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CUCUMBER MODELS IN RELATION TO RADIATION AND TEMPERATURE

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Abstract: The current study was carried out at the Ohio Agricultural Research and Development Center, Ohio State University, in order to study the relationship between radiation and cucumber , *Cucumis sativus* L. cv. Figaro F1, dry weight using photosynthesis models. Cucumber seeds were sown on Aug. 10, 1994 and Jan.27, 1995, transplanted on Aug. 18, 94 and Feb. 6, 95 and moved into in a double polyethylene greenhouse, one of the two compartments was shaded with 33%-shade (nominal) black net, on Aug. 29, 94 and Feb. 15, 95. Two night temperatures were used 10°C for 50 days followed by 15° for another similar period in the first season; and the reverse was applied in the second. Sixteen of 204 plants were marked in each compartment for vegetative data collection. Solar radiation and air temperature were monitored on a 10-minute interval basis. Using an optimum value for the mean hourly total solar radiation of 168 and 175 $W \cdot m^{-2}$ gave correlation coefficients between actual and calculated TDW of 0.82 and 0.85 for fall and spring crops, respectively. Daily TDW under the shaded treatment was lower than under sun due to lower hourly radiation than the assumed saturation value for most of the hours of the day. Using saturation values for hourly total solar radiation of 168 and 175 $W \cdot m^{-2}$ for the fall and spring season, respectively, gave the best predicted dry weight rate.

INTRODUCTION

Cucumber is one of the major crops grown under plastic greenhouses in Egypt (Abou-Hadid et al. 1990). Yield of cucumber is largely determined by the accumulation of fresh weight of the harvested fruit. Fresh weight is closely related to dry weight (Heuvelink and Marcelis, 1989). Dry weight is primarily a result of the total amount of assimilates available for growth and the processes of photosynthesis and respiration.

Several different equations have been proposed for calculating leaf photosynthesis of greenhouse crops (France and Thornley, 1984; Marcelis and Heuvelink, 1989; Thornley et al., 1992; Challa and Heuvelink, 1993). Problems associated with calculating photosynthesis are based on uneven and highly variable radiation distribution and nonlinear crop responses to the input parameters of radiation, CO_2, temperature, and leaf area. Practically, direct comparison of these parameters to photosynthesis has not been successful possibly due to plant architecture and non linear plant response rates (France and Thornley, 1984).

Nederhoff et al.(1989) found unexplainable discrepancies between measured and simulated photosynthesis, particularly when total solar radiation exceeded 360 $W \cdot m^{-2}$. On the other hand, under low artificial light intensity conditions of 65-75 $W \cdot m^{-2}$, (Marcelis and Heuvelink, 1989), or under short period of time (3 days) in a particular plant stage (mature plant with LAI of 3.4) (Hand et al., 1992; Wilson et al., 1992), it was possible to obtain better fit with the simulated vs. the predicted data. Under actual radiation fluctuations and extended life span of cucumber plant, prediction of dry matter was considerably difficult due to various biological and climatic factors involved (Enoch and

Kimball, 1986).
The emphasis of this study was to determine the radiation levels at which the best simulation for dry matter could be obtained. A secondary concern was to determine the best possible dry weight conversion factor that reflected the age of the leaves as leaf area index increased.

MATERIAL AND METHODS

Greenhouse and plant material

The experiment was done in two compartments of a gutter connected, double-layer polyethylene greenhouse at The Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio (Lat. 40°47' N; Long. 81°56' W). The greenhouse dimensions of each side were 30m long, 7m wide and 3.5m high and the length was oriented east-west There was a 35% (nominal) white shade netted cloth separating the two houses. The cooling pads were located on the East Side, while the fans and the heaters were on the west. The north side compartment was shaded from outside using 33% (nominal) black cloth shade over the outside of the double plastic roof. The greenhouse ground was covered with black, water-permeable fabric.

