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The Canopy Temperature Response to Vapor Pressure Deficit of Grapevine cv. Semillon and Razaki

Yeşim AHİ[a]*, Halim ORTA[a], Arzu GÜNDÜZ[b], Hüseyin T. GÜLTAŞ[c]

[a]*Department of Biosystem Engineering, Faculty of Agriculture, Namık Kemal University, 59030 Tekirdağ, TURKEY*
[b]*Konya Soil Water and Combat Desertification Research Institute,42151 Konya, TURKEY*
[c]*Department of Biosystem Engineering, Faculty of Agricultural Sciences and Techno., Bilecik Seyh Edebali University, 11210 Bilecik, TURKEY*

Abstract

The main objective of this study was to determine canopy-air temperature differential, which can be used to quantify crop water stress index (CWSI) for grapevine (*Vitis vinifera* L.) grown with drip irrigation during the spring cultivation period of 2005. Specifically, crop response to water loss, atmospheric temperature and air vapor pressure deficit (VPD) in the soil–plant–atmosphere continuum were examined to detect crop water stress. The effects of three irrigation programs (when depleted 30, 50 and 70% of the available water holding capacity within 0.90 m soil profile depth) on two grape cultivar (semillon and razaki) yields, and resulting CWSI were investigated. The non–irrigation treatment (NI) was also used for determination of fully stressed baseline. The lower (non-stressed) and upper (stressed) baselines were determined from measurements of canopy temperatures, ambient air temperatures and vapor pressure deficit values and the CWSI was calculated with three irrigation levels using the empirical approach. The CWSI value was useful for evaluating crop water stress in grapevine and should be useful for timing irrigation and predicting yield.

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Keywords: Baselines equations; canopy temperature; crop water stress index (CWSI); grape yield

1. Introduction

To state the feasibility of the different methods and models suggested in the literature, it is necessary to test them on different regions and plant types and improve them as well. Especially in the regions with limited water sources, such as the Thrace located in northwestern of Turkey, application of the best irrigation techniques and schedules are vital to maximize the benefit of the unit water usage. Water shortage is an important limiting criteria in many crop production especially grapevine which is one of the main horticultural crops in the semi-arid region of Thrace. The present production under both irrigated and non-irrigated conditions in Turkey is about 2.6 million tons of fruit from

* Corresponding author. Tel.: +90 282 250 2263. *E-mail address*: yesimahi@nku.edu.tr, yesimahi@gmail.com (Y. Ahi)

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334,000 ha. Regional grapevine production capacity is about 50,923 tons from 6,154 ha (TUIK, 2013), this is especially important since the region contains an important part of the wine industry.

As reported by Opaza et al. (2010) several studies have shown that changes in grapevine water status, at critical phenological stages, have a direct effect on grape composition and quality attributes by influencing vegetative growth, yield, canopy microclimate and fruit metabolism. Thus, the implementation of water stress can result in substantial improvements on fruit quality through decreasing yield (Pellegrino et al., 2004; Santos et al., 2007; Azevedo et al., 2008; Du et al., 2008; Edwards et al., 2011; Lopes et al. 2011).

To arrange irrigation schedules, some measurements related to plant have become more important as well as climate and soil parameters. These are used in predicting stress levels as related to the lack of water in plants and soil water. Porometer, infrared thermometer, leaf area-meter, photosynthetically active radiation sensor (PAR) and the other stated measurements are necessary to put forth water stress, stoma resistance, differences between leaf temperature and atmospheric temperatures, leaf area index and active radiation values which represent photosynthesis in crops (Idso et al., 1981; Jackson, 1982; Idso, 1983; Gallo and Daughtry, 1986; Rachidi et al., 1993).

