ISSN 0367-6315 (Print) / ISSN 2288-2162 (Online)
Korean J. Soil Sci. Fert. 48(5), 499-504 (2015)
http://dx.doi.org/10.7745/KJSSF.2015.48.5.499

Short communication

Infrared Estimation of Canopy Temperature as Crop Water Stress Indicator

Minyoung Kim*, Seounghee Kim, Youngjin Kim, Yonghun Choi, and Myungchul Seo[1]

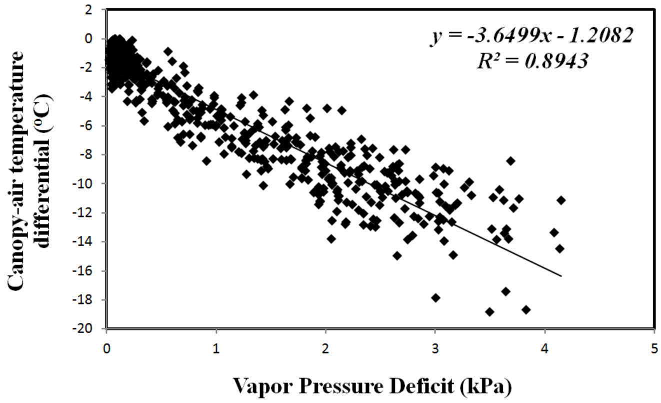
Department of Agricultural Engineering, National Academy of Agricultural Science, Rural Development Administration, Wanju-gun, 55365, Republic of Korea

[1]Crop Production and Physiology Research Division, National Institute of Crop Science, Rural Development Administration, Wanju-gun, 55365, Republic of Korea

(Received: October 5 2015, Revised: October 24 2015, Accepted: October 26 2015)

Decision making by farmers regarding irrigation is critical for crop production. Therefore, the precision irrigation technique is very important to improve crop quality and yield. Recently, much attention has been given to remote sensing of crop canopy temperature as a crop water-stress indicator, because it is a scientifically based and easily applicable method even at field scales. This study monitored a series of time-variant canopy temperature of cucumber under three different irrigation treatments: under-irrigation (control), optimal-irrigation, and over-irrigation. The difference between canopy temperature (T_c) and air temperature (T_a), $T_c - T_a$, was calculated as an indicator of cucumber water stress. Vapor pressure deficit (VPD) was evaluated to define water stress on the basis of the temperature difference between leaf and air. The values of $T_c - T_a$ was negatively related to VPD; further, cucumber growth in the under- and over-irrigated fields showed water stress, in contrast to that grown in the optimally irrigated field. Thus, thermal infrared measurements could be useful for evaluating crop water status and play an important role in irrigation scheduling of agricultural crops.

Key words: Precision irrigation, Infrared estimation, Crop water stress index (CWSI), Canopy temperature, Vapor pressure deficit



Relationship between canopy–air temperature difference ($T_c - T_a$) and VPD under optimal irrigation treatment

---

*Corresponding author : Phone: +82632384156, Fax: +82632384145, E-mail: mykim75@korea.kr

§Acknowledgement : This study was supported by the Research Program for Agricultural Science & Technology Development (Project No. PJ0100832015), National Academy of Agricultural Science (NAAS), Rural Development Administration, Republic of Korea

Introduction

According to the annual report by the Food and Agriculture Organization (FAO) of the United Nations, agriculture is by far the biggest water user, which accounts for worldwide consumption of approximately 70% of all withdrawals (FAO, 2002). Whereas expansion of irrigated land areas is a vital means to guarantee food supply for the growing world population, it is restricted by the scarcity of available water resources (FAO, 2002).

Under the circumstances of inadequate rainfall and available water resource for food production, farmers have always sought ways to supply water to crops as needed for development. Recent techniques that use direct and indirect sensing methods for irrigation have been developed to supply the right amount of water at the right time and right place to crops, which is the so-called precision irrigation. These techniques can increase crop yields and save water usage, energy and labor costs as compared with the conventional manual methods (Levidow et al., 2014). Several methods of inferring crop water stress for precision irrigation scheduling are based on environmental measurements (soil, weather and crop itself) where crops grow. These measurements include parameters such as soil water content, air temperature, canopy temperature, pan evaporation, solar radiation and so on (White and Raine, 2008). The sensing methods (direct and/or indirect) have advantages and disadvantages, and an appropriate method should be chosen in accordance with a given monitoring situation (Table 1).

