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Allometric prediction models of growth variables of *Daniella oliveri* in the Nigerian Guinea Savanna

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Trees show considerable variation and flexibility in their size of crowns, height, stem diameters, crown height and crown length. Stem diameter at breast height is an important tree characteristics and an accurate prediction of tree growth dimensions. Relationships between stem diameter and crown length with other variables of *Daniella oliveri* was studied. The result reveal positive correlations between stem diameter, tree height, crown height and crown length which were all significant at *F*0.05 (1), 8. 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 values of Pearson correlation coefficients (r) between the stem diameter, tree height, crown height and crown length were 0.693, 0.693 and 0.733 respectively. The coefficients of determination (r^2) were 0.480, 0.617 and 0.537 also respectively. Taking the crown length as a predictor variable, there were also positive correlations with tree height and crown height. Here the r-values were 0.679 and 0.698 respectively and the r^2-values were 0.461 and 0.487 also respectively. These means that stronger correlations were found with tree height and crown height when the stem diameter was taken as predictor variable than crown length.

Key words: Toma Buba, Bauchi, stem diameter, tree height, correlation, regression, *Daniella oliveri,* clinometers, minitab.

INTRODUCTION

Daniella oliveri (Caesalpiniacea) is a plant found in the Amazon region and other parts of South America and Africa. The tree may reach a height of 100 feet and trunk diameter of 4 feet.

Trees generally 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 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 influence fire susceptibility, physical stability, and microclimate (Aaron, 2003).

Crown size is an important factor for tree growth which determines the amount of solar radiation intercepted by a tree. The total amount of solar radiation intercepted by individual trees is used as one of the most important inputs in the physiological process based on tree growth models (Tanka, 2006). Therefore it is important to model tree crown size to predict the total amount of radiation intercepted and hence the growth of the tree. Among the major aspects of crown morphology, crown ratio, (defined

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as the ratio of crown length 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). Low values of crown ratio are likely to be associated with low leaf areas and possibly variation in foliage distribution within the crown (Tanka, 2006). 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 of 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 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 (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. Significant differences in height-diameter relationship were found between 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 *Daniella oliveri* growing in the Nigerian guinea savanna.

MATERIALS AND METHODS

The 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 (Figure 1). The soils are generally classified as Altisols (Amba et al., 2011). The wet season lasts for about five months (May to September) and the dry season (October to April). The annual rainfall ranges from 1,000 - 1,300 mm. The hottest months are April and May, with maximum temperature of 40.56ºC while the coldest months are usually December and January with minimum temperatures of 6.11and 22ºC, respectively (Haruna et al., 2012).

The tree species used in this study was *Daniella oliveri.* It was identified at the herbarium of Abubakar Tafawa Balewa University, Bauchi. Ten individuals of this tree species were selected for the study. The biggest, smallest and the medium in size were all included. To measure the sizes of their different dimensions, the following variables of the selected trees were measured: tree total height, crown height, crown diameter (the width or length of crown), and stem diameter at the breast height. 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 clinometers and the distance of the tree base to the operator were recorded. The calculations were as described by Jibrin (2013). 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. 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 (1.37 m above ground level) 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 Regression analyses were carried out on the raw data using the statistical software Minitab 11© 1996.

RESULTS

Stem diameter and crown length were the predictor variables used in this study. The maximum and minimum stem diameters were 0.54 and 0.95 m respectively. The