In field conditions, methods using point measurements involving observation of only one crop or one part of the crop have been used to specify water stress quantitatively. In the last 20 years, researches using portable infrared thermometers to monitor water stress in the crops are becoming more popular (Gardner et al., 1992a, b; Jackson, 1982; Nielsen, 1994; Gençoğlan and Yazar, 1999; Yazar et al., 1999; Irmak et al., 2000; Alderfasi and Nielsen, 2001; Colaizzi et al., 2003; Yuan et al., 2004; Payero and Irmak, 2006; Ben-Gal et al., 2009; O'Shaughnessy et al., 2012; Paltineanu et al., 2012; Agam et al., 2013). Crop Water Stress Index (CWSI) approaches are being used as defined in Idso et al. (1981) and Jackson et al. (1981) to determine water stress in the crop. The first approach (Idso et al., 1981) uses the temperature difference between the canopy of the plant and the atmosphere (T_c-T_a, ˚C) as a function of atmospheric vapour pressure deficit (VPD, kPa) for a plant transpiring at the potential speed. Whereas, Jackson et al. (1981) defines a term, "energy balance", to show the relationship between T_c-T_a, VPD and net radiation (R_n) (Ödemiş and Baştuğ, 1999).

This study was planned to develop baseline equations that can be used to calculate CWSI, to determine the variation in CWSI of grapevine grown with drip irrigation and to evaluate the relationships amongst CWSI, yield, soil water content and leaf water resistance of physiological parameters.

2. Experimental details

The experiment was carried out on a cultivated grape (*Vitis vinifera* L. cv Semillon and cv Razaki) grown in a 1.5 ha vineyard during the 2005 growing season at the research field of the Viticulture Research Institute of Tekirdağ (semi-arid climate region) in Turkey, at 40˚59′ N latitude, 27˚29′ E longitude and 4 m altitude. The averages of long term temperature, relative humidity, wind speed and sunshine duration are 13.8 ºC, 75%, 2.8 m s^{-1} and 6.5 h, respectively. Climate in this region is semi – arid with annual precipitation averaging 575 mm and about 30% of this precipitation falls during the months of April through October. The soil type in the plot area is deep, heavy textured, well drained and the available water holding capacity within 1.20 m of the soil profile is approximately 0.26 m. The electrical conductivity (EC) of irrigation water was 0.42 dS m^{-1} and the sodium absorption rate was 2.7, which was classified as C_2S_1 according to U.S. Salinity Lab. (US Salinity Laboratory Staff, 1954).

The four years old grapevines had an east-west row orientation, with row spacing of 3.0 m and plant spacing of 1.5 m. Each of the two vine varieties trained on vertical shoot positioning with three pairs of wires and spur pruned on Guyot+T system at a height of 1.0 m. Cultivation is considered as a period of March to November and standard cultural practices in the area were applied to all treatments.

The experiment was arranged in a random arrangement with three irrigation regimes and replicated three times. For irrigation regime treatments, irrigation was applied when 30, 50 and 70% of available soil moisture was consumed in the 0.90 m root zone. Irrigation water was applied by drip irrigation and the plots were irrigated by pressure compensating drippers. Irrigation water was taken by a pump from a reservoir near the experimental site.

In order to evaluate the changes in soil water status in the effective root depth, the volumetric water content was measured using the gravimetric method of Evett et al., (1993). The focus was 0–90 cm of the soil layer. Evapotranspiration for ten–day periods was calculated applying the water balance method to the upper 1.20 m soil layer (Heerman, 1985). The lower (non-stressed) baselines for all irrigation regimes and two grape cultivar (Razaki and Semillon) were determined from measurements of canopy temperatures, ambient air temperatures and vapor pressure deficit values and the crop water stress index (CWSI) was calculated with three irrigation levels using the empirical approach (Idso et al. 1981). The non–irrigation treatment (NI) was also used for determination of fully stressed baseline.

The canopy temperature (T_c) was determined using a hand-held infrared thermometer (Raynger ST8 model, Raytek Corporation, Santa Cruz, CA) with a 3° field of view and equipped with a 7 – 18 µm spectral band-pass filter. The infrared thermometer was operated with the emissivity adjustment set at 0.98. The IRT data collection was initiated on the 7^{th} June (DOY157) and continued to 19^{th} July (DOY200). The foliage temperature was measured on four plants from four directions (east, west, north, south) at 0.50 m from the crop with oblique measurements at 20 - 30° from the horizon to minimize soil background in the field of view and then averaged. The T_c measurements were made from 11:00 to 14:00 at hourly intervals under clear skies. The dry and wet bulb temperatures were measured with an aspirated psychrometer at a height of 2.0 m in the open area adjacent to the experimental plots. The mean air temperature (T_a) was determined from the average of the dry–bulb temperature readings during the measurement period. The mean VPD was computed as the average of the calculated instantaneous VPD using the corresponding instantaneous wet and dry–bulb temperatures and the standard pyschrometer equation (Allen et al., 1998) using a mean barometric pressure of 101.25 kPa for Tekirdag.

