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Regression Model for Computing Leaf Area and Assessment of Total Leaf Area Variation with Frond Ages in Oil Palm

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Abstract: In this study a regression models for accurate estimation of leaf area from simple measured leaves length and middle width were described as well as assessment of total leaf area variation with frond ages. Results shows that total leaf area of the frond are decreased with increase frond ages and upper frond represents more leaf area than lower frond at same palm. In this study two models (linear and log-linear) were proposed for accurate estimation of leaf area. (a) $L_{ac} = 0.80 \times (L.W)$ And (b) $\text{Log } L_{ac} = 0.957 \times \text{Log } (L.W)$, where L_{ac}, L and W represents the actual leaf area, leaf length and leaf width respectively. Statistical analysis indicates a high degree of association ($R^2 = 0.99$) and the low standard errors of estimation were 0.7477. The standard error of estimate of coefficient was 0.0032 (model 'a'). Logarithmic transform of data were also well fitted both linear and non-linear regression. However, it is considered only linear model for simplicity. These Logarithmic transform of data also indicate a high degree of association ($R^2 = 0.99$) and the low standard error of estimation were 0.02. The standard error of estimate of coefficient was (0.0005). This model was validated using other experimental results, which showed a good agreement between measured and estimated leaf area.

Key words: Regression model, leaf area variation, oil palm frond

INTRODUCTION

Leaf area is of value as an index of plant growth and in addition, is related to the accumulation of dry matter, plant metabolism and yield. Crop quality and maturity may also be related to leaf area. Accurate estimates of leaf area index (LAI, projected leaf area per unit of ground area) are needed in ecosystem analysis because of the importance of canopy structure in gas, water, carbon and energy exchange. Methods to rapidly obtained accurate estimates of LAI in the forest are needed as ecologists attempt to scale-up ecosystem process pressing regional and global ecological questions[1]. Leaf area production is essential for energy transference and mass accumulation processes in crop canopies. Leaf area in indicative of light interception and growth[2] and also essential component of plant growth analysis and is often used in plant physiology research[3]. So, rapid, reliable and objective estimations of leaf area index (LAI) are essential for numerous studies of atmosphere-vegetation interaction, as LAI is very often a critical parameter in process-based models of vegetation canopy response to global environmental change[4].

Leaf area is also important for analysis of canopy structure. Canopy structure is usually quantified in terms of leaf area and the spatial and geometric organization of individual elements within a defined canopy envelope. The problems associated with quantification generally increase with the size and temporal and spatial heterogeneity of the canopy. Norman and Campbell[5] broadly classified the methods available for quantifying canopy structure as being either direct or indirect. Direct methods are often reliable but are usually destructive and become excessively laborious when applied to large or temporally heterogeneous canopies. However, the closeness of the coupling between radiation exchange and canopy structure often enables canopy characteristics to be inferred from radiation measurements using theory developed from the Monsi and Saeki/Beer's law equation[6,7]. Simple and accurate methods for estimating leaf area are therefore necessary.

The choice of a sufficiently accurate method of measuring leaf area depends both on the properties of the leaves and on the purpose of the measurement. Several methods have been devised to determine leaf area of various crops, the most common method being the

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development of a mathematical regression formula using easily measured leaf parameters. Although simple methods exist for estimating leaf area of some common crops, like maize, sorghum, cotton sugar cane and sunflower. In oil palm, it is needs to develop. The main objective of this study was to determine the coefficient for estimating accurate leaf area and to find out leaf area variation with frond ages of oil palm.

MATERIALS AND METHODS

Study site: Measurements were made in Malaysian Palm Oil Board (MPOB) ENOVECY research plot. MPOB is situated about 30 km north from Kuala-Lumpur, Latitude 2° 58′ 0.36″ N, Longitude 101° 44′ 26″ E) at an average altitude of 66.5 m from sea level. Agronomy division at MPOB in 1998 planted the plantations. 5-6 years old uniform palm Tenera (DxP) for this study, were considered.

Instrument description

LI-3000a leaf area meter: The LI-3000A combines an easy to use, microprocessor controlled readout console with the proven scanning technology of the LI-COR LI-3000 sensor head to provide a powerful system for portable non-destructive leaf area measurements. The LI-3000A utilizes an electronic method of rectangular approximation to provide one mm^2 resolution. The readout console logs leaf area, leaf length, average width and maximum width as the scanning head is drawn over a leaf. Files can be viewed on the display or output through the RS-232C interface to a computer or printer. For large numbers of detached leaves, the LI-3000A can be used with the LI-3050A Transparent Belt Conveyor Accessory for greater measurement efficiency (Li-cor).