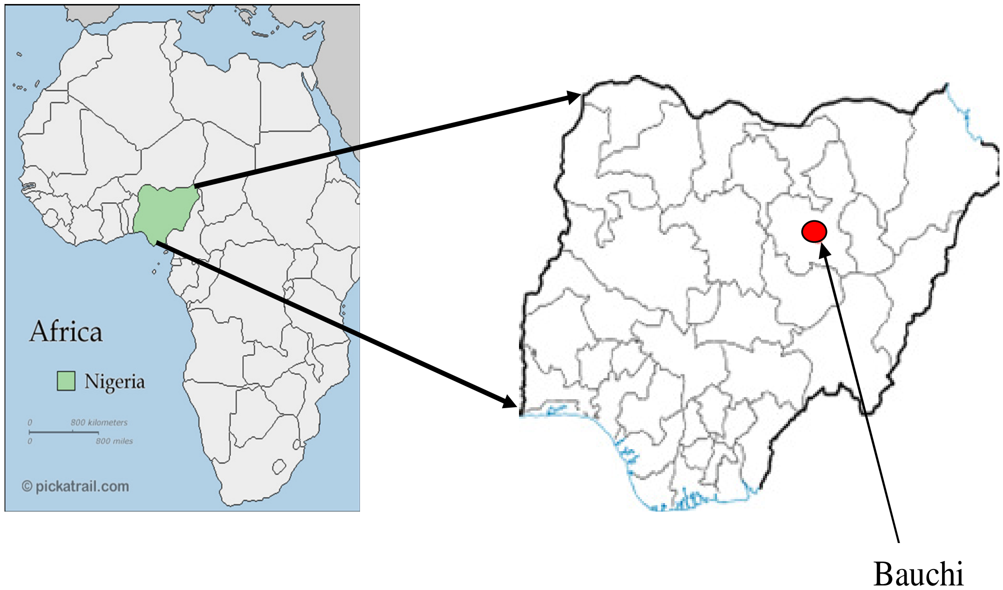

Figure 1. Location of the study area on map.

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

Variable	N	Mean	Median	Tr Mean	StDev	SE Mean
Stem Diameter	10	0.7040	0.7000	0.6938	0.1290	0.0408
Tree height	10	19.34	18.15	18.58	4.39	1.39
Crown Diameter	10	15.960	15.150	15.875	3.019	0.955
Crown height	10	15.53	14.39	14.94	4.05	1.28
Crown ratio	10	0.8390	0.8300	0.8338	0.1485	0.0470
Variable	**Min**	**Max**	**Q1**	**Q3**		
Stem Diameter	0.5400	0.9500	0.6000	0.7850		
Tree height	14.47	30.26	16.80	21.10		
Crown Diameter	11.100	21.500	14.025	18.175		
Crown height	10.87	24.96	13.06	17.55		
Crown ratio	0.6600	1.0600	0.6975	0.9800		

mean was 0.7 m. The crown diameter had the minimum and maximum values of 11.1 and 21.5 m respectively, and the mean is 15.9 m. The descriptive statistical summary of the study is presented in Table 1.

Graphs of the relationships between stem diameter and tree height, crown diameter and crown height show positive relationships (Figures 2, 3, and 4). There was no relationship between the stem diameter and crown ratio (Figure 5). With crown diameter as predictor variable, there was also a positive correlations with tree height and crown height (Figures 6 and 7).

The results also reveal positive correlations between stem diameter, tree height, crown height and crown diameter which were significant at *F*0.05 (1), (Table 2). The corresponding F-values from Analyses of variance were also significant (*P*=0.05), except for stem diameter with crown ratio, which showed no relationship. The values of Pearson correlation coefficients (r) between the stem diameter, tree height, crown height and crown diameter were 0.693, 0.693 and 0.733 respectively. The corresponding values of the coefficients of determination (r^2) were 0.480, 0.617 and 0.537 also respectively. This means that 48% of tree height, 61% of crown diameter and 53% of crown height were accounted for by the stem diameter. Taking the crown diameter as a predictor variable, there were positive correlations with tree height and crown height. Here, the r- values were 0.679 and 0.698 respectively and the r^2- values were 0.461 and 0.487 also respectively. These means that stronger correlations were found with tree height and crown height

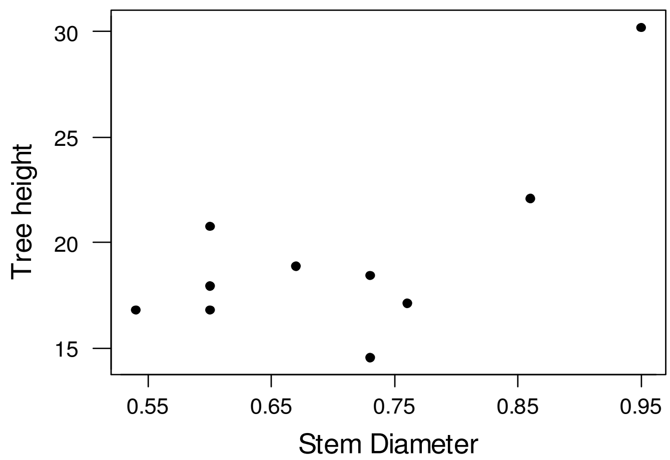

Figure 2. Relationship between stem diameter versus tree height.

