Leaf Temperature as an Index to Determine the Irrigation Interval

ABDOLREZA EGHTEDARI NAEENI[1*], ELHAM MOHRI ESFAHANI[1], MOHSEN BEIGI HARCHEGANI[2], MEHRDAD JAFARPOUR[1], MARYAM GOLABADI[1]

1- Faculty of Agriculture Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Isfahan, Iran

2- Tiran Branch, Islamic Azad University, Isfahan, Iran.

*Corresponding author Email: a.eghtedar@gmail.com

ABSTRACT

Evapotranspiration and plant water absorption reduce when exposed to water stress and this reduction results in an increase in leaf temperature. To determine the effect of water stress on leaf temperature and timing of irrigation using leaf temperature, a research was conducted on the Research and Education Greenhouse Production Center of Islamic Azad University, Isfahan Branch (Khorasgan). This study was conducted in controlled conditions and soilless culture of cucumber, tomato, pepper and strawberry. The index of difference between the temperature of air and leaf ($\Delta T = T_{Air} - T_{Leaf}$) showed leaf temperature which then could indicate the amount of water absorbed by the root; therefore, transpiration rates were measured. With an acceptable coefficient of determination model, we concluded that this index (difference between the temperature of air and leaf) was dependent on the intake of water from the roots and leaf transpiration rate, so it can be used as an indicator to determine the time of irrigation.

Keywords: Water stress, Leaf temperature, Timing of irrigation.
ABBREVIATION: VPD: Vapor Pressure Deficit, PAR: Photosynthetically Active Radiation, RH: Relative Humidity, $\Delta T = T_{Air} - T_{Leaf}$.

INTRODUCTION

In soilless media (in according to limitation of root volume) several times a day plants are irrigated, because a few minutes delay in irrigation could create irreparable damage. Therefore, we need a technique through which we can recognize the irrigation time accurately and quickly.

Decreased water uptake closes stomata, which then reduces transpiration and increases leaf temperature (Blonquist *et al.,* 2009). In general, water stress causes stomata closure in plants, and this leads to higher leaf temperature (Sdoodee, Kaewkong, 2006).

Canopy temperature has long been recognized as an indicator of plant water status and as a potential tool for irrigation scheduling (Cohen *et al*. 2005). Leaf temperature is a physiological trait that can be used for monitoring plant water status (Jimenez-Bello *et al.,* 2011).

Surface temperature measured with infrared thermometers is an important tool which also is useful for both the crop water stress index (CWSI) and irrigation scheduling for some decades. A new definition of a non- water -stressed baseline theoretically based and driven by weather variables that can easily be measured and/or estimated proposed that measurements at any time of the day, regardless of the weather conditions, can simplify the task of the irrigator. The non-water-stressed baseline is a useful concept that can effectively guide the irrigator when maximum yields are to be obtained (Alves and Pereira, 2000). The CWSI calculated based on crop temperatures was applied so the use of the CWSI was successful and the expected yield surplus with supplementary water supplies was 10-20% (Anda, 2003). Bao-Zhong (2003) showed that the amount of irrigation water had significant effects on decreasing the canopy temperature. Yuan (2003) introduced CWSI as a most often used index which is based on canopy temperature to detect crop water stress. Erdem (2010) showed that the CWSI was calculated using the empirical approach from measurements of infrared canopy temperatures, ambient air temperatures and vapor pressure deficit values for five irrigation levels. An average threshold CWSI value of about 0.51 before irrigation produced the maximum yield.

The semi empirical equations developed for CWSI can be used to determine the crop water stress using observed canopy–air temperature difference (Tc - Ta) and VPD for the wheat crop grown in the study region (Gontia and Tiwari, 2008). Hackl (2012) indicated that there were significant and close relationships between canopy temperature and leaf water potential.

Stomatal closure or decreasing stomatal conductance caused increasing of Tc-Ta in the leaves. Hence, it suggests that infrared thermometer is a convenient device for the assessment of plant water stress in neck orange (Sdoodee and Kaewkong, 2006).

