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Relationships between stem diameter at breast height (DBH), tree height, crown length, and crown ratio of *Vitellaria paradoxa* C.F. Gaertn in the Nigerian Guinea Savanna

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Trees show considerable variation and flexibility in their size of crowns, height and stem diameter at breast height (dbh). Dbh has been used as predictor variables in diameter and height growth equations. Relationships between dbh, tree height, crown length, crown height and crown ratio of *Vitellaria paradoxa* were investigated and regression prediction models were derived. Dbh, as a predictor variable, was positively correlated with tree height and crown length (*F*0.05 (1), 8). The correlation coefficients of determination (r^2) were 0.447 and 0.399, respectively. The dbh has no correlation with crown height and crown ratio. Here the r^2 were 0.241 and 0.051, respectively. Stronger correlation was observed when crown length, as a predictor variable, was used against tree height and crown height. The r^2 values were 0.522 and 0.497, respectively. Hence, regression prediction models derived from this study suggests that the use of crown length as predictor variable is more accurate than the use of dbh in estimating tree height and crown height.

Key words: Stem diameter, tree height, correlation, regression, *Butyrospermum paradoxum*, clinometers, minitab.

INTRODUCTION

Trees show considerably variation and flexibility in their size of crowns, height and diameter-at-breast. The size of a tree canopy and its height above the ground is significant to the 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 are modeled using stem diameter at breast height (dbh) relationships with tree height, crown height, and crown length (Paula et al., 2001). Crown size is an important factor for tree growth which determines the amount of solar radiation intercepted by a tree (Tanka, 2006). Stem dbh is also 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 height, crown ratio and crown length could be estimated by means of stem dbh, which is easy to measure for the studies in ground-based forest inventory and stand structure determination (Turan, 2009).

Vitellaria paradoxa C.F. Gaertn (also known as Shea tree) is member of the Family *Sapotaceae* (Metafro 2011). *V. paradoxa* is a tree of great socio-economic importance for

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the people in parts of West Africa, especially in rural areas (Djossa et al., 2008). It contributes greatly to reduction of rural poverty, hunger and disease and enhancing environmental sustainability (Ugese et al., 2010). It is a valuable commodity in local, national and international markets, making it the ideal candidate to research and invest into (Moore, 2008). The butter is used in the food, pharmaceutical and cosmetic industries (Aculey et al., 2012) and traditional medicine in many rural areas (Okullo et al., 2010).

Shea-nut cake is increasingly used as fodder for livestock and poultry feed. The wood is excellent-quality firewood. Timber from this tree is strong, hard, heavy, durable and resilient. Latex can also be extracted from shea tree for making glue. The shea butter has great medicinal values (Orwa, 2009). It is used to relieve pains and heals wounds, swellings, and other skin problems (Nikiema and Umali, 2007).

The objective of this study is to find the relationships and develop regression prediction models for tree height, crown length, crown ratio and crown height from stem dbh and crown length for *V. paradoxa* growing in the Nigerian guinea savanna. This is because crown length and dbh are easier to measure in the savanna than other variables. The development of equations to predict tree height, crown length, crown height from stem dbh 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). Hence modeling the growth dimentions of *V. paradoxa* will help in its conservation.

MATERIALS AND METHODS

The study was conducted in the Yelwa campus of Abubakar Tafawa Balewa University, Bauchi. The topography of the study area ranges from flat to gently sloping land. The area is used for cultivation and animal grazing. 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). The rainfall in Bauchi starts in April and ends in October with the highest record amount of 1300 mm per annum (Haruna, 2003).

The tree species used in this study was *V. paradoxa.* It was identified from high resolution images at the West African Plants Data Base web site (http://www.westafricanplants.senckenberg.de/root/index.php). Ten (10) individuals of this tree species were selected for the study (there was no sign of pruning on the trees in this area). To measure the sizes of their different dimensions, the following variables of the selected trees were measured: total height, crown height, crown length, and stem dbh. All measurements were taken in meters using measuring tape. 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 clinometer at certain distance from the tree, and then the reading of the angle on the clinometer and the distance of the tree base to the operator were recorded. The calculations were as described by Farm Forest Line, 2012. The calculation was as follows: Tree height = distance from the tree × tangent of the angle + operator's height at eye level (= 1.72 m).