Measurement of leaf area

Measurement of leaf area by manual method: A general rule of chosen the leaf is rank 17, near the middle of the crown, which is assumed to be representative of the crown as a whole. For more accurate measurement, the leaf rank of 1, 9, 17 and 25 were chosen in this study.

The chosen leaf (frond 1, 9, 17 and 25) was cut at the petiole level. After cutting the frond was brought in cool room as soon as possible to prevent from shrinkage. The length of the rachis was measured by counting the leaflet in both side of rachis. Rachis length was divided in to equal ten sections.

Leaflets were chosen from both sides of the rachis. An upper and lower leaflet with good edges was taken from the middle of each section. Both side leaflets were numbered 1 to 10 on the underside by using permanent marker.

Total twenty leaflets (each side ten leaflets) were placed according to numbering on the table. For measurement, a steel measuring scale was taken and carefully measured length (L) and middle width (W) in cm of each leaflet.

The area of each leaflet were measured by following equation:

Leaf Area = k x Length x Width

Where, K = Empirical Co-efficient which needs to compute.

So, the appropriate dimension was sought among samples of 400 fresh leaves.

Measurement of leaf area by leaf area meter: After chosen the leaflets, cutting, numbering and placing was performed on the table as same way as manual measurement. After placing on the table, each leaflet area was measured by portable Leaf Area Meter. For more information, leaf area, maximum width, average width and maximum length was recorded and this maximum length was compared by manually measured length and then adjusted the length of the Leaf Area Meter. Finally, more perfect results were recorded in the data sheet.

Relationship of linear measurement of leaf: The most frequently used leaf properties to be measured and related to leaf area have been leaf length and leaf width. Relationships, which have been found satisfactory, include:

$$A = k.\ L.\ W$$

Where, K is the coefficient, which have to determine for accurate measurement of leaf area.

The standard linear regression equation can be express generally by:

$$y = bx + a$$

Where, y = leaf area, b is an empirical coefficient, "a" is a constant and x is a product of length (L) and width (W).

RESULTS AND DISCUSSION

Variation of total leaf area per frond with frond ages: A good relation was found between total leaf area per frond with frond ages. Figure 1 shows that total leaf area was decreased with increased frond ages.

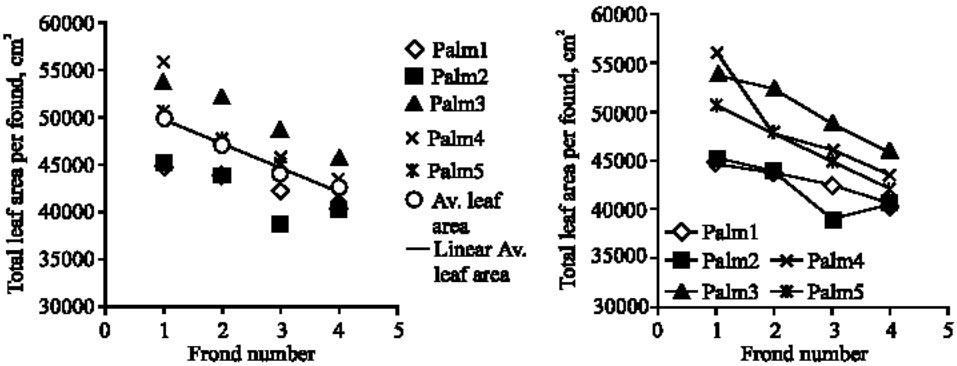

Fig. 1: Relationship between total leaf areas per frond with frond ages. (Scale 1, 2, 3 and 4, represents of frond 1, 9, 17 and 25)