The application of infrared thermometry is versatile, for example, in building inspection, R&D, process control, nondestructive testing, firefighting, automotive night vision, security/surveillance, and personal vision system (Mershon, 2015). Since the late 1800, many studies have evaluated infrared thermal sensing to measure crop surface temperature, which had been useful for crop water stress index (CWSI), crop yield prediction, and irrigation scheduling for some decades (Naeeni et al., 2014; Peñuelas et al., 1995; Orta et al., 2002).

As water supplies become limited, stomatal conductance and transpiration decrease, and the leaf temperature increases (Reginato, 1983). Similar to this, temperature virtually affects all aspects of crop growth and development through various mechanisms (Farquhar and Sharkey, 1982). The major role of transpiration is leaf cooling; therefore, canopy temperature and its reduction relative to ambient air temperature is an indication of how capable transpiration cools off leaves under demanding environmental loads (Farquhar and Sharkey, 1982).

Many studies investigated the relationship between the air–canopy temperatures and transpiration (which is not simple) that involves atmospheric conditions [vapor pressure deficit (VPD), air temperature, relative humidity, and wind velocity], soil (available soil moisture), and crop (canopy size and architecture and leaf adjustments to water deficit) (Jensen et al., 1990; Kaukoranta et al., 2005; Hackl et al., 2012; Ahi et al., 2015). The first approach was conducted by Idso et al. (1981) to define the linear relationship between canopy and atmospheric temperatures ($T_c - T_a$) as a function of atmospheric VPD for a plant transpiring at a potential speed (Idso et al., 1981). The succeeding studies revealed the semi-empirical equations between the observed canopy–air temperature difference ($T_c - T_a$) and VPD for CWSI estimation (Hackl, 2012). Thus, temperature measurement on individual leaves turned out to be a good

Table 1. Advantage and disadvantage of sensing methods for crop water stress (modified from Peters, 2015; Esteves et al., 2015).

Target	Methods	Advantage	Disadvantage
Soil	• Tensiometer • Psycrometers • Gravimetric method • Dielectric sensor (e.g., TDR) • Neutron probe	- Continuous measurement - Safe, easy to use, low cost, accurate, and wide measurement - Integration with commercial irrigation system	- Impossible to apply in heterogeneous soils - Atmospheric evaporative demand not considered - Level of plant stress not considered
Plant	• Pressure chamber • Psycrometers • Stem-trunk diameter • Porometer • Infrared thermography • Sapflow	- Direct measurement of plant water status and response - Advise time or quantity to irrigate - Applicable for current irrigation system - Consideration of environmental effect - High sensitivity	- Calibration needed - Threshold values need to be established - Most methods still at the research stage
Weather	• Penman–Monteith • Hargraves–Samani • Soil water balance	- Weather measurements normally available (no sensing method required if online data are available) - Relatively simple to apply	- Less precise than direct measurement - Local evaluation of weather variables and a good estimation of crop-soil parameters

indicator of crop stress (Jackson et al., 1981), being one of the most promising and valuable crop responses (Baille, 1992; Hashimoto et al., 1981; Ehret et al., 2001).

In contrast, little information has been known in implementing indirect sensing technologies (e.g., infrared thermometer) for plant-based irrigation (Kim et al., 2015). The previous two studies by Kim et al. (1999) and Kim et al. (1999) measured the change in crop temperature under stressful conditions caused by chemical fertilization and irrigation treatment in Korea (Kim et al., 1999; Kim et al., 1999). These were the first studies to evaluate the feasibility of infrared estimation to determine crop water stress under various water conditions. These studies also defined the relationship between canopy–air temperature difference and VPD under water-stress level.

Materials and Methods

A plastic greenhouse with an area of 5,290 m^2, located in Ansung City (Gyeonggi Province, South Korea), cultivates cucumber and tomato and is divided into two blocks. In the current study, cucumber (Baekdadagi), particularly sensitive to temperature change, was chosen for the experiment. Cucumbers are very sensitive to imbalance or changes in growing conditions. Careful attention should be given to cucumber growth factors, such as fertilizer salts, light, air temperature, humidity, carbon dioxide, and moisture, to avoid reduced crop production with poor quality (e.g., bitter tasting) (University of Alaska Fairbanks, 2015).

