Determination of corn leaf area using simple mathematic models

Somchai Butnan[1*] and Banyong Toomsan

ABSTRACT: Leaf area is one of the parameters indicating growth and expected economic yield of plants. However, many leaf area determination methods employed nowadays need high cost equipment, destructive to plant leaves, time consuming, and laborious task. There are many simple mathematic models proposed for corn leaf area determination, but a specific model which is appropriate to edaphic conditions which affect corn leaf architecture is needed. To address these issues, four simple mathematic models were used to compare leaf area of a whole corn plant which was grown in a pot containing a sandy textured soil. The plants were in the seventh leaf growth stage. It was found that the most suitable simple mathematic model was formulized as: leaf area = $(W_{lat} \times L_{lat} \times 0.75)_n$, where W_{lat} is the maximum width of the latest expanded leaf, L_{lat} is the length from base to tip of the latest expanded leaf, and $_n$ is number of all expanded leaves. This model had $R^2 = 0.93$, *y*-intercept (*a*) value = 31.4, and slope (*b*) value = 1.1. Further research is needed to measure leaf area of different corn varieties and different growth stages.
Keywords: Calculation of leaf area, Corn, Prediction, Vegetative growth stage, *Zea mays*

Introduction

Leaf area is a key parameter indicating growth and expected economic yield of plants (Chanda and Singh, 2002; Sezer et al., 2009; Pandey and Singh, 2011). It is related to plant photosynthetic rate, transpiration rate, biomass partitioning, and yield (Mutisya and Geadelmann, 1988; Chanda and Singh, 2002; Sezer et al., 2009). This is in particular true for corn which is the most important food, after rice and wheat, for both human and animals (FAOSTAT, 2016). Estimation of growth in the early vegetative stage leads to expectation of corn's economic yield and makes decisions on crop managements (Sammis et al., 1988). Currently, there are many liable techniques for determination of corn leaf area such as leaf weighing, grid counting, photoelectric scanning, and mathematic models (Li et al., 2008). However, the first three methodologies are time consuming, laborious task, and destructive to plant (Li et al., 2008). In addition, the photoelectric scanning technique have to employ the expensive equipment which is difficult to be accessed by researchers in small institutes. Furthermore, a simple and cheap techniques, e.g., simple mathematic models, may help smart farmers, who want to conduct research themselves, which has been increasing in the era of Farming 4.0 nowadays.

Determination of corn leaf area using simple mathematic models have been developed. Montgomery (1911) reported accurate method for determination of an individual leaf area of corn grown in Illinois, Iowa, and Nebraska of USA by using formula: leaf area (*LA*) = leaf width (*W*) x leaf length (*L*)

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x 0.75. However, the method of Montgomery (1911) takes much time when the whole leaf area of corn plant is required. Mutisya and Geadelmann (1988) developed a simple calculation method for determination of leaf area of the whole plant from three corn varieties in Minnesota, USA, and proposed a formula: $LA = W \times L \times 0.66 \times 5.03$. In the last decade, Sezer et al. (2009) showed that the formula: $LA = 13.31 + (2.45 \times W^2) + (1.17 \times W \times L)$ which possessed the highest coefficient of the determination (R^2) for determination of whole leaf area of a corn plant in Turkey.

Findings of these studies imply that a mathematic model is specifically appropriate to a corn variety and environment which may bring about different leaf architectures. Ohsowski et al. (2016) claimed that differences in corn leaf architecture were regulated by variety and environmental conditions such as edaphic and weather conditions. Therefore, this study aimed at exploring simple mathematic models suitable to determine leaf area of a whole corn plant in specifically a sandy textured soil in Northeast Thailand.

Materials and methods

A sweet-corn variety, which was a commercial F1 hybrid, was planted in a sandy textured soil under a greenhouse pot condition. The soil belonged to Khorat soil series (isohyperthermic Typic Oxyaquic Kandiustults) which represented 21% of soils in Northeast Thailand (Puttaso et al., 2011). It was collected from 0 – 15 cm-depth at Warichapum district, Sakon Nakhon province, Thailand (17° 20' 30"N; 103°41'57"E). Characteristics of this soil were bulk density 1.46 g cm^{-3}, soil organic matter 3.8 g kg^{-1} soil, pH 5.98, electrical conductivity 0.013 mS cm^{-1}, lime requirement 2.5 Mg $CaCO_3$ ha^{-1}, available P 6.9 mg P kg^{-1}, and exchangeable K 20.7 mg K kg^{-1}. The pot dimension was 10.5 cm in height and 15.2 cm in diameter. Corn leaves from fifty-three plants were collected at the seventh leaf growth stage (31 days after planting) and used to measure the leaf area required in the four simple mathematic models. The four models were:

(i) Determination method no.1 modified from Montgomery (1911) (denominated as *MM1*) as the following equation:

$$LA_{MM1} = (W_1 \times L_1 \times 0.75) + (W_2 \times L_2 \times 0.75) + \dots + (W_n \times L_n \times 0.75)$$

where LA_{MM1} is total leaf area per corn plant modified from Montgomery (1911),

W_1, W_2, and W_n are the maximum width of the first, second, and latest expanded leaves, and

L_1, L_2, and L_n are the length from base to tip of the first, second, and latest expanded leaves.

