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Diurnal Variation of Remotely Sensed ET and Some Indices on Sweet Cherry Trees in Subhumid Climate Conditions

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Abstract: In this study, an experiment was conducted in sub-humid condition, several observations made to determine Tc, spectral indexes, LWP and daily ET of sweet cherry trees with different irrigation treatments (T_1 and T_2). The results showed that, Tc-Ta were increased from sunrise to noon and decreased from noon to sunset throughout the day on DOY 171-172 (T_1-T_2) and DOY 233-234 (T_2). However, it was increased from sunrise to sunset on DOY 233-234 for T_1 treatment. It is very close the values of ET_d and ET_{cum} which were determined based on remotely sensed data with daily ET values determined by soil water budget for Gisela 5 rootstock. The cherry trees with non-water stress condition (T_2) have had also the highest spectral index values and the tree with water stress condition (T_1) has had the lowest spectral index values. According to statistical analysis, most significant relationships were determined between LWP-SAVI (r = 0.88 for T_1; r = 0.77 for T_2), ET_i-LWP (r = 0.89 for T_1; r = 0.92 for T_2), ET_i-SAVI (r = 0.88 for T_1; r = 0.70 for T_2) and ET_i-Tc-Ta (r = 0.85 for T_2). Based on these findings, the canopy temperature of sweet cherry trees is more sensitive to water stress than leaf water potential and spectral indexes and daily ET for sweet cherry trees may be defined with remotely sensed data. Spectral indexes may be used efficiently to monitor vegetation growth periods and may be beneficial to determine ET of sweet cherry trees.

Key words: Water stress, remote sensing, leaf water potential, sweet cherry

INTRODUCTION

The best way for optimum irrigation scheduling is to monitor and manage the water based on plant monitoring. Several studies have shown that information on crop water status, required when planning irrigation programs, is provided more reliably by physiological indicators. However, there is no general agreement on the most suitable indicator (Katerji *et al*., 1988)

Pre-dawn leaf water potential (Ferreira *et al*., 1997; Valancogne *et al*., 1997) is frequently used, while other indicators have also been employed, such as stem water potential (McCutchan and Shackel, 1992; Naor *et al*., 1999), leaf temperature (Glenn *et al*., 1989; Girona *et al*., 1993; Cohen *et al*.,1997; Jones *et al*., 1997; Massai *et al*., 2000a) and soil water content (Goldhamer *et al*., 1999).

By the support of climatic data, one can define irrigation time and water amount by the infrared thermometry measurement of canopy temperature. The relationship between plant canopy temperature and water availability in the soil has been investigated by infrared thermometer (Idso *et al*., 1981; Jackson *et al*., 1981; Clawson and Blad, 1982), in search for a suitable thermal index to establish the proper irrigation time. One of the first indices was the stress-degree day, based on the relationship between the difference of the canopy and air temperature with the yield and water requirement of the crop (Jackson *et al*., 1977). Ehrler (1973) suggested that the difference between the leaf and air temperatures would be directly correlated with the water vapor pressure deficit. Crop Water Stress Index (CWSI), based on canopy-air temperature difference and vapor pressure deficit of air, is the most known stress index (Idso *et al*., 1981).

The concept of using remotely sensed surface temperatures in evapotranspiration estimations was espoused by Bartholic *et al*. (1972), Brown and Rosenberg (1973) and Stone and Horton (1974). The physical basis for the concept was outlined some years earlier by Monteith and Szeicz (1962) and Monteith (1963). Perrier (1975a, b, c) presented a detailed account of evapotranspiration under natural conditions, including the role of surface temperatures in the evapotranspiration process. Jackson *et al*. (1977) combined several variables in to a constant that was empirically obtained by

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regressing one time of day surface-air temperature differences and daily net radiation to the total daily evapotranspiration, in an attempt to evaluate evapotranspiration from predominately remotely sensed data. It is possible to define instantaneous evapotranspiration (ET_i) by the use of remotely sensed surface temperature and some climatic parameters (Hatfield *et al.*, 1983). According to this assumption, Jackson *et al.* (1983) proposed a method to convert ET_i determined within about 2 h of solar noon, to daily total evapotranspiration (ET_d).

Glenn *et al.* (1989) showed that, daily evapotranspiration of peach trees estimated from latent heat flux are harmonious with evapotranspiration defined from lysimeters. They stated that infrared thermometry has a potential application to monitor water use and schedule irrigation in peach orchard systems.

Numerous studies related to field crops and vegetables have been made with energy balance and crop water stress index approaches, but there are few study on trees. As example studies, Evans *et al.* (1982) for apple; Torman (1986) for nectarine; Remoini and Massai (2003) for peach can be given to infrared thermometry of trees.

The aim of this study was to determine irrigation scheduling for irrigation of cherry trees by remote sensing. For this purpose instantaneous evapotranspiration (ET_i), daily evapotranspiration (ET_d), Leaf Water Potential (LWP), spectral reflectance, spectral indexes and crop-air temperature difference were analyzed.

MATERIALS AND METHODS

Experimental procedures: This study was carried out during the growing season of 2004, on the experimental field, located in Bursa (western part of Turkey), latitude 40° 15′ 29″ N, longitude 28° 53′ 39″ E and altitude 100 m above sea level.

Plant material studied was sweet cherry trees (*Prunus cerasus* x *Prunus canescens,* variety Z-900) on 2 years old Gisela-5 dwarf rootstocks. Gisela-5 rootstock produces a dwarf tree with and very weak anchorage and best compatible with sweet cherries.

The trees were planted in 2002, spaced 5×2.5 m apart. Uniform six trees were selected for observation. Micro-sprinkler irrigation was selected as the irrigation method. The trees were subjected to two micro-sprinkler irrigation treatments (T_1 and T_2). T_1 and T_2 treatments were programmed using two reduction percentages of the US Weather Bureau Class A pan evaporation. The water applied in treatment T_2 was considered sufficient to satisfy fully needs of the crop (100% of ET_c) and to allow good rooting and tree growth.

