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Non-destructive Method for Estimation of Leaf Area of Clerodendrum Volubile, a West African Non-conventional Vegetable

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Abstract In this study, mathematical models for calculating the area (A) of each of 486 randomly selected leaves of clerodendrum volubile were developed from the well-known general equation A = KLW where L is the length and W is the maximum width of the leaf. Each leaf was first photocopied on A4 paper of known weight per unit area, and after measuring the length (L) and maximum width (W), the leaf template was cut out from the paper to determine its weight. The true area of each leaf was determined from the weight and area of the A4 paper and the weight of the leaf template. Multiple regression analysis of data was done with SPSS 16.0 computer package program to find the relation between the leaf area and the leaf linear dimensions. The model equations obtained are stated as follows: (i) A = 0.683 LW with R^2 = 0.992 and RMSE = 2.516, (i) Log(A) = 0.157 + 0.994Log(LW) with R^2 = 0.976 and RMSE = 0.038, (ii) Log(A) = - 0.118 +0.884Log(L) + 1.097log(W) with R^2 = 0.976 and RMSE = 0.037, (iii) Log(A) = 0.891Log(LW) with R^2 = 0.999 and RMSE = 0.045, A simplified model equation for obtaining the area of the leaf of clerodendrum volubile in the field is found to be A = $0.321L^2$ with R^2 = 0.980 and RMSE = 3.919 as W = kL (R^2= 0.988, RMSE = 0.460) and LogA = - 0.450 + 1.956LogL with R^2 = 0.928 and RMSE = 0.646.

Keywords: *clerodendrum volubile, leaf area, linear measurement, RMSE*

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1. Introduction

Clerodendrum volubile is a largely grown leafy vegetable in South-South Nigeria and it belongs to the family of Lamiaceae. It is a climbing shrub that can climb to about 3m high and it grows in the deciduous forest and secondary jungle across the region of Senegal to Fernando Po [6]. Its general use include (i) Agrihorticulture ornamental, cultivated or partially tended, (ii) social, religion, magic, (ii) food, medicine to cure arthritis, rheumatism, dropsy, swellings oedema, gout, pain and as sedative [13]. Locally, the fresh leaves are blended and used for cooking and the leaves are at times dried and used as spice. The leaf contains high % of protein and ash content. Mineral anylysis revealed high content of sulphur, chlorine, manganese, iodine and zinc [8].

It is found that the biologically active components of the plants are concentrated in the leaves [1,4,5,17,20,22,25]. Therefore leaves are the most important organs of those plants and are very important when considering industrial production of the leaf active components.

The leaf area of many plants has been measured in experiments concerning physiological phenomenon such as light, photosynthesis, respiration, plant water consumption and transpiration [7,10,12,21,23,27]. In addition, leaf number and area have an important role in some cultural practices such as training, pruning, irrigation and fertilisation.

The leaf area estimation model aiming to predict the leaf area non-destructively can provide researchers with many advantages in agricultural experiments. It enables researchers to carry out leaf area measurements on the same plants over the course of study, and this results in reduced experimental variability [9,18,19].

Leaf area can be measured by using expensive instruments and/or predictive models. Recently, new instruments, tools and machines such as hand scanners and laser optical apparatuses have been developed for leaf area measurements. These are however very expensive and complex devices for both basic and simple studies. In contrast, non-destructive estimation of leaf area is simple and saves time when compared with the methods above [24]. They are quicker and easier to be executed and present good precision for the study of plant growth in several crops [11].

Several leaf area prediction models were produced for some plant species in previous studies; but to the authors' knowledge, there are no published models concerning the leaf area of clerodendrum *volubile* plants. Due to the lack of such information, we aimed in the present study to develop reliable equations that will allow for the non-destructive estimation of the area of *clerodendrum volubile* leaves through linear measurements.

2. Mathematical Formulation

The most popular model used for determining the area (A) of a leaf from linear measurements of its leaf length (L) and maximum with (W) is

$$A = KLW \quad (1)$$

which is also the general expression for the geometrical area of an ellipse or a kite of length (L) and maximum width W) with K as a constant. Because the geometrical shape of a leaf is not exactly that of an ellipse or a kite, it is found that the scatter of points on the graph of the product of (LxW) against (A) tends to become larger with the increase in leaf area [14,16].

Three correction procedures are therefore used to reduce the scatter of points of data on the graph and these are:

(a) A linear correction procedure which converts equation (1) into a form

$$A = a + KLW \quad (2)$$

where a the linear correction factor and K are constants.