Seeds of Cucumber, *Cucumis sativus* L. cv. Figaro F1, were sown in 3.5 x 3.5 x 4.0 cm^3 rockwool "cones" on Aug. 10, 1994 and Jan. 27, 1995. Seedlings were first transplanted to 6 x 10 x 10 cm^3 rockwool "cuboids" on Aug. 18, 1994 and Feb. 6, 1995. Finally, seedling cuboids were moved onto 7.5 x 20 x 90 cm^3 rockwool "slabs" on Aug. 29, 1994 and Feb. 15, 1995 with two plants on each slab. There were 6 rows of 34 plants in each compartment of the greenhouse as illustrated in Fig. 1.

After brought to slabs, minimum night temperature was set at 15.5 °C from the beginning until the 9th week in the first season. In the second season, it was set at 15.5 °C in the first week and then from 9th week until the end. The rest of the periods, minimum night temperature was set at 8 °C. Fans were set to begin ventilating at 25 °C and inlet cooling pads at were activated 28 °C.

Instruments and measurements

Dry bulb air temperature, wet bulb air temperature, air carbon dioxide concentration and total solar radiation were monitored in the greenhouse during these experiments. Air temperatures were measured using type-T thermocouples and taken at 2m height above canopy and at 0.85m vertically into the top of the canopy. Temperature sensors were located in the middle of four equal longitudinal zones in each compartment as shown in Fig. 1.

One infrared CO_2 analyzer (model 202 LIRA, Mine Safety Appliances Company, Pittsburgh, PA, USA) was used to observe changes in the CO_2 levels. The sampling tube was positioned to sample the air at 1.5m height above the floor in the middle of the non-shaded compartment. The CO_2 analyzer was calibrated daily.

Measurements of total solar radiation incident on a horizontal surface were measured at 2.1m above the floor using one Eppley black and white pyranometer in each compartment.

All sensors were connected to a Kaye DIGISTRIP III datalogger. Data were transferred to an MFE tape recorder from which they were loaded onto an HP-3000 computer and an IBM-PC for analysis. The time used throughout the study was the solar time calculated from the longitude of the site and data were recorded every 10 minutes.

Three plants in each of the four locations of each compartment were randomly selected to monitor vegetative and productive development. Vegetative growth in terms of plant height, from the cotyledon level, leaf length and leaf width was measured weekly for 15 successive weeks.