Multiple linear regression models of leaf temperature as functions of stem water potential, air temperature, relative humidity, photosynthetically active radiation, and wind speed were developed and validated for almond and walnut crops under sunlit and shaded conditions (Udompetaikul, 2010). The relative humidity and air temperature values were used to calculate the equivalent temperature, also considering latent heat flux, and finally the evapotranspiration of plantation was calculated. From differences in the equivalent and air temperatures, conclusions can be drawn on the intensity and daily course of transpiration (Tokei and Dunkle, 2005).

Labourgeois *et al*. (2010) showed that the application of the leaf temperature method in determining the timing of irrigation depends on calibrating it for ideal plant and designing a mathematical model, and Gontia *et al*. (2008) used as quantify crop water stress index (CWSI) to schedule irrigation in winter wheat crop.

MATERIALS AND METHODS

In order to recognize the effect of amount (percent or potential) of water in media on leaf temperature, these studies were done in the greenhouse of Islamic Azad University (Khorasgan Branch) located in the east of Isfahan, in 2011. It is a Gothic arch shaped building with polyethylene cover. Other specifications of this system are 520 cm height, adjustable temperature and humidity, warm air heating system, and evaporating cooling system. Night and day temperatures are adjusted to 19-21°C and 25-30°C, respectively depending on factors like growth stage, light intensity, and so on. This research was done on cucumber, tomato, pepper and strawberry soilless media. In controlled greenhouse condition, plants implanted in soilless media (50 percent perlite, 25 percent cocopeat, 25 percent peat) were not irrigated up to high water stress, and at the same time difference between air and leaf temperature was measured.

After the irrigation, the temperature difference between air and the leaf index as well as moisture content of planting ambient were measured every five minutes. To increase accuracy, these indices are measured 50 times for each plant. Moisture content of planting ambient, air temperature and leaf surface temperature were measured by 100 TDR -America FIELDSCOUT company- with 1 percentage accuracy, Testo 625 with 0.5 ° C accuracy and Testo 625 with 0.1 ° C accuracy. The resulting data were analyzed by MATLAB software.

RESULTS AND DISCUSSIONS

Leaf temperature and ΔT were slightly different in each of four plants (cucumber, tomatoes, peppers and strawberries) after irrigation and water uptake by plants decreased at high speed. In other words, leaf temperature decreased after the irrigation. In this case, the difference between ambient temperature and leaf area (ΔT) increased (Figure1). Based on the similar results of these four plants, the best model (equation) was:

$$\Delta T = T_{Air} - T_{Leaf} = \frac{at + b}{ct^2 + dt + e} + f$$

Where t= Time after irrigation (min), T_{Air} = air temperature (°C), T_{Leaf} = Leaf temperature (°C) and a, b, c, d, e, f= constant index for each plants (cucumber, tomato, pepper and strawberry).

The coefficient of determination between the two parameters- leaf temperature and time after irrigation- of plants including cucumbers, tomatoes, peppers and strawberries are 0.96, 0.93, 0.93 and 0.98, respectively.

The results (the basic model was similar for all plants and the coefficient of determination was high) showed that the index of difference between the temperature of air and leaf (ΔT) could indicate the amount of water absorbed by the roots and plant transpiration. Grey (2010) stated that the regression coefficient (R^2) between evapotranspiration (ET) and mean leaf temperature of tomato was 0.648. Therefore, ΔT can be considered as a useful index for detecting used water. However other factors can help the preciseness of this index to improve .

Ahmed *et al*. (2006) showed that the modified Penman equation was correlated with the canopy temperature difference. They found that this correlation (R= 0.94) can be used for the

detection of water stress in Faba bean. Overall, the results showed that after the irrigation of all plants (cucumber, tomato, pepper and strawberry) the leaf temperature reduced in the first time, then by reducing the amount of water in ambient planting the leaf temperature increased gradually.

In 5 minutes after the irrigation of cucumber, the leaf temperature quickly decreased and the ΔT reached the highest level (Figure 1. section A.). Maximum ΔTs for tomatoes, pepper and strawberry were 18, 5 and 20 minutes, respectively (Figure 1. section B., C. and D.).