(b) A lumped power correction procedure which converts equation (1) into a form

$$A = (KLW)^{\mu}, \quad (3)$$

where μ is a constant, and

(c) A distributed power correction procedure which converts equation (1) into a form

$$A = K^{\alpha}L^{\beta}W^{\gamma} \quad (4)$$

where α, β, γ are constants.

Linear regression analysis of logarithmically transformed data has the property of automatically weighting the data. Therefore, equation (3) and (4) can respectively be re-written in the forms

$$LogA = a_{1+}b_1 LogLW, \quad (5)$$

where $a_1 = \mu LogK$ and $b_1 = \mu$, and

$$LogA = a_2 + b_2 LogL + c_2 LogW, \quad (6)$$

Where $a_2 = \alpha LogK$, $b_2 = \beta$ and $c_2 = \gamma$.

And for a very small value of the constant a_1 in equation (5),

$$LogA = b1LW \quad (7)$$

If the leaf shape is approximately equal to that of an ellipse or a kite,

$$A = KLW \text{ and } \mu \approx \alpha \approx \beta \approx \gamma \approx 1$$

If there is a strong linear relation between W and L such that

W = σL, equation (5) can be re-written in the form

$$LogA = a_3 + b_3 LogL \quad (8)$$

where $a_3 = (\mu LogK + \mu Log\sigma)$ and $b_3 = 2\mu$ **,** and equation 2 can be written in the form

$$A = a + b_4 L^2, \quad (9)$$

where $b_4 = K\boldsymbol{\sigma}$

If the linear correction factor **a** is small, equation 9 can be written as

$$A = b_4 L^2. \quad (10)$$

3. Materials and Methods

A total of 486 leaves of Clerodendrum volubile were randomly selected and measured for length (L), maximum width (W) and true area (A). The true area of each leaf was obtained by photocopying it on an A4 paper of known weight per unit area and cutting out the leaf template and weighing. The degree of precision involved in cutting out the leaf template for weighing has been stated in the previous reports [2,3].

The relationships between the true leaf area and the linear measurements were evaluated by fitting regression models with linear regression procedure of SPSS (SPSS Inc. Chicago IL),and the plotted graphs were obtained by using the SPSS graph facility. The internal validity of the models was evaluated by the coefficient of determination (R^2) and the root mean square error (RMSE); and the final model was selected based on the combination of the highest R^2 and the lowest RMSE. A high value of R^2 shows that there is a high correlation and a low value of R^2 shows a poor correlation as it is the R^2 that gives the percentage of the true area that is explained by the linear dimensions. Also a large value of RMSE indicates a large scatter of data about the best straight line, and a poor fit; and a low value of RMSE shows that the scatter of data points about the best straight line is small, showing that there is a good fit. Thus a combination of R^2 and RMSE will be used in the decision process to know when the model equation is a good fit.

Table 1. The regression parameters a, b; describing the relationship between the Leaf length, L and leaf maximum width, W for the model equations (i) and (ii)

s/n	Models Equation	Regression coefficients		R^2	df	RMSE
		a	b			
(i)	W = bL	0	0.475 ±0.002	0.988	485	0.460
(ii)	W = a + bL	0.180 ±0.079	0.455 ±0.009	0.838	484	0.458

4. Results and Discussion

Relationship between the maximum width W and the length L of the leaves of clerodendrum volubile as given in Figure 1 shows that the leaf maximum width W is linearly related to the length L. The fitted model equation to the figure is that of a straight line of equation (i): W = 0.475L when the intercept is zero and equation (ii): W = 0.180 + 0.455L when the intercept is non-zero. The regression coefficients, the coefficient of multiple determinations and the RMSE of the scatter about the fitted straight lines are shown in Table 1. The coefficient of multiple determinations (R^2) in the table is preferred to the correlation coefficient R, as it gives the fraction of the variation of the leaf's maximum width (W) that is explained by its relation with the leaf length (L). The higher the R^2 is, the better the model fit becomes.