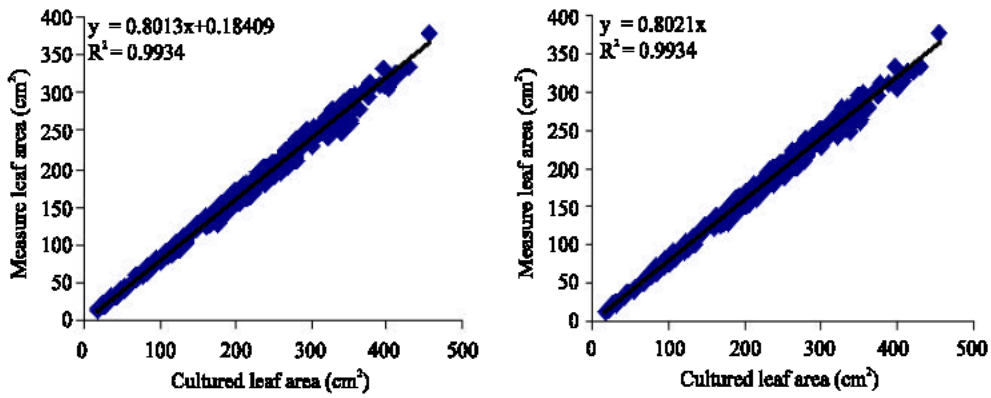

Fig. 2: Scatter diagram of relationship between measured and calculated leaf area in oil palm

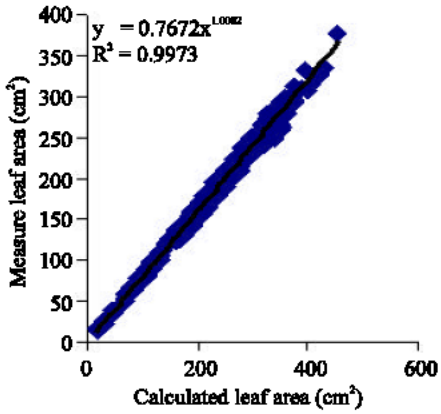

Fig. 3: Scatter diagram of relationship between measured and calculated leaf area in oil palm

For manual leaf area measurement, normally we chose frond 17. From these observations it is clear that the total leaf area varied from frond to frond for every palm. It is also mentioned that lower frond always represent lower leaf area. So if ones would like to determine LAI or use leaf area for modeling, needs to consider different ages frond, such as frond 1 to frond 25.

Calculation of co-efficient and developed a simple regression model: Linear relationships between calculated and measured leaf area:

Points are plotted for calculated leaf area and measured leaf area (Fig. 2). Figure shows that the relation between calculated leaf area and measured leaf area was linear. Data indicate a high degree of association ($R^2 = 0.99$) and the low standard error of estimation were 0.7477. The standard error of estimate of coefficient was (0.0032). From these observations we proposed two linear models:

$$L_{ac} = 0.801\ (L.W) + 0.18 \qquad (1)$$

Where, L_{ac} is represents the actual leaf area, 0.801 is a coefficient, L is a maximum length, W is a middle width and 0.18 is a constant value. Without considering constant, the equation will be following form:

$$L_{ac} = 0.802\ (L.W) \qquad (2)$$

In this case, the coefficient is 0.802 and estimation of standard error of coefficient is 0.0014, which lower then previous one. So for oil palm the 2nd

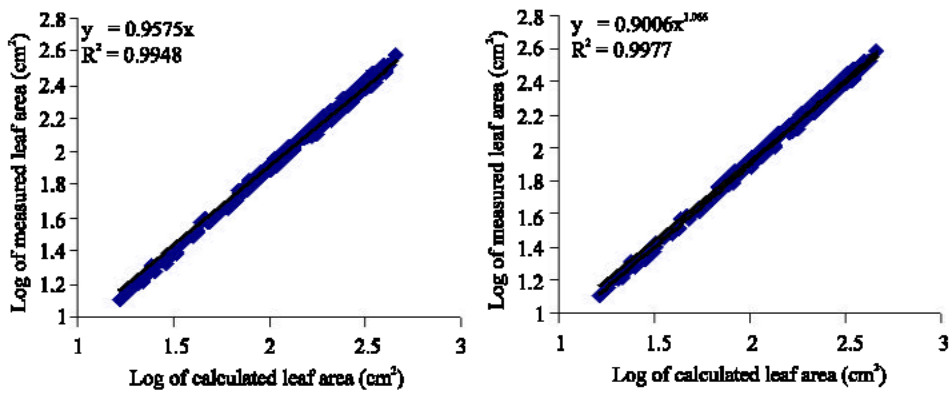

Fig. 4: A logarithmic transformation of the data was represents calculated leaf area vs. measured leaf area