In cucumber, ΔT decreased from 16°C to 10°C after 25 minutes of stating (constant) irrigation (Figure 1. section A.). Approximately 20 minutes after starting tomato irrigation, leaf temperature decreased, but this decreasing trend occurred longer than cucumbers irrigation. After 70 minutes, reduction of the leaf temperature reached the balance in tomato leaves (Figure 1. section B.). Likewise cucumbers, peppers leaf temperature reduced, except that pepper leaf temperature reduced from 16°C to 4°C (Figure 1. section C.). In strawberry leaf temperature reached equilibrium after 160 minutes, from 14°C to 6°C (Figure 1. section D.).

Differences in the strength of root water uptake, leaf area index and transpiration rate of the studied plants can cause the time differences in ΔT.

Strong relationship between leaf temperature and water stress can be seen in the R^2 parameter.

Çamoglu (2013) have studied evapotranspiration (ET) and leaf temperatures in fully irrigated and water-stressed plants. Their results showed that the relationship between difference leaf temperature (T_L) and ambient air temperature (T_a) (T_L- T_a) and ET was linear and the coefficients of determination ($R^2 = 0.62$ and 0.74 according to the analysis of linear regression) were statistically significant at $p < 0.001$ for both cultivars of olive. Their study showed that leaf temperature change depending on ET, and infrared thermometer can be used for measuring daily ET in olive seedlings (Çamoglu, 2013).

Blonquist et al. (2009) showed that decreased water uptake closes stomates, which reduces transpiration and increases leaf temperature. The leaf or canopy temperature has long been used to make an empirical estimate of plant water stress. Infrared measurement of canopy temperature can be used to calculate canopy stomatal conductance (g_c). A sensitivity analysis of the input measurements/estimates showed g_c was highly sensitive to small changes in canopy and air temperature, and less sensitive to the other required measurements (relative humidity, net radiation, wind speed, and plant canopy height).