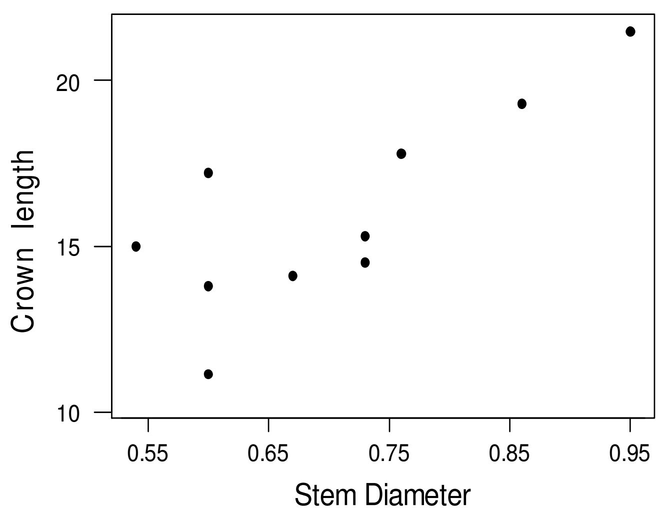

Figure 3. Relationship between stem diameter versus crown diameter.

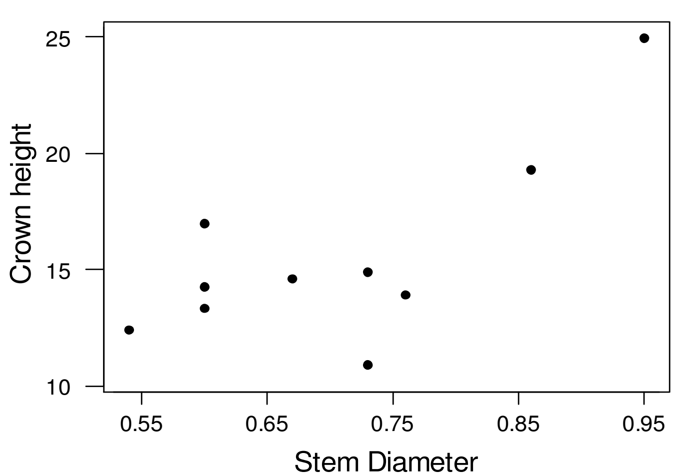

Figure 4. Relationship between stem diameter versus crown height.

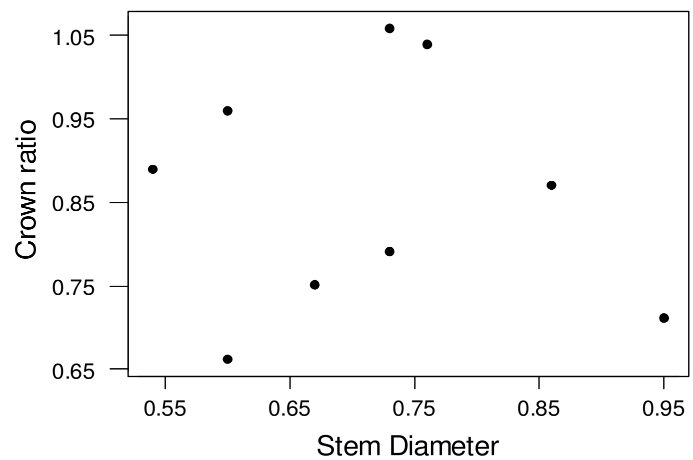

Figure 5. Relationship between stem diameter versus crown ratio.

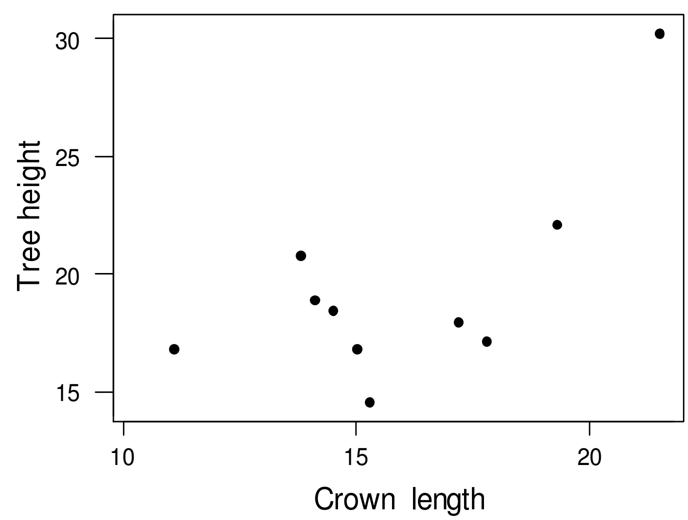

Figure 6. Relationship between crown diameter versus tree height.

