A SIMPLE MATHEMATICAL MODEL FOR ESTIMATING LEAF AREA OF *CORCHORUS OLITORIUS* FROM LINEAR MEASUREMENTS

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Abstract

*Leaf area measurements are of value in physiological and agronomic studies. The use of prediction models to estimate leaf area is a simple, accurate and non–destructive method. A total of 300 leaves were selected randomly from an experimental field over a period of three months, which represented different leaf sizes ranging from very small (< 1 cm width), small (2 cm width), medium(3 cm width), large(4 cm width) and very large leaves (> 5 cm width). The maximum lamina length (L) and lamina width (W) were measured with a meter rule (cm), while the actual leaf area (ALA) were measured with LI–COR 3000 leaf area meter. Data were subjected to regression analysis. The best fit model was selected based on F test, mean square error (MSE) and coefficient of determination (R^2). Correlation coefficients (r) of all the parameters were significant at P < 0.001. Product of Length and width (L*W) correlated best with actual leaf area having a correlation coefficient (r) of 0.968. The results of asymptotic, quadratic–by–linear (qdl), quadratic–by–quadratic (qdq) and linear regression produced twenty–six (26) different possible models of the linear measurement. Out of which product of length and width (LW)of quadratic–by–quadratic regression, model number 20 (LA = 142.1 + (–142.3 + 6.67*LW)/(1– 0.04179*LW – 0.000236 ($LW)^2$) had the highest coefficient of determination (R^2) of 95.7% and the lowest mean square error and standard error of estimate of 0.6435 and 0.802 respectively. However model number 22– linear regression without constant (ALA = 0.635 LW; R^2 = 95.2 %, MSE = 0.711 and SE = 0.844) was recommended as the model for predicting leaf area of Corchorus olitorius because of its simplicity and ease of utilization.*

Keywords: *Corchorus olitorius*, linear model, leaf area prediction

INTRODUCTION

The use of regression equations to estimate leaf area is a non–destructive, simple, quick, accurate, reliable and cheap method. Accurate and simple mathematical models eliminate the need for leaf area meters or time–consuming, geometric reconstructions (Gamiely *et al.*, 1991). Leaf area measurements are of value in physiological and agronomic studies (Guo & Sun, 2001). Among the various methods to measure leaf area (Sepaskhah, 1977; Strik & Proctor, 1985; Pedro Júnior *et al.*, 1986; Robbins & Pharr, 1987; Silva *et al.*, 1998;), the nondestructive methods allow the replication of measurements during the growth period, reducing some of the experimental variability associated with destructive sampling procedures (NeSmith, 1992). They are very useful in studies of plant activity, which require a non–destructive method of measuring leaf area and also when the number of available plants is limited.

*Corchorus olitorius***,** called Jew's mallow or jute mallow in English and *Corete potagére* in French, is popular as a vegetable in dry or semi–arid regions and in the humid areas of Africa. Due to the fact that *C. olitorius* is basically grown for its leafy vegetable, the leaves constitute the economic part of the plant. Agronomic evaluation of the plant involving leave sampling, should be non–destructive to reduce economic loses. Although many methods are available for leaf area measurements, the use of leaf area as a variable in plant growth analysis and physiological studies is limited owing to the time consuming and laborious methods involved in its measurement. Moreover, although sophisticated electronic instruments provide accurate and fast leaf area measurement, they are expensive especially in developing countries (Bhatt & Chanda, 2003) and sometimes require detachment of leaves, which is destructive particularly for leafy vegetable like *Corchorus olitorius*. Hence, there is the need to develop economically cheaper and technically easier but sound method for leaf area measurement. The objective of the study therefore, was to develop a simple mathematical model for leaf area prediction of *Corchorus olitorius* from linear measurement.

