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Modelling the Growing Space of *Parkia biglobosa* Benth for Agroforestry Project

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Abstract

Parkia biglobosa is a leguminous tree that plays a significant role in the socio-economic wellbeing of people especially in rural communities of sub-Saharan Africa. The trees are maintained on farms by farmers because of the benefits derived from them. Its inclusion in agroforestry practice is often limited due to inadequate information on appropriate growing space or planting distance. Agroforestry practice often requires the determination of planting distance in the form of alleys to reduce the effect of canopy cover. Therefore, in this study, the growing space requirement of *P. biglobosa* for agroforestry project was determined. The dataset used consists of 288 trees measured from the *P. Biglobosa* plantation in Markurdi, Nigeria. Quantile regression technique was used to establish a simple relationship between tree crown width (Cw) and diameter at breast height (dbh) of the species. This relationship was used to estimate the growing space required for the establishment of agroforestry project. The limiting density and stand basal area were also estimated. The result shows that the relationship of the form: Cw = 2.674 + 0.095dbh, explained 56.2% of the variation in crown width with a mean bias of 0.985. Also, the study shows e.g., that *P. biglobosa* trees of 10 cm dbh would each require 3.2 m of growing space with limiting density and basal area of about 982 trees/ha and 6.06 m^2/ha, respectively. Furthermore, trees of 50 cm dbh would each require 6.6 m of growing space with a limiting density and basal area of about 232 trees/ha and 35.86 m^2/ha, respectively. In agroforestry practice, alleys are predetermined from the onset of the project, and as such, information from this study could be used to determine the planting distance and the limiting density of the species. Thus, arable crops can be integrated between the alleys.

Keywords: Crown width*;* quantile regression; limiting density; stand basal area; Parkia biglobosa

Introduction, scope and main objectives

A land-use management system where woody perennials such as trees and shrubs are deliberately combined with arable crops and/or animals on the same piece of land in a spatial or temporal arrangement is known as Agroforestry (Lundgren and Raintree 1982). Maintaining increased production while conserving the potential of the resource base are some of the attributes of agroforestry (Nair 1993). Although all trees are multipurpose, however, multipurpose trees/shrubs in Agroforestry are referred to as "those trees and shrubs which are deliberately kept and managed for more than one preferred use, product, and/or service; the retention or cultivation of these trees is economically and sometimes ecologically motivated, in a multiple-output land-use system." (Nair 1993).

Among the several multipurpose tree species used in agroforestry is *Parkia biglobosa*. *P. biglobosa* belongs to the family Fabaceae and sub-family Mimosoideae, it is commonly referred to as locust bean but its trade name is dadawa or dawa-dawa. *P. biglobosa*is is a perennial deciduous tree that can attain a height of 7 to 20 m when mature, in rare case, it can reach 30 m. The crown is generally large and has a widespread with a stout bole (Orwa*et* al. 2009). *P. biglobosa* thrives in different agro-ecological zones. *P. biglobosa* is usually retained on farmland even after felling other tree species because of the diverse benefits associated with it (Amoako 2012). Its utilisation ranges from medicinal, glaze for ceramic pots, fodder, firewood, charcoal production (Kwon-Ndung et al. 2009). In agroforestry system, *P. biglobosa,* helps in breaking wind, providing shade for both crops and animals as well as fodder for the animal. The soil benefits through improve nutrient uptake efficiency because of the activities of endomycorrhizal fungi (Amoako 2012).

Growing space as defined by Foli et al*.* (2003) refers to the availability of all resources required for the survival of a tree in a site. For optimal growth and development of any tree, a definite amount of growing space is essential (Foli et al*.* 2003). The optimal or ideal growing space of a plant may be defined as the adequacy of all available resources that are necessary for the growth and survival of the plant. The amount of growing space maintained in an agroforestry system would likely contribute to the growth and size of trees and subsequently, arable crops incorporated. Wider spacing generally results in a larger tree and wider canopies and vice versa. It has been shown that the concentration of minerals increases with an increase in tree size (Kater et al. 1992, Tomlinson et al. 1995). This implies that maintaining wider space in an agroforestry system may lead to an increase in mineral concentration; in consequence, increasing arable crops yield. Therefore, the aim of the study was to determine the growing space requirement of *P. biglobosa* for the establishment agroforestry project.

Methodology/approach

Study area

This study was carried out in the natural stand of *P. biglobosa*, Makurdi, Nigeria. It is located between latitudes 7°21′ and 8°0′N and longitudes 8°21′ and 9°0′E with an area of about 7,978 km^2 (Chukwu et al. 2017). The dataset consists of 288 trees measured from nine samples of a hectare size. Diameter at breast height (dbh, measured at 1.3 m above the ground), tree height and crown width (Cw) were measured to the nearest 0.1 cm, 0.1 m and 0.3 m, respectively. Diameter tape and hypsometer were used to measure dbh and height, respectively. Cw was measured as the linear distance of the projected tree crown in four directions i.e., north-south and east-west. The mean value of these measures was recorded as the crown width (Cw). The data set was randomly split into 75% fitting and 25% validation data set. The descriptive statistics of the data are presented in Table 1.

