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*Full Length Research Paper*

# Prediction equations for estimating tree height, crown diameter, crown height and crown ratio of *Parkia biglobosa* in the Nigerian guinea savanna

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**Relationships between stem diameter, tree height, crown diameter, crown height and crown ratio of *Parkia biglobosa* were investigated and regression prediction models were derived. The result revealed positive correlations between stem diameter, tree height, crown height and crown diameter which are significant. The corresponding F-values from analyses of variance are also significant (P=0.05), except for stem diameter with crown ratio, which show no relationship. The values of Pearson correlation coefficients (r) between the stem diameter and tree height, crown height and crown diameter are 0.825, 0.846 and 0.846, respectively. The corresponding coefficients of determination ($r^2$) are 0.680, 0.715 and 0.767, respectively. This means that 68% of tree height, 71% of crown diameter and 76% of crown height were accounted for by the stem diameter. Taking the crown diameter as a predictor variable, there were also positive correlations with tree height and crown height. Here the r- values were 0.728 and 0.776 and the $r^2$- values were 0.529 and 0.602 respectively. These show that stronger correlations were found with tree height and crown height when the stem diameter was taken as predictor variable than crown diameter.**

**Key words:** Stem diameter, tree height, correlation, regression, *Parkia biglobosa*, Nigerian Guinea Savanna.

## INTRODUCTION

*Parkia biglobosa* (Jacq.) Benth. belongs to the family Leguminosae and the subfamily Mimosoideae. The tree plays a vital ecological role in cycling of nutrients from deep soils, by holding the soil particles to prevent soil erosion with the aid of roots (Alabi et al., 2005). Soils under *P. biglobosa* trees are improved by leaf fall. It is common practice to grow several crops such as maize, cassava, yams, sorghum and millet under *P. biglobosa* canopy (Kiptot and Franzel, 2011). This tree is endangered and is facing a threat of extinction due to rapid and continued exploitation without replacement, and over harvest of forest resources as a result of ever-increasing human population and improper land practices that hampered their regeneration capacity (Odebiyi et al., 2004).

In general, trees show considerably variation and flexibility in their size of crowns, height and stem diameters. The size of a tree canopy and its height above the ground is significant to a tree in that it determines the total amount of light that the tree intercepts for photosynthesis. The tree stem size has its own adaptive significance to a tree. It must be strong enough to withstand the forces that act on it. These forces are the weight of the tree and the drag exerted on it by the wind (Arzai and Aliyu, 2010). Growth and yield of trees are modeled using stem diameter-at-breast height relationships with tree height, crown height, and crown diameter (Paula et al., 2001).

The crown is the center of physiological activity, particularly gas exchange, which drives growth and development. Tree crowns also directly influence fire susceptibility, physical stability, and microclimate (Aaron, 2003). Among the major aspects of crown morphology, crown ratio, (defined as the ratio of crown diameter to tree height) is considered as one of the most important, since it strongly influences light interception and growth (Tanka, 2006). Crown ratio can also serve as a good indicator of the growth potential of individual trees, as an index of carbohydrate balance (that is, ratio of photosynthesizing tissue to aboveground respiring tissue). Also, crown ratio is a useful indicator of tree vigor, wood quality, stand density, competition and survival potential, wind firmness, and is a feature of interest in management and can be an important habitat variable (Hailemariam et al., 2005). Tree crown parameters have been used as predictor variables in diameter and height growth equations. Tree crown ratio can be predicted directly from tree variables such as total height and stem diameter at the breast height (Tanka, 2006).

Stem diameter at breast height is an important tree characteristics and an accurate prediction of tree dimensions. It has become prominent as analysis techniques, models, and other statistical tools to allow for the rapid evaluation of extensive volumes of data (Turan, 2009). Total tree height, crown ratio and crown diameter could be estimated by means of stem diameter, which is easy to measure for the studies in ground-based forest inventory and stand structure determination (Turan, 2009).