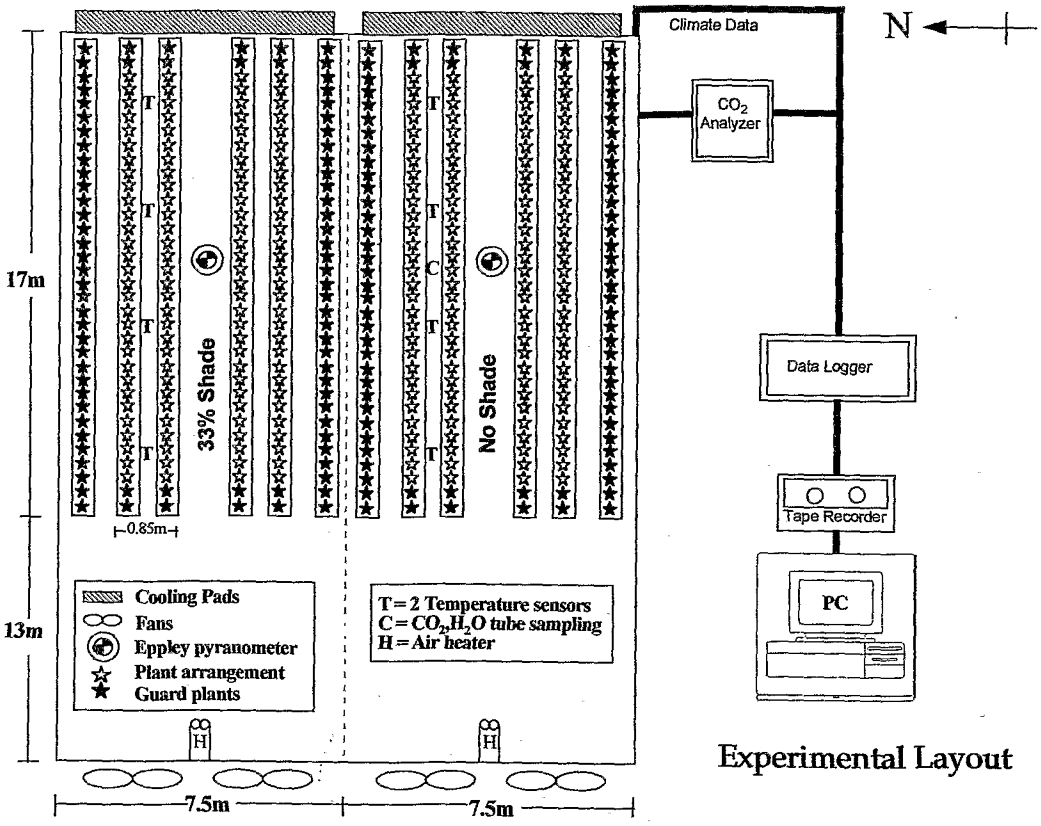

Figure 1. **Schematic diagram for an overview of the two zone greenhouse showing the experimental layout in terms of sensors locations, plant arrangements, greenhouse area and orientation, and data flow from the sensors to the computer**

Radiation

In order to search for the hourly total solar radiation level that best predict dry weight (DW), different saturation values for hourly total solar radiation were used. For example, if the saturation value was $250 W m^{-2}$, this assumed that hourly radiation of $250 W m^{-2}$ or higher were 250, and lower radiation values were left unchanged. Linear regression analysis between daily sum of assumed saturation hourly total radiation (I_{sat}) of 1, 3, 5, 10, 15, 25, 50, 75, 100, 125, 150, 175, 200, 225 and 250 $W m^{-2}$, as well as the actual radiation, as independent variables (x), and leaf number, leaf area, height, fruit dry weight (FDW), total dry weight (TDW) and vegetative DW (TDW-FDW), as dependent variables (y), were conducted according to the formula: $y = a + bx$, where b is the x-coefficient. I_{sat} values were plotted against the correlation coefficients (r^2).

The hourly radiation of I_{sat} values of 50, 100, 150, 175, 200 and 250 as well as the actual values, after being converted to photosynthetically active radiation (PAR), were used to calculate the hourly TDW for a hundred successive days for both radiation treatments of both seasons. A linear regression analysis was carried out between actual daily TDW, as independent variable (x) and estimated daily TDW as dependent variable (y) according to the formula: $y = bx$, where b is the x-coefficient.

Leaf area and actual dry weight.

Leaf area [cm²] was calculated from leaf length, LL, [cm] and leaf width, LW, [cm] according to:

$$\text{Leaf area} = 0.667 \times LL \times LW - 1.25 \qquad \text{(Medany et al., 1995)} \qquad (1)$$

Similar leaf area equation was suggested by Yang et al. (1989). Fruit diameter and length were measured weekly, starting from the first measurable ovary after the tenth leaf. Thirty-two fruits was used to correlate fruit dimensions in terms of fruit length, F_L, and fruit diameter, F_D, [cm] with the fruit fresh weight, FFW, [g]. The resulted equation, which was used to estimate fruit fresh weight from fruit diameter and fruit length, was as follows:

$$FFW = 0.200694 + 8.88E\text{-}04\ p\ F_L\ (F_D/2)^2 \qquad r^2 = 99.5\% \qquad (2)$$

Twelve plants and 50 fruits were harvested and used to determine plant vegetative (leaf-blade, petiole and stem) and fruit, Fr, fresh and dry weights, DW, as well as leaf area and stem length on the 5th and 10th week of the first seasons. Leaf area was measured using DT Area Meter (Delta-T Devices, Burwell, Cambridge, England). Leaf fresh weight, stem length and stem fresh weight and fruit fresh weights were obtained. Leaves, stems and fruits were dried at 105°C for 24h. Specific leaf area , SLA, [$cm^2 \cdot g^{-1}$ DW] was estimated as follows:

$$SLA = \frac{\text{Plant leaf area, cm}^2}{\text{Leaf dry weight, g}} \qquad (3)$$

Specific stem length, SSL, [$cm \cdot g^{-1}$ DW] was similarly estimated as follows:

$$SSL = \frac{\text{Stem length, cm}}{\text{Stem dry weight, g}} \qquad (4)$$

Petiole dry weight to leaf dry weight ratio, [g DW petiole $\cdot g^{-1}$ DW leaf] was estimated according to:

$$\text{Petiole/leaf} = \frac{\text{Petiole dry weight, g}}{\text{Leaf dry weight, g}} \qquad (5)$$

Using SLA, SSL and Petiole: leaf ratio, it was possible to theoretically estimate leaf, stem and petiole dry weigh from leaf area, which was estimated from leaf dimensions, and plant height weekly measurements.