The Total Amount of Irrigation Water (TIW) applied was calculated from (Allen *et al.*, 1998);

$$TIW = \frac{K_p.K_c.K_1}{E_a.E_u} E_{pan} \quad (1)$$

where K_p is the pan coefficient (0.70; Doorenbos and Pruitt, 1977), K_c the crop coefficient (0.50 for June, 1.20 for July and August and 0.95 for September and October; Allen *et al.*, 1998), K_l the shade coefficient (0.61; Vermeiren and Jobling, 1986) taking into account that the estimated mean shade surface provided by the tree canopies was 46 % of the total surface of the orchard, E_u the coefficient of uniformity of emitters (0.9).

Applying the reduction percentage mentioned above to Eq. (1) gives the following total amounts of irrigation water treatment:

$$TIW_{(T1)} = 0.32\ E_{pan} \quad (2)$$
$$TIW_{(T2)} = 0.63\ E_{pan} \quad (3)$$

Water amount calculated for T_2 treatment was applied to both T_1 and T_2 treatments until DOY 171. Between DOY 172 and DOY 233, full and deficit irrigation water were applied to T_2 and T_1 treatments, respectively.

Measurements: The diurnal measurements were carried out on June 20-21 and August 21-22, 2004. Air wet and dry bulb temperature were measured at the height of 1.5 m. Canopy temperatures were measured by an infrared thermometer (Model 100.3ZL, Everest Interscience Inc.,USA) with a 4° filed-of-view. Twelve temperature data were taken from the four view azimuths (90 degree increments from the solar azimuth) by viewing the tree horizontally at about 1.4 m above the ground level, 1.5 m from the tree. All the measurements were arithmetically averaged to obtain the mean canopy temperature. The leaf water potential measurements were made by pressure chamber (PMS Model 3000, Soil Moisture Equipment Corp., Santa Barbara, CA, USA) utilizing compressed N gas. Reading precision was 1% for 0 to 70 bars. Measurements were made at the field so pressure was read within 1 minute of leaf removal from the tree. Spectral observations were made using spectroradiometer (LI-1800) with 15° field- of-view lenses. The radiance of the tree in the region from 650-1100 nm, at 2 nm interval was detected from 0.5 m above the top of the tree with nadir orientation of telescope body. Irradiance spectra of sunlight were taken before and after each measurement with a $BaSO_4$ panel and the average were used as the reflectance standard (Jackson *et al.*, 1980). All measurements were replicated tree times and average of these measurements was computed by spectroradiometer. Reflectance of individual wavelength was calculated by dividing the vegetation radiance measurements with the irradiance measurements. Soil water level measured with a well calibrated neutron probe (503 DR neutron probe, CPN International, Inc., Martinez, California, USA) at 9 point per tree.

Evapotranspiration: The energy balance for a crop was given by Monteith (1963) as;

$$R_n = G + H + \lambda E \quad (4)$$

where R_n is the net radiant heat flux density, G is the soil heat flux density, H is the sensible heat flux density and λE is the latent heat flux density to the air (the product of evapotranspiration rate, E and the heat of vaporization, λ). All terms in the equation are in units of W m^{-2}.

According to Allen *et al*. (1998) Rn can be expressed as,

$$R_n = R_{ns}\text{-}R_{nl} \quad (5)$$

$$R_{ns} = (1\text{-}\alpha)R_s \quad (6)$$

$$R_{nl} = \sigma\left[\frac{\text{Tmax,K}^4 + \text{Tmin,K}^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad (7)$$

$$R_{so} = 0.75\text{+}2\ 10^{-5}\ z)\ R_a \quad (8)$$

$$R_a = \frac{12(60)}{\pi}G_{sc}d_r\left[\begin{array}{l}(\omega_2 + \omega_1)\sin(\varphi)\sin(\delta) + \\ \cos(\varphi)\cos(\delta)(\sin(\omega_2) - \sin(\omega_1))\end{array}\right] \quad (9)$$

$$d_r = 1 + 0.033\cos\left(\frac{2\pi}{365}j\right) \quad (10)$$

$$\delta = 0.409\sin\left(\frac{2\pi}{365}j - 1.39\right) \quad (11)$$

$$\omega_1 = \omega - \frac{\pi t_1}{24} \quad (12)$$

$$\omega_2 = \omega + \frac{\pi t_1}{24} \quad (13)$$

$$\omega = \frac{\pi}{12}\left[(t + 0{,}06667(Lz - Lm) + S_c) - 12\right] \quad (14)$$

$$S_c = 0,\ 1645\sin(2b)\text{-}0{,}1255\cos(b)\text{-}0{,}025\sin(b) \quad (15)$$

$$b = \frac{2\pi(j - 81)}{364} \quad (16)$$

where, R_n is the net radiation (MJ m^{-2} s^{-1}), R_{ns} is the in coming net shortwave radiation (MJ m^{-2} s^{-1}), R_{nl} is the out going long wave radiation (MJ m^{-2} s^{-1}), α is the albedo, R_s is the incoming solar radiation (measured) (MJ m^{-2} s^{-1}), σ is the Stefan Boltzmann constant Monteith and Unsworth (1990) suggested a value of 5.67×10^{-8} W m^{-2} K^{-4}, T max and T min air temperature (one value used for instantaneous calculation as Ta), R_{so} is the calculated clear sky radiation (MJ m^{-2} s^{-1}), R_a is the extraterrestrial radiation (MJ m^{-2} s^{-1}), G_{sc} is the solar constant (0.082 Mj m^{-2} min^{-1}), dr is the inverse relative distance Earth-Sun, δ is the solar declination (rad), φ is the latitude (rad), ω_1 is he solar time angle at beginning of period (rad), ω_2 solar time angle at the end of period (rad), t_1 is the length of calculation period, ω is the solar time angle at midpoint of period, t is the standard clock time at the mid point of period, Lz is the longitude of the center of the local time zone (330), Lm is the longitude of the measurement site (328), Sc is the seasonal correction for solar time, j is the number of the day in the year. Albedo (α) were calculated according to Brest and Goward (1987) with above equation;

$$\alpha = 0.526(\text{VIS}) + 0.326(\text{NIR})\text{+}0.112(0.5\text{NIR}) \quad (17)$$

where VIS and NIR represent reflectance data collected in the visible (usually red wavelengths; 650nm-720 nm) and near-infrared wavelengths (720-880).