MATERIALS AND METHODS

The study was conducted at Federal College of Forestry, Ibadan situated on latitude 7º 26' N and longitude 3º 26' E. The eco–climate of the area is tropical rain forest. Leaf samples were taken from the young and mature plants. The leaves were grouped according to their sizes (very small (< 1 cm width), small (2 cm width), medium (3 cm width), large (4 cm width) & very large leaves (> 5 cm width)). A total of 300 leaves were measured in the experiment. The actual leaf area (ALA) of the leaves were measured using a LI–COR – 3000 leaf area meter (LI–COR, Lincoln, NE, USA) and it was calibrated with standard metal disk of 10 and 50 cm^2. The lamina leaf length (L) was measured in cm from the lamina tip to the point of petiole intersection along the lamina midrib with the aid of a meter rule graduated in centimeter (cm) while the lamina leaf width (W) was also measured in cm tip to tip at the widest part of the lamina.

Correlation analysis of the actual leaf area (ALA) and for the independent variables L, W, their squares (L^2 and W^2), sums of length and width (L+W) and the products of length and width (LW) were calculated. Data were fitted to asymptotic, quadratic–by–linear (qdl), quadratic–by–quadratic (qdq) and linear regressions to establish the best fitted regression model, which represents the relationship between ALA and combinations of L and W. ALA was taken as the dependent variable (Y) and the combinations of L and W as the independent variable (X). Statistical criteria for model selection were F test, mean square error (MSE), standard error of estimate (SE) and coefficient of determination (R^2) (Cousens, 1985),

RESULTS AND DISCUSSION

Correlations of all the parameters are shown in Table 1. The linear measurements, lamina length and square lamina length were fairly correlated to the actual leaf area with correlation coefficients (r) of 0.802 and 0.767 respectively, while lamina width and square lamina width correlated better with actual leaf area having r values of 0.880 and 0.874, respectively. However, products of lamina length and width (L*W) correlated best with actual leaf area with correlation coefficient (r) of 0.977. The sum of lamina length and width (L+W) had correlation coefficient, (r) of 0.945. All the coefficients were statistically significant at P = 0.001

Table 1: Correlation matrix of actual leaf area and linear leaf measurements of *Corchorus olitorius*

	Actual Leaf area	*Length*	*Length²*	*Width*	*Width ²*	**L*W**	*L+W*
Actual leaf area	1.000						
Length	0.802**	1.000					
Length²	0.767**	0.989**	1.000				
Width	0.880**	0.502**	0.451**	1.000			
width ²	0.874**	0.487**	0.439**	0.993**	1.000		
L*W	0.977**	0.848**	0.819**	0.873**	0.869**	1.000	
L+W	0.945**	0.935**	0.907**	0.776**	0.762**	0.976**	1.000

**Correlation is significant at the 0.01 level (2–tailed).

The results of regression models of relationships between actual leaf area and linear leaf measurements (length and width), square of length and width (L^2 and W^2), product of length and width (L*W), and sum of length and width (L+W) measurements of *Corchorus olitorius* are presented in Table 2 and figures 1–6. Twenty–six (26) possible leaf area predicting models of *Corchorus olitorius* were derived from the linear measurements. The single dimensional parameters – lamina length (L) and lamina width (W) poorly estimated actual leaf area with rather low coefficients of determination, (R^2) range of 64.0 – 70.2 % and 76.7 – 77.1 % for lamina length and width respectively. This concurred with earlier studies that leaf area measurement is not a uni–dimensional phenomenon (Kathirvelan & Kalaiselvan, 2007; Jayeoba *et al.*, 2006; Cristofori *et al*, 2007). The square of the leaf length and width (L^2 and W^2) equally estimated the leaf area poorly with R^2 and mean square error (MSE) ranges of 58.4 – 69.8 % and 4.502 – 6.205 for square leaf length (L^2) and 76.1 –77.0 % and 1.8 –1.89 for square leaf width (W^2), respectively. However, the sum of lamina length and width explained the variation of leaf area measurement better than the single dimensional measurement with a range of R^2 and MSE of 89.2 – 89.6 and 1.56 – 1.60, respectively.