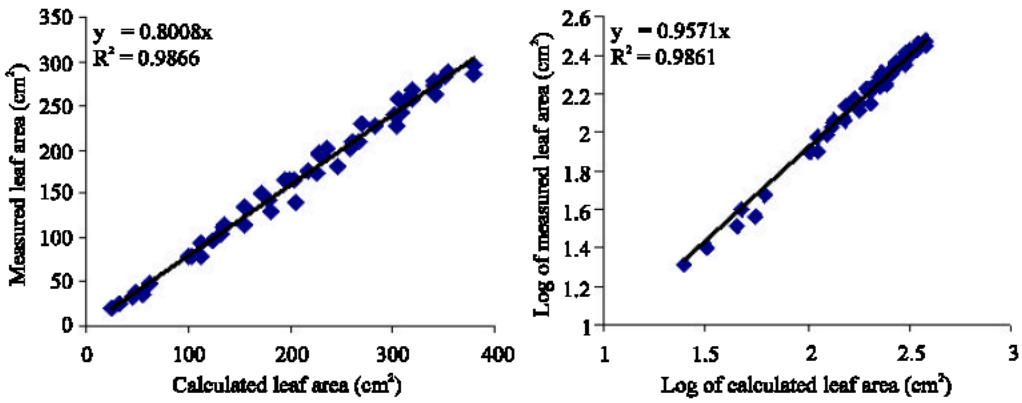

Fig. 5: Relationship between measured to predicted leaf area for both linear and log-linear models

regression equation is more appropriate to actual leaf area estimation.

We also represent the relationship between measured and calculated leaf area by non-linear regression equation. From Fig. 3, we get found a non-linear model for calculating actual leaf area from measured leaf length and width.

Data indicate a high degree of association ($R^2 = 0.999$) and the low standard error of estimation were 0.03. The standard error of estimate of coefficient was (0.002) and the standard error of estimate of constant was 0.01. It clear shows that data were also strongly fitted in non-linear relationships.

Figure 4 shows that logarithmic transform of data were well fitted both linear and non-linear regression. For linear regression data indicate a high degree of association ($R^2 = 0.99$) and the low standard error of estimation were 0.02. The standard error of estimate of coefficient was (0.0005). For non-linear regression $R^2 = 0.99$, standard error of estimation were 0.008 and the standard error of estimation of coefficient was (0.002) and the standard error of estimate of constant was 0.001. From this observation we proposed a mathematical linear model for calculating actual leaf area as follows:

$$Lac = 0.957 \times Log\ (L.W) \quad (3)$$

Validation of the regression models: A separate experiment was conducted for validation of the models at same experimental location. Leaflets were selected randomly from whole of the oil palm plantation including small and large leaflet. Total fifty leaflets were selected for the validation experiment. Both direct and indirect (according to above description) were used to determination of Leaf area. Leaf area obtained independently of this study used to validate the developed models by plotting calculated leaf area and measured leaf area (Fig. 5).

Figure 5 shows that both linear and non-linear model provided the closed estimation of leaf area. However linear relation was more appropriate. From linear relationships $R^2 = 0.98$, standard error of estimation were 9.37, the standard error of estimate of coefficient was (0.005) and predicted coefficient was.801. For log-linear

regression $R^2 = 0.99$, standard error of estimation were 0.07 and the standard error of estimation of coefficient was (0.003) and predicted coefficient was 0.957. So from statistical analysis it show that log-linear relationship was all most same as measured leaf area. Therefore, we consider the non-linear model for leaf area measurement.

Actual leaf area can be estimated from simply measurement by leaf length and leaf width using proposed following generalized linear or log-linear model:

$$L_{ac} = 0.80 \times (L.W) \quad (a)$$

or

$$\text{Log } L_{ac} = 0.957 \times \text{Log } (L.W) \quad (b)$$

From the results it is shown that linear or log linear model was more precise than non-linear models. From linear model, the empirical coefficient was 0.80, which were comparable of other author who estimated the coefficient for another crop. Such as 0.77 for sunflower[8], 0.668 also for sunflower[9], 0.74 for sugarcane and 0.64 for cowpea[10], 0.73 for maize[11] and 0.75 for fully expand sorghum leaves[12]. Norman and Campbell[5] stated that this empirical coefficient could provide non-destructive leaves are estimates to within 0.05% accuracy. But in oil palm nobody attempt this. From other crop observation and model validation it seems to be appropriate. So these models could be used for measured LAI or accurate leaf area measurements in the oil palm plantation.

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