The relationship between stem diameter at the breast height and the total tree height is fundamental for developing growth and yield models for forest stands. Height and stem diameter are needed to estimate timber volume, site index, and in forest growth and yield models (Tanka, 2006).Tree height-diameter equations are required by forest resource managers to obtain accurate yield estimations. These estimates are used for decision making processes in forest management. When actual height measurements are not available, height-diameter functions can also be used to predict height growth indirectly (Tanka, 2006).

Height-diameter relationships of a given species depend on local environmental conditions and vary within a geographic region. The local environmental conditions (for example, climate, soil and vegetation type) play a significant role in affecting the height-diameter relationships. There are distinct variations in height-diameter relationships for trees in different ecological regions (Tanka, 2006).The modeling of air pollution uptake, rainfall interception, and microclimate modification associated with trees depends on data relating crown height and crown diameter to stem diameter (Paula et al., 2001). Such information is lacking for most of the common Nigerian savanna tree species. The development of equations to predict tree height, crown diameter, crown height from stem diameter of a tree species will enable arborists, researchers, and urban forest managers to model costs and benefits, analyze alternative management scenarios, and determine the best management practices for sustainable forests (Paula et al., 2001). The objective of this study was to develop regression prediction models for tree height, crown diameter, crown ratio and crown height from stem diameter and crown diameter for *P. biglobosa* growing in the Nigerian guinea savanna.

## MATERIALS AND METHODS

This study was conducted in the Yelwa campus of Abubakar Tafawa Balewa University, Bauchi. Bauchi is located between latitude 10°74'N and 9°47'E and situated at 690.3 m above sea level in the northern guinea savanna ecological zone of Nigeria. The soils are generally classified as Altisols (Amba et al., 2011). Situated in the Northern Guinea Savanna ecological zone, Bauchi receives annual rainfall of about 882 mm, and has 7 months (October to April) of dry season, With the diurnal temperatures averaging from 31.6°C maximum to 13.1°C minimum (Hassan, 2010).

The tree species used in this study was *P. biglobosa.* It was identified at Abubakar Tafawa Balewa University herbarium. Ten individuals of this tree species were selected at random for this study. Individual trees of different sizes were included. These were based on the visual estimate. The following variables of the selected trees were measured: crown height, crown diameter, and stem diameter at the breast height. All measurements were taken in meters using measuring tape except the total tree height where clinometers were included. Total tree heights were measured using INVICTA® clinometers (INVICTA Plastics ltd, 200 5th avenue, New York, USA). To measure the total height, the peak of the tree was pointed with the clinometers at certain distance from the tree (where the top was visible), and then the reading of the angle on the clinometers and the distance of the tree base to the operator (measured with the measuring tape) were recorded. The calculations were as described by Watson et al. (2011). The calculation was as follows:

Tree height = distance from the tree × tangent of the angle + operator's height at eye level (= 1.72 m).

The distance between the ground level and the base of the live crown was also measured by raising the tip of the measuring tape with a meter rule to the base of the first branch of the tree. Crown height was estimated as the total height minus the distance from the ground level to the base of the live crown. As tree crown may not form a perfect cycle, the crown diameter was estimated by taking the average measurements of the longest and the shortest diameters of the crown zone. Crown ratio was estimated as the crown diameter divided by total tree height. Stem diameter (D) at breast height at the standard of 1.37 m above ground level (Nature Conservation Practice Note, 2006, Ngomanda et al., 2012), was taken by measuring the circumference (C) of the stem. The stem diameter was calculated as follows:

$$C = D \times \pi.$$

$$D = \frac{C}{\pi.}$$

where $\pi = \frac{22}{7}$

The Pearson's Correlations and Simple Linear Regression analyses (were carried out on the raw data using the statistical software Minitab 11.