The product of lamina length and width predicted the leaf area of *C. olitorus* best with a much higher range of R^2 (95.2 – 95.7) and much lower mean square error of (0.644 – 0.713) and lowest standard error range of (0.802 – 0.844).

Product of lamina length and width (L*W) had the lowest mean square error (MSE) of 0.6887, compared to other measured linear parameters (Table 2). This implied that the product of lamina length and width model had the lowest prediction/estimation error; therefore the model is most likely to give a more accurate estimate of actual leaf area measurement of *Corchorus olitorius*. Many researchers have also reported that leaf area can be estimated by linear measurements such as leaf width and leaf length in the following plants: cucumbers (Robin & Pharr, 1987), onions (Gamiely *et al.*, 1991), oranges (Arias *et al.*, 1989), coconuts (Mathes *et al.*, 1990) and bananas (Potdar & Pawar, 1991). The same authors found that there were close relationships between leaf area value, leaf length and leaf width for these plants (R^2 = 0.76 to 0. 99 for cucumber, R^2 = 0.9841 to 0.9884 for grapes, R^2 = 0.89 to 0.93 for oranges, and R^2 = 0.95 to 0.98 for coconut).

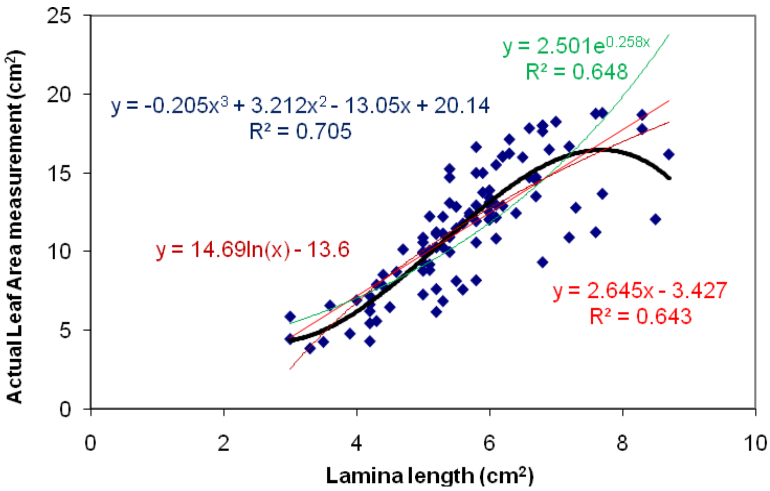

Fig. 1: Relationship between actual leaf area and the lamina leaf length of *Corchorus olitorius*

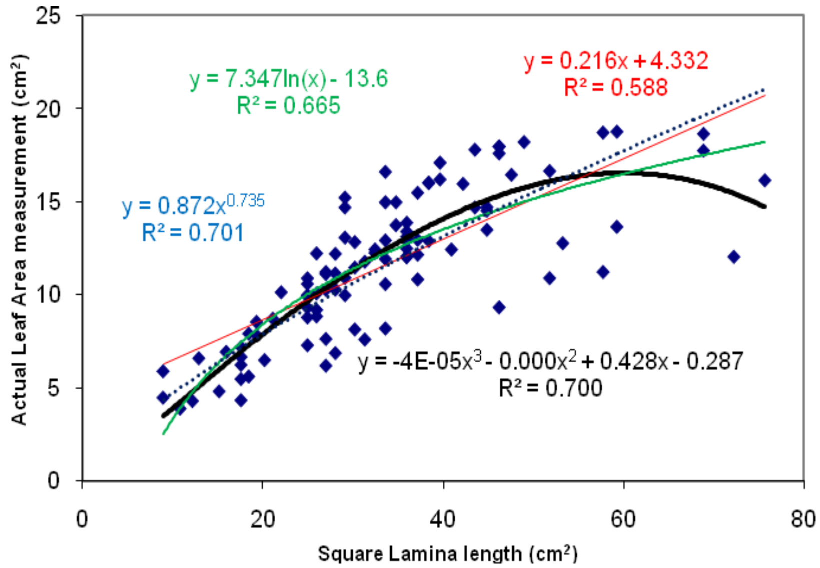

Fig. 2: Relationship between actual leaf area and the square lamina leaf length of *Corchorus olitorius*