Soil heat flux (G) were calculated with the use of equation below (Daughtry *et al*., 1990),

$$G = (0.325\text{-}0.208\ \text{NDVI})\ \text{Rn} \quad (18)$$

Sensible heat flux (H) can be expressed as;

$$H = \rho\ C_p\ (\text{Tc-Ta})/r_a \quad (19)$$

where ρ is the density of air (g m^{-3}), C_p is the specific heat of air (J g^{-1} °K^{-1}) and r_a is the stability corrected aerodynamic resistance (s m^{-1}). According to Garratt (1978) aerodynamic resistance can be expressed as;

$$r_a = 4.72\frac{\ln[(z - d_0)/z_0]\{\ln[(z - d_0)/z_0] + 2.5\}}{1 + 0.54\mu} \quad (20)$$

where u is the wind speed measured at height z and d_0 and z_0 are the displacement height and roughness length for momentum, respectively. The factor accounts for the smaller roughness length for heat observed in plant studies.

Hourly ET (ET_h) calculated based on instantaneous ET (ET_i) and cumulative ET (ET_{cum}) determined with the sum of ET_h values.

Jackson *et al.* (1983) showed that the ratio of total daily irradiance (S_d) to the instantaneous irradiance (S_i) at any time equal to the ratio of total daily evapotranspiration (ET_d) to the one time of day measurements of evapotranspiration (ET_i).

$$J = S_d / S_i = ET_d / ET_i \quad (21)$$

The time units will be mixed in J so that one time of day value of S_i and ET_i can be determined in W m^{-2} and multiplied by J to give S_d or ET_d in units of MJ m^{-2} day^{-1}. In this study S_i values of 1330 h to 1400 h time period have been used to calculate value of J. However ET_i value of same time of day with S_i is used to calculate ET_d.

Spectral indexes: To determine the efficiency of spectral data in detecting the water stress of trees, Normalized Difference Vegetative Index (NDVI), Soil Adjusted Vegetation Index (SAVI) and Ratio Vegetation Index (RVI) were calculated according to equations given below.

NDVI = (R800-R680)/(R800+R680) (Penuelas, 1997) (22)

SAVI = (R800-R680)/(R800+R680+0.5)1.5 (Huete, 1988) (23)

RVI = R900/R680 (Jordan, 1969) (24)

where R900, R800 and R680 are the reflectance's at 900, 800 and 680 nm wavelength, respectively.

RESULTS AND DISCUSSION

The daily course of canopy-air temperature difference (Tc-Ta) and Leaf Water Potential (LWP) related to DOY 171 and 172 and DOY 233 and 234 for T_1 and T_2 irrigation treatments shown in Fig. 1 and Fig. 2, respectively. Since there is no difference between water application levels on DOY 171-172, the values of Tc-Ta showed a similar diurnal variation. The Tc-Ta values ranged from -1.4 to -2.0 in T_1 and -2.9 to -3.1 in T_2 treatments on DOY 233 and 234, respectively.

Tc-Ta value was increased until 1400-1500 h in the day and showed a decreasing trend after those hours on DOY 171-172, which represents a fully watered crop.

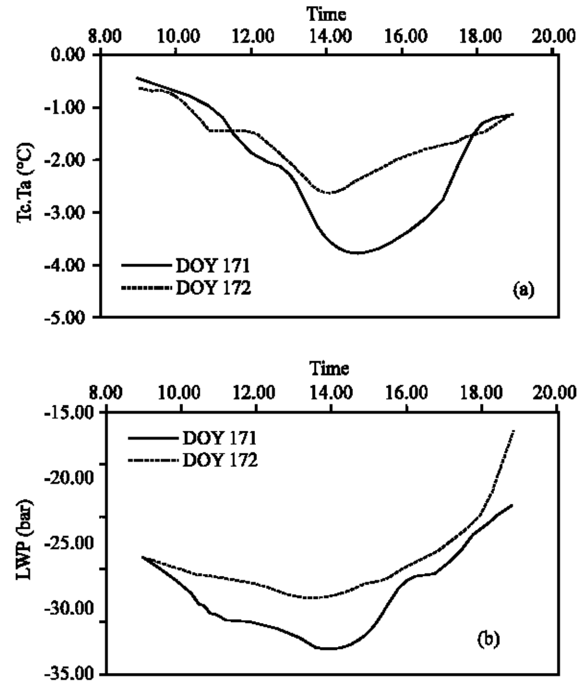

Fig. 1: Diurnal variation of Tc-Ta and LWP on DOY 171 and 172

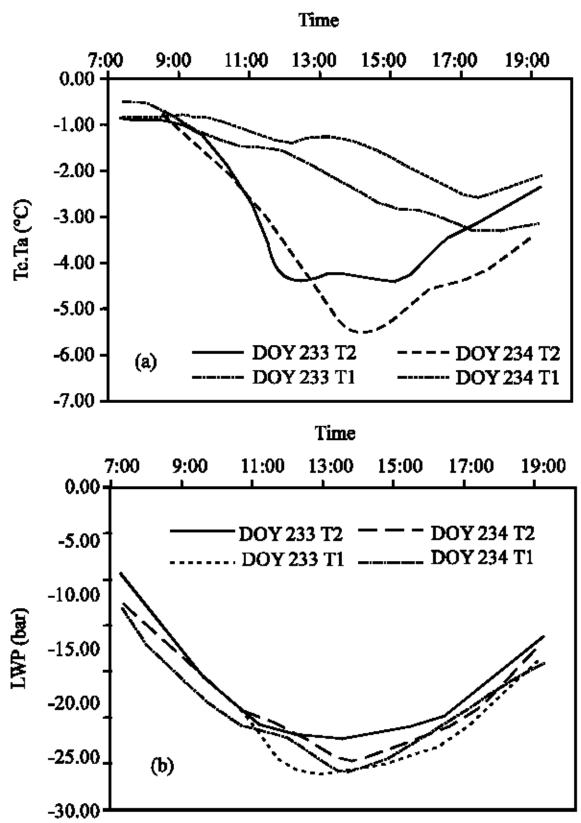

Fig. 2: Diurnal variation of Tc-Ta and LWP on DOY 233 and 234

Table 1: Some measured and calculated parameters for cherry during the trial days