**Table 1.** Summary of descriptive statistics of the data used in regression and correlation analyses.

| Variable | N | Mean | Median | Standard deviation | S.E. of the mean | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| Stem diameter | 10 | 0.68 | 0.65 | 0.19 | 0.06 | 10.47 | 1.08 |
| Tree height | 10 | 14.81 | 14.51 | 2.72 | 0.86 | 10.46 | 19.20 |
| Crown diameter | 10 | 16.32 | 15.15 | 3.83 | 1.21 | 12.40 | 24.00 |
| Crown height | 10 | 11.63 | 11.22 | 2.90 | 0.92 | 7.81 | 15.90 |
| Crown ratio | 10 | 1.11 | 1.05 | 0.20 | 0.06 | 0.88 | 1.49 |

**Table 2.** Regression prediction model, Pearson correlations coefficient (r) and correlation coefficient of determination ($r^2$) of the different tree dimensions.

| Variable | F-value | Prediction model | r | r2 |
|---|---|---|---|---|
| Stem diameter vs. tree height | 16.99* | Y = 6.64 + 12.0x | 0.825* | 0.680 (68%) |
| Stem diameter vs. crown diameter | 26.33* | Y = 4.10 + 17.9x | 0.846* | 0.767 (76%) |
| Stem diameter vs. crown height | 20.15* | Y = 2.67 + 13.1x | 0.846* | 0.715 (71%) |
| Crown diameter vs. tree height | 9.03* | Y = 6.37 + 0.517x | 0.728* | 0. 529 (52%) |
| Crown diameter vs. crown height | 12.15* | Y = 2.02 + 0.589x | 0.776* | 0. 602 (60%) |

The correlation r-values with * are significant at P = 0.05. The regression F-values with * are significant at P = 0.05. In No. 1, 2 and 3, X = stem diameter (the predictor variable). In No. 5 and 6, X = crown diameter (the predictor variable)

## RESULTS

The descriptive statistics summary of the raw data is presented in Table 1. The minimum and maximum stem diameter recorded in this study was 0.47 and 1.08 m respectively. The mean of the ten (10) trees of the stem diameter was 0.68 m. The minimum and maximum crown diameters were 12.40 and 24.00 m respectively, with the mean of 16.32 m from the ten trees. Stem diameter and crown diameters were the predictor variables used in the regression analysis. In the savanna, these variables are easier to be measured than other variables.

The result also revealed positive correlations between stem diameter, tree height, crown height and crown diameter which are significant (Table 2). The corresponding F-values from Analyses of variance were also significant (P=0.05), except for stem diameter with crown ratio, which show no relationship. The correlation is insignificant between the stem diameter and crown ratio. Here the $r^2$ value is 0.036. The values of Pearson correlation coefficients (r) between the stem diameter and tree height, crown height and crown diameter are respectively 0.825, 0.846 and 0.846. The corresponding coefficients of determination ($r^2$) are respectively 0.680, 0.715 and 0.767. This implies that 68% of tree height, 71% of crown diameter and 76% of crown height were accounted for by the stem diameter.

Taking the crown diameter as a predictor variable, there are also positive correlations with tree height and crown height. Here the r- values are 0.728 and 0.776 and the $r^2$- values are 0.529 and 0.602 respectively. These show that stronger correlations were found with tree height and crown height when the stem diameter was taken as predictor variable than crown diameter. Various prediction models for tree height, crown height and crown diameter by stem diameter are presented in Table 2, except for crown ratio which shows no relationship with stem diameter. The prediction models for tree height and crown height with crown diameter as predictor variable are also presented.

Graphs of the relationships between stem diameter and tree height, crown diameter and crown height show positive relationships (Figures 1 to 3). With crown diameter as predictor variable there is also a positive correlation with tree height and crown height (Figures 4 and 5).