Crown height was estimated as the total height minus the distance from the ground level to the base of the live crown, that is, lowest green leaves. As tree crown may not form a perfect circle, the crown length 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 length divided by total tree height. Stem dbh (D) (that is, 1.37 m above ground level) was taken by measuring the circumference (C) of the stem. The stem dbh was calculated as follows:

$C = D \times \pi.$

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

The Pearson's correlations and regression analyses and the analysis of variance were carried out on the raw data using the statistical software Minitab 11© 1996.

RESULTS AND DISCUSSION

The descriptive statistics summary of the raw data is presented in Table 1. The minimum and maximum stem diameter recoded in this study was 0.32 and 0.70 m, respectively. The mean of the 10 samples of the stem diameter is 0.52 m. According to Metafro (2011), stem dbh of *V. paradoxa* ranges from 0.3 to 1 m and the mean is 0.6 m. The minimum and maximum crown lengths were 7.70 and 16.60 m, respectively, with the mean of 11.36 m from the 10 samples. Stem dbh and crown lengths were the predictor variables used in the regression analysis.

Graphs indicate positive correlations between the stem dbh and crown length as independent variables with other dimensions of the tree as response variables, except for stem diameter with crown height and crown ratio. The presence of the outliers may be due to microhabitat variations of the individual trees (Figures 1, 2, 3, 4, 5 and 6). With stem dbh as the predictor variable, Pearson's correlation coefficient was significant with the dbh against tree height and crown length (*F*0.05 (1), 8) but not significant against crown height and crown ratio (Table 2). These results are also the same as the F-values from the analysis of variance. With the crown length as the predictor variable, greater correlations was found with crown length against tree height and crown height. This is also suggested by the coefficient of determinations as it can be seen from the Table 2. All significant correlations were positive.

Study of the relationships dbh as an independent variable against tree height and crown length of *V. paradoxa* revealed positive correlations. The coefficient of determination (r^2) in the correlation between dbh and tree height is 44% (Table 2). This means that 44% of the variations in tree heights in the 10 sampled trees were accounted for by variation in the diameter of their stems. The r^2 value between dbh and crown length is 39%. The correlations are not significant (*F*0.05 (1), 8) with the dbh against crown height and crown ratio. Here the r^2 values are

Table 1. Descriptive statistics summary of the data entered for the regression and correlation analyses.

Variable	N	Mean	Median	Tr mean	StDev	SE mean
Stem dbh	10	0.5220	0.5250	0.5250	0.1129	0.0357
Tree height	10	14.271	14.730	14.569	2.436	0.770
Crown diameter	10	11.350	11.000	11.150	2.892	0.914
Crown height	10	11.362	11.930	11.794	2.688	0.850
Crown ratio	10	0.7830	0.8050	0.7850	0.1601	0.0506
Variable	Min	Max	Q1	Q3		
Stem dbh	0.3200	0.7000	0.4400	0.6100		
Tree height	8.960	17.200	12.770	16.333		
Crown length	7.700	16.600	8.575	13.650		
Crown height	5.070	14.200	9.875	13.195		
Crown ratio	0.5300	1.0200	0.6725	0.8725		