Using the upper and lower limit estimates, a CWSI can be defined as (Idso et al., 1981);

$$\mathrm{CWSI} = \frac{\left[(T_c - T_a) - (T_c - T_a)_{ll}\right]}{\left[(T_c - T_a)_{ul} - (T_c - T_a)_{ll}\right]} \qquad (1)$$

Where, T_c is the canopy temperature (°C), T_a the air temperature (°C), ll is the non- water stressed baseline (lower baseline) and ul is the non – transpiring upper baseline.

The cumulated marketable yield per hectare was calculated from each harvest and each treatment. The irrigation use efficiency (IWUE) and water use efficiency (WUE) on yield bases which are important parameters in yield estimation were calculated as the production of total yield divided by the total amount of irrigation water (I) and total evapotranspiration (ET), respectively (Zhang et al., 1999). Depending on the results of higher cumulative yield and WUE, the optimum treatment which is suggested as the basis for irrigation scheduling of grapevine of the region was described. Following the leaf temperature measurements with the IRT, a single, upper canopy, fully sunlit leaf of each of four plants in each plot was measured for leaf stomatal resistance with a portable porometer (Delta-T, AP4), and averaged to represent the value of this parameter for each plot.

3. Irrigation water applications

Total water applications and seasonal evapotranspiration (ET) for three irrigation regimes were close to and these values are presented in Table 1. Precipitation during the irrigation season of 2005, from April to November, was 135 mm. In the non water-stressed treatments ($T_{0.30}$, $T_{0.50}$ and $T_{0.70}$) for each irrigation regime, the seasonal ET was 532 mm for 30% irrigation regime, 445 mm for 50% irrigation regime and 391 mm for 70% irrigation regime for Razaki and also 490, 435 and 376 mm for 30, 50 and 70% irrigation regimes, respectively, for Semillon. Many earlier researchers reported that seasonal grapevine ET ranged from 295 to 950 mm for different climatic and environmental conditions (Teixeira et al., 2007; Lopez-Urrea et al., 2012; Du et al., 2013; Er-raki et al., 2013; Faci et al., 2014). The non-irrigation treatments gave lower seasonal ET.

4. Baseline equations and crop water stress index

The lower baselines (non water-stressed) shown in the Figure 1 were derived from measurements of grape cultivated under three irrigation regimes for two cultivar. The CWSI values were calculated between upper and lower baselines relating the difference between canopy (T_c) and air (T_a) temperatures (°C) to vapor pressure deficit (kPa) as given by Idso et al., (1981).

Table 1. Effect of irrigation treatment and cultivars on irrigation characteristics

Grape cultivars	Treatment	Number of irrigation	Soil water depletion	Irrigation water applied	Rainfall	Seasonal evapotranspiration

			(mm 120cm^{-1})	(mm)	(mm)	(mm)
Razaki	$T_{0.30}$	12	69	328	135	532
	$T_{0.50}$	7	74	236		445
	$T_{0.70}$	3	127	129		391
	NI	-	150	-		285
Semillon	$T_{0.30}$	12	21	334	135	490
	$T_{0.50}$	6	81	219		435
	$T_{0.70}$	3	102	139		376
	NI	-	123	-		258

The crop canopy temperature measurements were obtained from the non–irrigated treatment (NI) for upper baseline. The lowest seasonal evapotranspiration (ET) and yield occurred in these treatments (Table 1). The average values of canopy temperatures obtained from these plots were computed and subtracted from the average air temperature values (T_a) and graphed against VPD. The upper and lower baselines were obtained from the data taken during the about two months period with irrigation intervals, and are shown in Figure 1 for all treatments, respectively. The lower baseline equations differ somewhat from each other due to the different irrigation regime and crop cultivars. The upper limits were determined as 4.91 and 4.61 °C, for Razaki and Semillon, respectively. The result agreed with the findings of Bellvert et al. (2013), who found that upper baseline for two years was 4.97 and 3.47 °C, respectively.

