

# Development of Three-Variable Canopy Photosynthesis Model of Romaine Lettuce (*Lactuca sativa* L.) Grown in Plant Factory

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## Introduction

- Photosynthetic rate is affected by environment factors, such as light intensity and temperature, and also photosynthetic efficiency varies with growth stage.
- To maintain adequate CO<sub>2</sub> concentrations for systematic crop production, use of photosynthetic models is essential.
- For practical applications to plant factory, canopy photosynthetic model is more feasible than leaf photosynthetic model.

## Objective

- To develop a three-variable canopy photosynthetic model of romaine lettuce using light intensity, temperature, and growth stage.

## Materials and Methods

### Growth conditions

Seoul National University - plant factory module II  
Romaine lettuce (*Lactuca sativa* L. cv. Asia Heuk Romaine)  
Temperature / Relative humidity: 25°C / 70-80%  
Nutrient solution: Yamazaki solution for lettuce (EC: 1.2 dS·m<sup>-1</sup>)  
Lighting condition: LEDs with 8:1:1 R:B:W, 200 μmol·m<sup>-2</sup>·s<sup>-1</sup>  
Lighting periods: 16h/8h

### Measurement of canopy photosynthetic rate

Lettuces at 4, 7, 14, 21, and 28 days after transplanting (DAT)  
Closed acrylic chambers (1.0 m x 0.8 m x 0.5 m) (Fig.1)  
LI-840 (LI-COR, USA) CO<sub>2</sub> analyzing sensor  
Temperature: 19°C, 22°C, 25°C, and 28°C  
Light intensity: 50, 200, 350, 500 μmol·m<sup>-2</sup>·s<sup>-1</sup> (8:1:1 R:B:W)  
Initial CO<sub>2</sub> level: 2000 μmol·mol<sup>-1</sup>

### Modified models for estimating canopy photosynthetic rate

Three-variable models

#### - Simple multiplication model

$$P = a \left( \frac{I * C}{I + b * C} \right) * (T^2 + c * T + d) * (e^{e * t}) + R$$

#### - Modified physiological model from Acock *et al.* (1976)

$$P = \left( \frac{\alpha * I * \beta * C}{\alpha * I + \beta * C} \right) + R \left\{ \begin{array}{l} \alpha = a_1 * e^{b_1 * t} * (T^2 + c_1 * T + d_1) \\ \beta = a_2 * (t^2 + b_2 * t + c_2) * (T^2 + d_2 * T + e_2) \\ R = a_3 * e^{b_3 * t} * e^{c_3 * T} \end{array} \right.$$

where, P: Net photosynthetic rate (μmolCO<sub>2</sub>·m<sup>-2</sup>·s<sup>-1</sup>)

I: Light intensity (μmol·m<sup>-2</sup>·s<sup>-1</sup>)

C: Intercellular CO<sub>2</sub> concentration (μmol·mol<sup>-1</sup>)

T: Temperature (°C); t: Growth stage (DAT)

α: Photochemical efficiency (μmolCO<sub>2</sub>·μmol<sup>-1</sup>)

β: Carboxylation conductance (s<sup>-1</sup>)

R: Dark respiration (μmolCO<sub>2</sub>·m<sup>-2</sup>·s<sup>-1</sup>)

a~e: Regression coefficients

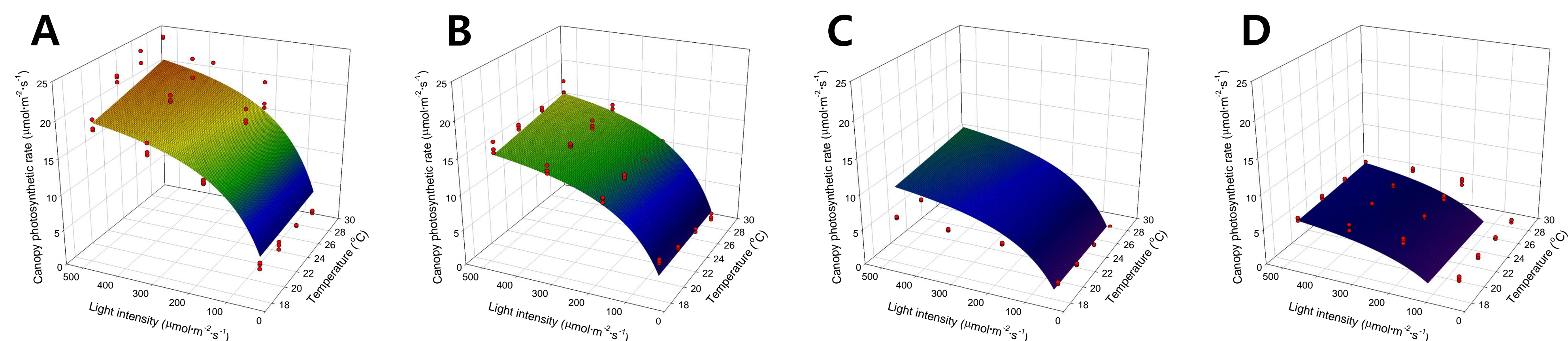
Analysis software: SPSS (IBM, USA),

Sigmaplot (Systat Software Inc., USA)



Fig. 1. Canopy photosynthetic rates of the lettuces were measured by using the acrylic chamber in which indoor temperature was controlled.