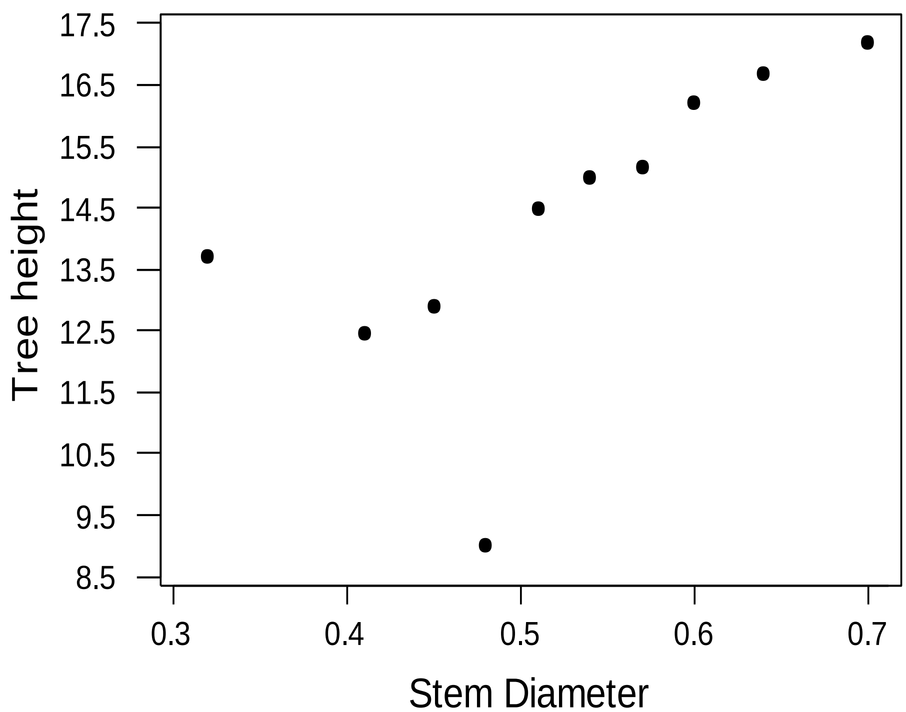

Figure 1. Graph of the relationship between stem dbh vs tree height.

Table 2. Regression prediction model, Pearson's Correlations coefficient (r), correlation coefficient of determination (r^2) and F-values of the Analysis of Variance of the different tree variables.

Tree variable	F-value	Prediction model	r	r^2
Stem dbh vs. tree height	6.48*	Y = 6.74 + 14.4x	0.669*	0.447 (44%)
Stem dbh vs. crown length	5.33*	Y = 2.90 + 16.2x	0.632*	0.399 (39%)
Stem diameter vs. crown height	2.54		0.491	0.241 (24%)
Stem dbh vs crown ratio	0.43		0.226	0.051 (5%)
Crown diameter vs. tree height	8.78*	Y = 7.35 + 0.609x	0.723*	0.522 (52%)
Crown diameter vs. Crown height	7.90*	Y = 3.93 + 0.655x	0.705*	0.497 (49%)

The correlation r-values with asterisk (*) are significant at *F*0.05 (1), 8. In No. 1, and 2, X = stem dbh (the predictor variable). In No. 5, and 6, X = crown length (the predictor variable).

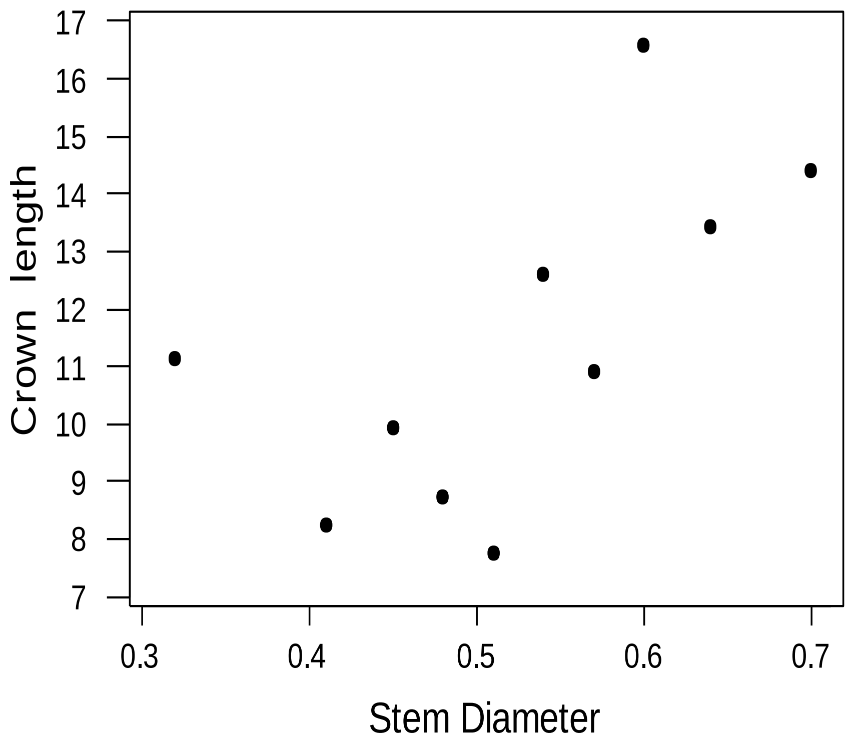

Figure 2. Graph of the relationship between stem dbh vs. crown crown length.