The seasonal mean CWSI values and average CWSI values before irrigation based on the Idso empirical model (Idso et al., 1981) under three different irrigation regime treatments for each grape cultivar are given in Table 2. As mentioned in main methodology studies such as Idso et al. (1981), Gardner and Shock (1989) and Gardner et al. (1992a) CWSI values vary between 0 and 1 since scientists studying plant water relations often consider the ratio ET/ETp, which similarly ranges from 1 (ample water) to 0 (no available water). But, the most results (Yuan et al., 2004; Alderfasi and Nielsen, 2001) show that the values of the CWSI based on empirical baselines would exceed the range of 0-1.0. In this study, the measured midday VPD during measurement period was generally in the range of 0.5-2.0 kPa. At low VPD values, small inaccuracies in temperature measurement can cause large fluctuations and variations of empirical CWSI. Generally, the values of CWSI increased with increasing water stress, sometimes exceeded 1.0. The seasonal mean CWSI values were almost parallel to the before irrigation CWSI values. After irrigations, CWSI values have dropped below zero but only CWSI values in the range of 0-1 were used for calculating averages.

CWSI values in non-irrigated treatments changed about 0.74 for Razaki and 0.77 for Semillon without decreasing so much because of lack of irrigation. The lower CWSI values were observed which irrigation when 30% of the available water holding capacity was consumed. The CWSI values before irrigation applications were measured as an average value of 0.16 and 0.12 under 30% irrigation regime, 0.20 and 0.21 under 50% irrigation regime and 0.27 and 0.26 under 70% irrigation regime for Razaki and Semillon, respectively. The seasonal CWSI and mean CWSI values before irrigations for 30% irrigation regime were lower than those for 50 and 70% irrigation regimes because of the close irrigation interval. The calculated mean CWSI values of each treatment were compared with the other indicators of crop water status, including total marketable yields, leaf stomatal resistance, water use efficiency (WUE) and irrigation water use efficiency (IWUE) for two cultivars are presented also in Table 2.

Table 2. Some characteristics as affected by irrigation treatment and grape cultivars

Grape cultivars	Treatment	Marketable yield (Mg ha^{-1})	Mean CWSI	Mean CWSI before irrig.	Resistance (s m^{-1})	IWUE (kg m^{-3})	WUE (kg m^{-3})
Razaki	$T_{0.30}$	9.49ab**	0.12	0.16	0.83	0.62b*	1.78b**
	$T_{0.50}$	12.69a	0.18	0.20	0.91	2.22ab	2.85a
	$T_{0.70}$	11.30ab	0.18	0.27	0.87	2.98a	2.89a
	NI	7.46b	0.74	-	1.08	-	2.62a
Semillon	$T_{0.30}$	20.01a**	0.11	0.12	0.87	1.95ns	4.08b*
	$T_{0.50}$	19.76ab	0.17	0.21	0.85	2.84	4.54ab
	$T_{0.70}$	15.67bc	0.19	0.26	0.84	1.54	4.17b
	NI	13.53c	0.77	-	1.05	-	5.24a

a, b, c: Duncan groups, ns: not significant; * : Significant at the P<0.05; **: Significant at the P<0.01