Cucumber root DW is assumed to be 14.9% of leaf and stem dry weights according to Heuvelink and Marcelis, (1989). TDW [$g \cdot plant^{-1}$] was calculated according to:

$$TDW = 1.149\ (\text{Leaf DW} + \text{Stem DW} + \text{Petiole DW}) + FDW \qquad (6)$$

Net photosynthesis

The net photosynthesis rate per unit of ground area cropped, P_{net} [kg $CO_2 \cdot m^{-2}$ ground$\cdot h^{-1}$], was estimated according to Jackson and Palmer (1979), France and Thornley (1984) and Thornley et al. (1992).

A dry weight conversion factor, f_c [g $DW \cdot g^{-1}$ CH_2O] was estimated from a sine function for LAI less than 2.5 as follows:

$$f_c = 0.7 \sin (2p\, LAI / l)\, T_{min} / 15.5 \qquad \begin{array}{l} 0 < LAI \le 2.5 \\ 5 \le T_{min} \le 19 \end{array} \qquad (7)$$

or a linear function for LAI greater than 2.5 as follows:

$$f_c = 0.7\, T_{min} / 15.5 \qquad 2.5 < LAI \le 3.8 \qquad (8)$$

where:
0.7 = [0.7g $DW \cdot g^{-1}$ CH_2O] maximum DW conversion (Challa and Heuvelink, 1993);
15.5 = [°C] minimum set point temperature;
T_{min} = [°C] greenhouse minimum temperature;
l = Adjustable parameter for the best statistical fit that was equal to 6 or 7 for fall and spring season, respectively.

RESULTS AND DISCUSSION

Two main concerns were emphasized with the prediction of dry weight using the photosynthesis models in a commercial-like situation. First was to determine the radiation level at which net dry matter production saturates. The second concern was to determine how dry matter production is affected by plant age.

Radiation and total dry weight gain.

Plotting daily total solar radiation against daily TDW gain for both fall and spring seasons in shaded and unshaded treatments is shown in Fig. (2) to have no trend or correlation (r^2=0.03). This was assumed to result from radiation levels at days of the plant growth that were significantly above photosynthesis saturation. Similar conclusions have been reported by Liebig (1984, 1989); and Liebig and Krug (1990).

When the assumed I_{sat} values were plotted against r^2 values that resulted from the linear regression between the daily sum of hourly I_{sat}, as independent variables, and some measured growth parameters of leaf number, leaf area, height, , fruit DW, vegetative DW and TDW as dependent variables over a 100-day period, it was found that there was relatively a high correlation at low radiation levels and a very low correlation at high radiation levels (Fig. 3). There was a tendency of a break point near I_{sat} of 75 $W \cdot m^{-2}$. The r^2 values for all evaluated growth parameters were less than 0.1 when I_{sat} was higher than 125 $W \cdot m^{-2}$. The relatively high r^2 values when I_{sat} went below 50 were attributed to the change in day length as the plant age was increasing. This reflected the sensitivity of the photosynthesis to low radiation level in the early and late minutes of the day. According to this assumption, it was possible to expect high prediction fit with low light level (Marcelis and Heuvelink, 1989) and the contrary in higher levels (Nederhoff et *al.* 1989).