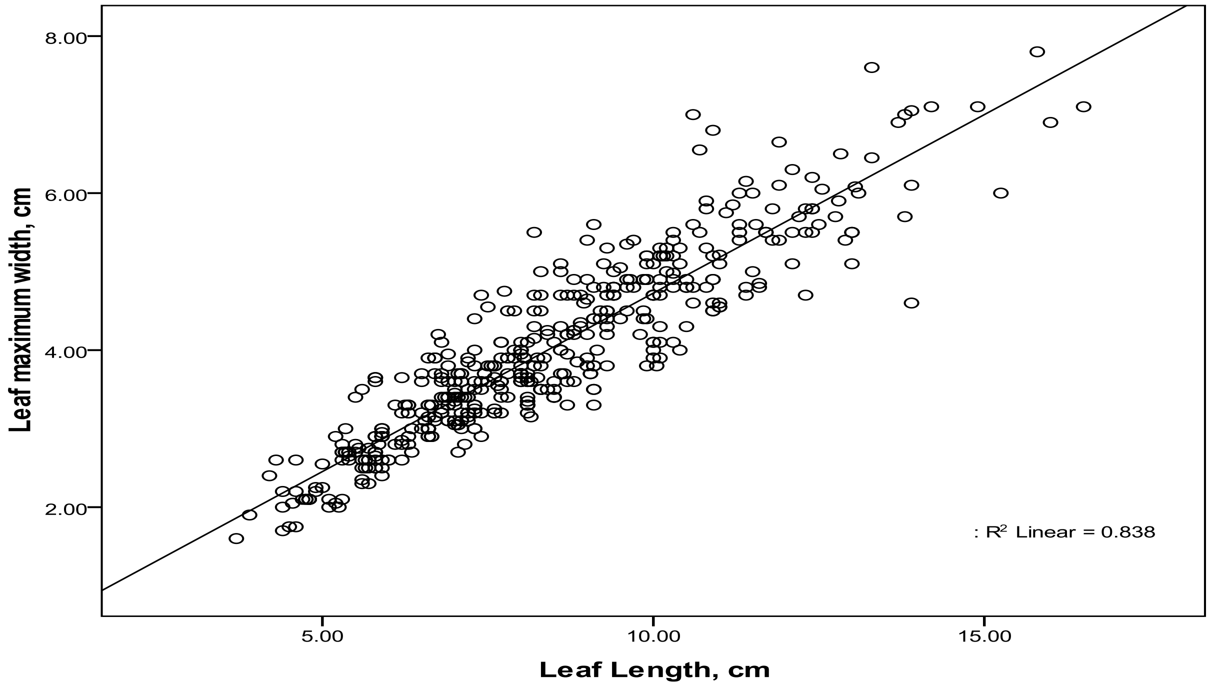

Figure 1. Relationship between Leaf length and Leaf maximum width

The RMSE values are about the same for the two equations (i) and (ii). But since R^2 is larger for the regression equation (i), and the regression equation (i) will later be used in this study for making further approximations.

Table 2 shows the regression coefficients, the coefficient of multiple determinations (R^2) and the RMSE for the model equations for determining the leaf area of Clerodendrum volubile. Since R^2 is generally greater than 0.95, all the model equations are good fits and the regression equations are therefore very useful for predicting the leaf area of the plant. When the values of the regression coefficients are known, the values of the leaf area can easily be calculated for any measured value of L and W.

Table 2. Parameter estimates for the model equations 1, 2, 5, 6, 7, 8, 9 and 10 which describe the relationship between the true leaf area (A) and leaf dimensions (Leaf length, L and leaf maximum width, W)

Equation	Models Equations	Regression coefficients			R^2	df	RMSE
		a	b	c			
1	A = bLW	-	0.682 ± 0.003	-	0.992	485	2.516
2	A = a + bLW	0.146 ±0.235	0.679 ±0.006	-	0.966	484	2.517
5	Log(A) = a + bLog(LW)	0.157 ±0.011	0.994 ±0.007	-	0.976	484	0.038
6	Log(A) = a +Log(L) + clog(W)	-0.118±0.017	0.884±0.037	1.097	0.976	484	0.037
7	Log(A) = bLog(LW)	-	0.891 ±0.001	-	0.999	485	0.045
8	LogA = a + bLog L	-0.450±0.023	1.956±0.025	-	0.928	484	0.646
9	$A = a + b L^2$	0.977 ±0.360	0.311 ±0.994	-	0.919	484	3.894
10	$A = bL^2$	-	0.321±0.002	-	0.980	485	3.919

The Table 2 shows that although the coefficient of determination is large for equations 1 and 2, the RMSE is also large, showing that there will be a lot of error in using equations 1 and 2 because of the scatter of points about the best straight line. Equation 1 is identical with that of an sellipse where b= 0.78 and a triangle where b = 0.5. Since b = 0.682 in equation 1, the shape of the leaf of Clerodendrum volubile is closer to an elliptical shape than that of a kite of the same length (L) and maximum width (W). The model assuming an elliptical shape of length L and width W will however lead to an overestimation and will therefore not adequately predict the area of the leaf.

Differences in leaf shape may occur within individual leaves from the same species as found in Salix Viminalis [26]. In this study we found random differences in leaf shape and major changes in the shape between small and expanding leaves with L, and the large leaves.