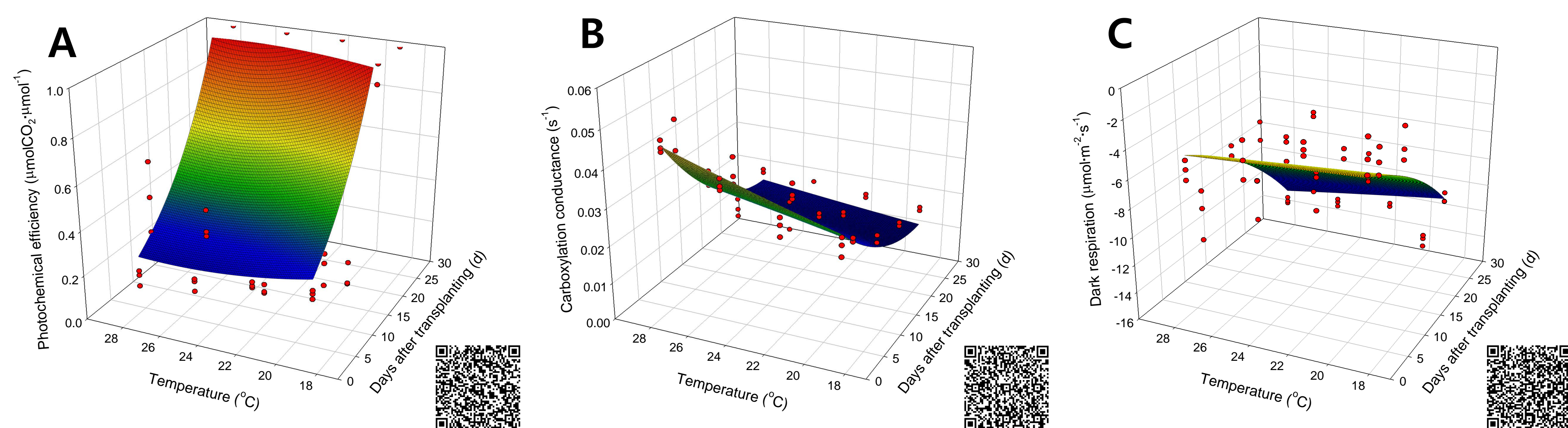
## Results and Discussion



$$P = 4.054 * 10^{-6} \left( \frac{I * 1110}{I + 0.087 * 1110} \right) * (T^2 + 69.734 * T + 5339.536) * (e^{-0.018 * t}) - 2.637 * e^{0.041 * t} * e^{0.015 * T}$$

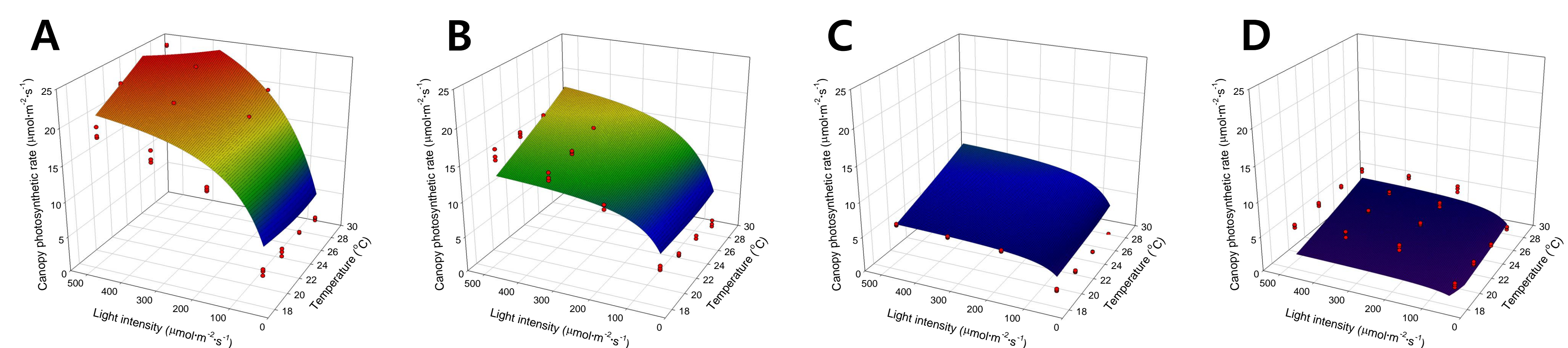
$$R^2 = 0.852$$

Fig. 2. Canopy photosynthetic rates of the lettuces expressed with the simple multiplication model according to temperature and light intensity at 7 (A), 14 (B), 21 (C), and 28 (D) days after transplanting.



