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Research article

Estimating the leaf area of *Khaya senegalensis* (Desv.) A. Juss. from linear measurement

Owokotomo Olayinka Oluwatobi

Department of Forestry and Wood Technology, Federal University of Technology, Akure, Nigeria

Corresponding Author: owokotomoolayinka@gmail.com [Accepted: 26 March 2020]

Abstract: This study was carried out to develop leaf area prediction models for *Khaya senegalensis* using linear measurement. The maximum lamina length (L) and lamina width (W) were measured with a graduated ruler (cm), while the actual leaf area (ALA) were measured with a software model WINRHIZO PRO 2005, installed on a computer system with an attached scanning machine. The best fit model was selected based on F-test; mean square error (MSE) and Coefficient of determination (R^2). All parameters were positively and significantly correlated at 1% level. The product of length and breadth (LB) had the highest coefficient of Determination of 0.75. Quadratic and linear regression of the data produced eight leaf area models. The best five models were product and sum of length and width while the least four models were derived from single-dimensional measurement of either lamina length or width. The top five models were recommended for leaf area estimation of *Khaya senegalensis*, but for ease of application model with the highest R^2 was preferred for its simplicity- $Y= -3E=0.5x^3+0.0046x^2+1.9839x+7.2194$; R^2 = 75%.

Keywords: Leaf area - Leaf length - Leaf breadth - Linear measurement - *Khaya senegalensis*.

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INTRODUCTION

Khaya senegalensis (Desv.) A. Juss. is a hardwood tree of maximum height upto 30 m (100 feet); it belongs to the family *Meliaceae* with the trade name “dry zone Mahogany”. It is widely distributed in the savannah region from West Africa, French Sudan to French Cameroon, extending to East Sudan and Uganda. *Khaya senegalensis* has some vernacular names like Madachi (Hausa), Oganwo (Yoruba). Generally found in many habitat types but seems to thrive in the moist and wet undisturbed evergreen forest (Keay 1989). Trees of *Khaya senegalensis* can have its maximum seed production upto the age of thirty (30), after planting, but subsequent seed production seems to occur only in every 3–4 years. The seeds of *Khaya senegslensis* are dispersed by wind (Hawthorne 1995).

Leaf area (LA) estimations are a useful criterion for fast-growing and early flowering genotype selection (Pritsa *et al.* 2003). Repeated measurements, such as leaf expansion studies demand non-destructive determination of LA which is feasible only by using portable and expensive instruments or by developing LA prediction models (Serdar & Demirsoy 2006). Till now, non-destructive models for LA prediction have been developed for many shrub and tree species such as banana (Potdar & Pawar 1991), cherry (Demirsoy & Demirsoy 2003), chestnut (Serdar & Demirsoy 2006), hazelnut (Cristofori *et al.* 2007), kiwi (Mendoza-de Gyves *et al.* 2007), peach (Demirsoy *et al.* 2004), pecan (Whitworth *et al.* 1992), and sago palm (*Metroxylon sagu* Rottb.) (Nakamura *et al.* 2005). These models are based on leaf length (L) and width (W) measurements, which are used individually or in combination to establish linear, quadratic, or exponential functions and the best-fitted curve to be chosen. Linear models based on only one dimension are preferable due to their simple application especially in the field (Lu *et al.* 2004, Tsialtas & Maslaris 2005, Chaturvedi *et al.* 2012, Chaturvedi & Raghubanshi 2013 Chaturvedi & Raghubanshi 2015, Chaturvedi *et al.* 2017).

All *Khaya* species are considered moderately durable and the strength of African mahogany compares favourably with that of American mahogany (Michael 2004). *Khaya senegalensis* is important for various

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purposes like construction of furniture because of its hardness for making aircraft propeller, production of decorative veneer and paneling. Its bark is bitter, and it can be used for curing stomach ache and treating of syphilis (Keay 1989).