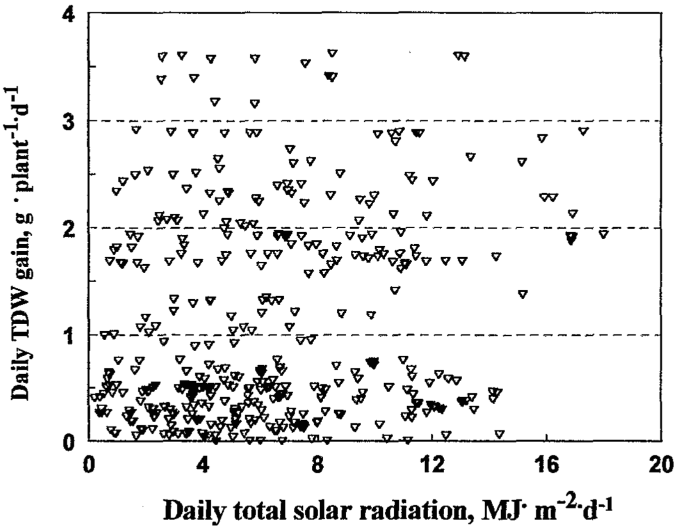

Figure 2. The relationship between daily total solar radiation, MJ·m^{-2}, and daily TDW gain, g·plant^{-1}·d^{-1}, for greenhouse cucumber. Data represent continuous 100 day-periods during both fall of 1994 and spring of 1995, unshaded and shaded plants. $r^2 = 0.03$.

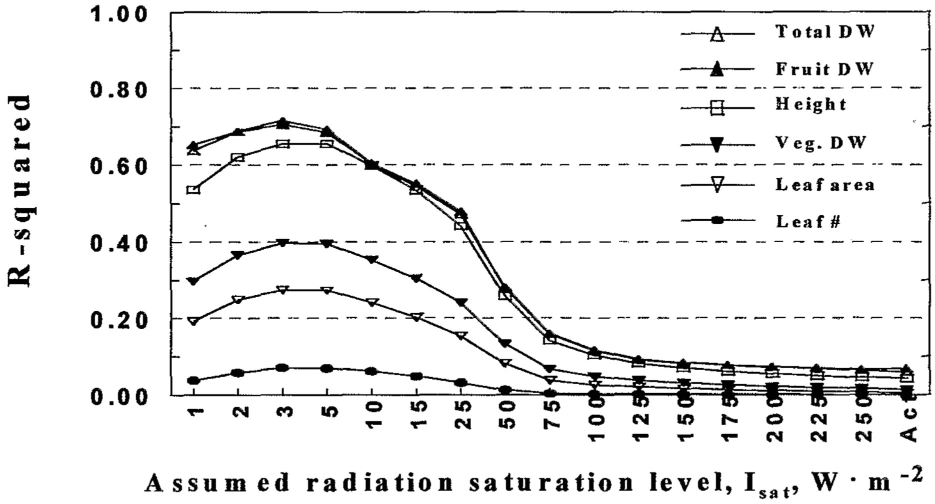

Figure 3. Correlation between assumed radiation saturation levels, I_{sat}, and actual (act) [W m^{-2}], and cucumber growth parameters, where Vegetative DW = TDW - Fruit DW. Linear regression was between daily sum of the hourly I_{sat} as independent variable, x, and the measured (mean of 12 samples) growth parameters, as dependent variable, y, for 100 successive days using the formula: $y = a + bx$.

As shown in Figures 4 and 5, I_{sat} values between 150 and 200 W m^{-2} have the closest x-coefficient to one compared to the actual radiation or the other values, considering fall and spring seasons and shade and no-shade treatments. In the fall, the I_{sat} value of 168 gave x-coefficient value of 0.998 and 1.002 for shade and no-shade, while in spring the I_{sat} value of 175 had x-coefficient of 0.98 and 0.99 for shade and no-shade, respectively.