## DISCUSSION

Study of the relationships of stem diameter as an independent variable against tree height, crown height and crown diameter of *P. biglobosa* revealed significant positive correlations. The coefficient of determination ($r^2$) in the correlation between stem diameter and tree height is 0.680 (Table 2). This implies that 68% of the variation in tree height in the 10 sampled trees is accounted for by variation in the diameter of the stem. There is also a positive and significant correlation between the stem diameter and the crown height. Here the $r^2$ value is 0.715. The $r^2$ value between stem diameter and crown diameter is 0.767. The correlation is insignificant between the stem diameter and crown ratio, where the $r^2$ value is 0.036. Greater correlations were found with stem diameter as

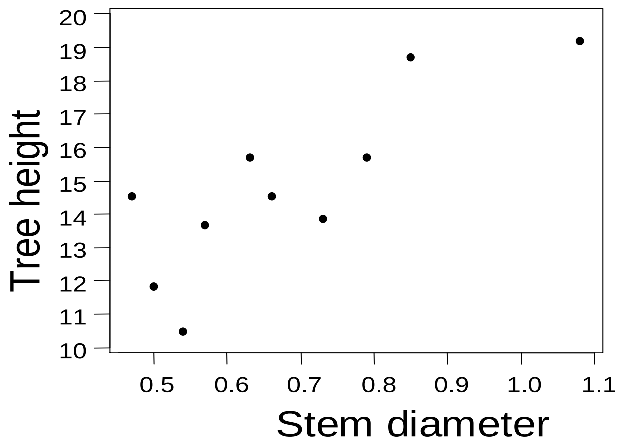


**Figure 1.** Scatter graph of the relationship between stem diameter vs. tree height.

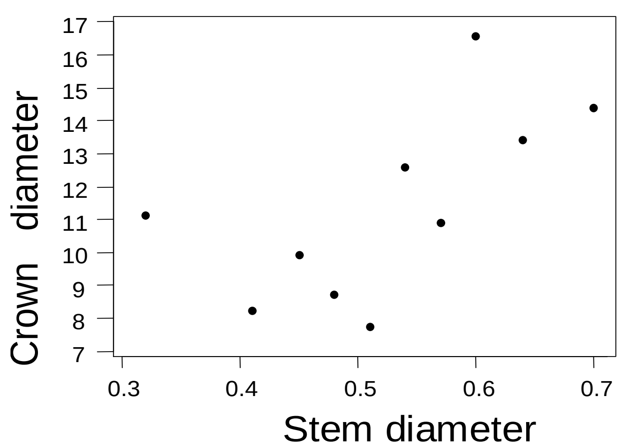


**Figure 2.** Scatter graph of the relationship between stem diameter vs. crown diameter.

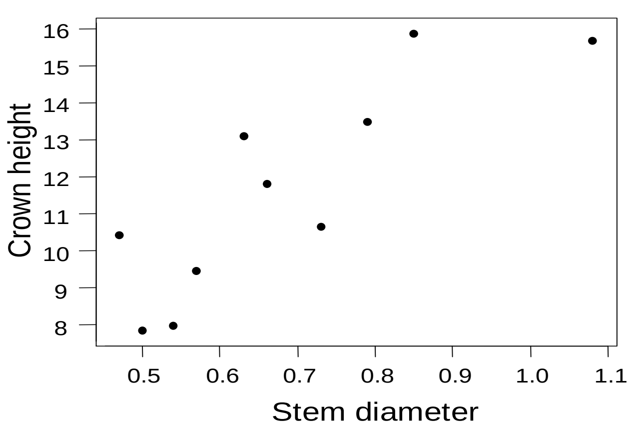


**Figure 3.** Scatter graph of the relationship between stem diameter vs. crown height.

predictor variable against tree height, crown diameter and crown height. There are also positive correlations between

