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## **Tree crown ratio model for *Hevea brasiliensis* (A. juss.) plantation in Rubber Research Institute of Nigeria (RRIN) Edo State, Nigeria**

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### **ABSTRACT**

Crown ratio is a term used to describe the ratio of the crown length to the total tree height. The crown length emphasizes the distance between the crown apex and the crown point while the distance between the tree apex and the ground level defines the total tree height. The tree crown ratio are predicted by the use of empirical models which assist in the provision of accurate estimates for both individual, stand growth as well as yield that are veritable tools for evaluating numerous management and utilization decision. However, no single type of model can provide sufficient information effectively for all levels of decision making, thus the essence of modeling tree crown ratio for *Hevea brasiliensis* plantation in Rubber Research Institute of Nigeria (RRIN). Tree growth variables are such as diameter at the base (DB), diameter at the breast height (DBH), crown diameter (CD), crown length (CL), total tree height (THT) were measured from a six year old plantation of 402 trees, while tree attributes such as crown projection area (CPA), basal area (BA), tree slenderness coefficient (TSC), crown ratio (CR) were estimated using their empirical formula. The data collected from the plantation was analyzed using descriptive and inferential statistics such as correlation and regression analyses with non-linear models used in fitting the data into CR equations and other growth attributed with individual data fitted to evaluate the robustness of the models using the fit indices. The result of the study reveals that there were significant variations in the growth attributes within the plantation in the study area. The result of the correlation analysis between CR and other growth characteristics revealed significant associations. The best adjudged CR model was the logistics model which is represented as  $CR = \frac{a_0}{1 - e^{-(1-a_1 CL + a_2 THT)}}$ ; (R<sup>2</sup> = 0.96 and SSE = 0.1177). The study has shown that crown ratio models developed has significant relationship with CL and THT and this can be successfully used for predictive studies on crown attributes for *Hevea brasiliensis* plantations in Nigeria.

**Keywords:** Crown models, growth attributes, prediction, sustainable management

## 1. INTRODUCTION

There is a high degree of correlation between tree crown and tree growth. Tree crown anchors the leaves which allow photosynthetic processes through capture of radiant energy. The measurement of the crown of trees is often done to assist in the quantification and understanding of the growth of trees in a stand [1]. Crown ratio is the characteristics used to describe the crown size [2]. Tree crown size is a veritable parameter of tree structure due to its array in usage which may include estimation of stand density, tree growth, and amount of timber volume assessment.

Crown ratio emphasizes the ratio of live crown length to tree height and is widely used to predict growth and yield of trees and forest [3,4]. Tree crown ratio has been utilized as a predictor of tree vigor [5]. Tree crown ratio can be predicted directly from tree variable such as total height and diameter at breast height [6]. It can also be predicted indirectly from estimates of the height to the base of the live crown [7].

Crown ratio has been predicted using empirical models [2,5,7-9]. Most of these models includes competition measures (e.g., density, crown competition factor), tree size (breast height diameter, tree height, age), and site (e.g. elevation, slope, aspect) variables [2,5,8]. Crown ratio is veritable indicator of tree quality, wind firmness, and stand density [10-12] which are significant characteristics in management of numerous non-timber resources including wildlife habitat and recreation [13]. Predictions of tree crown ratio have been used on allometric relationship between stand and tree variables [14]. Many authors have solid basis for applying crown ratio equation on logistics functions [5,15] or exponential function [7,16] or chapman Richard function [6,17], but there paucity of literatures on crown ratio models on monoculture plantation such as *Hevea brasiliensis* in Nigeria. The objective of this study therefore, is to develop tree crown ratio prediction model for *Hevea brasiliensis* in Rubber Research Institute of Nigeria, Edo State, Nigeria.