Date	Treatments	Et_{cum} (mm/day)	ET_d (mm/day)	Average Ta (°C)	Average Tc-Ta (°C)	Average U (m h^{-1})	Total Rs	Average LWP (bar)	Average soil water content (120 cm/mm)
DOY 171.	-	8.5	8.9	27.7	-2.0	1.6	25.4	-24.1	376.8
DOY 172.	-	8.5	9.0	28.7	-1.2	2.4	27.7	-24.3	369.9
DOY	T_2	8.8	10.1	31.1	-2.9	1.2	20.8	-18.8	342.1
233.	T_1	6.1	6.0		-1.4			-20.6	318.1
DOY	T_2	9.7	10.9	32.3	-3.1	1.6	20.9	-18.0	334.3
234.	T_1	7.9	7.5		-2.0			-19.1	311.0

Maximum Tc-Ta value was determined as -3.8 (Fig. 1a). Although there is no significant difference of air temperature for these two days, the difference between Tc-Ta values may be attributed to decrease in soil water content and change in wind speed (Table 1). Variation in Tc-Ta values of DOY 233-234 was become similar to the values of DOY 171-172 and maximum values were obtained at 1400-1500 h of the day for T_2 treatment, confirming Remorini and Massai (2003) results. A sharp decrease in Tc-Ta values in between 0930 h and 1300 h of the day on DOY 233-234 for T_2 treatment were occurred due to increase of air temperature. Maximum Tc-Ta value for T_1 treatment was measured at almost sunset time on DOY 233 and 234. The Tc-Ta values ranged from –0.5 in both T_1 and T_2 treatments to maximum values of -3.3 in T_1 and -5.4 in T_2 treatment trees on DOY 233 and 234. Tc-Ta were increased from sunrise to noon and decreased from noon to sunset throughout the day on DOY 171-172 (T_1-T_2) and DOY 233-234 (T_2). However, it was increased from sunrise to sunset on DOY 233-234 for T_1 treatment. Trends in Tc-Ta values are compatible with the idea, T_1 treatment has the highest Tc-Ta (Fig. 2a) and T_2 has the lowest Tc-Ta values (Fig. 1a and 2a). On the other hand, Tc-Ta values of deficit irrigation are less than values of non-deficit irrigation and the results are compatible with that of Glenn *et al*. (1989).

Instantaneous evapotranspiration (ET_i) values were calculated according to Eq.(4), daily evapotranspiration (ET_d) values were defined with Eq. (21), daily cumulative evapotranspiration (ET_{cum}) were calculated with sum of ET_i (Fig. 3). ET_{cum} and ET_d values of DOY 171-172 in which same amount of water was applied in T_1 and T_2 treatments were found as 8.5-9.0 mm/day. However, ET values of DOY 233-234 in which different amount of water was applied were found as 6.1-7.9 mm/day and 8.8.-9.7 mm/day for T_1 and T_2, respectively (Table 1). When considering accumulated ET values, a significant change of ET values was observed between 1000 h and 1600 h in a day in both observation periods depending upon temperature increase (Fig. 3). In the same observation days, the soil water content gradients were measured as 6.9 mm/120 cm (on DOY 171-172 for T_1 and T_2) and 7.1 mm/120 cm for T_1, 7.8 mm/120 cm for T_2 (on DOY 233-234).

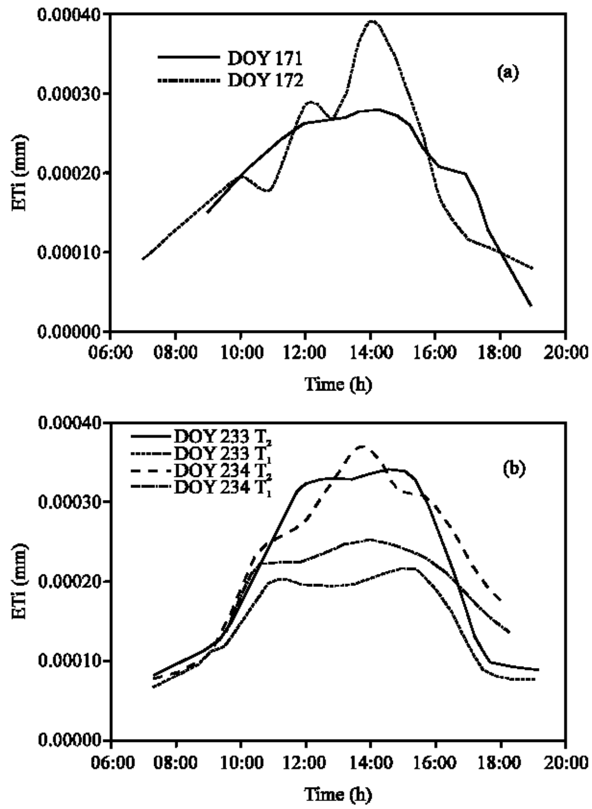

Fig. 3: Instantaneous ET throughout the trial days

LWP of cherry trees were increased from sunrise to midday and decreased from midday to sunset (Fig. 1b and 2b). Minimum LWP values were measured as -33 bar and -26.8 bar (T_1) on DOY 171-172 and DOY 233-234, respectively. LWP of T_1 and T_2 irrigation treatments were differed from each other with the value of -1.5 bar (Table 1). LWP values were very close to each other for T_1 and T_2 treatments on DOY 234 (Fig. 1b). LWP values were increased from sunrise to noon and decreased from noon to sunset on DOY 233-234 for T_1, whereas Tc-Ta values were increased from sunrise to sun set (Fig. 2). According to these results, Tc-Ta is more sensible to water stress than LWP for cherry trees.

