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Estimation of individual leaf area, fresh weight, and dry weight of hydroponically grown cucumbers (*Cucumis sativus* L.) using leaf length, width, and SPAD value

Young Yeol Cho [a,b], Sungbong Oh [a], Myoung Min Oh [a], Jung Eek Son [a,b,*]

[a] *Department of Plant Science, Seoul National University, San 56-1 Sillim-dong, Seoul 151-921, Republic of Korea*
[b] *Research Institute for Agriculture and Life Sciences, Seoul National University, Seoul, 151-921, Republic of Korea*

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Abstract

Non-destructive and mathematical approaches of modeling can be very convenient and useful for plant growth estimation. To predict individual leaf area, fresh weight, and dry weight of a cucumber (*Cucumis sativus* L.), models were developed using leaf length, leaf width, SPAD value, and different combinations of these variables. Eight regression equations, commonly used for developing growth models, were compared for accuracy and adaptability. The three nonlinear models developed were as follows: individual leaf area (LA) = $-210.61 + 13.358W + 0.5356LW$ ($R^2 = 0.980^{***}$), fresh weight (FW) = $-2.72 + 0.0135LW + 0.00022LWS$ ($R^2 = 0.956^{***}$), and dry weight (DW) = $0.25 - 0.00102LS + 0.000077LWS$ ($R^2 = 0.956^{***}$), where L is the leaf length, W the leaf width, S the SPAD value, and $LWS = L \times W \times S$. For validation of the model, estimated values for individual leaf area, fresh weight, and dry weight showed strong agreement with the measured values, respectively. Leaf dry weight, especially, was estimated with a higher degree of accuracy through the use of a SPAD value, as well as leaf length and width. Therefore, it is concluded that models presented herein may be useful for the estimation of the individual leaf area, fresh weight, and dry weight of a cucumber with a high degree of accuracy.

Keywords: Leaf area; Leaf length; Leaf width; Cucumber; Model; SPAD value

1. Introduction

Since leaf area plays an important role in photosynthesis, light interception, water and nutrient use, crop growth, and yield potential (Aase, 1978; Smart, 1985; Williams, 1987), a simple, rapid, accurate, and non-destructive method for the estimation of leaf area may be useful to determine the relationship between leaf area and plant growth rate Robbins and Pharr, 1987; Gamiely et al., 1991; Montero et al., 2000). To monitor continuous changes in leaf area and the subsequent growth, a modeling approach is essential.

Simple regression models, related to leaf area and crop growth rate, were applied to estimate crop yields (Aase, 1978; Montero et al., 2000). To estimate leaf area, variables, such as leaf length, leaf width, petiole length, or a combination of these variables, were used (Robbins and Pharr, 1987; Gamiely et al., 1991; Montero et al., 2000; Williams III and Martinson, 2003). Since leaf development has a strong relationship with crop growth, knowing the change in leaf area may be useful for estimating crop growth. In some studies, both fresh weight and dry weight appeared to be highly related to leaf area (Aase, 1978) but not consistently (Montero et al., 2000). Considering that leaf area and crop growth are both affected by nutritional conditions, more reliable results may be obtained through the addition of nutritional factors to the models.

A chlorophyll meter is also useful for the prediction of crop production (Le Bail et al., 2005). SPAD values are indirectly related to nitrogen concentration. For simple, rapid, and accurate estimation of leaf fresh and dry weights, various non-destructive tests, measurable with ease, should be added. The objective of this study was to develop models capable of accurately estimating leaf area, shoot fresh weight, and shoot dry weight of a cucumber using leaf length, leaf width, and SPAD values.

* Corresponding author at: Department of Plant Science, Seoul National University, San 56-1 Sillim-dong, Seoul 151-921, Republic of Korea.
Tel.: +82 2 880 4564; fax: +82 2 873 2056.
E-mail address: sjeenv@snu.ac.kr (J.E. Son).

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2. Materials and methods

2.1. Plant material and experimental conditions

An experiment was conducted in Venlo-type glasshouses at Seoul National University in Korea from March 5 to May 16, 1999 (37.3°N, 127.0°E). Seeds of the cucumber cultivar 'Euinchimbaekdadagi' (Heungnong seeds Co. Ltd., Korea) were sown in 9 cm Petri dishes. After germinated, seedlings were transferred to 2.5 cm × 2.5 cm × 2.5 cm polyurethane resins. One week after sowing, seedlings were transferred to a rock wool cube (10 cm × 10 cm × 6.5 cm). Thirteen to eighteen days later, after the appearance of the second or third true leaf, seedlings were transplanted into a culture bed (76 cm × 48 cm × 20 cm) filled with perlite substrates (Parat 3, Samson Co. Ltd., Korea). Plants were spaced in double rows with a planting density of 20 cm × 20 cm. Suckers, blossoms and fruits were removed up to the fifth true leaf.

