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Research Report

Modeling of Transpiration of Paprika (*Capsicum annuum* L.) Plants Based on Radiation and Leaf Area Index in Soilless Culture

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Abstract. Modeling of crop transpiration is important to manage the irrigation strategy in soilless culture. In this study, the transpiration of paprika plants (*Capsicum annuum* L.) grown in rockwool was analyzed considering the relationship between incident radiation (RAD) and leaf area index (LAI). Coefficients of the simplified Penman-Monteith formula were calibrated in order to calculate the transpiration rate of the crop (T_r). Transpiration rate per floor area was measured by weighing plants with load cells. The following model was developed: $T_r = a\,[1 - \exp(-k \times LAI)] \times RAD / \lambda + b$ for estimating transpiration of paprika. Determination coefficient for the linear regression between estimations and measurements of daily transpiration was 0.80 with a slope of 0.93. In validation, the model showed high agreement between estimated and measured values of daily transpiration. Radiation showed a great effect on transpiration of paprika plants. The results indicated the simplified Penman-Monteith formula could be used to predict water requirements and improve irrigation control in soilless culture. However the model coefficients require parameter adjustments for specific climate and crop conditions.

***Additional key words*:** canopy, linear regression, Penman-Monteith equation, prediction, rockwool

Introduction

Paprika (*Capsicum annuum* L.) is one of the more valuable and widely grown greenhouse crops. Since it is considered one of the most susceptible crops to water stress in horticulture (Smittle et al., 1994), adequate irrigation is essential for production of high-quality paprika fruits. Effect of water stress has been documented in several reports that studied yield reductions (Antony and Singadhupe, 2004; Moreno et al., 2003; Sezen et al., 2006). This yield reduction has been linked with low transpiration which creates calcium deficiencies and limits leaf development (Jolliet and Bailey, 1992). These adverse effects could be avoided by an appropriate irrigation strategy. To define an effective irrigation control strategy, it is necessary to know how transpiration depends on the climatic conditions and ontogeny development and to able to predict this transpiration. Therefore, the development of methods or models to estimate paprika water requirement is crucial to improve the irrigation efficiency in greenhouse cultivation. Several studies have been conducted to model the water requirements of important crops, as tomato (Carmassi et al., 2007; Joilliet and Bailey, 1992; Marcelis et al., 1998; Stanghellini, 1987), cucumber (Medrano et al., 2005; Nederhoff et al., 1984). These models are principally based on the relationships between leaf transpiration and climatic parameters, such as solar radiation and vapor pressure deficit. Until now, there has been a little literature information on study about modeling of paprika transpiration. For all reasons, in this study, a simplified Penman-Monteith model based on solar radiation and leaf area index was developed for prediction of the transpiration of paprika plants grown in soilless culture.

The objectives of this study were to analyze the transpiration of paprika plants in soilless culture with regard to greenhouse microclimate factors, and to calibrate the simplified model of transpiration derived from the Penman-Monteith equation (Baille et al., 1994) for its possible use in soilless irrigation management.

Materials and Methods

Growing Conditions

The experiment was conducted in a venlo-type glasshouse which is located at the experimental farm of Seoul National University (Suwon, Korea, latitude 37.3° N, longitude 127.0° E). The vents on the roof and sidewall were opened when the temperature was higher than 26℃. Paprika plants (*Capsicum*

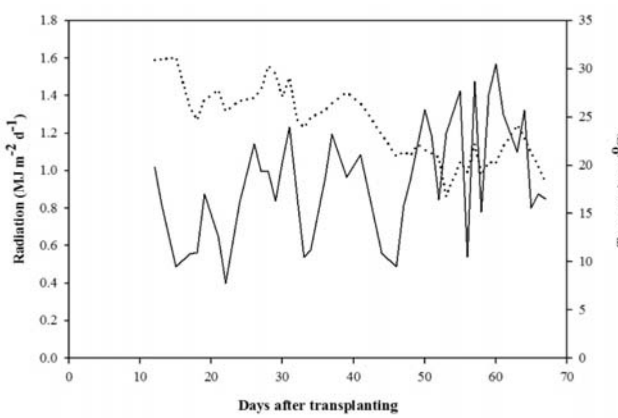

Fig. 1. Incident solar radiation (solid line) and temperature (dotted line) during the growing seasons from August to October 2010.

