Estimation of Individual Leaf Area by Leaf Dimension using a Linear Regression for Various Tropical Plant Species

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Abstract. Leaf area estimation is significant to assess leaf development and plant growth. A simple and efficient model (Regression model) was developed to estimate leaf area of various tropical plant species using leaf dimension (length x width). The objective of this study was to determine a relation between leaf area and leaf dimension to get the best fit line of a linear regression. A total of twenty plant species were selected at Miri, Sarawak, Malaysia. The leaf shape and plant growing environment were investigated as a background data. The leaf shapes were elliptic, acuminate, aristate, obtuse, lobed, linear, peltate and lanceolate. The recorded plant growing environment were location, soil pH and sunlight exposure. The plants grew at a slope or flat, shaded or high exposure of sunlight with the soil pH between 4.8 and 7.3. A regression equation for each leaf was established with coefficient of determination (R²) of 0.9. It strongly proved that the leaf areas of all the plant species are well correlated with leaf dimension (length x width). The linear regression is not influenced by different leaf shape and growing environment. Generally, the plant grew at high exposure of sunlight indicated higher leaf area. There is no obvious trend of leaf area at different soil pH. From the R² values, it concluded that the leaf area of individual plant can be estimated by the linear regression established in this study by determining the leaf length and width.

1. Introduction
Leaf area is an important parameter to determine biophysical condition such as light interception, photosynthesis and evapotranspiration [1]. Leaf area can be estimated accurately by establishing its regression model from the measurement of leaf length and leaf width [2]. The regression model is a non-destructive analysis technique because this technique does not destroy the plant, and the plant growth can be determined periodically [3]. Leaf area estimation is useful for a phenology study which the plant development could be assessed in responding to environment. This phenology study may contribute to the field of conservation, agriculture, ecology and evolution [4]. Phenological stages responding to environmental factors provide a consistent ecological biometric identification of climate change [5]. The aim of this research was to develop a linear regression analysis models to analyse relationship between leaf area and leaf dimension (length x width) for various tropical plant species. These linear regression analysis models are able to be used for plant leaf area estimation.

2. Materials and Methods
A total of twenty plant species were selected at Miri, Sarawak, Malaysia. The leaf shape and plant growing environment were investigated as background data. The plant growing environment recorded were location, soil pH and growing sunlight condition.

2.1. Plant species
The selected plant species were adult plant with 90% fully expanded leaves which are healthy and active in photosynthesis. The scientific name of selected plant species are listed in Table 1. For each plant species, total of thirty (30) leaves collected were in the different sizes ranging from the smallest to the biggest. The leaf shapes collected were linear, elliptic, acuminate, obtuse, lobed, peltate, lanceolate, aristate (Table 1).

| No | Plant species                  | Leaf shape | Soil pH | Growing environment                                      |
|----|--------------------------------|------------|---------|---------------------------------------------------------|
| 1  | Annona muricate                | Elliptic   | 6.7     | Near to the small drainage, whole-day sunlight exposure  |
| 2  | Arbutus menziesii              | Elliptic   | 5.9     | Roadside, whole-day sunlight exposure                    |
| 3  | Artocarpus integer             | Elliptic   | 6.5     | Roadside, whole-day sunlight exposure                    |
| 4  | Bougainvillea glabra           | Acuminate  | 7.3     | Down-slope area, expose to sunlight during afternoon time only |
| 5  | Cassia fistula                 | Aristate   | 6.3     | Flat ground, whole-day sunlight exposure                 |
| 6  | Citrus limon                   | Elliptic   | 6.8     | Flat ground, whole-day sunlight exposure                 |
| 7  | Duranta erecta                 | Aristate   | 5.3     | Compete with other same species, under shaded area with less sunlight exposure |
| 8  | Excoecaria cochinchinensis     | Elliptic   | 7.0     | Compete with other same species, under shaded area with less sunlight exposure |
| 9  | Gardenia jasminoides           | Elliptic   | 5.5     | Compete with other same species, whole-day sunlight exposure |
| 10 | Hibiscus rosa-sinensis         | Aristate   | 7.2     | Shaded area with less sunlight exposure                  |
| 11 | Hypoestes phyllostachya        | Obtuse     | 5.3     | Compete with other same species, under shaded area with less sunlight exposure |
| 12 | Jatropha integerrima            | Lobed      | 6.9     | Roadside, whole-day sunlight exposure                    |
| 13 | Lantana camara                 | Obtuse     | 6.0     | Compete with other same species under shaded area with less sunlight exposure |
| 14 | Mangifera indica               | Linear     | 6.4     | Roadside, whole-day sunlight exposure                    |
| 15 | Nephelium lappaceum            | Obtuse     | 7.0     | Compete with other same species, under shaded area with less sunlight exposure |
| 16 | Photinia fraseri               | Elliptic   | 6.6     | Sunlight exposure during afternoon time only             |
2.2. Growing environment
A pH meter was used to measure soil pH for each plant species by digging up 2 – 3 inches hole into the soil. The hole was filled with rain water to create a pool for pH measurement. The soil pH ranged between 4.8 and 7.3 (Table 1). The location and sunlight condition were observed for the plant which the leaves were collected. The sunlight condition of sampling areas were shaded, less exposure or whole-day exposure as shown in Table 1.