Cucumber is suited to drip irrigation in combination with plastic mulch. The soil type in the experimental plot was clay soil (44% clay, 30% silt, and 26% sand), and the available water holding capacity at the top 0.90 m of the soil profile was approximately 131 mm. A schematic of the experimental setup overview is shown in Fig. 1. To simulate various water stresses, three different irrigation treatments were prepared: under-irrigation (30% of optimal irrigation), optimal-irrigation, and over-irrigation (200% of optimal irrigation). The layout of the experiment was a completely randomized block design with three replications for each of the three treatments tested. The irrigation system was performed by a drip system using key clipped emitters (1.2 L/h), spaced 20 cm apart for each plant on 16-mm inside-diameter laterals, with one per two cucumbers. The emitters operated at a pressure of 100–150 kPa and were controlled using a bypass arrangement.

During the experimental period, the leaf temperature (°C), air temperature (°C), relative humidity (%), solar radiation ($W.m^{-2}$), soil moisture content (%), soil electrical conductivity (EC) ($dS.m^{-1}$), and soil temperature (°C) were measured using the sensor suites. The canopy temperature (T_c) was determined using an infrared thermometer (CT-300-232, Diwell, Korea), and its specifications were as follows: temperature range, from -30°C to 300°C; operating temperature, from 20°C to 70°C; resolution 0.1°C; accuracy, ±2%; and input voltage, 5 V. The thermometer was also connected to a data logger (WP700, Mirae sensor, South Korea). The canopy temperature was measured on a single, healthy, upper canopy and fully sunlit leaves of the three plants and then averaged. The soil water level in each plot was monitored by a frequency-domain reflectometry (FDR) sensor (FDR, WT2000, Mirae sensor, Korea) for each 0.10-m soil layer during the growing season. The canopy temperature and soil moisture content were measured from the same set of plants. A weather station was mounted at the center of the greenhouse to measure all weather-related parameters. All data collections were made at 1-h interval from March 29 to May 19, 2014.

Results and Discussion

The individual weather parameters were continuously collected and averaged as 524 ppm for CO_2, 275 $W.m^{-2}$ for solar radiation, 20°C for air temperature, and 78% for relative humidity. Daily routine irrigation was conducted in the morning around 7:00 am, and the daily amount of irrigation ranged from 500 to 800 mL per plant, depending on the crop and weather status (optimal irrigation). In the under- and over-irrigated cases, the ranges of water applied were 150–240 mL and 1,000–1,600 mL, respectively. During

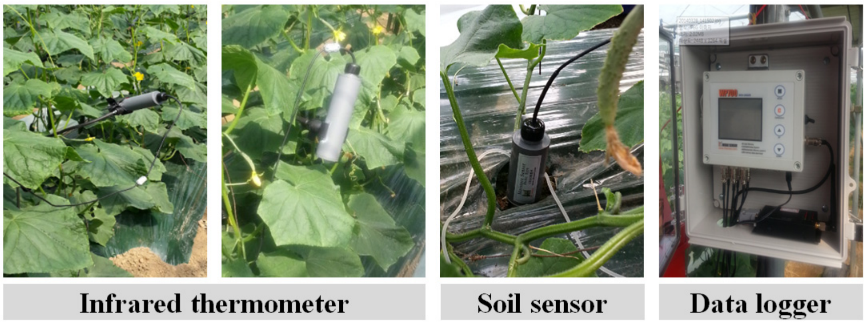

Infrared thermometer
Soil sensor
Data logger

Fig. 1. Schematic of the experimental setup.