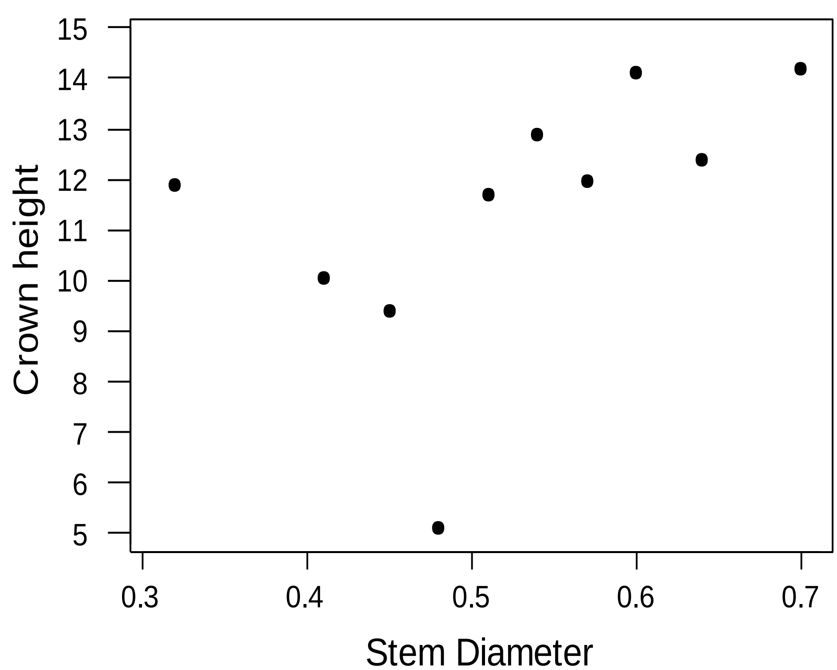

Figure 3. Graph of the relationship between stem dbh vs. crown height.

24 and 5%, respectively. Greater correlations were found with crown length as predictor variable against tree height and crown height. The r^2 values are 52 and 49%, respectively.

The regression prediction models are also presented in Table 2. The reason for taking the dbh and crown length as predictor variables is because they are easy to measure in contrast to tree height and crown height (measuring

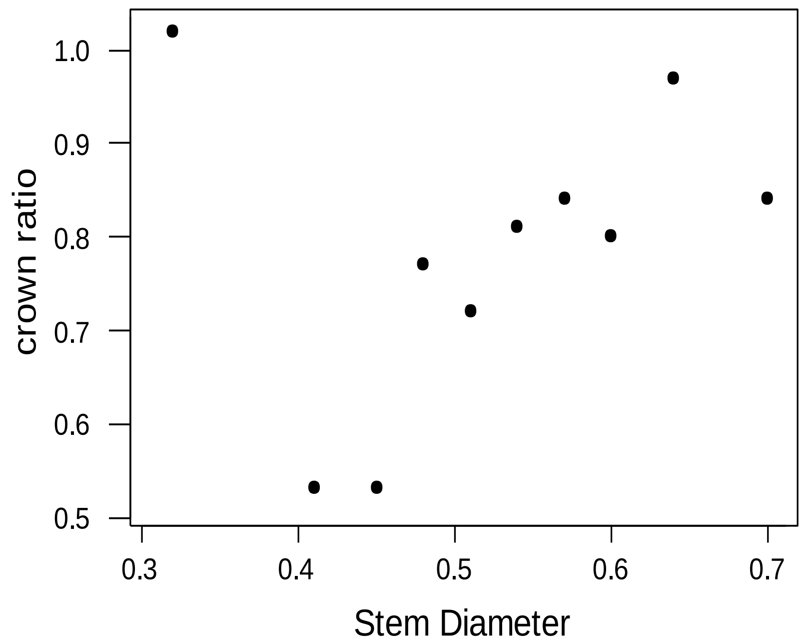

Figure 4. Graph of the relationship between stem dbh vs. crown ratio.

