INCORPORATING CROWN DIMENSIONS INTO STEM HEIGHT AND BASAL AREA GROWTH MODELS FOR AFRICAN WHITE WOOD *(TRIPLOCHITON SCLEROXYLON)*

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ABSTRACT

*Four crown dimensions (crown diameter, crown projection area, crown length and crown ratio) were each, incorporated into nonlinear individual tree total height and basal area increment models for African white wood (**Triplochiton scleroxylon K. Schum**). The basic height/basal area growth model was formulated as a function of the tree size (i.e. total height or basal area), age and tree form (i.e. taper which is the ratio of diameter at breast height to total height). These increment models, with and without crown dimension were fitted to a modelling data set and the statistical significance of each of the crown dimensions was examined. All the models were then compared for predictive ability using an independent validation data set. The results obtained were similar for both the total height and basal area increment models. All the crown dimensions except crown projection area were found to be significant in the basic models (i.e. models without crown dimensions) in terms of model fit. However, for predictive ability, increment models (for both total height and basal area) with crown ratio term were found to have the smallest bias and the greatest prediction precision of all the models examined both with and without crown dimension. Therefore, for tree total height and basal area prediction of African white wood, models with added crown ratio term were found to be most appropriate.*

Keywords: Crown dimension, growth and yield models, *Triplochiton scleroxylon,* African white wood

INTRODUCTION

Crown information is an important component of many growth and yield models. The growth of a tree depends to a large extent on the tree crown characteristics. An obvious advantage of using crown characteristics in growth and yield models stems from the fact that growth relationships exist between tree crowns and stem. The significance of crown size to tree growth has been documented. Hamilton (1969) and spurr and Barner (1980) pointed out that the crown size can determine tree's growth and survival. Smith (1986) showed that a tree's height and crown dimension determine the length of its clear bole, which is important in merchandizing of the tree into various wood products. Wykoff *et al* (1982) and Zhang *et al* (1996) demonstrated the usefulness of crown size in modelling of stem and stand dynamics through time. Short III and Burkhart (1992) and Valentine *et al* (1994) predicted crown height increment under thinned and unthinned loblolly pine stands. Leites and Robinsonn (2004) demonstrated that crown dimension can be used to improve taper equations.

The implications of integrating crown information into prediction models are numerous. Crown dimensions and development are affected by stocking level, spacing configuration, intensity, timing and method of thinning. Stem and stand characteristics are in turn affected by crown development. Quantifying the effects of various silvicultural treatments on crown development makes it possible to better understand and predict treatment effects on stem and stand characteristics.

African white wood (*Triplochiton scleroxylon* K. Schum) popularly called obeche or samba, is an important species commonly found in southwestern Nigeria. It is an excellent source of timber for export, readily available in both veneer and lumber form. Obeche is a large deciduous forest tree commonly attaining 45m in height and 1.5m in diameter (Howland & Bowen, 1977). It is found mainly in forest at low and medium altitudes in monsoon equatorial forest belt. High mean temperatures that vary relatively little throughout the year characterize this belt. The tree occurs naturally from Guinea to Democratic Republic of Congo and from Gabon to Nigeria. Throughout its natural range, there is always a marked dry period between December and April. Obeche normally occur in clusters of ten or more and isolated trees are very rare.

Tree crown dimensions and development have not been thoroughly investigated as a means to improve the predictive ability of individual tree and stand level growth models. Crown information is considered as a measure of stem vigour. It is envisaged that stem growth will be biologically realistic and more accurate with models that account for tree crown information than those that do not. The objectives of this study are to explore ways of incorporating crown information into individual tree based growth models, to compare the models with and without crown information and to determine which form has the greatest predictive ability for stem growth of *Triplochiton scleroxylon* in terms of height and basal area growth.

THE DATA

The data for this study were collected from the experimental stations of Forestry Research Institute of Nigeria (FRIN) in 2002. A total of 348 trees of obeche cutting across four different stands planted in 1958, 1968, 1972 and 1975 were assessed. The plantations lie between latitudes 6^{o} $05'$ and 7^{o} $50'$ N and longitudes 3^{o} $59'$ and 4^{o} $20'$ E and at a distance of between 4.5km and 6km from Cocoa Research Institute of Nigeria (CRIN), Idiayunre, Ibadan.