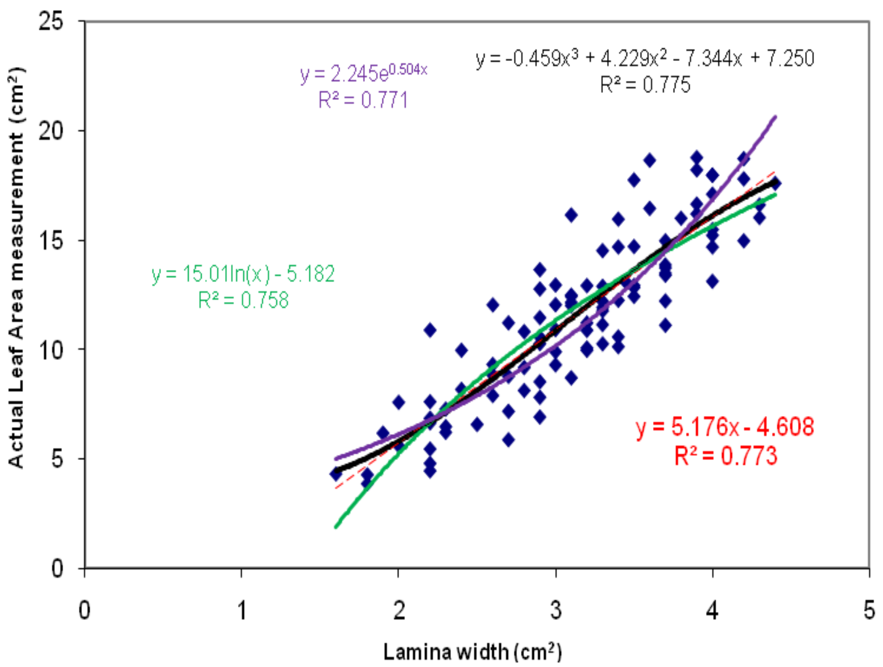

Fig. 3: Relationship between actual leaf area and the lamina leaf width of *Corchorus olitorius*

Table 2: Regression models of relationships between actual leaf area and linear leaf measurements (length and width), square of length and width (l^2 & w^2), product of length and width (l*w), and sum of length and width (l+w) measurements