(ii) Determination method no.2 modified from Montgomery (1911) (denominated as *MM2*) as the following equation:

$$LA_{MM2} = (W_{lat} \times L_{lat} \times 0.75)_n$$

where LA_{MM2} is total leaf area per corn plant modified from Montgomery (1911),

W_{lat} is the maximum width of the latest expanded leaf,

L_{lat} is the length from base to tip of the latest expanded leaf, and

$_n$ is number of all expanded leaves.

(iii) Determination method modified from Mutisya and Geadelmann (1988) (denominated as *MG*) as the following equation:

$$LA_{MG} = W_{lat} \times L_{lat} \times 0.66 \times 5.03$$

where LA_{MG} is total leaf area per corn plant modified from Mutisya and Geadelmann (1988),

W_{lat} is the maximum width of the latest expanded leaf, and

L_{lat} is the length from base to tip of the latest expanded leaf,

(iv) Determination method of Sezer et al. (2009) (denominated as *SZ*) as the following equation:

$$LA_{SZ} = 13.31 + (2.45 \times (W_{lat})^2) + (1.17 \times W_{lat} \times L_{lat})$$

where LA_{SZ} is total leaf area per corn plant of Sezer et al. (2009),

W_{lat} is the maximum width of the latest expanded leaf, and

L_{lat} is the length from base to tip of the latest expanded leaf.

Actual leaf area of each corn plant was measured by ImageJ software (Image Processing and Analysis in Java, National Institutes of Health, Maryland, USA) which had been tested as the accurate and precise digital analyzer technique (Ahmad et al., 2015). Simple linear regression analysis of corn leaf area which was calculated using *MM1*, *MM2*, *MG*, and *SZ* methods on actual leaf area was carried out to evaluate the accuracy of these four simple mathematic models in determination of leaf area of a whole corn plant.

To evaluate the accuracy of each leaf area determination method, the simple linear regression analysis was used. The equation was: $y = a + bx$; where *y* represented values of the actual leaf area of each plant, *x* represented values of the calculated leaf area of each simple mathematic model, *a* represented *y*-intercept value, and *b* represented the slope of the fitted straight line or the changes of actual leaf area in responses to calculated leaf area of each model (Gomez and Gomez, 1984). Theoretically, the best mathematic model should have calculated leaf area values (*x*) equivalent to actual leaf area values (*y*), *y*-intercept (*a*) equal to zero, slope (*b*) equal to 1 (Palaniswamy and Palaniswamy, 2006), and coefficient of the determination or the goodness-of-fit index (R^2) equal to 1 (Chatterjee and Hadi, 2006).

Root mean square error (*RMSE*) was used to estimate error of each determination method. The RMSE was defined as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}$$

Where $\hat{y}_i$ was a leaf area determination method, while y_i was the actual leaf area.

Results and discussion

Results of this study demonstrated that *MM1* was the best model as it produced the highest accuracy in determination of leaf area of each corn plant. This can be indicated as *MM1* had the highest R^2 (0.98), *b* value close to 1 (0.95), the lowest *y*-intercept value ($a = 20.2$), and the lowest *RMSE* (77) (**Table 1**). In addition, the scatter values using *MM1* had the least deviation from the fitted straight line (**Figure 1a**). Nevertheless, *MM1* was not suitable when corn plant's leaf area was assigned as primary and routine tasks. This was because the *MM1* was time- and labor-consuming as all leaves had to be measured. Mutisya and Geadelmann (1988), Pandey and Singh (2011), and Sezer et al. (2009) emphasized that good mathematic models for leaf area determination need nondestructive, rapid, less laborious, and inexpensive procedures.