In the four available ages, the 1958 plantation belongs to Oyo State, while the other three are owned by FRIN. Six temporary sample plots of size 20m x 20m were randomly laid in each of the four stands. The following tree parameters were measured in each sample plot, diameter at breast height (dbh) over bark of all trees (m), diameters over bark at the base, middle and top of all the trees (m), total height, crown length and crown diameter (m) of all the trees. The girth-diameter tape was used for the measurement of dbh and diameter at the base of all the trees within each plot. The Spiegel relaskop and 30m linen tape were used for the measurement of total height, crown length and diameters at the middle and top of all the trees within each plot. The crown diameters were measured with two ranging poles and 30m linen tape using crown projection technique. This involved measuring the distance between edges of the crown in a north-south and east-west directions. The two values obtained were then averaged and the result taken as the crown diameter. Crown ratio was computed as the ratio of crown length to the total height. Crown projection area was computed as the square of crown diameter multiplied by a constant ($\pi/4$). Taper (a measure of tree form) was computed as the ratio of dbh to the total height as done by Short III and Burkhart (1992). The height and basal area increments are mean annual values computed as the ratios of height to age and basal area to age respectively. Roughly one third of the whole data set (i.e. 116 trees) was selected at random across the stand ages to provide a validation data set for determining the predictive ability of the growth models. The summary of the statistics of the raw data is presented in Table 1.

Table 1: Summary of the Statistics of the Raw Data

S/N	Variable	Mean	Minimum	Maximum	Standard deviation
1.	Total height increment (m/year)				
	Modelling data set	0.7164	0.1029	1.3824	0.2512
	Validation data set	0.7393	0.2000	1.3971	0.2464
2.	Basal area increment (m^2/year)				
	Modelling data set	0.0026	0.0001	0.0322	0.0031
	Validation data set	0.0030	0.0003	0.0204	0.0033
3.	Taper				
	Modelling data set	0.0125	0.0067	0.0279	0.0036
	Validation data set	0.0133	0.0047	0.0663	0.0069
4.	Crown diameter (m)				
	Modelling data set	6.2370	0.0000	19.3000	3.1691
	Validation data set	6.4391	1.4500	22.4000	3.2144
5.	Crown projection area (m^2)				
	Modelling data set	38.4064	0.0000	292.5530	41.9441
	Validation data set	40.6095	1.6513	394.0814	47.5576
6.	Crown length (m)				
	Modelling data set	17.7438	2.7500	38.0000	6.6087
	Validation data set	18.4216	2.2500	36.5000	7.2395
7.	Crown ratio				
	Modelling data set	0.7792	0.5714	0.9524	0.0726
	Validation data set	0.7962	0.1406	3.6667	0.3014

Number of stems: Modelling data set = 232; Validation data set = 116

Model Development

The model development was based on nonlinear individual tree growth models. The development of growth models was achieved in three stages:

a. Development of the basic growth models for total height and basal area increment.
b. Choice of individual tree crown attributes. The choice of crown attributes was made to cover both horizontal crown development and vertical measures of crown dimensions.
c. Incorporation of crown attributes to the basic growth models and assessment of the significance of the crown attributes inclusion.

Growth Models for Total Height and Basal Area Growth

Total height growth model

The basic height growth model was formulated as a function of the initial size, age and tree form. Thus the basic individual tree increment model formulated was:

$$\Delta HT = b_0 HT^{b_1} \exp(b_2 T + b_3 A) \text{.......} eqn\ 1$$

This model was preferred on the basis of its desirable properties from a biological standpoint for calibration of the total height increment. Where ΔHT is total height increment (m/year), HT is the tree total height (m), T is the tree taper and A is the tree age (years).

Basal area growth model

The basic basal area growth (ΔBA) model is similar to the total height growth model. The model is of the form:

$$Ln\Delta BA = b_0 BA^{b_1} \exp(b_2 T + b_3 A) \text{..} eqn2$$

The natural logarithm transformation (i.e. Ln) was introduced to the basal area increment data to ensure that the data conform to the basic assumption of the parametric test.

Tree Crown Attributes Used

Certain crown dimensions appear logical for improving the prediction of stem growth attributes since these dimensions indirectly reflect photosynthetic area or distance that photosynthetic substances must travel to other tree parts. Only crown variables that can be readily measured were investigated in this study. Hence, for horizontal crown development, crown diameter (CD) and crown projection area (CPA) were investigated. Vertical crown development investigated were crown length (CL) and crown ratio (CR).

Incorporating Crown Attributes into the Basic Growth Models

The chosen crown attributes were investigated one after the other by incorporating them into the basic growth models. The resulting growth models were:

(a) Height growth models with crown attributes

$$\Delta HT = b_0 HT^{b_1} \exp(b_2 T + b_3 A + b_4 CA) \text{...} eqn.3$$

Where, CA represents the crown attributes (i.e. CD, CPA, CL and CR) and the rest of the variables are as earlier defined.