2.3. Leaf dimension
Leaf length and width were measured using a ruler for every single leaf. The leaf length was measured from leaf apex until the leaf edge connecting to petiole. The leaf width was measured from left to right for its wide margin. The leaf dimension was obtained by multiplying leaf length and leaf width (LW).

2.4. Linear regression
The ImageJ software was used to analyse the leaf image captured for adaxial and abaxial surfaces to measure actual leaf area. From the data obtained or the leaf area and leaf dimension, the relation between leaf area and leaf dimension was plotted to get the best fit line of a linear regression. A coefficient of determination ($R^2$) was identified to indicate the estimation of leaf area via leaf dimension related to the actual leaf area.

3. Results and Discussion
A regression equation for each plant species was established with coefficient of determination ($R^2$) of 0.9 (Table 2). It showed that the linear regression models with leaf dimension (LW) is accurate to be used for leaf area estimation for all the selected tropical plant species in this experiment. If $R^2$ closes to 1.0, it indicated a more accurate leaf area estimation [6]. Among all the plant species, *Arbutus menziesii*, *Cassia fistula* and *Viburnum suspensum* (Figure 1) were the plant species indicating the highest $R^2$. The leaves of both *Arbutus menziesii* and *Viburnum suspensum* were in elliptic shape. The leaf of *Cassia fistula* was in aristate shape. *Jatropha integerrima* which the leaf was in lobed shape showed the lowest $R^2$, 0.9436. The plant species were under different growing environment such as various soil pH and sunlight condition, however, they could perform in a strong relation in the linear regression [7, 8].

Table 2. Linear regression relation between actual leaf area (A) and leaf dimension (LW).

| No | Plant species           | Regression equation | Coefficient of determination, $R^2$ |
|----|------------------------|---------------------|-------------------------------------|
| 1  | *Annona muricate*      | A = 0.7181 LW + 1.4882 | 0.9869                              |
| 2  | *Arbutus menziesii*    | A = 0.6502 LW + 0.3589 | 0.9952                              |
| 3  | *Artocarpus integer*   | A = 0.7211 LW - 2.126 | 0.9942                              |
| 4  | *Bougainvillea glabra*| A = 0.636 LW - 0.7235  | 0.9925                              |
| 5  | *Cassia fistula*       | A = 0.7341 LW + 0.4823 | 0.9945                              |
| 6  | *Citrus limon*         | A = 0.7642 LW + 0.0628 | 0.9902                              |
| Plant Name                  | Equation                              | R²    |
|----------------------------|---------------------------------------|-------|
| 7  Duranta erecta          | A = 0.6107 LW + 0.2933                | 0.9687|
| 8  Excoecaria cochinensis  | A = 0.7135 LW - 0.4776                | 0.9941|
| 9  Gardenia jasminoides    | A = 0.6142 LW + 0.7824                | 0.9864|
| 10 Hibiscus rosa-sinensis  | A = 0.6776 LW - 1.2945                | 0.9867|
| 11 Hypoestes phyllostachya | A = 0.6342 LW + 0.6808                | 0.9769|
| 12 Jatropha integerrima     | A = 0.5115 LW + 3.0722                | 0.9436|
| 13 Lantana camara          | A = 0.6485 LW + 0.0771                | 0.9829|
| 14 Mangifera indica        | A = 0.9528 LW - 11.78                 | 0.9922|
| 15 Nephelium lappaceum     | A = 0.6177 LW + 0.1912                | 0.9937|
| 16 Photinia fraseri        | A = 0.7545 LW - 0.7981                | 0.9828|
| 17 Plectranthus verticillatus | A = 0.973 LW - 1.1596              | 0.9932|
| 18 Psidium guajava         | A = 0.6873 LW + 1.2865                | 0.9871|
| 19 Viburnum suspensum      | A = 0.6971 LW - 0.192                 | 0.9948|
| 20 Xanthostemon sp.        | A = 0.6107 LW + 0.9614                | 0.9737|

**Figure 1.** Relationship between leaf area (A) and leaf dimension (LW) for (a) *Arbutus menziesii*, (b) *Cassia fistula* and (c) *Viburnum suspensum*.

**4. Conclusion**

The equation derived can be used to estimate the actual leaf area of the plant. The best correlation in linear regression derived between actual leaf area with the leaf dimension (length x width) is applicable for all different plant species [9, 10]. The linear regression analysis model that using LW as independent variable is suitable for all species at any growing environment [11, 12]. Among all the leaf shapes, the elliptic leaf shape plant was more prone to develop a high efficient linear regression analysis model. Lobed leaf shape plant was observed to create a less accurate leaf area estimation models.

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