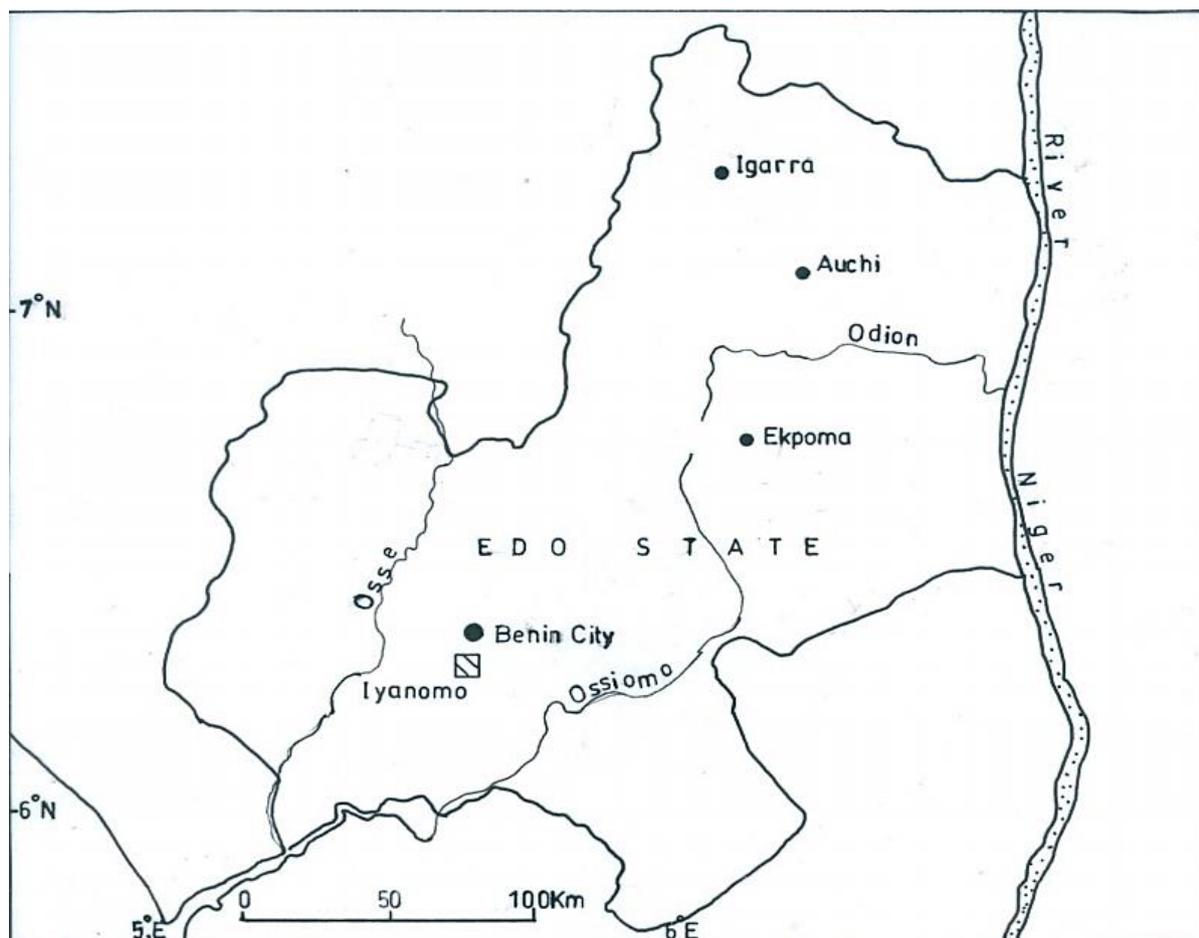
## 2. METHODOLOGY

### 2. 1. Study area

The study area was at Rubber Research Institute of Nigeria, Iyanomo, Edo State, Nigeria and itlies between latitudes 6° 05' and 6° 10' N and longitudes 5° 32' and 5° 37' E having a total area of 2,078 m<sup>2</sup>. Iyanomo is a relatively large community in Ikpoba-okhia Local Government Area of Edo State. Geologically, the area is within the Benin Formation (coastal plain sandstone) which is of Plieocene-Pleistocene age and consists of yellow and white sands with pebble horizons. The formation has clays and sandy-clays in lenses and is partly marine, partly deltaic, and partly fluvio-lacustrine in origin [18]. The beds vary from deltaic sands to fully marine clays and shales. The terrain is characterized by highly undulating ridges and nearly flat topography. The climate in Iyanomo is typical of tropical equatorial regions, with continuous warm temperature throughout the year (mean annual temperature around 26 °C) and high rainfall (mean annual rainfall between 1800 – 2200 mm)

with two distinct seasons, rainy and dry. The rainy season lasts from March to November while the dry season is from December to February.