(b) Basal area growth models with crown attributes

$$Ln\Delta BA = b_0 BA^{b_1} \exp(b_2 T + b_3 A + b_4 CA) \text{..} eqn4$$

The t-test was used to check all the models for significance of the crown attributes and the other variables in the model. All the candidate models were assessed based on the following criteria:

Mean square error (MSE)

Proportion of the variation in the dependent variable explained (fit index, R^2).

As Green (1983) demonstrated, model selection based on the index of fit may not be the same as model selection based on their ability to predict an independent validation data set. Therefore, for each model, the mean difference between predicted and observed tree total height and basal area increment for the validation data set was used to assess model bias. The bias values were checked with a t-test to determine whether they are significantly different from zero. The standard deviation of those differences about the mean bias was then used to assess prediction precision. Combining these two statistics (i.e. mean bias and prediction precision) by taking the square root of the sum of their squared values gave a measure of overall prediction error. The three statistics (i.e. bias, prediction precision and overall prediction error) can be related by the expression of each as a percentage of the average tree total height and basal area increment in the validation set.

RESULTS AND DISCUSSION

Adequate models for estimating individual stem total height and basal area increments of *Triplochiton scleroxylon* stands generally require information on the initial tree size, age, stem form and crown dimension. This modelling pattern was also observed by Sprinz and Burkhart (1987) and Biging and Dobbertin (1992). The final fitted models for the individual stem total height and basal area increment of *Triplochiton scleroxylon* are presented as follows (models with crown projection area did not give very good result and therefore were not included):

Individual Stem Basal Area Increment Models:

Basal area increment model without crown information:

$Ln\Delta BA = -3.689\, BA^{-0.15} \exp(0.004A - 2.196T)$... *equation* 1;

$(R^2 = 99.316, \quad SE = 0.083)$

Basal area increment model with crown diameter:

$Ln\Delta BA = -3.9BA^{-0.147} \exp(0.003A - 2.028T - 0.002CD)$... *equation2.*;

$(R^2 = 99.282, \quad SE = 0.085)$

Basal area increment model with crown length:

$LnBA = -3.995BA^{-0.138} \exp.(0.004A - 3.755.T - 0.002.CL)$.. *equation3.*;

$(R^2 = 99.399, \quad SE = 0.078.)$

Basal area increment model with crown ratio:

$LnBA = -3.686BA^{-0.15} \exp.(.0.004A - 2.196T + 0.001.CR)$.. *equation..4*;

$(R^2 = 99.316, \quad SE = 0.083.)$

Where, ΔBA = stem basal area increment (m^2/year), BA = stem basal area (m^2), A = stem age (years), T = taper (a measure of stem form obtained as the ratio dbh to stem total height), CD = crown diameter (m), CL = crown length (m), and CR = crown ratio.

Generally all the basal area increment models gave very good fit. The very high values found for the coefficients of determination indicate that the models fitted well to the data in this study. Among the individual tree basal area increment models both with and without crown information, equation 3 (i.e. model with crown length) had the highest coefficient of determination (R^2 = 99.399) and the least standard error (SE = 0.078). However, as Green (1983) pointed out, ranking of models based on index of fit may not be the same as ranking them according to their ability to predict an independent validation data set. A closer look at the comparative statistics of the basal area increment models on Table 2 (which measure model performance with independent validation data set) quite confirm this finding. The bias and precision statistics (Table 2) revealed that equation 3 (i.e. basal area increment model with crown ratio) is the most accurate judging from its least mean bias (1.49 %) and least combined bias and precision (10.04 %).

Table 2: Comparative Statistics for Basal area Increment Models for *Triplochiton scleroxylon*

Equation	R^2 (%)	Mean Bias (%)	Prediction Precision (%)	Combined Bias & Precision (%)
1 (*Without crown information)*	99.316 ($2^1/_2$)	1.50 (2)	10.02 (3)	10.13 (3)
2 (*With crown diameter)*	99.282 (4)	4.47 (3)	9.06 (1)	10.10 (2)
3 (*With crown length)*	99.399 (1)	5.67 (4)	12.68 (4)	13.89 (4)
4 (*With crown ratio)*	99.316 ($2^1/_2$)	1.49 (1)	9.93 (2)	10.04 (1)

Note: Numbers in parentheses indicate equation ranking.