However, *Khaya senegalensis* is considered by many to be among the endangered species, due largely to depletion of its stock in the African forest. Natural regeneration of the species has also been constrained by wild animals; consequently, due to a combination of these constraints, the available stocks in the nursery are usually guided jealously. Therefore, all physiological and agronomic studies of this plant had to be conservative in design. There is therefore the need to develop leaf factors for non-destructive leaf area measurement of *Khaya senegalensis*. Moreover, leaf area is determined for many physiological studies such as growth analysis, photosynthesis and transpiration measurement (Kvet & Marshall 1971, Coombs *et al*. 1985). This study was carried out to develop leaf area prediction models for *Khaya senegalensis* using linear measurement. The aims and objectives of this study were to develop leaf area prediction model for *Khaya senegalensis* using linear measurement, to validate the model using independent field measurement, and determine the best fit linear measurement model for leaf area prediction of *Khaya senegalensis.*

MATERIALS AND METHODS

Study area

This study was conducted at Federal College of Forestry, Ibadan, situated on Latitude 7º 26′ N and Longitude 3º 26′ E. The samples were taken from the nursery stock and mature plants.

Materials used were meter rule, 50 small sized *Khaya senegalensis* leaf, 50 medium sized *Khaya senegalensis* leaf, 50 large sized *Khaya senegalensis* leaf, Leaf area software and scanning machine, WinRHizoPRO 2005.

Sampling and measurements

The leaves were grouped according to their sizes, *viz.*, small (4 cm width), medium (17 cm width), and large (20 cm width). A total of 150 leaves were measured. Each leaf was processed by following protocol:

Actual leaf measurement: The actual leaf area (ALA) of the leaves were measured using a software model WinRHizoPRO 2005, installed on a computer system with an attached scanning machine, the scanning machine and computer system is switched on. The leaf is placed on the scanning machine and with the aid of the software WinRHizoPRO, the total leaf area/surface area were automatically measured.

Linear measurement: The leaf length (L) was measured in Centimetre (cm) from the lamina tip to the point of petiole intersection along the lamina midrib with the aid of a ruler, while the leaf width (B) was also measured in cm tip to tip at the widest part of the lamina.

Statistical analysis/model development

Correlation analysis of the actual leaf area (LA) and for the independent variables, L, B, their squares (L^2 and B^2), sums of length and width (L+B) and the products length and width (LB) were calculated. Data were fitted to linear and quadratic regressions to establish the best fitted regression model, which represents the relationship between LA, and combinations of L and B as the independent variable (X). Statistical criteria for model selection were F test, mean square error (MSE) and coefficient of determination (R2) using Microsoft excel 2017.

Validation

The primary objective of the validation process is to establish the reliability of the model predictions. Validation involves a statistical comparison of model predictions with independent data. The goodness-of-fit of the model was evaluated by the root mean squared error (e), a criterion commonly used to quantify the mean difference between simulation and measurement, and it is defined as:

$$\sqrt{\sqrt{N}\sum ni(xi-yi)2 \Big/ \sum_{i=i}^{n} ni}$$

e=i=1

With xi being the simulation result and yi the mean of observed data. N is the number of sampling dates and ni is the sample size . The smaller the *e* in comparison to measurements, the better the goodness of fit. This idea can be represented through relative e:

$$^{e}\text{rel} = \text{RMSE}$$

Where, yi is the mean of all observed values.

$$=\sum niyi/\sum^{N}_{i=1}$$
$$i=1$$

RESULTS AND DISCUSSION

Correlation relationships of linear measurement

Correlations of all the parameters are shown in table 1. The linear measurements, lamina length lamina breadth and product of square lamina breadth were fairly correlated to the actual leaf area with a correlation coefficient (r) of 0.20, 0.48 and 0.16 respectively while the square of lamina length, the product of lamina length and breadth correlated better with actual leaf area having r=0. 83 and 0.84 respectively.