a	b	c	d	e	f
-17.28	18.25	-0.8757	5.405	-15.56	8.739

Sectin A. Cucamber

a	b	c	d	e	F
-8.858	-33.78	-0.1062	2.421	-33.9	5.535

Sectin B.Tomato

a	b	c	d	e	f
-17.62	-31.14	-0.1293	0.5247	-6.005	-2.223

Sectin C. Pepper

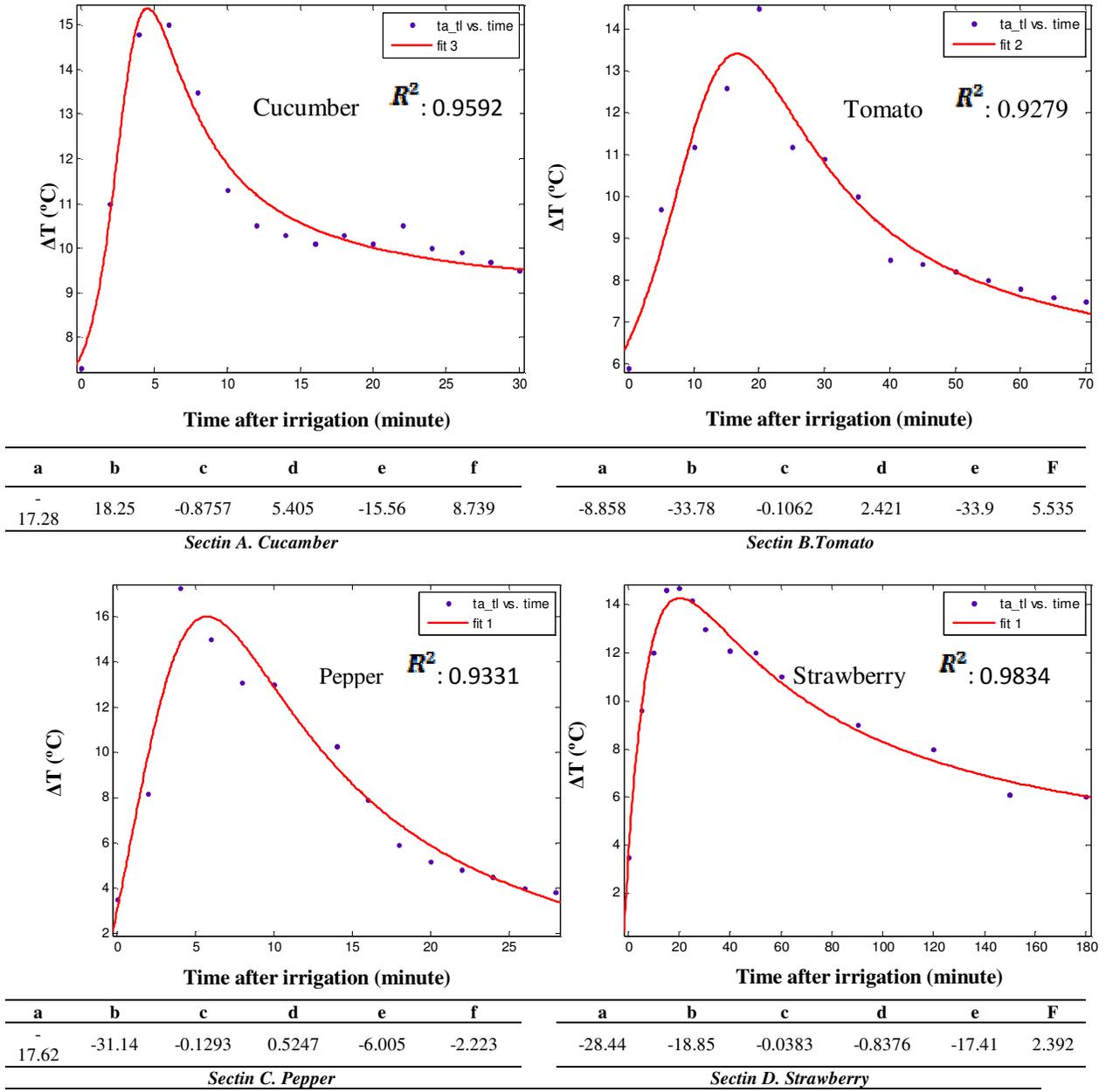| a	b	c	d	e	F
-28.44	-18.85	-0.0383	-0.8376	-17.41	2.392

Sectin D. Strawberry

Figure 1. The process of variation differences of environment temperature (vertical axis- Centigrade) and the surface of leaf after irrigation (horizontal axis- minute)

CONCLUSION

Results of experiments on four plants, cucumbers, tomatoes, peppers and strawberries showed that the leaf temperature could be measured by the degree of water stress in the examined plants. Thus, leaf temperature can be widely used as an effective indicator of the estimated timing of irrigation.

However, to better estimate the effect of plant water stress on other elements, different environmental factors such as relative humidity and wind speed - must also be studied.

REFERENCE

Ahmed MF, Dawi I, Ibrahim OH. 2006. Use of infrared thermometer for water stress detection in Faba bean. Sudan Journal of Agricultural Research, 6: 43-51.

Alves I, Pereira LS. 2000. Non-water-stressed baselines for irrigation scheduling with infrared thermometers: A new approach. Irrigation Science, 19: 101-106.

Anda A. 2003. Determination of irrigation timing in maize by measuring crop temperatures. Novenytermeles. 52: 203-215.

Bao-Zhong Y, Soichi N, Yaohu K. 2003. Effects of different irrigation regimes on the growth and yield of drip-irrigated potato. Agricultural Water Management, 63(3): 153-167.

Blonquist JM, Norman JM, Bugbee B. 2009. Automated measurement of canopy stomatal conductance based on infrared temperature. Agricultural and Forest Meteorology. 149: 2183-2197.

Çamoglu G. 2013. The effects of water stress on evapotranspiration and leaf temperatures of two olive (Olea europaea L.) cultivars. Zemdirbyste-Agriculture, 100(1): 91-98.

