in Sondu-Nyando River Catchment, Kenya; Asian J Agricult Sci. 2011; 3(2): 119-126.
32. Avsar MD, Ayyildiz V. The relationships between diameter at breast height, tree height and crown diameter in Lebanon cedars (*Cedrus libani* A. Rich.) of the Yavsan mountain, Kahramanmaras, Turkey. Pak J Biol Sci. 2005; 8(9): 1228-1232.
33. Furnival GM. An index for comparing equations used in constructing volume tables. For Sci. 1961; 7: 337-341.