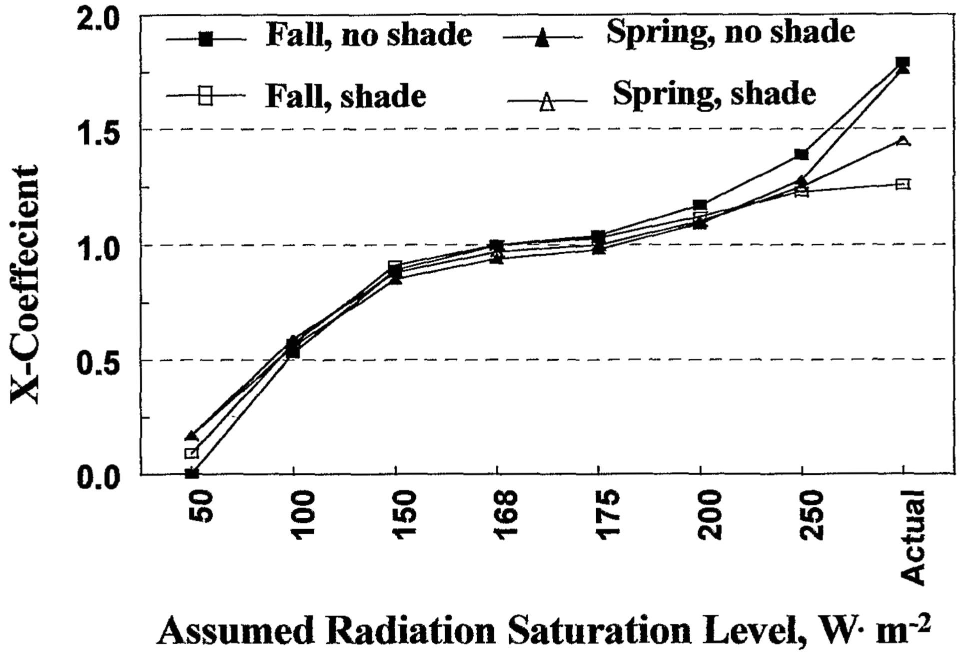

Figure 4. The effect of the assumed total solar radiation saturation level (I_{sat}) on *x*-coefficient values. I_{sat} was used to calculate DW using net photosynthesis models. Each point was the result of a linear regression between measured (mean of 12 samples) TDW, as independent variable, *x*, and the predicted TDW as dependent variable, *y*, for 100 successive days using the formula: $y = bx$, where *b* is the *x*-coefficient.

Net photosynthesis and total dry weight

In equation 7, the adjustable parameter l was found to be equal to 6 and 7 for the fall and spring seasons with r^2 values between measured and predicted daily TDW of 0.82 and 0.85, respectively. The LAI limit of 2.5 gave the best fit between measured and predicted daily TDW. This was due to the balance between exposed and shaded leaf area.

Figure 6 shows measured vs. predicted TDW using net photosynthesis model. Shaded treatments showed daily TDW gain less than the non-shaded treatments, especially in the late fall and early spring, due to many days of hourly radiation that was lower than optimum and possibly the increased maintenance respiration of shaded leaves, (Schapendonk, 1984).