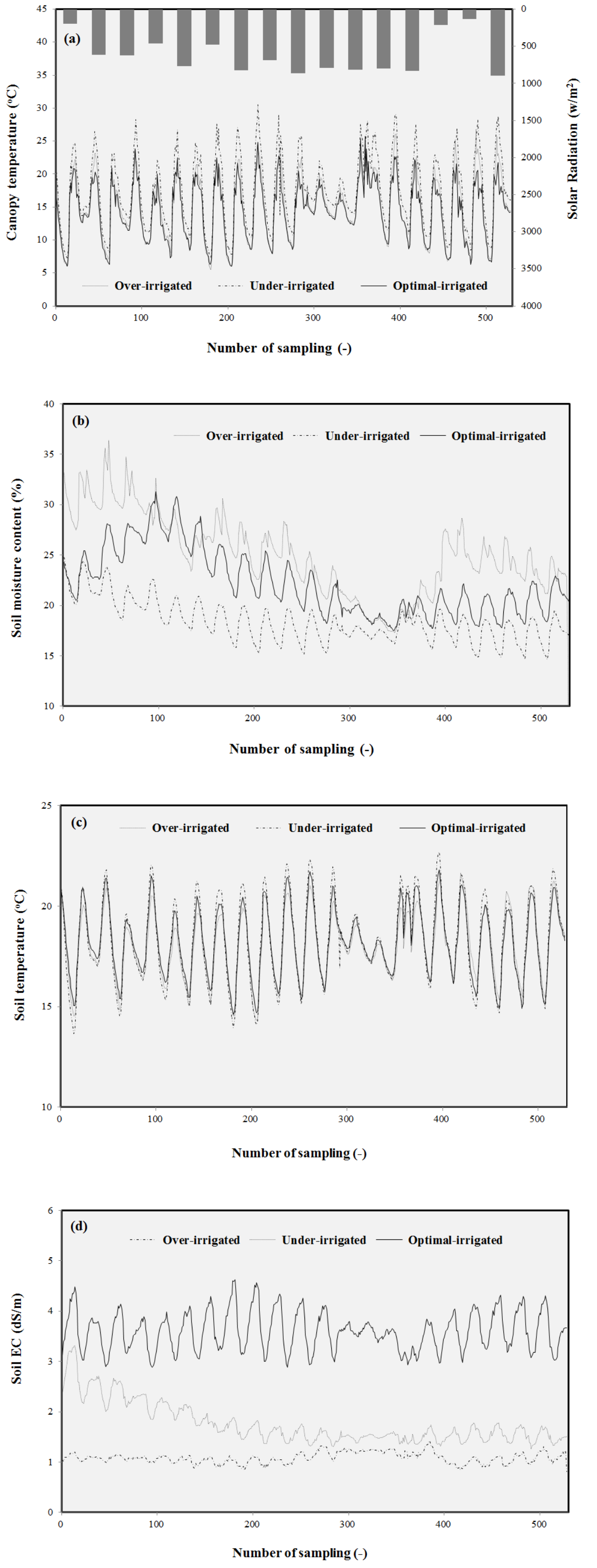


Fig. 2. Response of canopy and soil factors to a change in the irrigation treatment