Parameter	Model method	Models	F–test	MSE	R^2	Se±
(A) Lamina length (L)	Asymptotic Regression	1) LA =A + B*(R$^{(L)}$) A= 24.33; B= – 41.49 ; R = 0.8079	<0.01	5.011	664	2.24
	Quadratic–by–linear(qdl)	2) LA = A + B / (1 + D*L) + C*L A = –6.61 B = – 2.05 ; C = 4.10 ; D= – 0.0984	<0.001	4.727	68.3	2.17
	Quadratic–by Quadratic (qdq)	3) LA = A + (B + C*L)/(1 + D*L + E*(L)^2 A= 9.81; B= –4.30; C= 0.843; D= – 0.3031; E= 0.0286	<0.001	4.502	69.8	2.12
	Gompertz Asymmetrical S–shaped curve	4) LA = A + C*EXP(–EXP(–B*(L–M))) A = 15.655: B= – 0.957 : C = – 12.21 : M = 5.434	<0.001	4.442	70.2	2.11
	Linear	5) LA = 2.646L – 3.34	<0.001	5.369	64.0	2.32
(B) Sq lamina length (L^2)	Asymptotic regression	6) LA =A + B*(R$^{(L)2}$) A = 18.55; B = – 22.33; R = 0.96244	<0.001	4.816	67.7	2.19
	Quadratic–by–linear (qdl)	7) LA = A + B / (1 + D*L^2) + C*L^2 A = 152: B = – 153; C = 1.14: D = – 0.00416	<0.001	4.621	69.0	2.15
	Quadratic–by–quadratic (qdq)	8) LA = A + (B + C*L^2)/(1 + D*L^2 + E*(L^2)^2 A = 11.93: B= – 7.50; C = 0.2388: D = – 0.0364 E = 0.000813	<0.001	4502	69.8	2.12
	Linear	9) A = 0.2162L^2 + 4.332	<0.001	6.205	584	2.49
(C) Lamina width (W)	Asymptotic regression	10) LA = A + B (R^{W}) A = – 550 B = 546; R = 1.009	<0.001	3.441	76.9	1.86
	Quadratic–by–linear	11) LA = A + B / (1 + D*W) + C*W A = – 4.71; B = 0.0122; C = 5.212 D = – 0.4934	<0.001	3.461	76.8	1.86
	Quadratic–by–quadratic	12) LA = A + (B + C*W)/(1 + D*W + E*(W)^2 A = – 23.2; B = 22.3; C = – 4.4; D = – 0.318; E = 0.0241	<0.001	3.472	76.7	1.86
	Linear	13) LA = 5.176 W – 4.608	<0.001	3.409	77.1	1.85
(D) Square Lamina width (W^2)	Asymptotic regression	14) LA = A + B* (R($^{(W)2}$) A = 27.41; B = – 26.88; R = 0.9473	<0.001	3.29	77.0	1.85
	Quadratic–by– linear (qdl)	15) LA = A + B / (1 + D*W^2) + C* W^2 A = 4.23; B = – 2.51; C = 1.155; D = – 0.038	<0.001	3.439	77.0	1.85
	Quadratic–by–quadratic	16) LA = A + (B + C* W^2)/(1 + D* W^2 + E*(W^2)^2 A = 211; B = – 209; C = 9; D = – 0.0357; E = –0.00023	<0.001	3.475	76.7	1.86
	Linear	17) LA = 0.8313W^2 + 3.094	<0.001	3.568	76.1	1.89
(E) Product of Lamina Length and Width (LW)	Asymptotic regression	18) LA = A + B (R^{LW}) A = 79.0: B= – 79.3; R =0.99101	<0.001	0.6807	95.4	0.825
	Quadratic–by–linear	19) LA = A + B / (1 + D*LW) + C*LW A = 0.320; B = – 0.128; C = 0.6398 D = – 0.02936	<0.001	0.6758	95.5	0.822
	Quadratic–by–quadratic	20) LA = A + (B + C*LW)/(1+D*LW + E (LW)^2 A = 142.1; B = –142.3; C = 6.67; D = – 0.04179; E = – 0.000236	<0.001	0.6435	95.7	0.802
	Linear (with constant)	21) LA = 0.608LW –0.544	<0.001	0.6887	95.4	0.830
	Linear (without constant)	**22) LA = 0.635LW**	**<0.001**	**0.713**	**95.2**	**0.844**
(F) Sum of Lamina Length and Width (L+ W)	Asymptotic regression	23) LA = A + B(R$^{(l+W)}$) A = –120; B = 113; R = 1.0175	<0.001	1.611	89.2	1.27
	Quadratic–by– linear (qdl)	24) LA = A + B / (1+D*(l+w)) + C*(l+w) A = –9.93; B = – 0.238; C = 2.406; D= – 0.2206	<0.001	1.599	89.3	1.27
	Quadratic–by–quadratic	25) LA = A + (B + C* (L+W))/(1 + D* (L+W) + E*((L+W))^2 A = 13.2; B = – 8.9; C = 0.944 ; D = – 0.1529; E = 0.00917	<0.001	1.559	89.6	1.25
	Linear	26) LA = 2.3276 (l+w) – 8.454	<0.001	1.579	89.3	1.26