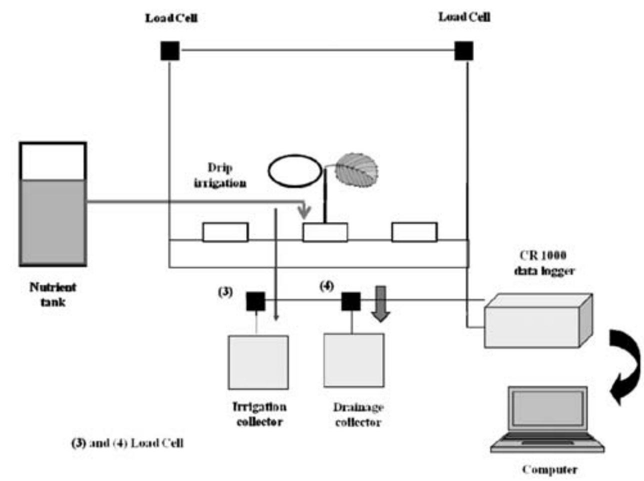

Fig. 2. Schematic diagram of a measurement system.

annuum L. 'Fiesta') were cultivated in rockwool slabs (90 cm × 15 cm × 7 cm) placed in the gutters (100 cm × 20 cm × 10 cm) from August to October, 2010, with a plant density of 3 plants·m^{-2}. The incident radiation (MJ·m^{-2}·d^{-1}) and temperature during the growing season are show in Fig. 1.

Drip irrigation system was automatically controlled on the basis of incoming radiation, which was measured by a pyranometer (SQ-110-L10, Apogee, USA) connected to a CR 1000 data logger. Electrical conductivity (EC) and pH of applied nutrient solution were between 2.6 to 3.0 dS·m^{-1} and 5.5 to 6.5, respectively. EC in rockwool was maintained at 2.5-3.5 dS·m^{-1} over the growing period.

Transpiration Model

Paprika plants transpiration (Tr) was estimated using the following formula derived from the Penman-Monteith equation (Baille et al., 1994):

$$T_r = a \times [1 - \exp(- k \times LAI)] \times RAD / \lambda + b \quad (1)$$

where T_r is the daily plants transpiration (kg·m^{-2}·d^{-1}), RAD is the daily value of incident radiation (MJ·m^{-2}), λ is the latent heat of vaporization (2.45 MJ·kg^{-1}), k the light extinction coefficient, a (dimensionless) and b (kg·m^{-2}·d^{-1}) are the regression parameters. Model parameters (a and b) were determined from statistical regression with data sets of measured daily transpiration, solar radiation, and leaf area index (LAI) throughout the growth of paprika plants. The calculated T_r from the simplified model and the observed values, were compared using data sets different from those used to estimated the coefficients of a and b.

LAI Model and K Determination

Every 7 or 10 days after transplanting three plants were sampled for the determination of leaf area. LAI from transplanting was to model using the Boltzman sigmoid equation (Motulsky and Christopoulos, 2003) to calculated days after transplanting:

$$LAI = a / [1 + \exp(x_0 - DAT) / b] \quad (2)$$

where a, b and x_0 are the constants, and DAT is the days after transplanting.

The value of k was determined with the following equation based on Lambert-Beer's law (Nobel and Long, 1985):

$$\exp(- k \times LAI) = RAD_o / RAD \quad (3)$$

where RAD and RAD_o are the radiation measured with a pyranometer placed above and below the plant canopy, respectively. The determination was performed in six different occasions.

Measurements

The daily transpiration was measured by weighing sensors (Load Cell). A metal frame with two weighing sensors held two rockwool slabs and an irrigation and a drain collector. Weight data of irrigation and drain amount were recorded every 5 sec by a CR1000 datalogger. The daily transpiration T_r was calculated with the following equation: T_r = total irrigation amount − total drain mount − changed of substrate. The leaf area was determined by using an area meter.

Results and Discussion

LAI Development and Radiation Intercepted by Canopy

The Boltzmann sigmoid equation was used to estimate the evolution of LAI as a function of DAT (Fig. 3). A derived equation was the following:

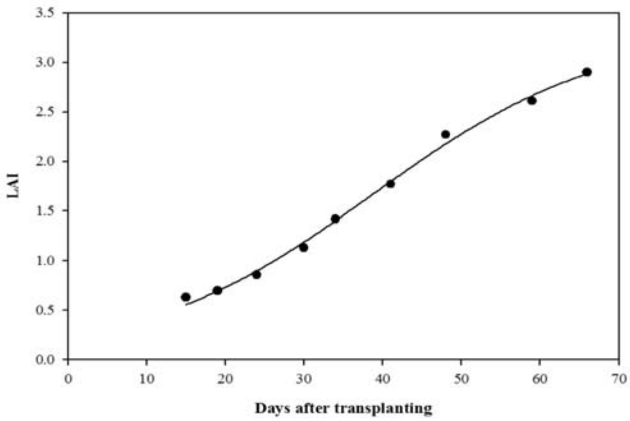

Fig. 3. Development of leaf area index (LAI) of paprika crop grown in a glasshouse. The solid line and symbols represent the fitted LAI and measured one, respectively.