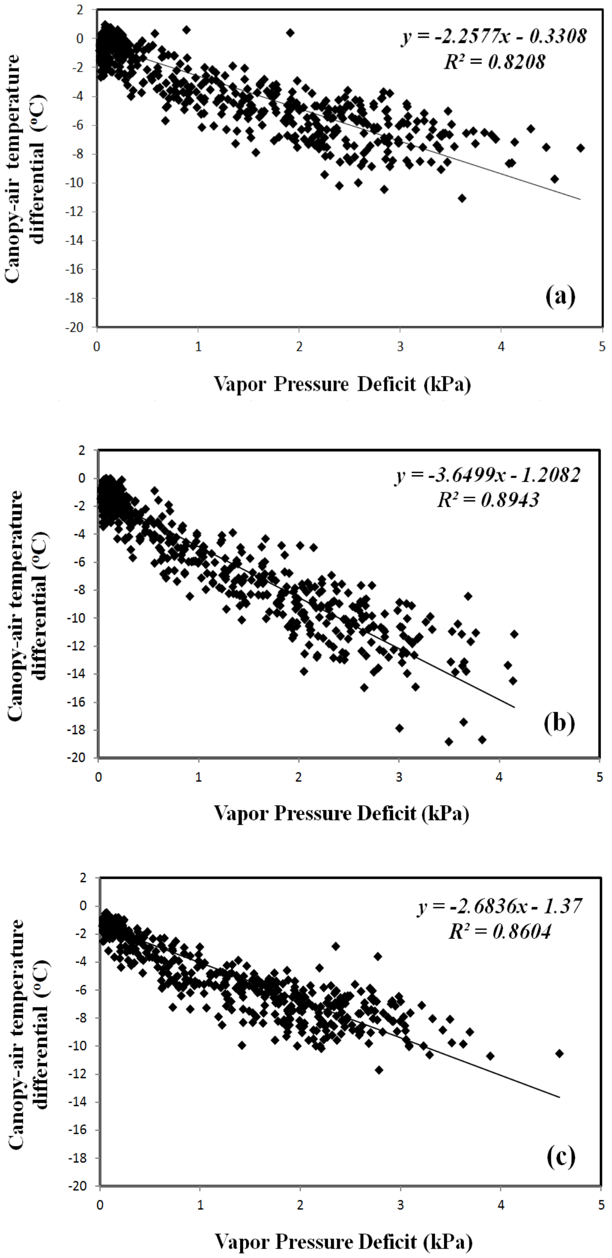


Fig. 3. Relationships between temperature differences and VPD under irrigation treatments (left: under-irrigated, Middle: optimally-irrigated, and right: over-irrigated)

the day, the plants experienced daily maximum water stress between 1:00 pm and 4:00 pm.

The response of soil moisture contents was rapid and positive as the drip irrigation system operated. Usually, the leaf and soil temperatures in the field is dynamic on a diurnal scale, and the soil EC is directly proportional to the irrigation event (Fig. 2). The growth of the under-irrigated cucumber showed the most sensitive response to the soil moisture content, followed by those of the over-irrigated and optimally irrigated cucumbers. In the middle of the data collection, leaks on the drip irrigation system occurred and was repaired (the measurement points were from 300 through 350). Therefore, misleading data were collected and resulted in no difference among the irrigation treatments.

Fig. 3 shows the cucumber condition under three different water stresses, where the steeper slope of the regression curve between the canopy–air temperature difference and VPD from the optimally irrigated plot (slope = -3.65) implies a greater effective canopy diffusion resistance relative to those that prevail in the under-irrigated (slope = -2.26) and over-irrigated (slope = -2.68) plots. Thus, more transpiration cooling occurred under less stressful circumstances. This study showed that cucumber became stressed in both under- and over-irrigation treatment.

The degree of difference among the irrigation treatments was not noticeable compared with our expectation. This result can be explained by the following facts: 1) the plastic greenhouse investigated in this study was built on a layer in the paddy fields and surrounded by them. The major soil texture of paddy fields is clay soil (mentioned earlier) has poor infiltration. Even though the bottom of the greenhouse was covered with plastic mulching material, movement of soil water underneath still occurred and linked between paddies and 2) the under- (30%), optimal- (100%), and over-irrigation (200%) treatments were not significantly different to visualize the effects on the canopy temperature, soil moisture content, soil EC, and soil temperature. However, the relationship between the canopy-air temperature difference and VPD clearly showed that cucumbers in the optimally irrigated condition grew better than those in the under- and over-irrigated conditions.

Conclusion

Effective irrigation management can increase marketable agricultural yield while reducing production costs by conserving water, energy, and even fertilizer (FAO, 2012). Therefore, this study has introduced an indirect sensing method using infrared thermometer to provide useful data for decision-making on precision irrigation.

The three irrigation treatments, namely, under-, optimal-, and over-irrigation treatments, clearly showed that cucumbers experienced the different levels of water stress. A real-time change in the canopy–air temperature was used to quantify and evaluate the crop water status. Negative correlations between the difference in the canopy–air temperature and VPD were realized as follows: under-irrigation (slope = -2.26, R^2 = 0.82), optimal-irrigation (slope = -3.65, R^2 = 0.89), and over-irrigation (slope = -2.68, R^2 = 0.86).

This study revealed that infrared estimation of canopy temperature could play a role as an efficient and strategic factor for crop water-stress control and smart water management against water scarcity and climate change. In addition, continuous measurement must be performed and integrated with meteorological data and remote sensing to obtain spatial water stress data to calculate the CWSI of cucumbers.

References

Ahi, Y., H. Orta, A. Gündüz, and H. Gültaş. 2015. The canopy temperature response to vapor pressure deficit of Grapevine cv. Semillon and Razaki, Agri. & Agri. Sci. Procedia. 4: 399-407.