Table 1: Descriptive statistics of the fitting (75%) and validation data sets (25%)

Variables	Fitting data (n = 216)				Validation data (n = 72)			
	Mean	**Max**	**Min**	**SD**	**Mean**	**Max**	**Min**	**SD**
dbh (cm)	40.4	95.4	15.3	14.83	40.1	79.8	14.6	14.83
Height (m)	6.8	17.8	2.1	1.89	6.6	12.0	3.3	1.89
CD (m)	6.5	12.6	2.8	1.97	6.6	10.8	3.4	1.97
BA (m^2)	0.15	0.72	0.02	0.11	0.14	0.49	0.02	0.11
N = 288 trees								

CD = crown diameter; BA = basal area; SD = standard deviation; N = number of trees

Modelling Crown width and DBH

A quantile regression technique was used to model the linear relationship between tree crown and DBH of *P. biglobosa*. The relationship is of the form:

$$Cw_i = b_0 + b_1 dbh_i + \epsilon_i - \qquad (1)$$

Where Cw is the crown width (m), dbh is the diameter at breast height (cm), b_0 and $b_1$are intercept and slope, respectively, ϵ represents error term in the model. The error is assumed to be normal and independent with zero mean and constant variance that is, $\epsilon_i \sim NID(0, \sigma^2)$. The subscript *i* is the individual tree. In quantile regression, the estimates of the regression parameters (b_0 and b_1) were obtained by minimizing the sum of absolute error. The 0.5 (i.e., median) was used in this study; expressed as:

$$\hat{\beta}_{(0.5)} = \mathrm{argmin}_{\beta \in R^2} \sum_{i=1}^{n} \rho_{0.5}(y_i - x_i^{'}\beta) \qquad (2)$$

Where $\hat{\beta}$ represents parameters b_0 and b_1; ρ is rho. This method was recently used by Raptist et al. (2018), Ozcelik et al. (2018) and Ogana (2019). The fitting method was assessed based on the coefficient of determination ($\overline{\mathrm{R}}^2$), root mean square error (RMSE) and mean absolute bias (MAB). The analysis was carried out in R (R Core Team, 2017).

Determination of growing space (GS, m) requirement

The growing space requirement of *P. Biglosbosa* was estimated from these relationships:

$$N(tree/ha) = \frac{40000}{\pi(b_0 + b_1 DBH)^2} \qquad (3)$$

$$GS\ (m) = \frac{100}{\sqrt{N(tree/ha)}} \qquad (4)$$

Where π is pi; b_0 and b_1 are the estimated regression parameter from equation 1. N is the number of trees per ha (i.e. the limiting density) which was derived from the estimated crown width. The basal area per ha of the stand at any given diameter was also estimated with this expression:

$$G(m^2/ha) = 10000\left(\frac{0.7854}{K}\right) \qquad (5)$$

Where G is the stand basal area in square meter per ha and K is the ratio of crown width to dbh.

Results

The result of the fitted model for the relationship between crown width and dbh is presented in Table 2. The model has a positive intercept and slope value with a relatively high adjusted coefficient of determination, low root mean square error and mean absolute bias. Positive intercept and slope are expected for most Cw-dbh relationships irrespective of the modelling method used.

The graphical relationship between K-ratio and tree size (i.e., dbh) is presented in Figure 1. The graph showed that *P. biglosbosa* has a higher K-ratio for younger trees (smaller dbh) and reduces with increase tree size. And then began to stabilize around dbh of 45 cm but never increases. It dropped by about 75% from dbh of 0.1 to 0.45 m (10 to 45 cm).

Table 2. Estimated parameters and fit indices

Data	b_0	b_1	$\bar{R}^2$	RMSE	MAB
Fitting	2.674	0.095	0.562	1.287	0.985
Validation				1.296	1.047