Most rubber plant is grown between 15° N and 10° S where the climate is humid with temperatures ranging from 23° C to 45°C and well distributed rainfall of 1800 mm to 2000 mm on a well drained soil [19]. The ecosystem of the area supports highly diverse species of terrestrial flora and fauna.



**Fig. 1.** Map of Edo State showing the location of Iyanomo (Rubber Research Institute of Nigeria - RRIN)

Source: Field Survey, 2016.

### 3. DATA COLLECTION

Quantitative data was collected from *Hevea brasiliensis* plantation at Rubber research institute of Nigeria, Iyanomo main station. Total enumeration of the plantation was carried out and the following tree growth variables was measured and used for modeling for all trees: diameter at breast height (cm), diameter at base (cm), crown length (m), total tree height (m), crown diameter (m), while other relevant variables were also estimated using established methods.

**4. STATISTICAL ANALYSIS**

**4. 1. Regression and Correlation Analyses**

Regression analysis is a statistical methodology employed in quantitative scientific investigation and it emphasizes the average relationship between two or more variables. It could be dependent or independent variable. The correlation analysis however measures the degree of association between two or more. Correlation values ranges from - 1 to 1.

**4. 2. Computation of Model Variables**

**4. 2. 1. Stand basal area**

The stem basal area for each tree was measured using the formular:

$$BA = \frac{\pi D^2}{4} \dots \dots \dots \text{eqn 1}$$

where:

BA = stem basal area

D = diameter at breast height (m)

**4. 2. 2. Tree slenderness coefficient**

The tree slenderness coefficient was determined for each tree using the formular:

$$TSC = \sum \frac{THT}{D} \dots \dots \dots \text{eqn 2}$$

where:

TSC = Tree slenderness coefficient

THT = Tree total height

D = diameter at breast height (cm)

**4. 2. 3. Crown competition factor**

This emphasizes the relationship between crown width (CW) and diameter (D). The general form of this relationship:

$$CW = \beta_0 + \beta_1 D \dots \dots \dots \text{eqn 3}$$

where:

$\beta_0$  and  $\beta_1$  are regression coefficients.

D = diameter at breast height (cm)

**4. 2. 4. Crown ratio computation**

This was computed for each of the species in the stand and given as:

$$CR = \frac{CLi}{THT} \dots \dots \dots \text{eqn 4}$$

where:

$CL_i$  = individual tree crown length

$THT_i$  = total height of the  $i$ th tree. This was computed for each of the species in the stand as a response variable for the crown ration prediction models.

**4. 2. 5. Crown projection area**

The tree crown projection area was determined using the formula:

$$CPA = \frac{\pi CD^2}{4} \text{ ----- eqn 5}$$

where:

CD = crown diameter (cm)

**4. 2. 6. Crown diameter**

The crown diameter for each was measured using the formula;

$$CD = \sum r_i / 2 \text{ ----- equ 6}$$

CD = crown diameter

$r_i$  = projected crown radii measured on four axes

**5. CROWN RATIO MODELS DEVELOPMENT**

The tree crown ratio model was formulated to express crown ratio as a function of tree size (e.g. basal area, merchantable height) and slenderness coefficient in accordance to [14]. Non-linear models were selected as candidate functions to model crown ratio. The total data set was used to fit and select the tree crown equations. The tree crown ratio models that was developed and tested were based on the Logistic, Chapman-Richard, Exponential and Polynomial models.