The second best basal area increment model is equation 2 (i.e. model with crown diameter), which was ranked fourth according to coefficient of determination. This difference in ranking which supports Green's (1983) finding could be as a result of the non normality of residuals for the models. The results obtained proved that height and basal area growth were better fitted and predicted with models containing crown information than models without crown attributes. Although the improvement is marginal, a justification for inclusion of crown information is that it provides a means to better understand and predict the effects of silvicultural treatments on stem growth of *Triplochiton scleroxylon.*

The results obtained also confirm previous studies by Laasasenah (1982), Lohrey (1983), Farrar (1985) and Hann *et al.* (1987) that inclusion of crown ratio to a model moderately improves model performance. Inclusion of crown ratio to the basal area growth model reduced the combined bias and precision statistic for the validation data set by 0.89% and improved the prediction precision by 0.9%. Inclusion of crown diameter reduced the combined bias and precision statistic by 0.3% and improved the prediction precision by 9.58%.

Individual Stem Total Height Increment Models

Stem total height increment model without crown information:

$$\Delta TH = 0.08TH^{0.99}\exp(-0.029A + 1.597T) \ldots \textit{equation } 5;$$

$$(R^2 = 99.899, \quad SE = 0.008)$$

Stem total height increment model with crown diameter:

$$\Delta TH = 0.079TH^{0.994}\exp(-0.029A + 1.855T - 0.001CD)$$

equation.6;

$$(R^2 = 99.900 \quad SE = 0.008)$$

Stem total height increment model with crown length:

$$\Delta TH = 0.074TH^{1.024}\exp(-0.029A + 1.452T - 0.002CL)\ldots$$

equation 7;

$$(R^2 = 99.915, \quad SE = 0.007)$$

Stem total height increment model with crown ratio:

$$\Delta TH = 0.083TH^{0.989}\exp(-0.029A + 1.438T - 0.039CR.)\ ..$$

equation..8;

$(R^2 = 99.905, \quad SE = 0.008)$

Results are similar between stem total height and basal area increment models. Total height growth is also clearly affected by crown information. Equation 8 (with crown ratio) was found to be most accurate judging from its least mean bias (-0.497 %), prediction precision (0.849%) and combined bias and precision (0.984 %) on Table 3.

Table 3: Comparative Statistics for Total Height Increment Models for *Triplochiton scleroxylon*

Equation	R^2 (%)	Mean Bias (%)	Prediction Precision (%)	Combined Bias & Precision (%)
1 (*Without crown information)*	99.899 (4)	-0.597 (2)	0.885 (2)	1.068 (2)
2 (*With crown diameter)*	99.900 (3)	-0.843 (3)	0.956 (3)	1.275 (3)
3 (*With crown length)*	99. 915 (1)	-1.407 (4)	1.056 (4)	1.759 (4)
4 (*With crown ratio)*	99.905 (2)	-0.497 (1)	0.849 (1)	0.984 (1)

Note: Numbers in parentheses indicate equation ranking.

Although equation 8 ranked second on the basis of coefficient of determination (R^2 = 99.905%), it was however found most accurate for predicting stem total height of *Triplochiton scleroxylon.* Inclusion of crown ratio to the total height growth model reduced the combined bias and precision statistic for the validation data set by 7.87 % and improved the prediction precision by 4.07 %.

Although the significance of crown ratio in both height and basal growth models was significant, adding crown ratio only slightly reduced the combined bias and precision statistics. One possible explanation is that taper (i.e. Dbh/HT) values tend to be smaller in long-crowned than in short-crowned trees. Therefore part of the variation that might be explained by crown ratio is already explained by taper.

CONCLUSION

Tree growth is under the control of age, stem form, genetics, site quality and crown dimensions. In our study, we established tree total height and basal area increment models as a function of the size, stem form and crown dimensions. The effect of site variation was not considered in the models because the study was carried out in a site in south western Nigeria where the stands of the species are available. The individual tree based model was preferred to stand model because of the ability of the former to examine individual tree characteristics.

Generally, crown ratio is considered as a useful indicator of tree vigour (Assmann, 1970, Hasenauer and Monserud, 1996), wood quality (Kershaw *et al.* 1990), stand density (Clutter *et al.* 1983), competition and survival potential (Oliver and Larson, 1996), wind firmness (Navratil, 1997) and is a feature of interest in management of many non-timber resources including wildlife habitat, recreation and visual quality (McGaughey, 1997).

For both total height and basal area increment models, we conclude that equations with crown ratio consistently gave most accurate results of all the crown dimensions examined in this study. Crown ratio is therefore recommended for inclusion into stem total height and basal area increment prediction models, since silvicultural practices directly affect crown dimensions. Fortunately, Crown ratio can be determined easily during field measurement.

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