Cohen Y, Alchanatis V, Meron M, Saranga Y, Tsipris J. 2005. Estimation of leaf water potential by thermal imagery and spatial analysis. Journal of Experimental Botany. 56(417): 1843–1852.

Erdem Y, Arin L, Erdem T, Polat S, Deveci M, Okursoy H, Gültaş HT, 2010. Crop water stress index for assessing irrigation scheduling of drip irrigated broccoli (Brassica oleracea L. var. italica): Article provided by Elsevier in its journal Agricultural Water Management. 98(1): 148-156.

Gontia NK, Tiwari KN. 2008. Development of crop water stress index of wheat crop for scheduling irrigation using infrared thermometry. Agricultural water management, 95: 1144-1152.

González-Dugo MP, Moran MS, Mateos L, Bryant R. 2006. Canopy temperature variability as an indicator of crop water stress severity. Irrigation Science, 24(4): 233-240.

Grey SN. 2010. Monitoring the simultaneous response of various water status indicators for use in the irrigation scheduling and drought stress detection of a greenhouse tomato crop. Master of Science thesis, University of Zimbabwe.

Hackl H, Baresel JP, Mistele B, Hu Y, Schmidhalter U. 2012. A Comparison of Plant Temperatures as Measured by Thermal Imaging and Infrared Thermometry. Journal of Agronomy and Crop Science, 198(6): 415-429.

Jimenez-Bello MA, Ballester C, Castel JR, Intrigliolo DS. 2011. Development and validation of an automatic thermal imaging process for assessing plant water status. Agricultural Water Management, 98: 1497-1504.

Lobo FDA, Oliva MA, Resende M, Lopes NF, Maestri M. 2004. Infrared thermometry to schedule irrigation of common bean. Pesquisa Agropecuária Brasileira, 39(2): 113-121.

McCutchan H, Shackel KA. 1992. Stem-water Potential as a Sensitive Indicator of Water Stress in Prune Trees (Prunus domestica L. cv. French). Journal of the American Society for Horticultural Science, 117(4): 607-611.

Moller M, Alchanatis V, Cohen Y, Meron M, Tsipris J, Naor A, Ostrovsky V, Sprintsin M, Cohen S. 2007. Use of thermal and visible imagery for estimating crop water status of irrigated grapevine. Journal of Experimental Botany, 58(4): 827-838.

Payero J, Irmak S. 2006. Variable upper and lower crop water stress index baselines for corn and soybean. Irrigation Science, 25(1): 21-32.

Raviv M, Lieth JH. 2008. Soilless Culture:Theory and Practice. Copyright © Elsevier BV.

Sdoodee S, Kaewkong P. 2006. Use of an infrared thermometer for assessment of plant water stress in neck orange (Citrus reticulata Blanco). Songklanakarin Journal of Science Technology, 28 (6): 1161-1167.

Shackel KA, Ahmadi H, Biasi W, Buchner R, Goldhamer D, Gurusinghe S, Hasey J, Kester D, Krueger B, Lampinen B, McGourty G, Micke W, Mitcham E, Olson B, Pelletrau K, Philips H, Ramos D, Schwankl L, Sibbett S, Snyder R, Southwick S, Stevenson M, Thorpe M, Weinbaum S, Yeager J. 1997. Plant water status as an index of irrigation need in deciduous fruit trees. HortTechnology, 7(1):23-29.

Testi L, Goldhamer D, Iniesta F, Salinas M. 2008. Crop water stress index is a sensitive water stress indicator in pistachio trees. Irrigation Science, 26(5):395-405.

Tokei L, Dunkle Z. 2005. Investigation of crop canopy temperature in apple orchard. Physics and Chemistry of the Earth, 30(1-3):249-253.

Udompetaikul V, Upadhyaya SK, Slaughter DC, Lampinen BD. 2010. Development of a sensor suite to determine plant water potential. 2010 ASABE Annual International Meeting, 6-7: 4768-4778.

Yuan G, Luo Y, Sun X, Tang D. 2004. Evaluation of a crop water stress index for detecting water stress in winter wheat in the North China Plain. Agricultural Water Management, 64: 29-40.