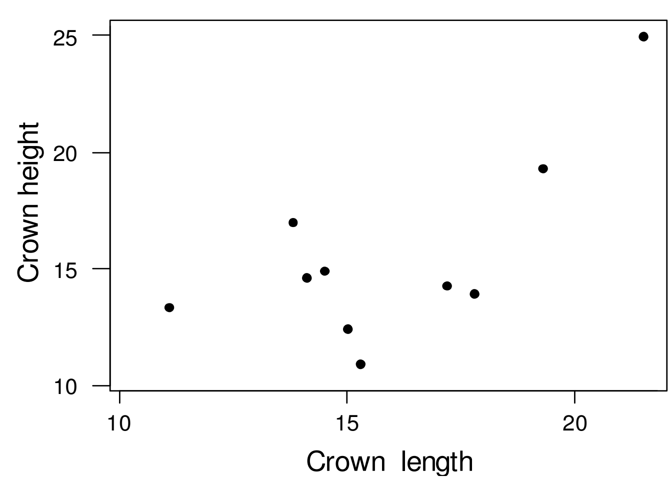

Figure 7. Relationship between crown diameter versus crown height.

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

S/N	Tree variable	F-value	Prediction model	r	r^2
1	Stem diameter vs tree height	7.39*	Y = 2.73 + 23.6x	0.693*	0.480 (48%)
2	Stem diameter vs crown diameter	12.89*	Y = 3.02 + 18.4x	0.786*	0.617 (61%)
3	Stem diameter vs crown height	9.27*	Y = - 0.65 + 23.0x	0.733*	0.537 (53%)
4	Stem diameter vs crown ratio	0.02		0.047	0.002 (00%)
5	Crown diameter vs tree height	6.83*	Y = 3.57 + 0.988x	0.679*	0.461 (46%)
6	Crown diameter vs Crown height	7.61*	Y = 0.59 + 0.936x	0.698*	0.487 (48%)

The correlation r-values with asterisk (*) are significant at F0.05 (1), 8**;** The regression F-values with asterisk (*) are significant at F0.05 (1), 1, 8**;** In no. 1, and 2, X = stem diameter (the predictor variable). In no. 5 and 6, X = Crown length (the predictor variable).

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 showed no relationship with stem diameter. The prediction models for tree height and crown height by crown diameter are also presented.

DISCUSSION

The maximum and minimum stem diameters of *D. oliveri* growing in the Nigerian guinea savanna were 0.54 and 0.95 m respectively. The mean was 0.7m. The crown diameter had the minimum and maximum values of 11.1 and 21.5 m respectively, and the mean was 15.9 m. Study of the relationship between stem diameter, tree height and crown diameter revealed positive correlations. Such relationships were also recorded for some young urban trees by (Troxela et al., 2013). This work did not found any correlation between the stem diameter and crown ratio. There were also positive correlations between crown diameter, tree height and crown height. Stronger correlations were found by using the stem diameter as an independent variable than by using crown diameter. This was also found by Troxela et al. (2013) and El-Mamoun et al. (2013) who worked on some economic trees. But Ige et al. (2013) found DBH to be a weak estimator of other growth dimensions in *Gmelina arborea.*

Regression prediction models were derived for these relationships in the present study. These models can be used to estimate tree height, crown diameter and crown height from the stem diameter. Also, tree height and crown height can be estimated from crown diameter. The use of these prediction models with stem diameter as predictor variable will yield more accurate estimate of tree height and crown height than the use of the prediction models with crown diameter as predictor variable. This is because of the stronger correlations of these tree variables found with stem diameter than with crown diameter. Stem diameter cannot be used to estimate crown ratio as there is no correlation between them. However, the pattern of growth for individuals of the same tree species is not always constant as it can be affected by the biophysical factors in different localities (Troxela et al., 2013; Zhang et al., 2013). It is also suggested that a successful predictor model for a given species might not be fitted for other species growing even in the same locality under similar conditions (Urban et al., 2010). El-Mamoun et al., (2013) also suggests that different tree species that grows in the same locality may not be fitted to one allometric model that is each species should have its unique model. It can be suggested that more study on the allometric relationships in *D. oliveri* be conducted in different location and comparisons be made.

This will give the opportunity to ascertain the validity for general application of prediction models in *D. oliveri* and other tree species.

Conclusion

There were positive and significant correlations between stem diameter, tree height, crown height and crown diameter of *D. oliveri* growing in the Nigerian guinea savanna. No correlation was found between stem diameter and crown ratio. There were also significant correlations between crown diameter, tree height and crown height. Regression prediction models were derived for these relationships and can be used to estimate tree height, crown diameter and crown height from stem diameter. Also, tree height and crown height can be estimated from crown diameter. The use of these prediction models with stem diameter as predictor variable will yield more accurate estimate of tree height and crown height than the use of the prediction models with crown diameter as predictor variable. This is because of the stronger correlations of these tree variables found with stem diameter than with crown diameter.

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