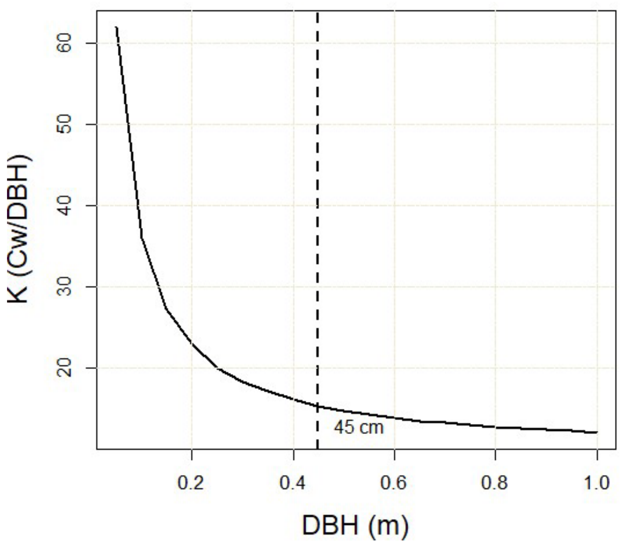

Fig. 1: Crown width-dbh ratio at different dbh for *P. biglobosa*

The results of the estimated growing space (GS), limiting density (N, trees/ha) and the stand basal area (G, m^2/ha) for different dbh of *P. biglobosa* are presented in Table 3. Predictions of GS, N and G within 10 – 100 cm dbh range were presented. From the table, *P. biglobosa* trees of 10 cm dbh would each require 3.2 m of growing space with a limiting density and basal area of about 982 trees/ha and 6.06 m^2/ha, respectively. Also, trees of 50 cm dbh would each require 6.6 m of growing space with a limiting density and basal area of about 232 trees/ha and 35.86 m^2/ha, respectively. Furthermore, trees of 100 cm dbh would each require 10.8 m of growing space with a limiting density and basal area of about 86 trees/ha and 53.64 m^2/ha, respectively.

Table 3. Limiting density (N), basal area (G) and growing space (GS) of *P. biglobosa*

DBH (cm)	CD (m)	N (tree/ha)	G (m^2/ha)	GS (m)
5.0	3.1	1324	2.04	2.7
10.0	3.6	982	6.06	3.2
15.0	4.1	757	10.52	3.6
20.0	4.6	601	14.85	4.1
25.0	5.0	509	19.63	4.4
30.0	5.5	420	23.38	4.9
35.0	6.0	353	26.73	5.3
40.0	6.5	301	29.74	5.8
45.0	6.9	267	33.42	6.1
50.0	7.4	232	35.86	6.6
55.0	7.9	203	38.09	7.0
60.0	8.3	184	41.06	7.4
65.0	8.8	164	42.84	7.8
70.0	9.3	147	44.47	8.2
75.0	9.8	132	45.98	8.7
80.0	10.2	122	48.31	9.1
85.0	10.7	111	49.55	9.5
90.0	11.2	101	50.75	10.0
95.0	11.7	93	51.75	10.4
100.0	12.1	86	53.64	10.8

CD = crown diameter, dbh= diameter at breast height (1.3m above the ground)

Discussion

Expected positive intercept (b_0) implies that the stand basal of *P. biglobosa* can grow to maximum i.e., maturity since the Cw-dbh ratio (K-ratio) decreases with tree size (Foli 2003). A drop of K-ratio was observed similar to what was reported by Hemery et al. (2005) for 11 temperate tree species. This K-ratio can be used to estimate the mean crown width of the stand (K x dbh) from which other stand variables including growing space can be determined.

Agroforestry practice often requires the determination of planting distance in the form of alleys to reduce the effect of canopy cover. These alleys are predetermined from the onset of the project. Thus, if *P. biglobosa* trees would be used in agrosilviculture (tree and arable crop) project and that the diameter of the tree at the establishment stage is 5.0 cm say, a growing space of about 2.7 m would be required. The stand density and basal area per ha would be 1324 trees/ha and 2.04 m^2/ha, respectively. Arable crops such as maize (*Zea mays*), cassava

(*Manihot* spp.), etc. can be planted between the alleys. Inappropriate specification of planting distance will lead to competition for space, nutrients, light, etc., and in consequence low yield. Bazié et al. (2012) reported a decrease in the yield of sorghum and maize grown under the canopy of *P. biglobosa*. Furthermore, Kater et al. (1992) observed a decrease in the yield of cotton grown under the canopy of *P. biglobosa*, however, the yield of millet was less affected. Although the amount of growing space or distance in the studies was not stated, it is possible that the amount of distance maintained could be one of the contributing factors responsible for the observed difference in yield. Dau et al. (2016) reported a 4 x 4 m planting distance of *P. biglobosa* for plantation establishment. Foli et al. (2003) also determined the growing space for some tropical tree species in Ghana for the same purpose of plantation establishment.

Conclusions/ wider implications of findings

In conclusion, this study has modelled the relation between crown width and diameter at breast height using quantile regression from which the growing space of *P. biglobosa* for agroforestry project was determined. Knowledge of the appropriate growing space or planting distance of a tree in an agroforestry system will not only ensure the optimal growth and development of the plant but also indirectly affect arable crop yield.

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