Baille, A. 1992. Water status monitoring in greenhouse crops. Acta Hortic. 304:15-27.

Ehret, D.L., A. Lau, S. Bittman, W. Lin, and T. Shelford. 2001. Automated monitoring of greenhouse crops. Agronomie. 21:403-414.

Esteves, B.S., L.L. Lousada, E.F. Sousa, and E. Campostrini. 2015. Advanced techniques using the plant as indicator of irrigation management. Ciênc. Rural, Santa Maria. 45(5): 821-827.

FAO. 2002. World Agriculture: Towards 2015/2030, an FAO Study. Rome.

Farquhar, G.D., and T.D. Sharkey. 1982. Stomatal conductance and photosynthesis. Ann. Rev. Plant Photosynth. 33:317-345.

Hackl, H., J.P. Baresel, B. Mistele, Y. Hu, and U. Schmidhalter. 2012. A comparison of plant temperatures as measured by thermal imaging and infrared thermometry. J. Agron. Crop Sci. 198(6):415-429.

Hashimoto, Y., T. Morimoto, and S. Funada. 1981. Computer processing of speaking plant for climate control and computer aided plantation (computer aided cultivation). Acta Hortic. 317-325.

Idso, S.B., R.D. Jackson, P.J. Pinter, R.J. Reginato, and J.L. Hatfield. 1981. Normalizing the stress degree day for environmental variability. Agric. Meteorol. 24:45-55.

Jensen, M.E., Burman, R.D., and R.G. Allen. 1990. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Pratice N. 70, Am. Sco. Civil Engr., New York, NY. pp.332.

Jackson, R.D., S.B. Idso, and R.J. Reginato. 1981. Canopy temperature as a crop water stress indicator. Water Resour. Res. 17:1133-1138.

Kaukoranta, T., J. Murto, J. Takala, and R. Tahvonen. 2005. Detection of water deficit in greenhouse cucumber by infrared thermography and reference surfaces. Sci. Hortic. 106:447-463.

Kim, G., K. Ryu, and H. Chae. 1999. Analysis of water stress of greenhouse crops using infrared thermography. Korean Soc. Agric. Machinery. 24:439-444.

Kim, G., K. Ryu, and H. Chae. 1999. Measurement of stress related crop temperature variations. Proceedings of the Korean Society for Bio-Environment Control. 233-236.

Kim, G., K. Lee, G. Kim, and B. Cho. 2015. Measurement and analysis of apparent temperature from the radiant heat of plant response. Proceedings of the Korean Society for Agricultural Machinery. 192-193.

Levidow, R., D. Zaccaria, R. Maia, E. Vivas, M. Todorovic, and A. Scardigno. 2014. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. Agricult. Water Manage. 146:84-94.

Mershon, J. 2015 Infrared thermometry: Introduction, history and application. Available from: http://www.advanced-energy.com/upload/File/White_Papers/ENG-THERMOME-TRY-270-01.pdf

Naeeni, A.E., E.M. Esfahani, M.B. Harchegani, M. Jafarpour, and M.A. Golabadi. 2014. Leaf temperature as an index to determine the irrigation interval. Research on Crop Eco-physiology. 9/1(2):89-95.

Orta, A.H., T. Erdem, and Y. Erdem. 2002. Determination of water stress index in sun-flower. Helia. 37:27-38.

Peters, R.T. 2015. Practical use of soil moisture sensors for irrigation scheduling. Available from: http://irrigation.wsu.edu/Content/Fact-Sheets/Practical-Soil-Moisture-Monitoring.pdf

Peñuelas, J., I. Filella, and G.A. Gamon. 1995. Assessment of photosynthetic radiation-use efficiency with spectral reflectance. New Phytologist. 131:291-296.

Reginato, R.J. 1983. Field quantification of crop water stress. Trans. ASAE. 26:772-775.

University of Alaska Fairbanks. 2015. Cucumber production in greenhouse. Available from: http://www.uaf.edu/files/ces/publications-db/catalog/anr/HGA-00434.pdfWhite, S.C. and S.R. Raine. 2008. A grower guide to plant based sensing for irrigation scheduling. NCEA publication 1001574/6.