Evaluation of yield, quality and crop water stress index of sugar beet under different irrigation regimes
Omid Bahmani, Ali Akbar Sabziparvar and Rezvan Khosravi

ABSTRACT
This study was carried out to evaluate the use of the crop water stress index (CWSI) for irrigation scheduling of sugar beet for two years under the semi-arid climate of Iran. Statistical relationships between CWSI and yield, quality parameters and irrigation water use efficiency (IWUE) were investigated. Irrigations were scheduled based on 100 (I100), 85 (I85), 70 (I50) and 0% (I0) of plant water requirement. CWSI values were calculated from the measurements of canopy temperatures by infrared thermometer, air temperatures and vapor pressure deficit values for all the irrigated treatments. The highest IWUE was found in I70 with 9.16 and 1.66 kg m\(^{-3}\) for the root and sugar yield, respectively, in 2013. A non-water stressed baseline (lower line) equation for sugar beet was measured from full irrigated plots as \((T_c - T_a)_{\text{ll}} = -0.832 \text{VPD} + 2.1811; R^2 = 0.6508\). There was a high determination coefficient between CWSI with the root and sugar yield and IWUE. The CWSI could be used to determine the irrigation time of sugar beet, and 0.3 could be offered as a threshold value. Results indicated that the CWSI can be used to evaluate crop water stress and improve irrigation scheduling for sugar beet under semiarid conditions.

Key words | crop water stress index (CWSI), deficit irrigation, sugar beet

INTRODUCTION
Water is one of the most important inputs of irrigation, which should be wisely used to identify appropriate strategies for planning and management of irrigated farmland (Kumar et al. 2015). Increasing water use efficiency in irrigated agriculture and promoting dry land farming will both play a significant role in maintaining food security (Deng et al. 2006). Irrigation should be scheduled in order to increase yield per unit of water applied and to increase the quality of the product. Deficit irrigation techniques have been studied such as irrigation scheduling, which relates aspect of irrigation management to plant physiology. Keremane & Mckay (2006) noted that provision of water needed to feed a growing population and balancing this with the other demands on water is one of the great challenges of this century.

With the development of the infrared thermometer (IRT), this has been widely applied to measure canopy temperature to detect the water stress of crops (Testi et al. 2008). The crop water stress index (CWSI) can be determined from the empirical approach proposed by Idso et al. (1982), which focuses on the relationship between the air and canopy temperature difference \((T_c - T_a)\) and the vapor pressure deficit (VPD) under non-water-stressed and fully water-stressed conditions.

For fully-irrigated plants, which are assumed to be transpiring at the potential value, the relationship is linear, and linear regression is used as the lowest non-water-stressed baseline. The upper baseline represents \((T_c - T_a)\) for fully-stressed plants that are not transpiring and independent of VPD. The value of CWSI can range from 0 to 1.0, where 0 = no stress and 1.0 = maximum stress. IRT is used for canopy temperature measurement, and with its development, it has been widely applied to detect the water stress of crops (Testi et al. 2008).

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Iran produced approximately 39 tons per hectare of sugar beet from a total area of 56,286 ha in 2010 (MAJ 2010). Lorestan is one of the most important Iranian provinces in terms of agriculture because it has a highly diverse climatic condition that allows the cultivation of various types of crops. Review of the resources indicated that the CWSI (Idso 1981) has been used as a method to assess crop water status and to schedule irrigations by many previous researchers including: Taghvaeian et al. (2012), corn; Gontia & Tiwari (2008), wheat; Kar & Kumar (2007), groundnut; Koksal (2008), green bean; Testi et al. (2008), pistachio trees; Nielsen (1997), canola; Erdem et al. (2010), broccoli; Lebourgeois et al. (2010), sugarcane. But little research has been done to evaluate the CWSI for industrial crops in Iran, especially the Middle East part, where crop water stress is frequent and pervasive.

Under conditions of water scarcity, deficit irrigation is an optimization solution for the cultivation of produce, with produce reduced in unit level and increasing with development (Sepaskhah et al. 2006). In areas where water is the most limiting factor, maximizing WP may be economically more profitable for the farmer than maximizing yields. Deficit irrigation limits plants receiving requested water and has effects on yield. Findings in northern Tunisia on two drip irrigated peach varieties with two deficit irrigation treatments, mild DI1 and severe DI2, indicated that a yield reduction in DI2 treatment of 14 to 22% was observed for both cultivars compared to DI1 (Ghrab et al. 2014). Sugar beet has a long growth period and its water requirement is high. Mahmoodi et al. (2008) demonstrated that irrigation levels had a significant effect on the sugar yield and quality of sugar beet, and showed that for maximum root yield and quality the optimum soil water content was 70% of the field capacity. The effect of various levels of irrigation on sugar beet indicated that white sugar yield decreased 16.6% and 39.7% by reducing the water consumption from 1,000 to 725 and to 655 mm, respectively. The work showed that the reduction in a high stress condition is high (Sharifi et al. 2002).