Basically, they are expressed as;

$$Cr = \frac{a_0}{1 - e^{-(1 - a_1 CL + a_2 THT)}} \text{ ----- equ 7}$$

$$Cr = \frac{a_0}{1 - e^{-(1 - a_1 CL + a_2 THT)^2}} \text{ ----- equ 8}$$

$$Cr = a_0 + e^{(a_1 CL + a_2 THT)} \text{ ----- equ 9}$$

$$Cr = b_0 + e^{(b_1+b_2CL+b_3THT)} \text{-----equ 10}$$

**6. TREE CROWN RATIO MODEL EVALUATION AND VALIDATION**

Model evaluation tends to form an integral part of the model development process which assist in ascertaining the best model that is representative of the data collected. Some of the variables that are recommended for modeling tree crown ratio include tree height, DBH, stand density, basal area etc. Nevertheless, models are valid when individual and dependent data obtained from measurement are required or utilized in predicting the final fitted crown ratio. The models evaluation methods that were used in validation are listed below:

**6. 1. Standard error of estimate (SEE)**

SEE emphasizes a measure of the accuracy of predictions made with a regression line. The formular for SEE is given as;

$$SEE = \sqrt{\frac{\sum_{i=1}^n \hat{e}_i^2}{n - k}}$$

where:

$\hat{e}$  is the difference between the measured ( $y_i$ ) and the estimated crown ratio values ( $\hat{y}$ )

**6. 2. Residual coefficient of variation (RCV)**

This tends to proffer solution to the weakness of residual standard deviation (RSD). However, standard deviation in solitary result to difficulty in comparing two or more series where either the units of measurement are different or the mean values are different [20]. It is given as;

$$RCV = \frac{RSD}{MPR}$$

where:

RSD is the residual standard deviation and MPR is the mean prediction residual

**6. 3. Coefficient of determination ( $R^2$ )**

Coefficient of determination of the regression emphasizes the proportion of variance explained by the regression model. It determines how significant the relationship between the variables is; and the higher the  $R^2$  value, the stronger the relationship and with least estimate of the standard error (SEE). Moreover, the coefficient of determination summarizes the explanatory power of a regression model and its expressed in terms of sum of squares. The application of coefficient of regression ( $R^2$ ) has become widely use in model evaluation.

However, its performances on external data has led to superfluous data aptness thus making it less efficient. It is given as;

$$R^2 = 1 - \frac{SSE}{SST}$$

where:

SEE is the standard error of estimate while the SST is the total sum of squares.

#### 6. 4. Mean prediction Residual

This is a statistical method of model evaluation and it is given as;

$$MPR = \frac{\sum_{i=1}^n (Observed - Predicted)}{n}$$

#### 6. 5. Prediction Sum of Square

It is given as;

$$PRESS = \sum_{i=1}^n (Observed - Predicted)^2$$

### 7. RESULTS

#### 7. 1. Growth attributes of *Hevea brasiliensis* in the study area

Table 1 below shows the summary statistics of the major growth attributes of *Hevea brasiliensis* in Rubber Research Institute of Nigeria (RRIN).

The result of the growth variables indicates that the CR mean value of  $0.494 \pm 0.095$  was obtained with a minimum value of 0.289 and maximum value of 0.716 respectively. The DBH mean value of  $8.280 \pm 3.273$  was obtained with a minimum value of 0.795 and maximum of 67.154 respectively. Moreover, the THT mean value of  $6.397 \pm 0.419$  m was obtained a with minimum and maximum value of 5.100 and 7.900 respectively.

The CD mean value of  $5.088 \pm 0.713$  was obtained with a minimum and maximum value of 3.200 and 7.360 respectively. Again the CL mean value of  $3.168 \pm 0.668$  was obtained with a minimum and maximum value of 2.000 and 5.300 respectively. The minimum and maximum value of CPA is 8.043 and 42.550 with a mean value of  $20.735 \pm 5.952$  m.