Spectral reflectance of a crop depends on some physiologic characteristics and water content. The altitude angle of the sun is the most important indicator that affects the reflectance. Penuelas *et al.* (1997) suggested that the most appropriate time for seasonal monitoring of reflectance is altitude angle at 50 °. Altitude angle of sun became nearly 50° at 0915 h on DOY 171-172 and 1100 h on DOY 233-234 for experimental site.

Figure 4 shows reflectance values at 650-1100 nm wavelength range for three different times on DOY 171-172, DOY 233-234 for T_1 and T_2 treatments, separately. As it is seen in Fig. 4, reflectance values have changed with the measurement times. Reflectance values were found 0.48 for DOY 171-172 and 0.49 in T_2 treatment, 0.39 in T_1 treatment on DOY 233-234 at the time of 50° sun altitude angle and these parameters showed parallel course with irrigation treatments. Lowest water level has the lowest reflectance and highest water level has highest reflectance.

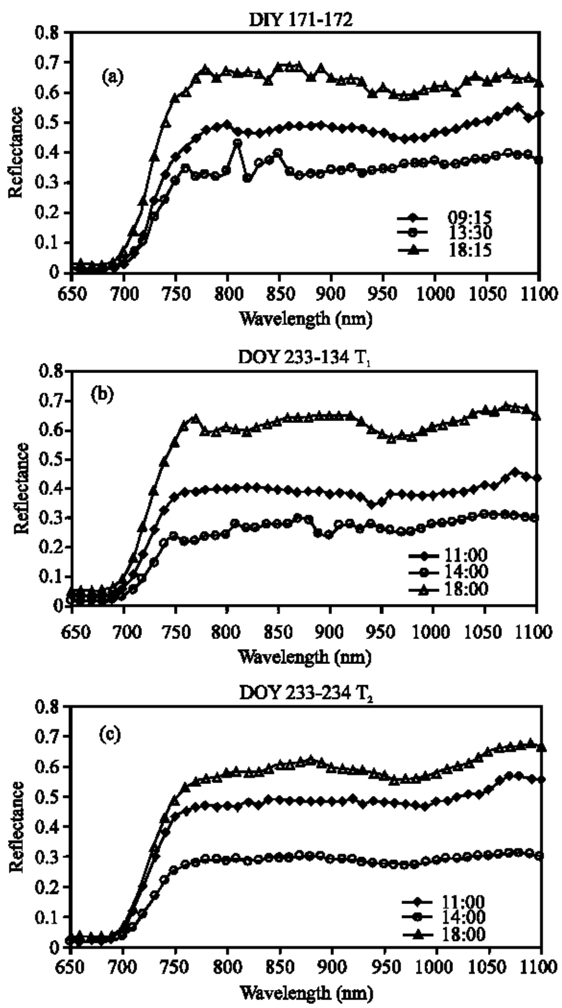

Fig. 4: Spectral reflectance variation of cherry tree on trial days

NDVI, SAVI and RVI were calculated according to Eq. (4), (5) and (6) for the trial days. All of three indexes have similar variation throughout the day (Fig. 5 and 6). Maximum values of spectral indexes were measured at midday in trial days. In water stressed treatment (T_1) NDVI and RVI values did not significantly vary from sunrise to midday. There was an evident distinction between two irrigation treatments on DOY 233-234. The spectral indexes of T_2 treatments were greater than T_1 treatment (Table 2). The cherry trees with non-water stress condition (T_2) have had also the highest spectral index values and the tree with water stress condition (T_1) has had the lowest spectral index values.

Penuelas *et al.* (1997) stated that, NDVI has significant relation with plant water concentration, but