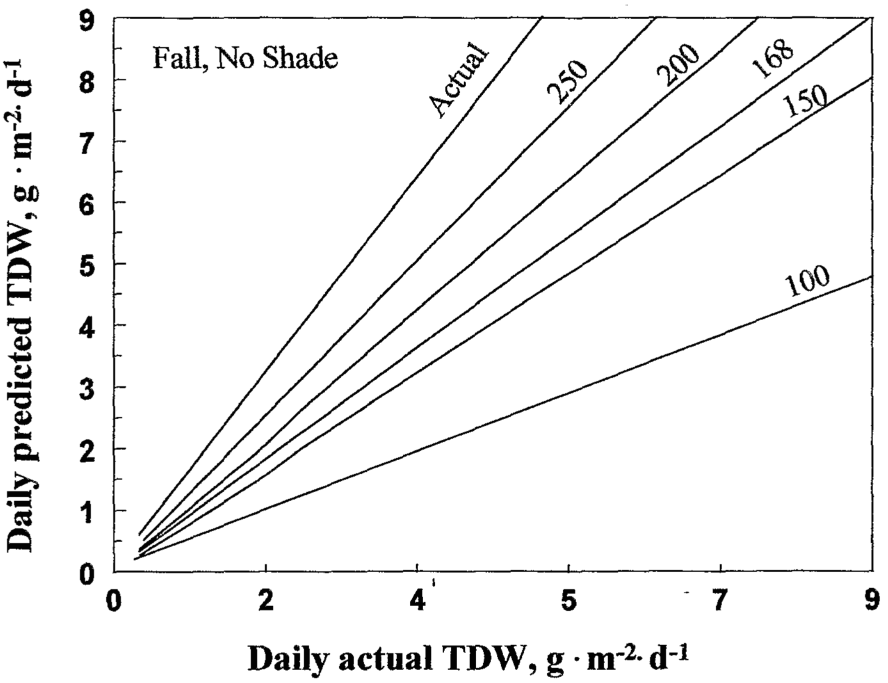

Figure 5. The correlation between measured TDW [g· M^{-2} · d^{-1}] and predicted TDW using I$_{sat}$ values of 100, 150, 168, 200 and 225 as well as actual total solar radiation [W· m^{-2}] using the linear regression results between actual TDW, as independent variable, *y*, and the calculated TDW as dependent variable, *y*, using the formula: $y = bx$, where *b* is the *x*-coefficient.

It was concluded that permanent shading did not give the best radiation level. Selective shading, however, could target the radiation levels that exceed an optimum such as 168-175 W·m^{-2}. Using actual hourly PAR for calculating net photosynthesis gave higher TDW values than the measured (Fig. 3 and 4). Using assumed radiation saturation level of 168 and 175 W·m^{-2} (total solar radiation) in fall and spring crops, respectively, gave acceptable predictions of daily TDW production over the 100 day-period. More studies are needed in the area of controlling radiation level when radiation exceeds certain level.

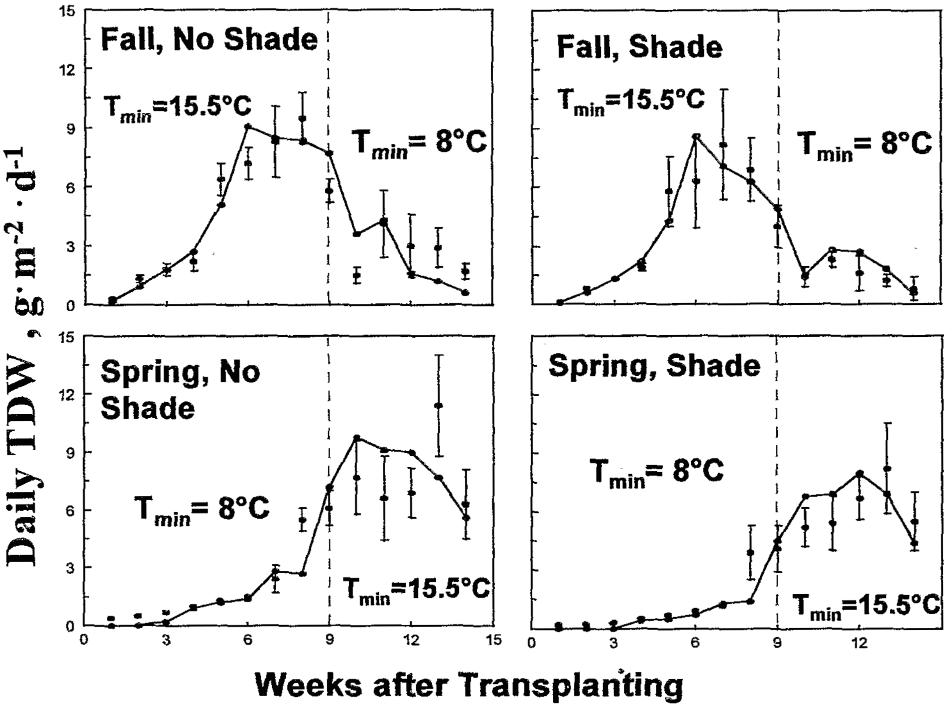

Figure 6. Actual (dots and bars) and predicted (line) TDW using assumed saturation hourly total solar radiation values of 168 (fall) and 175 (spring) $W. m^{-2}$. Each data point is the mean of twelve samples in four greenhouse locations. Vertical bars are ± SE of the mean; bars not shown are within the height of the data point symbol.

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