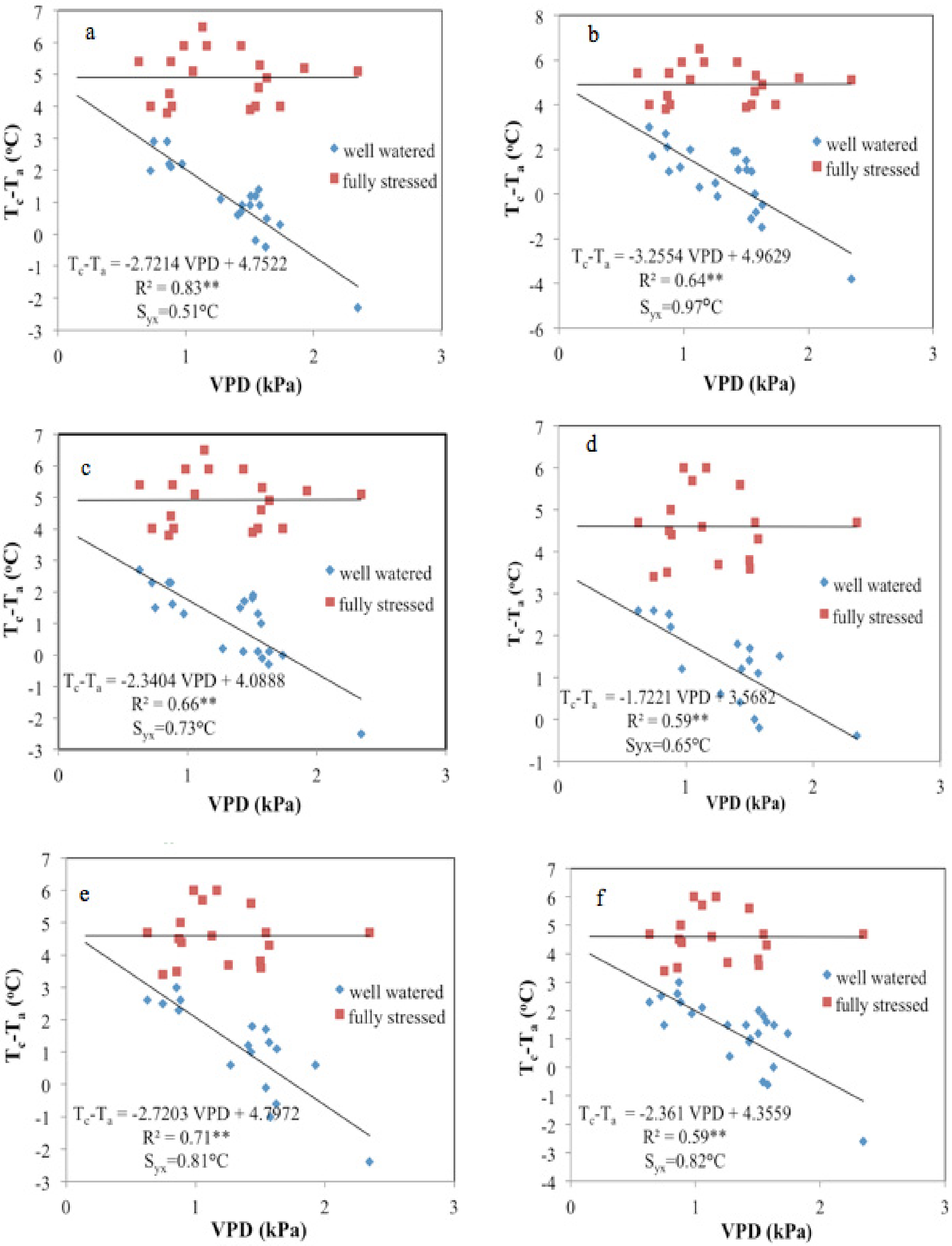

Fig. 1. Canopy-air temperature differential (T_c-T_a) versus air VPD for well watered and maximally stressed grapevine (a) Razaki 30%, (b) Razaki 50%, (c) Razaki 70%, (d) Semillon 30%, (e) Semillon 50%, (f) Semillon 70%

Grape yield was significantly increased by the irrigation level ($p < 0.01, 0.05$). As would be expected, the highest yields were obtained from non water-stressed treatments ($T_{0.30}$, $T_{0.50}$ and $T_{0.70}$) and the lowest yield was obtained from non–irrigation treatment (NI). The highest yield found to be in $T_{0.50}$ treatment with an average of 12.69 t ha^{-1} for Razaki and in $T_{0.30}$ treatment with an average of 20.01 t ha^{-1} for Semillon.

These results are relatively supported by the water use efficiency and irrigation water use efficiency. In cultivars, WUE and IWUE values of $I_{0.50}$ treatment were higher and located in the highest same statistical group in compared to others (Table 2). Similar results under different irrigation regimes have been obtained in various researches carried out before (Chaves et al., 2007; De La Hera et al., 2007; Du et al., 2013).