**Table 1.** Descriptive statistics for tree variables of *Hevea brasiliensis* in the study area

Variable	Valid N	Mean	Minimum	Maximum	Standard Dev.
DBH	402	8.28045	0.79567	67.15468	3.273741
DB	402	47.48072	26.70000	60.30000	5.782852
THT	402	6.39772	5.10000	7.90000	0.419143
CL	402	3.16891	2.00000	5.30000	0.663891
CD	402	5.08833	3.20000	7.36000	0.713072
CR	402	0.49481	0.28986	0.71622	0.095186
TSC	402	0.83169	0.09679	7.49246	0.463131
SBA	402	0.00535	0.00005	0.01492	0.001941
CPA	402	20.73590	8.04352	42.55022	5.925448

N- number of trees, DBH- diameter at breast height, DB- diameter at the base, THT- total height, CL- crown length, CD- crown diameter, CR- crown ratio, TSC- tree slenderness coefficient, SBA- stand basal area, CPA- crown projection area  
Source: Field Survey, 2016.

## 7. 2. Correlation Analysis

Table 2 shows the correlation matrix between crown ratio (CR) and growth attributes for *Hevea brasiliensis* in the study area. The analysis emphasizes the degree of association between response variable and independent variable.

**Table 2.** Correlation matrix between crown ratio (CR) and growth attributes for *Hevea brasiliensis* in the study area

	CR	DBH(cm)	DB(cm)	THT(m)	CL(m)	CD(m)	TSC	SBA	CPA(m <sup>2</sup> )
CR	1.00								
DBH	0.06	1.00							
DB	- 0.11*	- 0.04	1.00						
THT	0.08	0.04	0.02	1.00					
CL	0.95*	0.07	- 0.09	0.39*	1.00				
CD	- 0.19*	0.06	0.01	0.04	- 0.16*	1.00			
TSC	0.07	- 0.32*	- 0.02	0.01	0.06	- 0.03	1.00		
SBA	- 0.07	0.39*	- 0.01	0.07	- 0.04	0.03	- 0.41*	1.00	
CPA	- 0.20*	0.06	0.01	0.03	-0.16	1.00*	- 0.03	0.04	1.00

\* Indicates that there is a significant difference

CR- crown ratio, DBH- diameter at breast height, DB- diameter at the base, CL- crown length, CD- crown diameter, TSC- tree slenderness coefficient, SBA- stand basal area, CPA- crown projection area

The result shown in the table reveals the general association between CR and the various growth variables for *Hevea brasiliensis* in the study area. The association between CR with DBH, THT, CL and TSC were positive with CL having the highest coefficient of correlation value ( $r$ ) of 0.95 at 0.05 level of significance. Inversely, the association between CR with DB, CD, SBA and CPA were negatively correlated. Moreover, the association between THT with CL had the highest correlation coefficient ( $r$ ) value of 0.39 at 0.05 level of significance and this tends to be similar with the association between DBH and SBA. A negative correlation coefficient value ( $r$ ) between CL with CD, SBA and CPA at 0.05 level of significance.

### 7. 3. Surface plot analysis of crown ratio and growth attributes

For the best adjudged crown ratio model, a three dimensional surface plots were generated from the crown ratio, tree height, and crown length values (Fig. 2).