Measurement of width and length of all leaves in the whole corn plants were not necessary for *MM2*, *MG*, and *SZ* methods. Only the latest expanded leaf needed to be measured. Among these three methods, the most suitable method was *MM2* since it had the highest R^2 (0.93), *b* value close to 1 (1.1), and the lowest *y*-intercept value ($a = 31.4$) as

Table 1 Coefficient values of simple linear regression analysis and root mean square error (*RMSE*) pertaining to different simple mathematic models in determination of leaf area of a corn plant

Determination method †	Coefficient value ($y = a + bx$) ‡		*RMSE* §
	a	*b*	(cm^2)
MM1	20.2	0.95	77
MM2	31.4	1.1	178
MG	110.9	0.85	174
SZ	89.5	2.0	455

† *MM1* is the method no.1 modified from Montgomery (1911); *MM2* is the method no.2 modified from Montgomery (1911); *MG* is the method modified from Mutisya and Geadelmann (1988); *SZ* is the method of Sezer et al. (2009)

‡ ($y = a + bx$) is the simple linear regression model: when y = the actual leaf area; x = the calculated leaf area of either simple mathematic model (i.e., *MM1*, *MM2*, *MG*, and *SZ*); a = y-intercept value; and b = slope of the fitted straight line

§ *RMSE*, Root mean square error

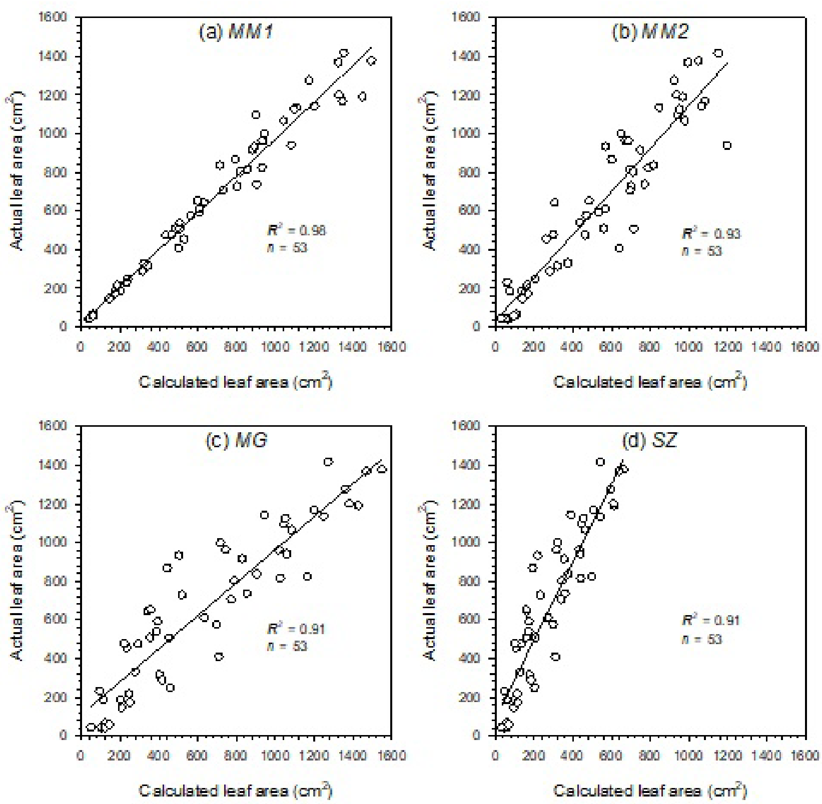

Figure 1 Relationships between different simple mathematic models including: (a) the method no.1 modified from Montgomery (1911) (*MM1*); (b) the method no.2 modified from Montgomery (1911) (*MM2*); (c) the method modified from Mutisya and Geadelmann (1988) (*MG*); and (d) the method of Sezer et al. (2009) (*SZ*), and actual leaf area of a corn plant

compared to *MG* and *SZ* (**Table 1**). Moreover, *MM2* had the lowest deviation of the scatters from the fitted straight line (**Figure 1b**) compared to *MG* and *SZ* (**Figure 1c** and **1d**). Even though the *MG* method produced lower *RMSE* than *MM2* (**Table 1**), *MG* was not proper for leaf area measurement of the whole plant due to the high value of *y*-intercept (*a* = 110.9), while *SZ* method produced very low accuracy because the calculated leaf area was twice lower (*b* = 2) than the actual leaf area (**Table 1**).

Conclusions

Results of this study have shown clearly that the modified method of Montgomery (1911) using the equation: $LA_{MM2} = (W_{lat} \times L_{lat} \times 0.75)_n$, denominated in this paper as *MM2*, was the most suitable for leaf area determination of the whole corn plant. This was because this method provided high accuracy, nondestructive leaves, inexpensive cost, and rapid and less laborious task as compared to other methods, i.e., *MM1*, *MG*, and *SZ*. Further study is needed to measure the leaf area in different varieties and different growth stages.

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