The main objectives of this study were: (a) to determine the non-water stressed baseline and maximum-stressed baseline for sugar beet; (b) to evaluate the use of CWSI for irrigation scheduling in sugar beet; and (c) to obtain quantitative output and irrigation water use efficiency (IWUE).

**METHODS**

A field experiment was conducted during the growing season of 2013–2014 at the Agricultural Research Centre, situated in Borujerd, Lorestan, Iran (48°45’ E, 33°55’ N, 1,629 m above sea level). During the growing periods (from the sowing to harvesting dates) of the year 2013 and 2014, average temperatures of 27.5 and 28.2 °C, total precipitation of 460.8 and 421 mm, and average relative humidities of 21.7 and 20.2% were recorded, respectively.

Before the experiments began, samples of soil were taken at a depth of 90 cm and subjected to a physicochemical analysis. Some physical and chemical properties of the soil are given in Table 1.

Figure 1 shows the relative air humidity (RH, %) and air temperature (Tair, °C) that were obtained from a meteorological observatory near the experimental site during the experiment. Data were also measured at a height of 2 m.

Based on soil tests, 250 kg of urea fertilizer (half at planting and half at four to eight leaf stage), and 50 kg potassium phosphate with 50 kg Triple super phosphate fertilizer were used per hectare. All treatment plots received the same amount of total fertilizer. The plot size was 25 m², each replication involved five furrows 10 m in length, and the

<table>
<thead>
<tr>
<th>Particle size distribution (%)</th>
<th>Soil depth (cm)</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Texture</th>
<th>Ec (ds m⁻¹)</th>
<th>pH</th>
<th>Ca (mg kg⁻¹)</th>
<th>Na (mg kg⁻¹)</th>
<th>K (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–30</td>
<td></td>
<td>33.8</td>
<td>28</td>
<td>38.2</td>
<td>CL</td>
<td>0.85</td>
<td>7.81</td>
<td>1,760</td>
<td>153</td>
<td>170</td>
</tr>
<tr>
<td>30–60</td>
<td></td>
<td>22.8</td>
<td>36</td>
<td>41.2</td>
<td>CL</td>
<td>1.09</td>
<td>8.12</td>
<td>2,640</td>
<td>192</td>
<td>194</td>
</tr>
<tr>
<td>60–90</td>
<td></td>
<td>18</td>
<td>36</td>
<td>46</td>
<td>C</td>
<td>0.78</td>
<td>8.08</td>
<td>2,240</td>
<td>173</td>
<td>204</td>
</tr>
</tbody>
</table>
row spacing was 50 cm. The experimental field was a completely randomized block design with three replications. The treatments studied were: furrow irrigation with non-irrigated (I0), 70% (I70), 85% (I85) and 100% (I100) of water requirements. Sugar beet is sensitive to water stress at the beginning of the growing period and it is recommended that the stress is applied three to four weeks after germination (Doorenbos & Kassam 1979).

The amount of irrigation water was calculated based on the pre-irrigation soil moisture ($\Theta_i$) in the measured soil profile according to the following equation:

$$I = (\Theta_{FC} - \Theta_i) \cdot D \cdot A$$

where $I$ is the amount of irrigation water (m$^3$); $\Theta_{FC}$ is the percentage of soil water moisture at field capacity; $D$ is the soil depth (0.9 m), and $A$ is the surface area of the plot (m$^2$).

$\text{IWUE values were calculated as the ratio of the root and sugar yield of total seasonal irrigation water applied for each treatment separately (Pala et al. 2007).}$

Sugar beet was harvested on 29 September 2013. After harvest, the root yield, sugar percentage and sugar yield were determined.

The canopy temperature ($T_c$) was measured with a handheld IRT, and $T_c$ measurements were made between 12:00 and 14:00 h (Model 100.3 ZL, Everest Inter science, Inc., USA). The mean $T_a$ was determined from the average of the dry-bulb temperature readings during the measurement period within the experimental field. The VPD was computed using the standard equation:

$$\text{VPD} = 10 \times \exp \left[ \frac{16.78 T_a - 116.9}{T_a + 237.3} \right] \left( 1 - \frac{\text{RH}}{100} \right)$$

where VPD is vapor pressure deficit (mbar), RH is relative humidity, and $T_a$ is air temperature (°C).
The CWSI was calculated according to Idso et al. (1981) by using Equation (3):

$$\text{CWSI} = \frac{(T_c - T_a)_{ll}}{(T_c - T_a)_{ul}}$$

where \((T_c - T_a)_{ll}\) is the lower limit of the canopy temperature minus the air temperature, representing the non-water-stressed baseline (lower baseline) and \((T_c - T_a)_{ul}\) is the upper limit of the canopy temperature minus the air temperature, representing the non-transpiring upper baseline.