The graphical relationships of the model equations 2, 5, 8 and 9 are shown in Figure 2, Figure 3, Figure 4 and Figure 5. The parameter estimates of the model equations are already given in Table 2.

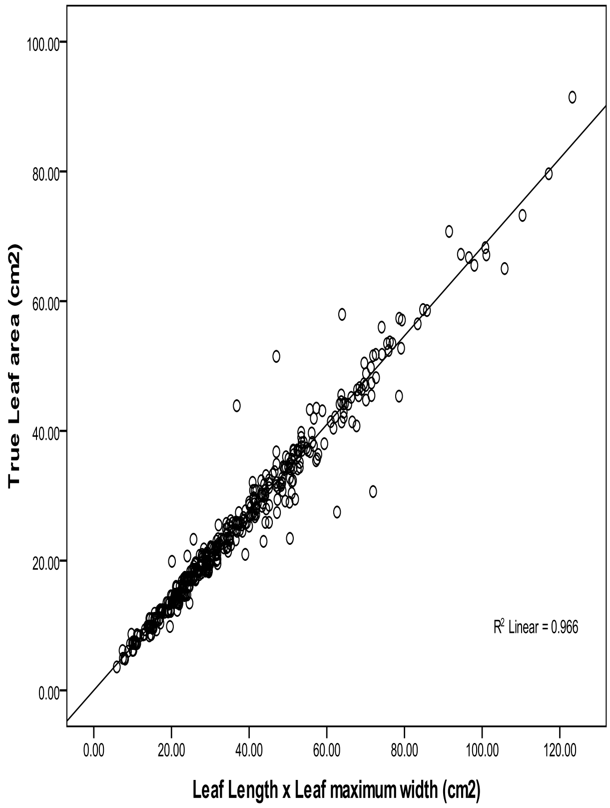

Figure 2. Relationship between the product of Leaf length x Leaf maximum width and the leaf True area

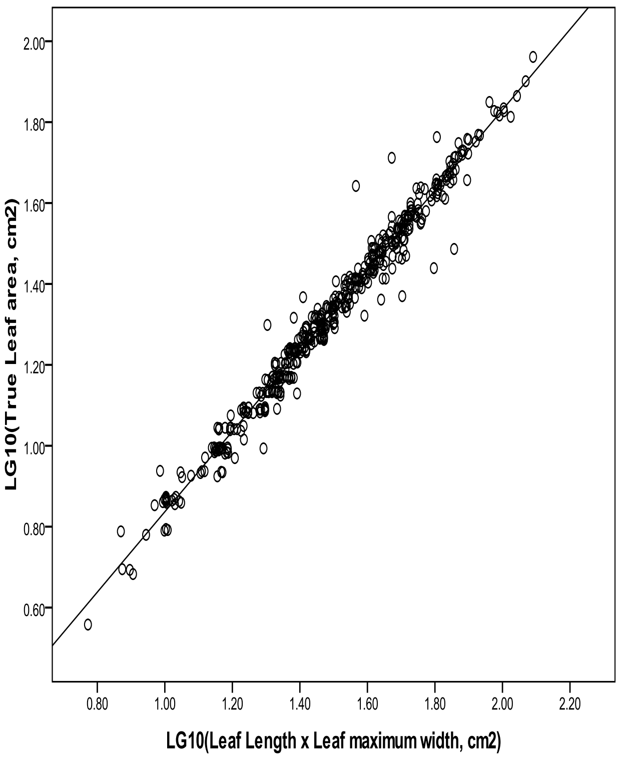

Figure 3. Relationship between logarithm of the product (Leaf length x Leaf maximum width) and the logarithm of the leaf True area (A)