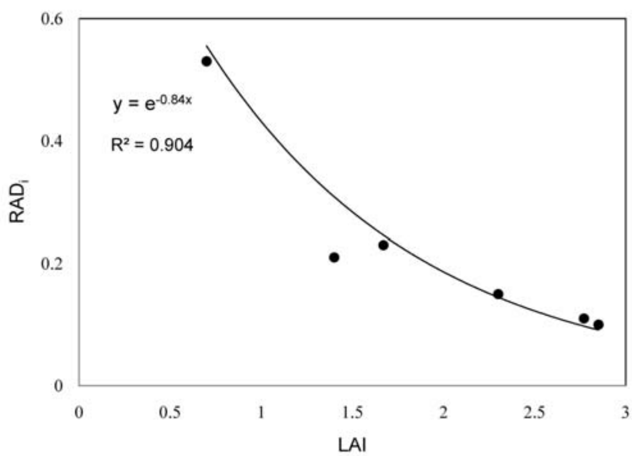

Fig. 4. Estimation of light extinction coefficient (k = 0.84) of the crop from the relationship between leaf area index (LAI) and transmittance of overall radiation through the canopy (RAD_i) at a plant density of 3 plants·m^{-2}.

$$LAI = 3.5 / [1 + \exp(37.2 - DAT) / 13.2] \quad (4)$$

where the determination coefficient R^2 was 0.99, RMSE was 2.85, and F-value was 738.32 ($P < 0.001$). This equation accurately predicted the development of LAI over time up to a LAI value 3.0. Eq. (4) can be used to calculate the solar radiation intercepted by the canopy (RAD_i) of a paprika plant as a function of the DAT:

$$RAD_i = [1 - \exp(-k \times LAI)] \times RAD = [1 - \exp\{-3.5 \times k / (1 + \exp(DAT / 13.2 - 2.82))\}] \times RAD \quad (5)$$

The measurements of light extinction (Fig. 4) within the canopy showed the evolution of solar radiation transmitted to the canopy (RAD_i) related to the increase in LAI. For growing season, the regression between k and (RAD_i) yielded

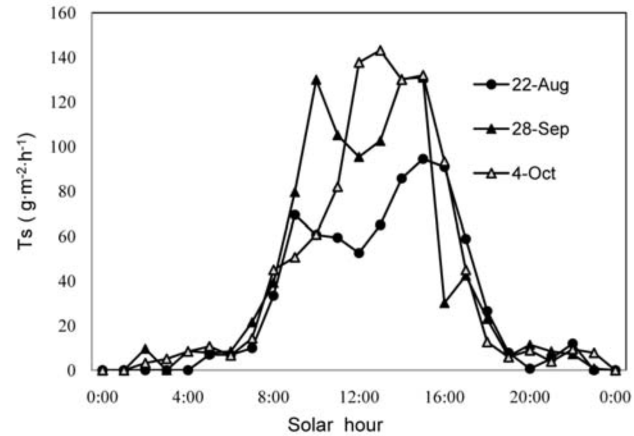

Fig. 5. Daily transpiration rate per ground area Ts (g·m^{-2}·h^{-1}) on three different days corresponding to different stages of plant development with similar radiation condition (0.88, 0.9, and 0.87 MJ·m^{-2}).

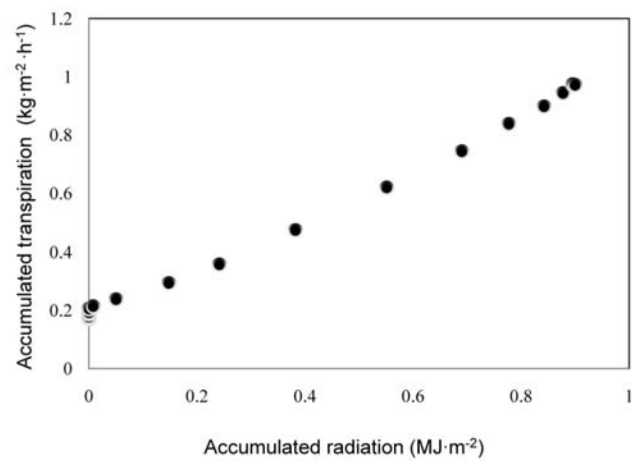

Fig. 6. Daily dynamics of transpiration rate in relation to the overall incident radiation on 4 October (LAI = 2.6).