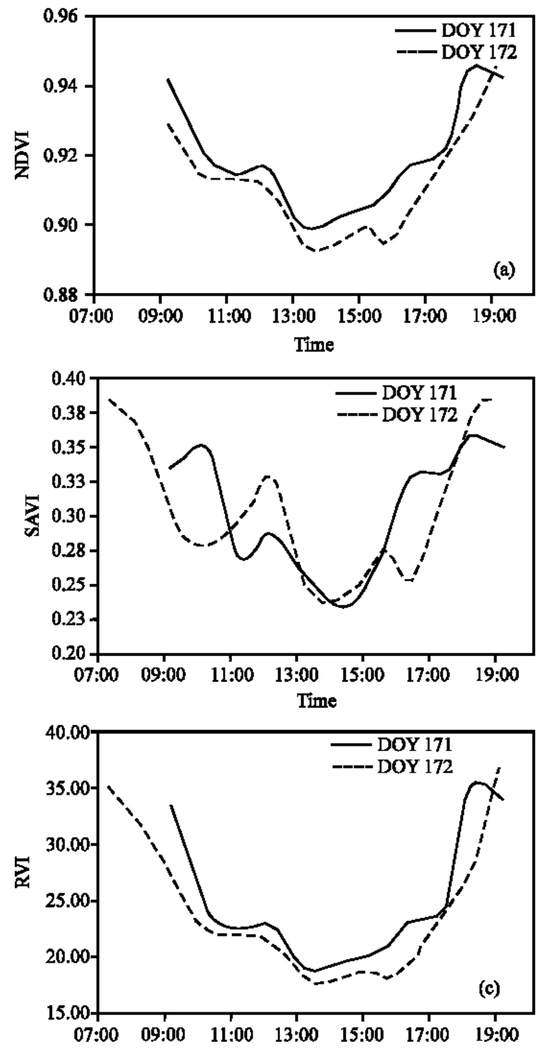

Fig. 5: Variation of NDVI, SAVI and RVI values on DOY 171-172

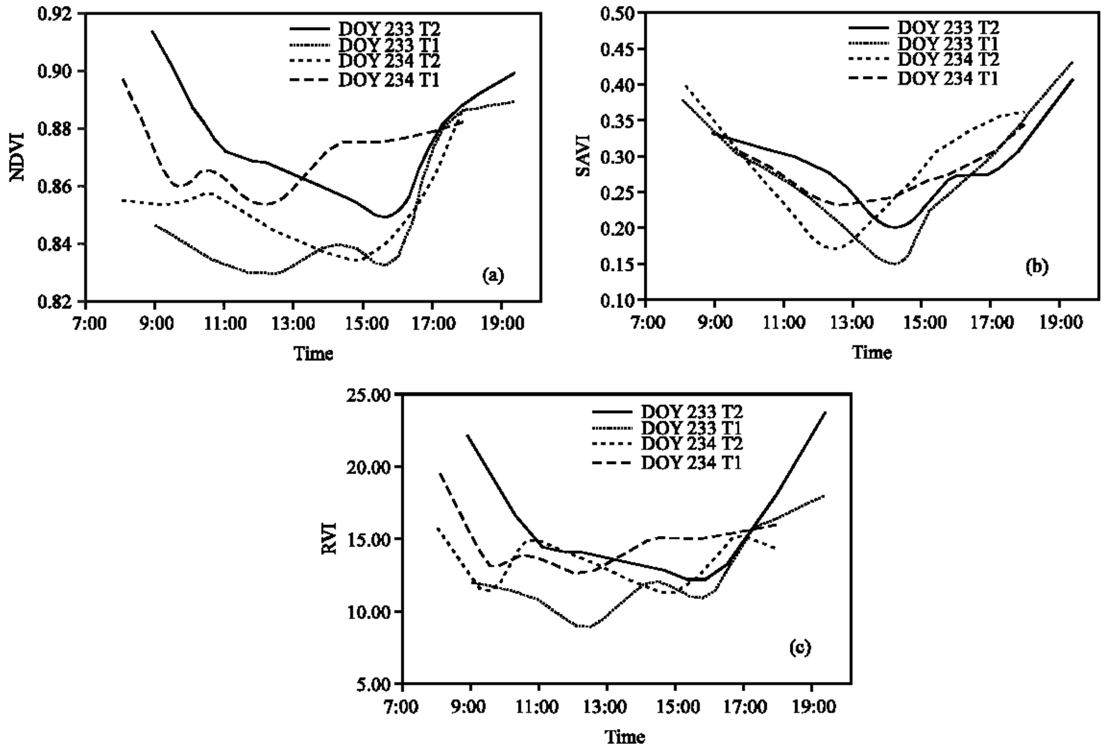

Fig. 6: Variation of NDVI, SAVI and RVI values on DOY 233-234

Table 2: Daily average values of spectral indexes

Spectral index	DOY 171-172 T_1 and T_2 treatments	DOY 233-234 T_1 treatment	DOY 233-234 T_2 treatment
NDVI	0.92	0.85	0.88
SAVI	0.30	0.28	0.30
RVI	24.22	13.52	15.91

Table 3: The relationships between measured and calculated parameters

	DOY 171-172 T_1 and T_2 treatments			DOY 233-234 T_1 treatment.			DOY 233-234 T_2 treatment		
		r			r			r	
	LWP	ET	Tc-Ta	LWP	ET	Tc-Ta	LWP	ET	Tc-Ta
ET			0.51**			0.29^{ns}			0.85**
LWP		0.79**	0.40*		0.89**	0.30^{ns}		0.92**	0.84**
NDVI	0.75**	068**	0.33^{ns}	0.66**	0.65**	0.37^{ns}	0.64**	0.61**	0.51*
SAVI	0.76**	0.73**	0.26^{ns}	0.89**	0.88**	0.06^{ns}	0.77**	0.70**	0.50*
RVI	0.87**	0.85**	0.31^{ns}	0.57**	0.54*	0.34^{ns}	0.68**	0.62**	0.48*

*: Significant, **: Highly significant, ns: Non Significant

NDVI is affected by structural and color changes in the drying plants and therefore NDVI is indirectly related to the living plants. SAVI, RVI and NDVI were computed with the same reflectance values of spectral bands (NIR and Red). According to assumption of Penuelas *et al.* (1997), all of three spectral indexes are indirectly related to water stress of crops.

A significant relationship (1 % level) between ET_i and LWP, NDVI, SAVI and RVI was found for T_1 and T_2 treatments on DOY 171-172 with non-deficit irrigation. Parallel results were obtained for T_2 treatment on DOY 233-234. For T_1 treatment on DOY 233-234, relationships were found as 1 and 5% level between ET_i and LWP, NDVI and SAVI and ET_i and RVI, respectively (Table 3). One of the most common methods in determining ET through remote sensing application is to determine the ET with energy balance based on Tc (Kustas *et al.*, 1990; Moran *et al.*, 1996; Moran *et al.*, 1994; Yunhao *et al.*, 2003; Yunhao *et al.*, 2005). Another one is the determination of ET through the use of crop coefficient calculated by spectral indexes (Hunsaker *et al.*, 2003a, b; Fitzgerald *et al.*, 2005; Hunsaker *et al.*, 2005) and reference ET. Analysis results were found compatible with these approaches.

Relationships between Tc-Ta and ET and Tc-Ta and LWP were significant at 1 and 5% level of probability for T_1 and T_2 treatments on DOY 171-172, respectively. Relationship between Tc-Ta and spectral indexes was found non-significant in statistical manner. On the other hand, relationships between Tc-Ta and other parameters were found significant at 1% (ET_i and LWP) and 5% (NDVI, SAVI and RVI) level of probability for T_2 treatments on DOY 233-234 (Table 3). Relationships among all parameters for T_1 treatment were non-significant on DOY 233-234. The main reason for that the increase from sunrise to midday and decrease after midday were observed in all parameters other than Tc-Ta in deficit irrigation treatment whereas Tc-Ta values were increased from sunrise to sunset. The existence of plant water stress may be determined by relationships between Tc-Ta and ET, LWP and spectral indexes.