### 7. 4. Crown ratio model

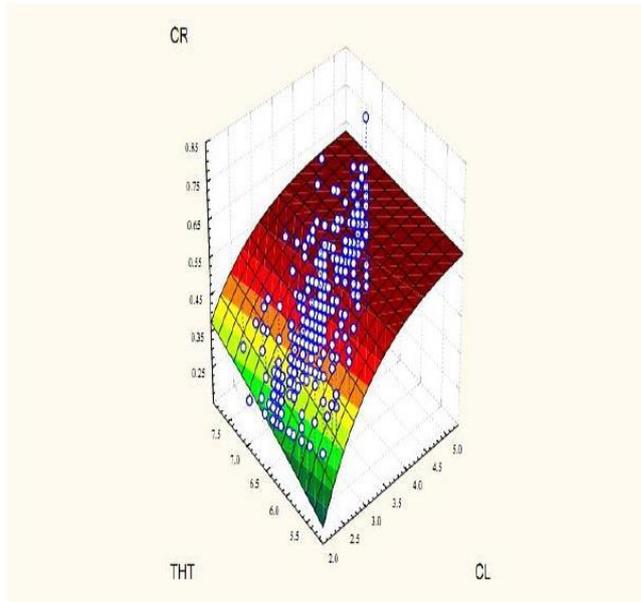
The result of estimated crown ratio model for *Hevea brasiliensis* in the study area are in Table 3. The results of estimates of non-linear models parameter are also shown in the Table 3, where four non-linear models were fitted into individual tree data. All the tree growth variables, apart from the crown ratio (the response variable), were tried during model-fitting processes. Tree height and crown length were found to consistently predict CR in all the functions. The result of the estimates was evaluated using coefficient of determination ( $R^2$ ), standard error of estimate (SEE) and probability of significance ( $p$ -value). The  $R^2$  value among the non-linear models ranges between (0.75 to 0.96) with the logistics function having the highest  $R^2$  value of 0.96 and SEE value of 0.1177. The exponential function had the second highest  $R^2$  value and SEE value of 0.90 and 0.380 respectively. However the Richard model had the lowest  $R^2$  value of 0.89 and highest SEE value of 0.908.

### 7. 5. Crown ratio model evaluation

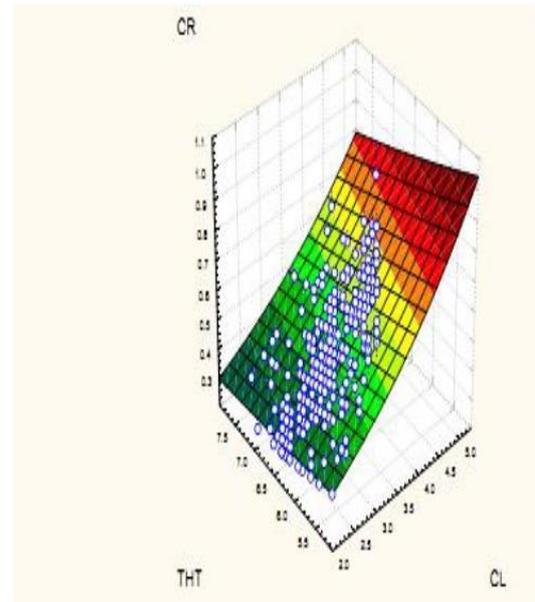
The evaluation statistics obtained for the four functions are presented in Table 4. The table includes the measures of precisions and the biases associated with the four functions in the *Hevea brasiliensis* plantation.

The mean prediction residual (MPR) values associated with all the functions were found to be negligible. Nevertheless the exponential and polynomial functions had the least mean prediction residual which however tends to be similar to the report of [6]. The residual standard deviation (RSD) values for the four functions were quite higher compared to the values reported by [20] for the same set of functions. Table 4 presented the RSD values with the Logistics function having the lowest RSD value and Richards function with the highest RSD value. However, the residual co-efficient of variations (RCV) were much different for the four functions used in the study.

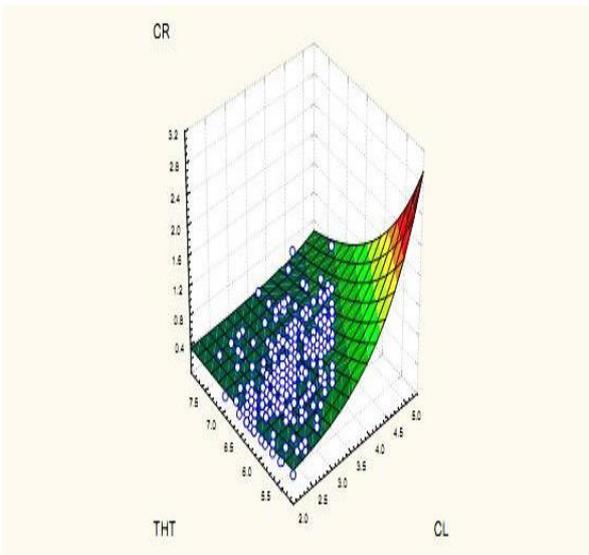
The RCV values for the polynomial function had the highest RCV value as against that reported by [20] which indicated the weibull function as having the highest RCV value. However the Logistics and the Exponential function had a low RCV value compared to the Richards and Polynomial functions. Nevertheless, the Exponential functions gave the least PRESS statistics in the data set tends to correspond to the report of [20].