The composition of the nutrient solution supplied was: NO_3 11.75 mmol L^{-1}, NH_4 1.0 mmol L^{-1}, H_2PO_4 1.25 mmol L^{-1}, K 6.5 mmol L^{-1}, Ca 2.75 mmol L^{-1}, Mg 1.0 mmol L^{-1}, SO_4 1.0 mmol L^{-1}; Fe 15 μmol L^{-1}, Mn 10 μmol L^{-1}, Zn 5 μmol L^{-1}, B 25 μmol L^{-1}, Cu 0.75 μmol L^{-1}, Mo 0.5 μmol L^{-1}. Every 2 days the pH and electrical conductivity (EC) of the nutrient solution were measured and adjusted to 5.5–6.5 and 2.2–2.4 dS m^{-1} using a pH meter (HM-14P, TOA, Japan) and an EC meter (CM-14P, TOA, Japan), respectively. Based on previous results (Roh and Lee, 1996), the nutrient solutions were supplied at rates of 500 mL/plant/day for 2 weeks after transplanting and of 800–1000 mL/plant/day for the rest 2 weeks until harvesting. The nutrient solution was provided to each plant using a trickle nozzle. Drainage water was collected and reused. Recommended pesticides were used to control insects as needed.

2.2. Model construction and validation

Leaf length was measured from lamina tip to the intersection of the lamina and petiole along the lamina midrib. Leaf width was measured from tip to tip between the widest lamina lobes (Fig. 1). Leaf area (LA) was measured using a LI-COR Li-3100 leaf area meter (LI-COR, Lincoln, NE, USA). Dry weights were determined after drying for 72 h at 70 °C after fresh weights were measured. The SPAD readings were taken with a chlorophyll meter (SPAD-502, Minolta, Japan) and recorded as a mean of 10 measurements for each individual leaf. Of the 258 leaves used in the experiment, 130 leaves previously transplanted were selected for model construction and 128 leaves transplanted later were used to validate the model for leaf area and leaf weight.

The most common regression equations used to develop plant growth models were evaluated for accuracy and adaptability. All equations were composed of various subsets of independent variables, such as leaf length (L), leaf width (W), SPAD values (S), L^2, W^2, LW, LS, and LWS. The eight models determined to be the most suitable for estimating total leaf area (LA), fresh weight (FW), and dry weight (DW) of cucumber were selected. All variables in the models below were significant at $P = 0.05$ level.

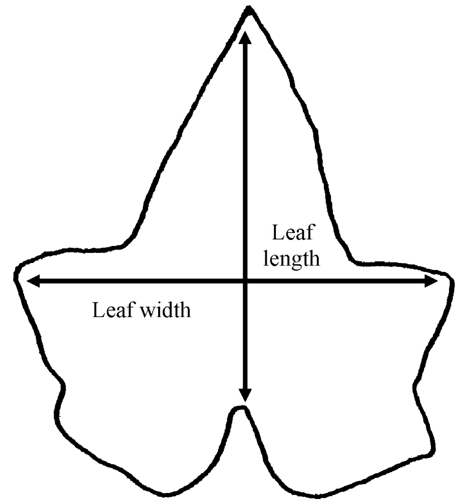

Fig. 1. Length and width of cucumber leaf, as used in the Robbins & Pharr model.

$$F = a + bLW \quad (1)$$

$$F = a + bW + cLW \quad (2)$$

$$F = a + bL + cW + dLW \quad (3)$$

$$F = a + bL + cW^2 + dLW \quad (4)$$

$$F = a + bW + cL^2 + dW^2 \quad (5)$$

$$F = a + bL + cL^2 + dW^2 \quad (6)$$

$$F = a + bLW + cLWS \quad (7)$$

$$F = a + bLS + cLWS \quad (8)$$

where F is the leaf area, fresh or dry weights; L the leaf length, W the leaf width, $LW = L \times W$, $LS = L \times$ SPAD, and $LWS = L \times W \times$ SPAD; a, b, c, or d are the constant.

All data was analyzed using the SAS (Statistical Analysis Software) Program. Slopes, intercepts and regression coefficients of the models were compared using the SAS REG procedure. Correlation coefficients were calculated between measured and estimated data.

3. Results

3.1. Model construction

Of the eight models, three consisting of leaf length (L) and leaf width (W) were selected for estimation of the leaf area (LA) of cucumber (Table 1). Eq. (3) had a higher R^2 value with a lower root mean square error (R.M.S.E.) than other equations tested.

$$\text{LA} = -210.61 + 13.358W + 0.5356LW \quad (R^2 = 0.980) \quad (9)$$

Fig. 2 shows that both leaf length and leaf width were highly related to leaf area of cucumber. Equations with $P > 0.05$