Relationship between LWP and spectral indexes was significant at 1% level of probability for T_1 and T_2 treatments on DOY 171-172 and DOY 233-234. Despite the relationship between LWP and spectral indexes is significant, the relationship between Tc-Ta and the parameters (LWP and spectral indexes) is non-significant for T1 treatment. Therefore, determination of plant water stress level through the use of relationship between LWP-spectral indexes is not preferable. However, the diurnal variation of spectral indexes depends on variation in plant conditions as well as angle of the sun. Although, LWP can be estimated through the use of relationships between LWP-spectral indexes, it may not give the reliable results.

CONCLUSIONS

It is very close the values of ET_d and ET_{cum} which were determined based on remotely sensed data with daily ET values determined by soil water budget for Gisela 5 rootstock. Daily ET for sweet cherry trees may be defined from instantaneous measurements in accordance with the method given in Jackson (1983) and/or by canopy temperature and net radiation measurements throughout the day.

The canopy temperature of sweet cherry trees is more sensitive to water stress than leaf water potential and spectral indexes. Despite the difference between T_1 and T_2 treatments in terms of applied amount is 86.2 mm from DOY 172 to DOY 233, difference in LWP of both treatments was found as 1.5 bar as an average on DOY 233-234. However, this difference in recommended measurement time of LWP was found as 2.2 bar as an average on DOY 233-234. As a conclusion, LWP may be used in determining irrigation time of sweet cherry trees, but indexes based on canopy temperature may give more reliable results.

Although the diurnal variation of spectral indexes depend on the angle of the sun, differences between deficit and non-deficit irrigation treatments in terms of spectral vegetation indexes were observed from June to August. These differences indicate that remote sensing tools may be used efficiently to monitor vegetation growth periods of sweet cherry trees. However, spectral indexes may define plant water stress indirectly. Statistical relationships between calculated ET_i and spectral indexes may be beneficial to determine ET of sweet cherry trees.

REFERENCES

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. Crop evapotranspiration guidelines for computing crop water requirement. FAO Irrigation and Drainage, Rome, pp: 56-300.

Bartholic, J.F., L.N. Namken and C.L. Wiegand, 1972. Aerial thermal scanner to determine temperatures of soils and crops canopies differing in water stress. Agron. J., 64: 603-608.

Brest, C.L. and S.N. Goward, 1987, Deriving surface albedo measurements from narrow band satellite data, Int. J. Remote Sens, 8: 351-367.

Brown, K.W. and N.J. Rosenberg, 1973. A resistance model to predict evapotranspiration and its application to a sugar beet field. Agron. J., 68: 635-641

Clawson, K.L. and B.L. Blad, 1982. Infrared thermometry for scheduling irrigation of corn. Agron. J., 74: 311-316.

Cohen, M., T. Ameglio, P. Cruiziat, P. Archer, C. Valancogne and S. Dayau, 1997. Yield and physiological responses of walnut trees in semiarid conditions: Application to irrigation scheduling. Acta Hortic., 449: 273-280.

Daughtry, C.S.T., W.P. Kustas, M.S. Moran, P.J.Pinter, Jr., R.D. Jackson, P.W. Brown, W.D. Nichols and L.W. Gay, 1990. Spectral estimates of net radiation and soil heat flux. Remote Sens. Environ., 32: 111-124.

Doorenbos, J. And W.O. Pruitt, 1977. Guidelines for prediction of crop water requirements. FAO Irrigation and Drainage Paper No. 24 (revised), FAO, Rome, pp: 179.

Ehrler, W.L., 1973. Cotton leaf temperature as related to soil water depletion and meteorological factors. Agron. J., 65: 04-409.

Evans, R.G., D.L. Basset and E.L. Proebsting, 1982. Indicating water stress in apples using infrared thermometry. Pro. Am. Soc. Agric. Eng., 82: 2531.

Ferreira, M.I., C.A. Pacheco, C. Valancogne, J. Michaelsen, T. Ameglio and F.A. Daudet, 1997. Evapotranspiration water stress indicators and soil water balance in a Prunus persica orchard, in central Portugal. Acta Hortic., 449: 379-385.

Fitzgerald, G.J., D.J. Hunsaker, E.M. Barnes, T.R. Vlarke, R. Roth and P.J, Pinter, Jr.,2005. Estimating Cotton Crop Water Use from Multispectral Aerial Imagery, 2003. Proceedings of the World Water and Environmental Resources Congress, May 15-19, 2005, Anchorage, Alaska, USA. pp: 525.

Garratt, J.R., 1978. Transfer characteristics for heterogeneous surface of large aerodynamic roughness, Quart. J. Ray. Meteorol. Soc., 104: 491-502.

Girona, J., M. Mata, D.A. Goldhamer, R.S. Johnson, T.M. DeJong, 1993. Patterns of soil and tree water status and leaf functioning during regulated deficit irrigation scheduling in peach. J. Am. Soc. Hortic. Sci., 188: 580-586.

Glenn, D.M., J.W. Worthington, W.V. Welker, M.J. McFarland, 1989. Estimation of peach tree water use using infrared thermometry. J. Am. Soc. Horic. Sci., 114: 737-741.

Goldhamer, D.A., E. Fereres, M. Mata, J. Girona, M. Cohen, 1999. Sensitivity of continuous and discrete plant and soil water status monitoring in peach trees subjected to deficit irrigation. J. Am. Soc. Hortic. Sci., 124: 437-444.

Hatfield, J.L., 1983. Evapotranspiration obtained from remote sensing methods. Adv. Irrigation, 2: 395-417.

Hatfield, J.L., A. Perrier and R.D. Jackson, 1983. Estimation of evapotranspiration at one time-of-day using remotely sensed surface temperatures. Agric, Water Manage., 7: 341-350.

Huete, A.R., 1988. A soil-adjusted vegetation index (SAVI). Remote Sens. Environ., 25: 295-309.

Hunsaker, D.J., P.J. Pinter, Jr.,E.B. Barnes, B.A. Kimball, 2003a. Estimating cotton evapotranspiration crop coefficients with a multispectral vegetation index. Irrig. Sci., 22: 95-104.