The correlation coefficient of all parameters was significant at 1% level. Product of length and breadth (LB) correlated best with actual leaf area having a correlation coefficient of 0.85. Hence there is need to develop an economically cheaper and technically easier but sound method for leaf area measurement. Additionally, the use of simple linear measurement for predicting the leaf area eliminates the need for expensive leaf area meter (Robbins & Pharr 1987); for this reason; the development of mathematical model and equation from linear measurement, for predicting total or undivided leaf area is needful.

Table 1. Correlation Matrix of actual leaf area and linear leaf measurement of *Khaya senegalensis* (Desv.) A. Juss.

	L (cm)	B (cm^2)	B2*B2	L (cm^2)	L2*L2	LB (CM)	(L+L)2	B+B	(B+B)2	SA(cm^2)
L (cm)	1									
B (cm^2)	0.1019	1								
B2*B2	0.0264	0.9109	1							
L (cm^2)	0.2916	0.4687	0.1386	1						
L2*L2	0.9247	0.0027	-0.0051	0.0763	1					
LB (CM)	0.3049	0.4643	0.1395	0.9889	0.0857	1				
(L+L)2	0.2916	0.4687	0.1386	1.0000	0.0763	0.9889	1			
B+B	0.1631	0.9293	0.6982	0.6929	0.0156	0.6907	0.6929	1		
(B+B)2	0.1019	1.0000	0.9109	0.4687	0.0027	0.4643	0.4687	0.9293	1	
SA (cm^2)	0.2012	0.4834	0.1634	0.8323	0.0405	0.8446	0.8323	0.6949	0.4834	1

Development of prediction model

Quadratic and linear regression analysis was also used for determination of best fitting equations for estimation of leaf area of *Khaya senegalensis* the results, (Table 2) showed that product of length and breadth (LB) explained variation of the leaf values significantly ($P < 0.001$). The variation explained by the parameter was 75%.

Table 2. Regression models of relationship, between actual leaf area and linear measurements (length and breadth) square of length (L^2), width (B^2) and product of length and width (LB).

Linear Measurement	Regression Model	Coefficient of determination R^2	Significance
Length (L)	$Y= 0.0227x^2-0.04522$ $X^2+15.92x-46.255$	0.7046	<0.001
Length (L^2)	$Y = 4E-06x^3 - 0.003x^2 + 1.2378x - 6.0399$	0.7089	<0.001
Breadth (B^2)	$Y = 1E-04x^3 - 0.0538x^2 + 8.2211x - 11.582$	0.6864	<0.001
Breadth (B)	Y=4.1497x+92.866x-192.03	0.6764	<0.001
Length X Breadth(LB)	$Y= 3E-0.5x^3+0.0046x2+1.9839x+7.2194$	0.7499	<0.001

The variation explained by the parameter was (0.7499) 75%, Other parameters had a coefficient of determination (R^2) of 0.70, 0.71, 0.68 and 0.67 for L, L^2, B^2, and B respectively. Many researchers have also reported that leaf area can be estimated by linear measurements such as leaf width and leaf length (Potdar & Pawar 1991, Tsialtas & Maslaris 2005).

According to Nesmith (1992) estimating summer squash leaf area could be non-destructively. It is shown in figure 1, that the relationship between ALA and lamina lengths has a coefficient of determination (R^2) of 0.72. In agreement with the work of Bhatt & Chanda (2003), it is shown in figure 2, that the square lamina length has a coefficient of determination (R^2) of 0.71. In accordance with Jayeoba (2001), working on simulation modeling, it is shown in figure 3 that the square lamina breadth is 0.68. This is in accordance with the work of Robbins & Pharr (1987), Leaf area prediction model for cucumber from linear measurement, it is shown in figure 4 that the lamina breadth is 0.67. It is shown in figure 5, that the lamina length and breadth has a coefficient of determination (R^2) of 0.75. It is shown in figure 6, that the lamina length + length have a coefficient of determination (R^2) of 0.70.