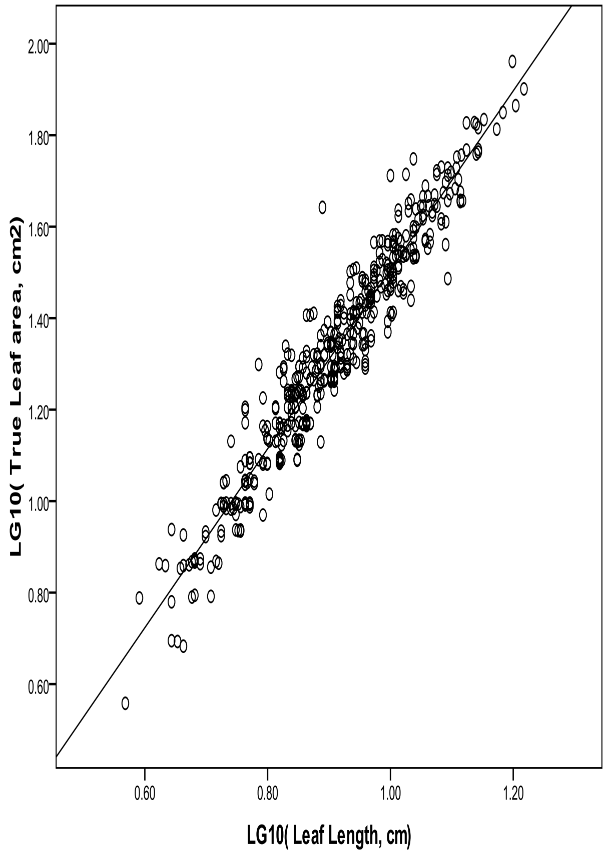

Figure 4. Relationship between logarithm of the Leaf length and the logarithm of the leaf True area (A)

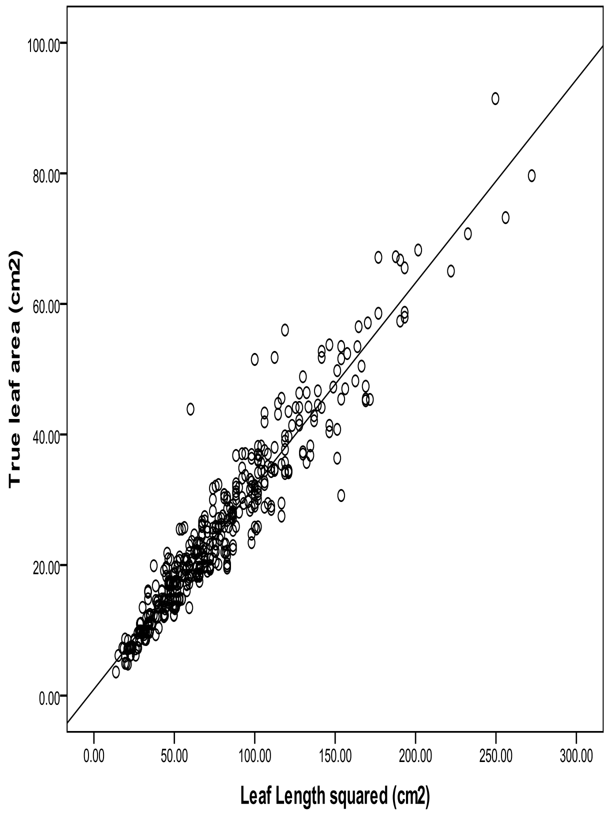

Figure 5. Relationship between the square of the leaf length (L^2) and the leaf True area (A)

When $W = \sigma L$**,** equation 1.0 ($A = KLW$) can be re-written for the small and large leaf areas as a power model of the form $A = b_4 L^2$, where b_4 is a constant. This simple leaf area power model is valuable as it requires measurement of only the leaf length which is easier to make for Clerodendrum volubile leaves, than the measurement of leaf maximum width. This simplifies the measurement procedures in the field [29], when large number of leaves have to be monitored and when one of the dimensions cannot be accurately or easily gauged. Of course at times in the field, the width of young leaves may be difficult to measure as the leaves do not open well enough to become perfectly flat. This is why the initial plot of Figure 1 is necessary for making a judicious judgment of what to do when preparing to carry out a large scale leaf area measurement in the field.

5. Conclusion

It is concluded that the equations 5, 6, and 7 provide more accurate estimation of leaf area than those based on single measurements of length (L). As the leaf length (L) is easier to measure in the field than the leaf maximum width for Clerodendrum volubile, the models of equations 8, 9 and 10 will enable researchers to make good rapid non-destructive measurements or repeated measurements on the same leaves when only the linear measurement of the leaf length is made.

The models for obtaining the leaf area of Clerodendrum volubile have been developed in a logical manner. As the understanding of plant growth and development increases, such logical mathematical models can be used for predicting the area of leaves of other shapes. Such equations will make it easy to relate the leaf area to plant factors such as response to fertilizers and irrigation, yield, drought stress, insect damage, soil nutrition and plant taxonomy. Finally, leaf area measurements based on linear dimensions of leaf length and leaf maximum width are very useful especially in cases where detachment of leaves from the plants are not required. The importance of estimating the leaf area precisely is stressed as precise model graphs constructed from the initial linear measurements of leaf length and leaf maximum width can later be used in the field to determine the area of individual leaves non-destructively.

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