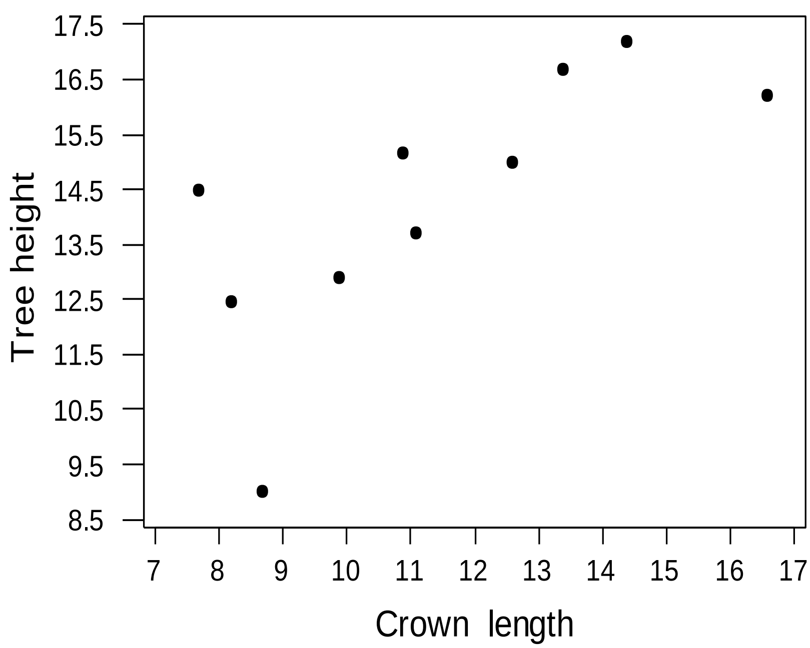

Figure 5. Graph of the relationship between crown crown length vs. tree height.

crown length may be more difficult in a dense stand). Therefore by taking the measurement of either the dbh or the crown length, one can use the prediction model to estimate the tree height and crown height. Although the tree height, crown length and crown height can be estimated from dbh as the predictor variable more accurate estimate will be found by using crown length as the predictor variable. This is because the analyses show that there are greater correlations between the crown length and other variables than between dbh and other dimensions of the tree. The tree crown height and crown ratio cannot be estimated from dbh because both the correlation and the F-value are not significant (Table 2). This is contrary to Tanka (2006) who stated that crown ratio can

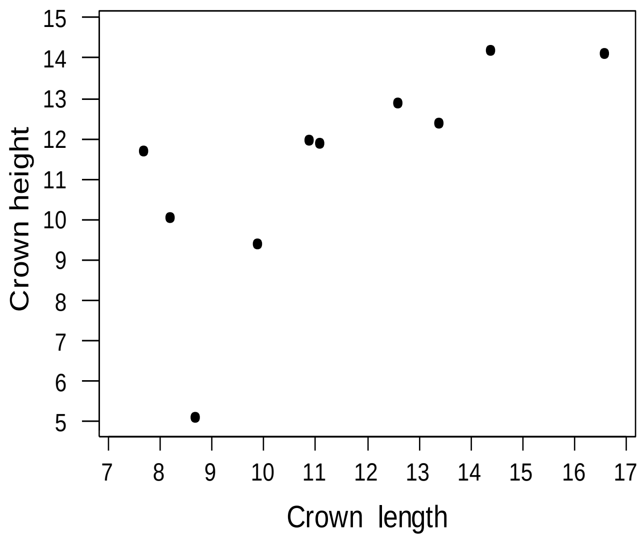

Figure 6. Graph of the relationship between crown crown length vs. crown height.

be estimated from stem dbh, unless crown ratio is defined in different ways. By using the crown length as a predictor variable, crown height can be estimated using the prediction model with greater precision because both the correlation and F-values of the analysis of variance are significant.

Conclusions

Allometry study of *V. paradoxa* revealed positive correlations between stem dbh, tree height and crown length, but there are no correlations between the dbh, crown height and crown ratio. Stronger correlations were found between crown length, tree height and crown height. Prediction models derived from these relationships can be used to estimate the tree height, crown length and crown height from dbh. Although, estimating the tree height and crown height from crown length will be more precise because there are stronger correlations. One should be cautious when applying the result of this study somewhere else as plants show plasticity due to climatic and soil variability.

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