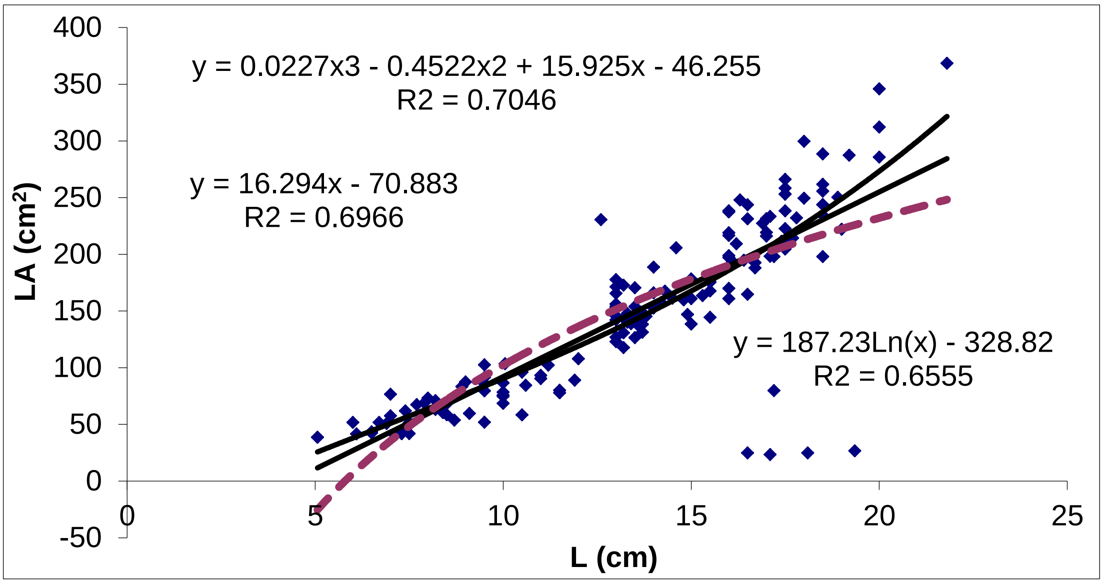

Figure 1. Relationship between actual leaf area and the lamina leaf length of *Khaya senegalensis* (Desv.) A. Juss.