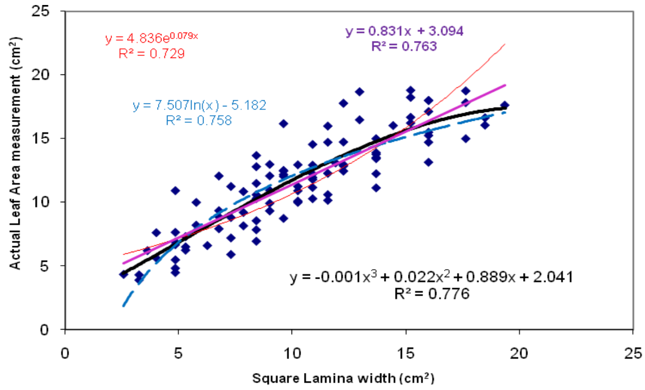

Fig. 4: Relationship between actual leaf area and the square lamina leaf width of *Corchorus olitorius*

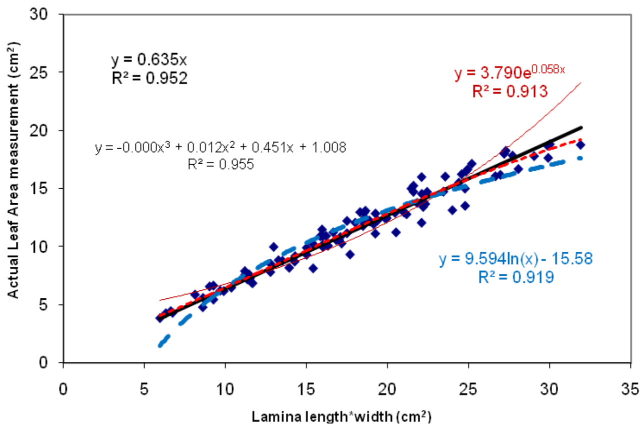

Fig. 5: Relationship between actual leaf area and product of the lamina length and leaf width of *Corchorus olitorius*

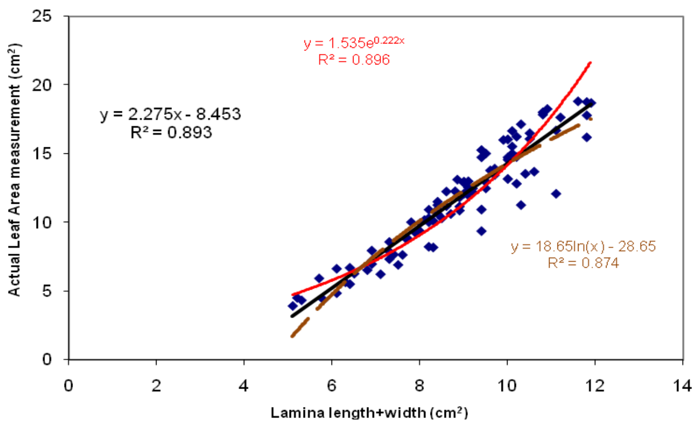

Fig. 6: Relationship between actual leaf area and sum of the lamina length and leaf width of *Corchorus olitorius*

CONCLUSION

The models developed from the study will enable researchers (breeders, agronomists and horticulturists) that are interested in the study of growth and development of *Corchorus olitorius* either in the field or at the green house to study the leaf physiology without destroying the leaves and compromise precision and accuracy. All the models developed could be adopted, depending on the level of precision desired. Based on the set statistical criteria, product of length and width (L*W) of quadratic–by–quadratic regression, model number 20 (LA = 142.1 + (–142.3 + 6.67*LW)/(1– 0.04179*LW – 0.000236 $(LW)^2$) had the highest coefficient of determination (R^2) of 95.7 % and the lowest mean square error and standard error of estimate of 0.6435 and 0.802, respectively. However model number 22– linear regression without constant (ALA = 0.635 LW; R^2 = 95.2 %, MSE = 0.711 and SE = 0.844) was recommended as the model for predicting leaf area of *Corchorus olitorius* because of its simplicity and ease of application. The equation could be utilized by inserting it into a cell in spreadsheet applications (EXCEL 5.0, 6.0, 7.0 or 8.0.) to calculate the leaf area of *Corchorus olitorius* or other plants with similar leaf configuration.

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