$$\left\{ \begin{array}{l} \alpha = 0.001 * e^{0.073 * t} * (T^2 - 52.272 * T + 872.589) \\ \beta = 1.707 * 10^{-8} * (t^2 - 56.543 * t + 1126.338) * (T^2 + 50.099 * T + 652.612) \\ R = -2.637 * e^{0.041 * t} * e^{0.015 * T} \end{array} \right. \left\{ \begin{array}{l} R^2 = 0.74 \\ R^2 = 0.85 \\ R^2 = 0.64 \end{array} \right.$$

Fig. 3. Regressed photochemical efficiency (A), carboxylation conductance (B), and dark respiration (C) with the modified physiological model according to growth stage and temperature.



$$P = \left( \frac{0.001 * e^{0.073 * t} * (T^2 - 52.272 * T + 872.589) * I * 1.707 * 10^{-8} * (t^2 - 56.543 * t + 1126.338) * (T^2 + 50.099 * T + 652.612) * 1110}{0.001 * e^{0.073 * t} * (T^2 - 52.272 * T + 872.589) * I + 1.707 * 10^{-8} * (t^2 - 56.543 * t + 1126.338) * (T^2 + 50.099 * T + 652.612) * 1110} \right) - 2.637 * e^{0.041 * t} * e^{0.015 * T}$$

Fig. 4. Canopy photosynthetic rates of the lettuces expressed with the modified physiological model according to temperature and light intensity at 7 (A), 14 (B), 21 (C), and 28 (D) days after transplanting.

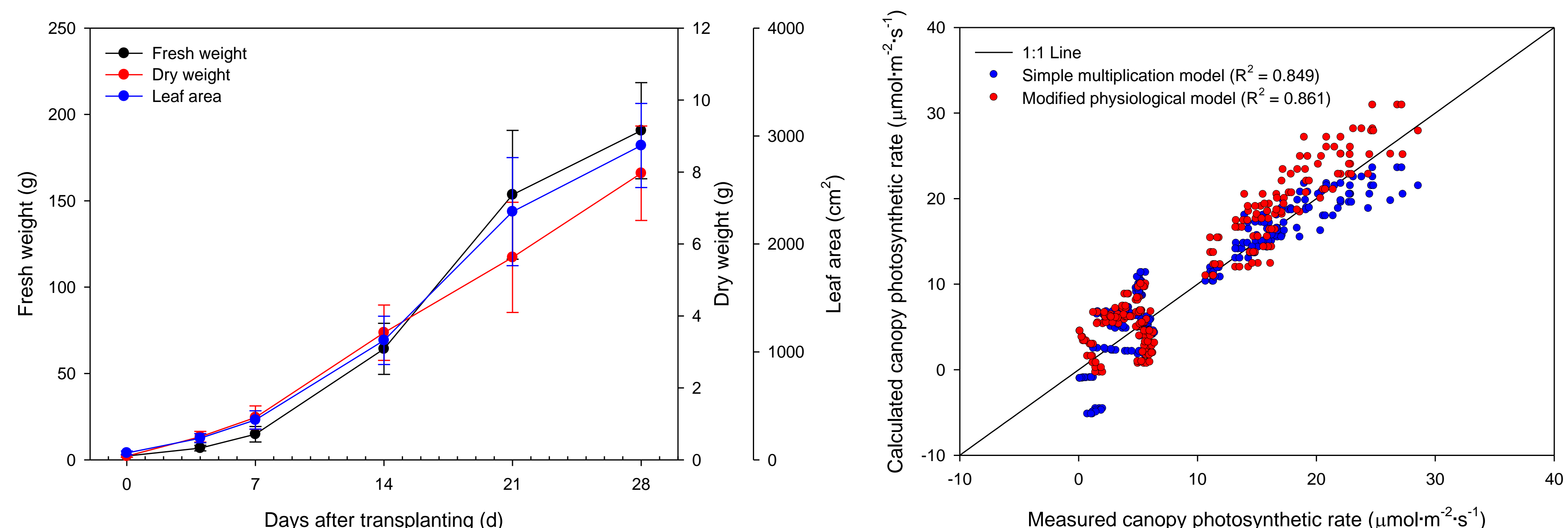


Fig. 5. Fresh and dry shoot weights and leaf areas of the lettuces from 0 to 28 days after transplanting. Vertical bars represent the mean ± SD (n = 24).

Fig. 6. Validation of the simple multiplication model and modified physiological model by comparing measured and calculated canopy photosynthetic rates.