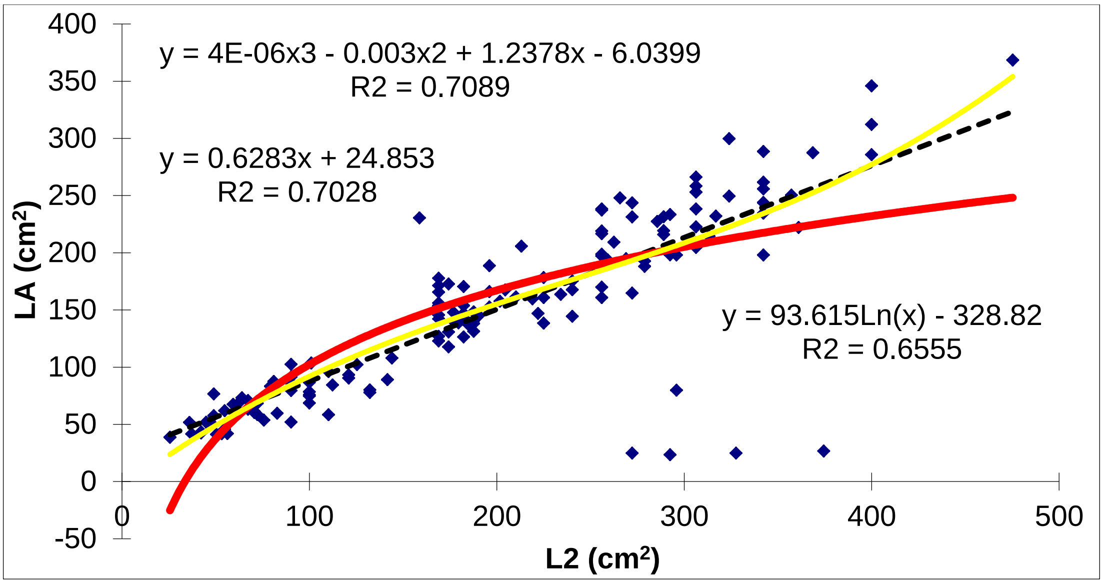

Figure 2. Relationship between actual leaf area and the square lamina leaf length of *Khaya senegalensis* (Desv.) A. Juss.

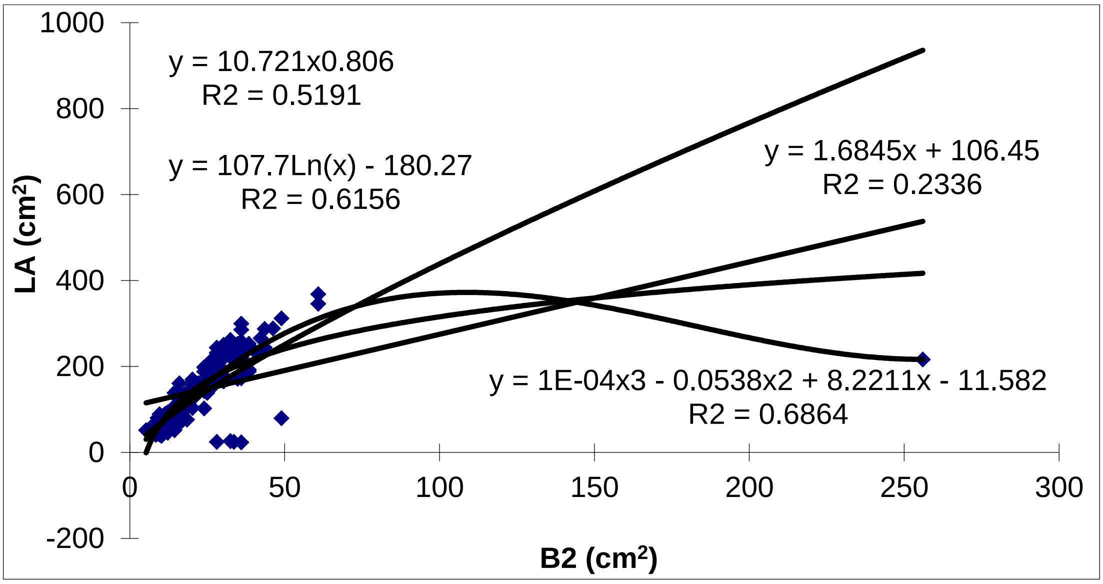

Figure 3. Relationship between actual leaf area and the square lamina leaf breadth of *Khaya senegalensis* (Desv.) A. Juss.