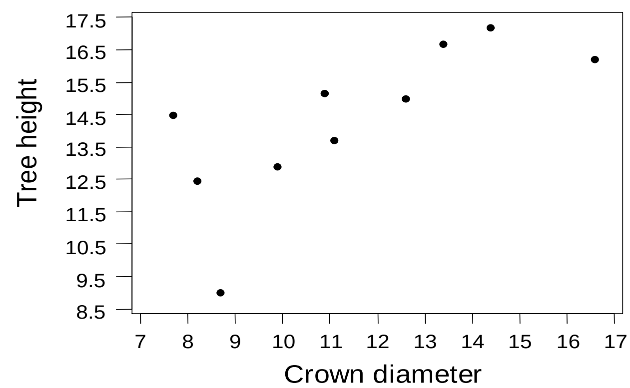


**Figure 4.** Scatter graph of the relationship between Crown diameter vs. Tree height.

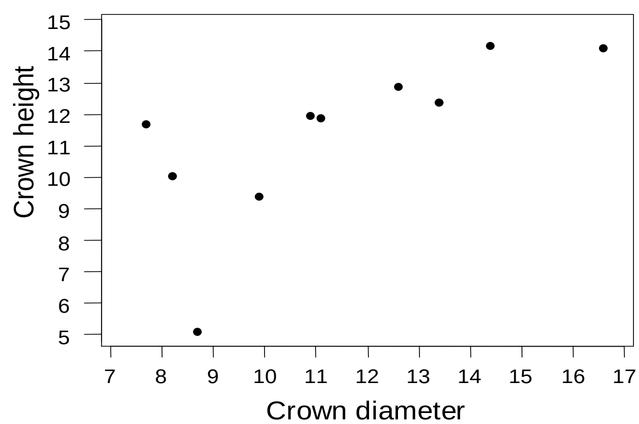


**Figure 5**. Scatter graph of the relationship between Crown diameter vs. Crown height.

the crown diameter as a predictor variable against tree height and crown height, with $r^2$ values of 0.529 and 0.602, respectively. When compared to crown diameter, taking the stem diameter as a predictor variable to predict tree height and crow height will yield greater accuracy due to the stronger correlation found in this relationship. By using the crown diameter as a predictor variable, crown height can be estimated using the prediction model because both the correlation and the F-value of the Analysis of Variance are significant.

In open savanna, where trees are scattered, the stem diameter and crown diameter are easier to measure than tree height or crown height. Therefore by taking the measurement of either the stem diameter or the crown diameter one can use the prediction model to estimate the tree height and crown height with relative ease.

Although the tree height and crown height can be estimated from crown diameter, using the stem diameter as the predictor variable will yield more precise estimate than using crown diameter. This is because the analyses show greater correlations between the stem diameter and other tree variables than between crown diameter and other dimensions of the tree. The crown ratio cannot be estimated from stem diameter because the correlation and the F-value of the analysis of variance are insignificant (Table 2). This is contrary to Tanka (2006) who said that crown ratio can be estimated from stem diameter.

Stoffberg et al. (2009), found strong correlation between stem diameter and crown diameter ($r^2 \geq 0.74$) but weaker Correlation for tree height and stem diameter ($r^2 \geq 0.63$), and stem diameter and crown height ($r^2 \geq 0.60$) of Combretum *spp* and two species of Searsia. Osunkoya et al. (2007), in the other hand found a strong but negative correlation between crown diameter and tree height in rainforest trees of Brunei. Most of eight *Cecropia* species in Amazonian and southeastern forests of Brazil investigated by Sposito and Santos (2001) did not vary in diameter–height and crown–height relationships. Generally, O'Brien et al. (1995), suggested that “if the primary adaptive forces acting on tree species in a diverse forest are their physical environment and the sum of competitive interactions with an ever—changing mix of neighbors, then different species may have similar resource allocation patterns”. This may lead to allometric variation within the same species from different environment or similar allometry between different species growing in the same environment.

## Conclusion

Allometry study of *P. biglobosa* revealed positive correlations between stem diameter, tree height, crown diameter and crown height. But there is no correlation between the stem diameter and crown ratio. Positive correlations were also found between crown diameter, tree height and crown height. Prediction models derived from these relationships can be used to estimate the tree height, crown diameter and crown height from stem diameter with greater precision. Estimating the tree height and crown height from crown diameter will yield result with less accuracy because of the weaker correlations.

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