Hunsaker, D.J., Jr.P.J. Pinter, G. Fitzgerald, T. Clarke, B.A Kimball and E.B. Barnes, 2003b. Tracking spatial and temporal cotton ET patterns with Normalized Difference Vegetation Index. Irrigation Associations Exposition and Technical Conference Proceedings. pp: 126-137.

Hunsaker, D.J., P.J. Pinter Jr. and B.A. Kimball, 2005. Wheat basal crop coefficients determined by normalized difference vegetation index. Irrg. Sci., 24: 1-14.

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

Jackson, R.D., R.J. Reginato and S.B. Idso, 1977. Wheat canopy temperature: A practical tool for evaluating water requirements. Water Resour. Res., 3: 651-656.

Jackson, R.D., Jr.P.J. Pinter, R.J. Reginato and S.B. Idso, 1980. Hand-held radiometry. A set of notes developed for use at the workshop on hand-held radiometry. Phoenix, Ariz, pp: 25-26.

Jackson, R.D., S.B. Idso, R.J. Reginato and P.J. Pinter, Jr., 1981. Canopy temperature as a crop water stress indicator. Agri. Water Manag., 4: 1133-1138.

Jackson, R.D., J.L. Hatfield, R.J. Reginato, S.B. Idso and P.J. Pinter, Jr., 1983. Estimation of daily evapotranspiration from one time-of-day measurements. Agriic. Water Manage., 7: 351-362.

Jones, H.G, D. Aikman, T.A. McBurney, 1997. Improvements to infrared thermometry for irrigation scheduling in humid climates. Acta Hortic., 449: 259-265.

Jordan, C.F., 1969. Derivation of leaf area index from quality of light on the forest floor. Ecology., 50: 663-666.

Katerji, N., B. Itier and I. Ferreira, 1988. Etude de quelques criteres indicateurs de I'etat hydrique d'une culture de tomate en region semi-aride. Agronomie, 8: 425-433.

Kustas, W.P., M.S. Moran, R.D. Jackson, L.W. Gay, L.F.W. Duel, K.E. Kunkel and A.D. Matthias, 1990. Instantaneous and daily values of the surface energy balance over agricultural fields using remote sensing and a reference field in an arid environment. Remote Sens. Environ., 32: 125-141.

Massai, R., D. Remorini, F. Casula, 2000a. Leaf temperature measured on peach trees in different climatic conditions and soil water contents. Acta Hortic., 537: 399-406.

McCutchan, H. and K.A. Shackel, 1992. Stem-water potential as a sensitive indicators of water stress in prune trees (*Prunus domestica* L. cv French) J. Am. Soc. Hortic. Sci., 117: 607-611.

Monteith, J.L., 1963. Gas exchange in plant communities. In: Environmental Control of Plant Growth. Evans, L.T. (Ed.), Academic Press, New York, NY., pp: 95-112.

Monteith, J.L. and G. Szeicz, 1962. Radiative temperature in the heat balance of natural surfaces. Q.J.R. Meteorol. Soc., 88: 496-507.

Monteith, J.L. and M.H. Unsworth, 1990. Principles of Environmental Physics. 2nd. Edn., pp: 291.

Moran, M.S., T.R. Clarke, Y. Inoue and A. Vidal, 1994. Estimating crop water deficit using the relation between surface-air temperature and spectral vegetation index. Remote Sens. Environ., 49: 246-263.

Moran, M.S., A.F. Rahman, J.C. Wasburne, D.C. Goodrich, M.A. Weltz and W.P. Kustas, 1996. Combining the Penman- Monteith equation with measurements of surface temperature and reflectance to estimate evaporation rates of semiarid grassland. Agric. For. Meteorol., 80: 87-109.

Naor, A., I. Klein, H. Hupert, Y. Grinblat, M. Peres and A. Kaufman, 1999. Water stress and crop level interactions in relation to nectarine yield, fruit size distribution and water potentials. J. Am. Soc. Hortic. Sci., 124: 189-183.

Penuelas, J., J. Pinol, R. Ogaya and I. Fiella, 1997. Estimation of plant water concentration by the reflectance Water Index WI (R900/R970). Int. J. Rem. Sens., 18: 2869-2875.

Perrier, A., 1975a. Etude physique de l'evapotranspiration dans les conditions naturelles: I. Evaporation et bilan d'energie des surfaces naturelles. Ann. Agron., 26: 1-18.

Perrier, A., 1975b. Etude physique de l'evapotranspiration dans les conditions naturelles: II. Ekspressions et parametres donnant l'evapotranspiration reelle d'une surface mince. Ann. Agron., 26: 105-123.

Perrier, A., 1975c. Etude physique de l'evapotranspiration dans les conditions naturelles: III. Evapotranspiration reelle et potentielle des couverts vegetaux. Ann. Agron., 26: 229-243.

Remoini, D. and R. Massai, 2003. Comparison of water status indicators for young peach trees. Irrig. Sci., 22: 39-46.

Stone, L.R. and M.L. Horton, 1974. Estimating evapotranspiration using canopy temperatures field evaluation. Agron. J., 66: 450-454.

Torman, H., 1986. Canopy temperature as a plant water stress indicator for nectarines. S. Afr. J. Plant Soil, 3: 110-114.

Valancogne, C., S. Dayau, T. Ameglio, M. Archer, F.A. Daudet, M.I. Ferreira Gama, M. Cohen, 1997. Relations between relative transpiration and predawn leaf water potential in different fruit tree species. Acta Hortic., 449: 423-429.

Vermeiren, L. and G.A. Jobling,, 1986. Localized irrigation. FAO Irrigation and Drainage Paper No. 36, FAO, Rome, pp: 203.

Yunhao, C., L. Xiaobing, J. Guifei and S. Peijun, 2003. An estimation model for daily regional evapotranspiration. Int. J. Remote Sensing, 24: 199-205.

Yunhao, C., L. Xiaobing,, L. Jing, S. Peijun and D. Wen, 2005. Estimation of daily evapotranspiration using a two-layer remote sensing model. Int. J. Remote Sensing, 26: 1755-1762.