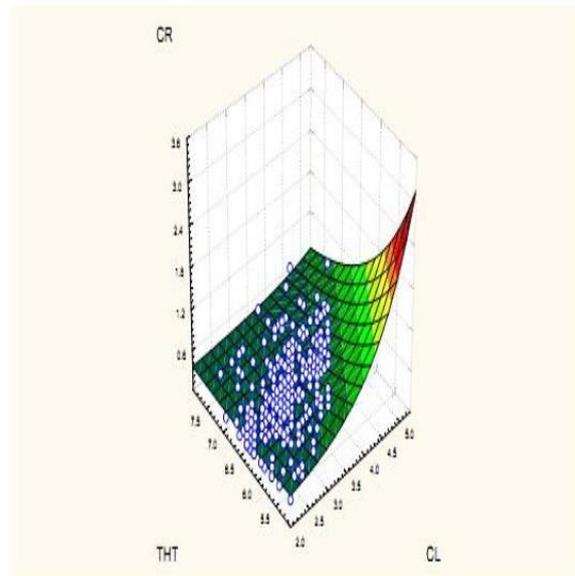
Logistics graph



Richard graph



Exponential graph



Polynomial graph

Fig.2: Surface plot for the various crown ratio models for *Hevea brasiliensis* in the study area

**Table 3.** Tree crown ratio models, parameter estimates and fit statistics for *Hevea brasiliensis* in the study area.

Function	Parameter	Estimate	SE	t(df = 399)	P-value
<b>Logistic</b>					
$Cr = \frac{a_0}{1 - e^{(1-a_1CL+a_2THT)}}$ R <sup>2</sup> = 0.96; SEE = 0.1177	a <sub>0</sub>	0.977222	0.118067	8.276811	0.00000*
	a <sub>1</sub>	0.29731	0.00326	91.31889	0.00000*
	a <sub>2</sub>	0.100074	0.019761	5.064218	0.000001*
<b>Richard model</b>					
$Cr = \frac{a_0}{1 - e^{(1-a_1CL+a_2THT)^2}}$ R <sup>2</sup> = 0.75; SEE = 0.908	a <sub>0</sub>	0.6379	0.00795	80.08899	0.0000*
	a <sub>1</sub>	0.46548	0.02395	19.43297	0.0000*
	a <sub>2</sub>	- 0.0937	0.0075	- 12.4475	0.0000*
<b>Polynomial model</b>					
$Cr = a_0 + e^{(a_1CL+a_2THT)}$ R <sup>2</sup> = 0.89; SEE = 0.409	a <sub>0</sub>	0.34359	0.00734	64.22674	0.0000*
	a <sub>1</sub>	0.965136	0.089778	4.978547	0.000001
	a <sub>2</sub>	- 0.800534	0.3193	- 9.53584	0.0000*
<b>Exponential model</b>					
$Cr = b_0 + e^{(b_1+b_2CL+b_3THT)}$ R <sup>2</sup> = 0.90; SEE = 0.380	b <sub>0</sub>	0.340949	0.06028	- 0.858656	0.391047
	b <sub>1</sub>	- 0.209520	0.15495	- 6.96594	0.000000
	b <sub>2</sub>	0.944731	0.024354	9.055235	0.000000
	b <sub>3</sub>	- 0.753624	0.01040	- 4.23877	0.00003

R<sup>2</sup> = coefficient of determination, SEE= standard error of estimate, F- value = Significance of the overall regression equation and P- value = probability significance  
 Source: Field survey, 2016.