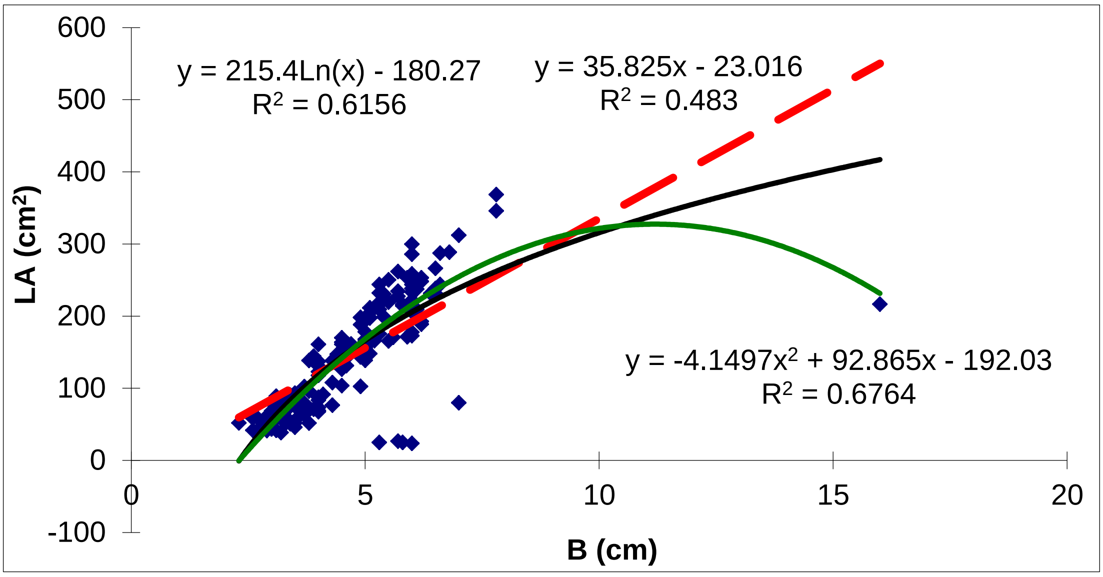

Figure 4. Relationship between actual leaf area and the lamina breadth of *Khaya senegalensis* (Desv.) A. Juss.

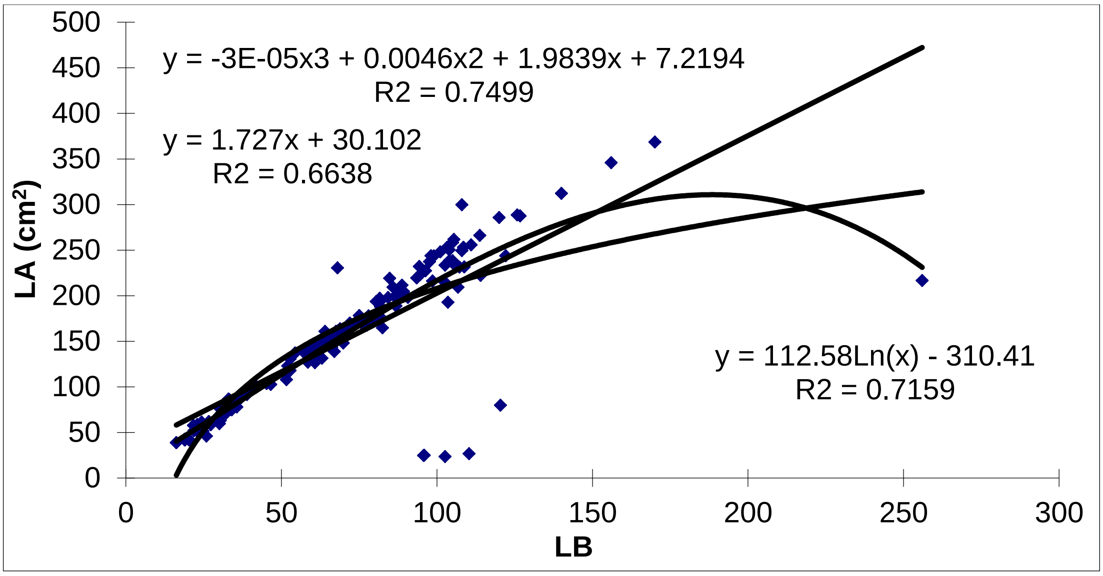

Figure 5. Relationship between actual leaf area and product of lamina length and leaf breadth of *Khaya senegalensis* (Desv.) A. Juss.