The relationship between yield and mean CWSI values was basically linear within the range of mean CWSI for two cultivars (Fig. 2). The linear equations can be used for yield prediction were determined as "Y = -5.9258 CWSI + 12.042 R^2 = 0.58, S_{yx} = 1.80 t ha^{-1}" for Razaki and "Y = -8.4909 CWSI + 19.875 R^2 = 0.68, S_{yx} = 2.20 t ha^{-1}" for Semillon.

The relations among CWSI and stomatal resistance for different cultivars are shown in Figure 3. Linear regression of CWSI against stomatal resistance was fitted to the data. Relationships were statistically important at the level of $P < 0.01$. The soil water content in the 0.90 m crop root zone declined while stomatal resistance increased with increasing CWSI for two cultivars. Since percent available soil water decreased, the stomata closed, transpiration rates declined, leaf temperatures increased and CWSI increased. Möller et al. (2007) and Edwards et al. (2011) reported similar results for grapevine. The canopy temperature to assess CWSI seems to be a good indicator of plant canopy response to available water also for grapevine. Similar results under different irrigation regimes, cultivars and areas have been obtained in various researches carried out before (Möller et al., 2007; Schultz and Stoll 2010; Serrano et al., 2010; Edwards et al., 2011; Bellvert et al., 2013).

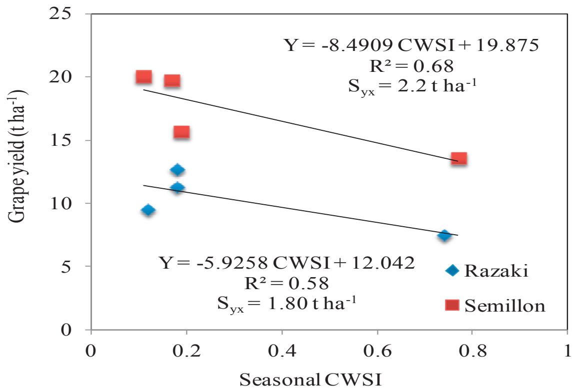

Fig. 2. Marketable yield as related to seasonal CWSI

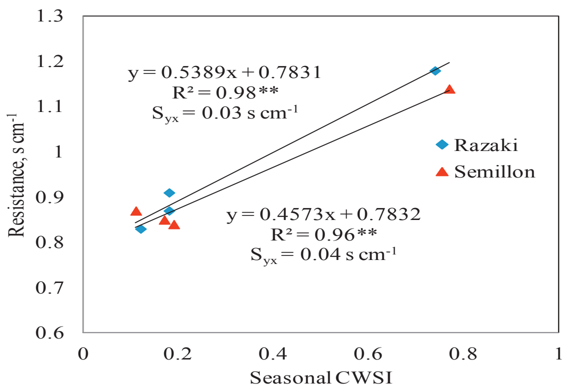

Fig. 3. Relationship between CWSI and stomatal resistance

5. Conclusions

The crop water stress index (CWSI) is valuable tools for monitoring and quantifying water stress and scheduling irrigations. In this study, the upper and lower baselines, and CWSI values determined for two grapevine cultivars grown drip irrigation method were slightly different for three irrigation regimes. Based on the fact that nowadays water resources need to be used efficiently, the usage of the $I_{0.50}$ irrigation programme with its relatively high WUE, IWUE and yield values may be advisable in grape farming. Resulting from this, the seasonal mean CWSI value of 0.18 and also before irrigation mean CWSI value of 0.21 for irrigation timing can be regarded as threshold values.

Based on these results, an average CWSI of about 0.21 before irrigation will produce the maximum yield and water saving irrigation depending on water use efficiency and also this value may be recommended in irrigation scheduling. However, we cannot conclude that this CWSI value should be used for timing of irrigation for grapevine certainly since scheduling irrigations using CWSI were not tested. So, different threshold values of crop water stress index should be evaluated to schedule irrigation. Further research may be required to reach such a conclusion and to evaluate the empirical CWSI for grapevine water stress monitoring in this and other areas. In addition, the CWSI values can be used to estimate yields.

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