a coefficient of determination (R^2) greater than 0.9, which demonstrates the strong dependence of the intercepted radiation (RAD_i) on LAI. For other plants, k values ranging from 0.63 to 0.86 have been reported for the cucumber (Medrano et al., 2005) and 0.69 for tomato (Carmassi et al., 2007).

Transpiration Rate per Ground Area (T_s)

The transpiration rate per ground area (T_s, g·m^{-2}·h^{-1}) increased as the canopy developed (Fig. 5). In the growing season, from 15 DAT to 51 DAT with similar RAD, the increasing in (T_s) was 25% whereas from 51 DAT to 55 DAT the increasing was 2.5%. Similar results have been observed in both vegetables (Boulard and Jemaa, 1993; De Graaf and Van den Ende, 1981) and ornamental plants (Baille et al., 1994).

The daily transpiration of T_s (Fig. 6) showed a linear relationship to the overall incident radiation. In the present

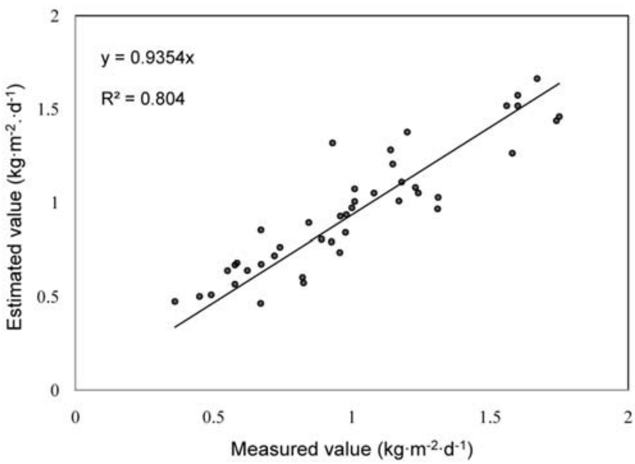

Fig. 7. Comparison between measured and estimated values of the daily transpiration in soilless culture of paprika greenhouse.

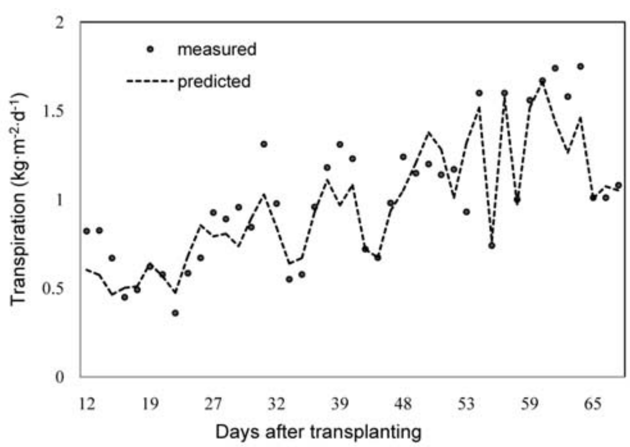

Fig. 8. Comparison between measured (symbols) and predicted (dotted line) values of daily transpiration in soilless culture of paprika greenhouse.

study, we found an increase in the transpiration per ground area of paprika plants over the growth period. The relationship of daily transpiration with incident radiation confirms the great influence of radiation on transpiration.

Model Calibration and Validation

The values of parameters a and b in Eq. (1), as determined by regression analysis, were 0.98 and 0.3 $kg \cdot m^{-2} \cdot d^{-1}$, respectively; the determination coefficient was 0.82 (n = 45) and the standard error of the model was 0.312. Therefore, the model considered appreciable daily transpiration. The comparison between estimated and measured values of the daily transpiration is reported in Fig. 7. The determination coefficient for the linear regression between estimated and measured was 0.80 (n = 47) with a slope of 0.93. When we applied the developed model for daily transpiration in real growth situations, we obtained good agreement between estimated and measured values (Fig. 8).