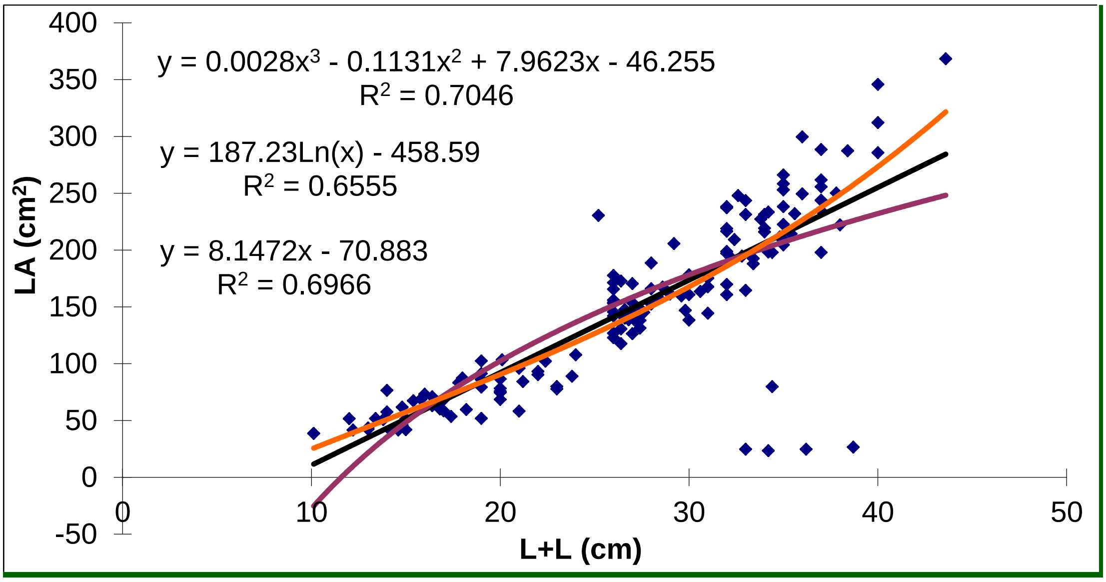

Figure 6. Relationship between actual leaf area and sum of lamina length and leaf length of *Khaya senegalensis* (Desv.) A. Juss.

Selection of best prediction model

Product of lamina and breadth (LB) had the best coefficient of determination (R^2) 0.7499, therefore, the model is most likely to give a more accurate estimate of actual leaf area measurement. Many researchers have also reported that leaf area can be estimated by linear measurements such as leaf breadth and leaf length in the following plants: cucumbers (Robbins & Pharr 1987), Onions (Gamiely *et al*. 1991), oranges (Potdar & Pawar 1991). The same authors found that there were close relationship between leaf area length and leaf breadth of other plants, e.g., R^2=0.76 to 0.99 for cucumber, R^2-0.9841 to 0.9884 for grapes, R^2=0.89 to 093 for oranges, and R^2 = 0.95 to 0.98 for coconut. The result reveals non-significance (P = 1), which implied that there is no significant difference in the values measured with the two methods. Although the software have a good estimate of leaf area, it is not recommended as a component of leaf area linear measurement prediction model because, the procedure for measurement could be cumbersome and may practically be impossible for some broadleaf plants such as teak (*Tectona grandis* L. f.) banana (*Musa* spp.) and coconut (*Cocos nucifera* L.).

CONCLUSION AND RECOMMENDATION

The models developed from the study as presented in figures 1–6, will enable researchers (Breeders, agronomists, horticulturists and foresters) that are interested in the study of growth and development of *Khaya senegalensis* either in the field or at the greenhouse to study the leaf growth, without destroying the leaves and compromise precision and accuracy based on the set statistical criteria. The product of lamina and width (LB) predicted leaf area (Y) better (R^2=0.75) than the other linear measurement combinations, therefore $Y=-3E-0.5x^3+0.046x^2+1.9839x+7.2194$ is recommended as the model for predicting leaf area of *Khaya senegalensis*. However, Jayeoba (2001) stated the need for model to be validated, before its application in an environment different from the place of development. Moreover, the model developing processes of this set may be used to developed leaf area prediction models for other trees and ornamentals.

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