However the Logistics function had the highest PRESS value. Although, the suitability of Richards and Logistics functions were further confirmed as observed by [15] and [17]. Moreover, Logistics and Exponential function were found, even more suitable in the study as they gave higher R<sup>2</sup>-values for the data set. This tends to conform with the reports by [6,15,17], where aptness of only the Richards and Logistic functions were used. This could be attributed to the highly diverse and complexity of the stand or a large data set.

**Table 4.** Evaluation of the four function for *Hevea brasiliensis* in the study area.

Function	MPR	RSD	RCV	PRESS
<b>Logistics</b>	- 0.00107	0.1177	110.0	0.185168
<b>Richards</b>	- 0.00037	0.908	2454.05	0.0225562
<b>Polynomial</b>	0.0000941372	0.4099	4354.283	0.001432
<b>Exponential</b>	- 0.0000578531	0.38031	- 6573.71	0.000541

MPR: mean prediction residual; RSD: residual standard deviation; RCV: residual coefficient of variation; PRESS: prediction sum of squares statistics.

## 8. DISCUSSION

### 8. 1. Growth Attributes

The results of the major growth attributes for *Hevea brasiliensis* plantation indicates that variation exist within the *Hevea brasiliensis* plantation. The mean value for diameter at the base (DB) was the highest in the stand while that for crown ratio was 0.494 with a standard deviation 0.095. This conforms to the statement of [21] who stated that the prediction intervals for crown ratio modeling are always between 0 and 1. Moreover the mean of the crown length tends to be lower than that of the tree height thus there is a measure of consistency with the predicted values for crown ratio [15]. The tree total height of the stand has a mean value of 6.397 and this tends to indicate that the tree height influences the crown ratio. However, the stand mean value of crown diameter tends to be higher than that of tree slenderness coefficient (TSC) and stand basal area (SBA) mean values. Nevertheless, the crown projection area has a relatively higher mean value than the crown diameter thus indicating that crown diameter decreases as crown projection area (CPA) increases for the stand with a corresponding influence on crown ratio.

### 8. 2. Correlation Analysis on CR

The result of the correlation among tree variables in the plantation and crown ratio (CR) shows significant variation. The correlation between crown ratio and DBH, THT, TSC were positive though they had low values. Inversely, there was a higher correlation between CR and CL at 0.05 level of significance. This contradicts the work done by [20] who stated that there was no significant difference of crown ratio in the secondary forest used in the study.

However, there exists a low and negative correlation between crown ratio and crown diameter at 5% level of significance. Meanwhile diameter at the base (DB) had a negative and low impact on the crown ratio at 0.05 level of significance.

### **8. 3. Regression Analysis on CR**

The result of this study shows that the logistics model had the best fit for the *Hevea brasiliensis* plantation. Several authors have employed quite a number of crown ratio relationships. For instance, [20] employed the weibull model and eventually gave the best fit for modeling crown ratio. However, this counteracts the works of [6] and [15], where only the Richards and logistics were established and could however be attributed to a larger data set, higher species and ecosystem diversity.

## **9. CONCLUSIONS**

The study has provided quantitative information on tree crown ratio models for *Hevea brasiliensis* in the Rubber Research Institute of Nigeria Iyanomo, Edo state. The result of modeling tree crown ratio with other growth attributes showed that the best adjudged model with required modeling fitting criteria was the logistics model. The result of this study can be used for tree crown ratio modeling studies on other Rubber plantation for sustainable management in Nigeria. It therefore paramount that quantitative assessment of the plantation should be executed for updated information on growth attributes of *Hevea brasiliensis*. This could easily be achieved if the government of the day revitalizes forestry practices by embarking on modern training and updating technical forestry staff in the area of quantitative forest management.

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( Received 24 March 2017; accepted 12 April 2017 )