The relationship between plant transpiration and climate parameters in greenhouse plants was investigated by many authors (e.g. Boulard and Wang, 2000; Hamer, 1996; Joiliet and Bailley, 1992; Medrano, 2005; Stanghellini, 1987). The transpiration model considered in this study is a simplification of the transpiration model proposed by Baille et al. (1994) for ornamental plants, which was based on the RAD intercepted by the canopy and vapor pressure deficit (VPD). In the development of empirical regression model, it is a normal practice to limit the number of variables by omitting those that are closely correlated to others. Although the model does not include VPD, which was significantly correlated to RAD (Carmassi, 2007) during the day, we confirmed a good estimation of daily transpiration of paprika plants with RAD and LAI because most of the transpiration occurred during the day.

Using empirical approach, a simplified model derived from the Penman-Monteith equation was developed, calibrated and validated to simulate how much water is needed for greenhouse paprika plants in soilless culture during the growing period. In this study, the model appeared suitable for the simulation of transpiration of paprika plants. Radiation showed a great effect on transpiration indicating that radiation data could be conveniently used for estimating transpiration of paprika plants in soilless culture. The method proposed in this paper could be applied to any plants for which a suitable transpiration model is required. The implementation of LAI and transpiration equation valid for a wider range of growing conditions may improve the generality of the model and extend its appliance to the assessment of the water use efficiency.

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Literature Cited

Antony, E. and R.B. Singadhupe. 2004. Impact of drip and surface on growth, yield and WUE of capsicum (*Casicum annuum* L.). Agr. Water Manage 65:121-132.
Boulard, T. and R. Jemaa. 1993. Greenhouse tomato crop transpiration model application to irrigation control. Acta Hort. 355:381-387.
Baille, M., A. Baill, and J.C. Laury. 1994. A simplified model for predicting evapotranspiration rate of nine ornamental species vs. climate factors and leaf area. Sci. Hort. 59:217-232.
Boulard, T. and S. Wang. 2000. Greenhouse crop transpiration simulation from external climate conditions. Agr. For. Moteorol. 100:25-34.
Carmassi, G., L. Incrocci, R. Maggini, F. Malorgio, F. Tognoni, and A. Pardossi. 2007. An aggregated model for water requirements of greenhouse tomato grown in closed rockwool culture with saline water. Agr. Water Manage. 88:73-82.
De Graaf, R. and J. Van den Ende. 1981. Transpiration of evapotranspiration of the glasshouse crops. Acta Hort. 119:147-158.

Hamer, P.J.C. 1996. Validation of model used for irrigation control of a greenhouse crop. Acta Hort. 458:75-81.

Jolliet, O. and B.J. Bailley. 1992. The effect of climate on tomato transpiration in greenhouse: measurements and models comparison. Agr. For. Meteorol. 58:43-63.

Marcelis, L.F.M., E. Heuvelink, and J. Goudrian. 1998. Modeling biomass production and yield of horticultural crops: a review. Sci. Hort. 74:83-111.

Moreno, M.M., F. Ribas, A. Moreno, and M.J. Cabello. 2003. Physiological response of a pepper (*Capsicum annuum* L.) crop to different trickle irrigation rate. J. Spain Agri. Hort. 1:65-74.

Motulsky, H. and A. Christopoulos. 2003. Fitting models to biological data using linear and nonlinear regression. A practical guide to curve fitting. GraphPad Sofware Inc. San Diego. CA., USA.

Medrano, E., P. Lorenzo, M.C. Sanchez-Guerrero, and J.I. Montero. 2005. Evaluation and modeling of greenhouse cucumber-crop transpiration under high and low radiation conditions. Sci. Hort. 105: 163-175.

Nedefhoff, E.M. 1984. Light interception of a cucumber crop at different stages of growth. Acta Hort. 148:525-534.

Nobel, P.S. and S.P. Long. 1985. Canopy structure and light interception, pp. 41-49. In: J. Coombs, D.O. Hal, S.P. Long, and J.M.O. Scurlock (eds.). Techniques in bioproductivity and photosynthesis. Pergamon Press. Oxford. UK.

Stanghellini, C. 1987. Transpiration of greenhouse crops: an aid to climate management. PhD dissertation. Wageningen Agricultural University, Wageningen, Netherlands, p. 150.

Smittle, D.A., W.L. Dickens, and J.R. Stansell. 1994. Irrigation regimes affect yield and water use by bell pepper. J. Amer. Soc. Hort. Sci. 119:396-939.

Senzen, S.M., A. Yazar, and S. Eker. 2006. Effect of drip irrigation regimes on yield and quality of filed grown bell pepper. Agr. Water Manage. 81:115-131.