All data were subjected to analysis of variance (ANOVA) using the Statistical Package Program (SAS); the significant differences between the groups mean \((P < 0.01 \text{ and } P < 0.05)\). Duncan’s test was used to compare and rank the treatment means.

RESULTS AND DISCUSSION

With regard to the total volume of water received, Table 2 shows the sugar beet yields, irrigation amounts, and IWUE for each treatment during the growth period.

In two years of 2013 and 2014, the results indicated that the water stress significantly reduced the sugar beet yield in the I70 treatment. Based on the Duncan test for the mean differences, it was verified that the differences between the I100 and I70 treatments was significant at the 0.01 significance level. In general, decreasing the amount of irrigation water applied decreased, the yield, but this difference between I100 and I85 was not significant (Table 2). The results of the study on quinoa showed that the differences in the crop cycle length of quinoa between deficit irrigation and full irrigation are negligible (Geerts et al. 2008).

Irrigation levels did not have a significantly different effect on sugar rate in the treatments. Results indicated that the percentages of sugar from 100%, 85% and 70% irrigation treatments were 17.6%, 18% and 18.5% in 2013 and 17%, 17.5% and 18.3% in 2014, respectively, which indicates the sugar rate increased with water stress, but these differences were not significant (Table 2). Baigy et al. (2015) reported that percentages of sugar from 100%, 75% and 50% drip irrigation treatments were 15.48%, 17.7% and 18.01%, respectively, which indicates the sugar rate increased with water stress.

Yonts (2014) showed that with full irrigation, the root and sugar yield of sugar beet was highest, and reducing irrigation to 25% did not significantly change the sugar content.

IWUE values were significantly influenced by irrigation treatments. The maximum IWUE was obtained from deficit irrigated furrow plots in the I70 treatment, at 9.17 and 1.61 kg m\(^{-3}\) for the root and sugar yield, respectively. I85 and I70 treatments have a higher IWUE (root yield) at 12.5 and 18% compared to the I100 treatment (Table 2). The effects of deficit irrigation on the quality and quantity of sugar beet showed that deficient irrigation increased water use efficiency and increasing the rate of water consumption and irrigation level reduced the sugar rate (Mehrandish et al. 2012). In a similar study in the semiarid region, root and white sugar yields of sugar beet were significantly decreased by the increasing water deficit (Topak et al. 2011). IWUE was highest at the lowest irrigation conditions. The IWUE of plants under stress is higher because stressed plants wilt far more than unstressed plants, and wilting invariably occurs at times when the saturation deficit of the atmosphere is large. Therefore, the plant assimilates only when the saturation deficit is small and hence loses

<table>
<thead>
<tr>
<th>Year</th>
<th>Treatment</th>
<th>Root yield (kg)</th>
<th>Sugar rate (%)</th>
<th>Sugar yield (kg)</th>
<th>IWUE (root yield) (kg m(^{-3}))</th>
<th>IWUE (sugar yield) (kg m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>I(_{70})</td>
<td>52,933(^{b})</td>
<td>18.5(^{a})</td>
<td>9,793(^{b})</td>
<td>9.17(^{a})</td>
<td>1.64(^{a})</td>
</tr>
<tr>
<td></td>
<td>I(_{85})</td>
<td>61,233(^{a})</td>
<td>18(^{a})</td>
<td>11,022(^{a})</td>
<td>8.73(^{a})</td>
<td>1.57(^{a,b})</td>
</tr>
<tr>
<td></td>
<td>I(_{100})</td>
<td>64,133(^{a})</td>
<td>17.6(^{a})</td>
<td>11287.5(^{a})</td>
<td>7.77(^{b})</td>
<td>1.37(^{b})</td>
</tr>
<tr>
<td>2014</td>
<td>I(_{70})</td>
<td>50,900(^{b})</td>
<td>18.6(^{a})</td>
<td>9,467(^{b})</td>
<td>8.55(^{a})</td>
<td>1.59(^{a})</td>
</tr>
<tr>
<td></td>
<td>I(_{85})</td>
<td>59,500(^{a})</td>
<td>17.5(^{a})</td>
<td>10412.5(^{a})</td>
<td>8.23(^{a})</td>
<td>1.44(^{a,b})</td>
</tr>
<tr>
<td></td>
<td>I(_{100})</td>
<td>62,700(^{a})</td>
<td>17.3(^{a})</td>
<td>10,890(^{a})</td>
<td>7.40(^{b})</td>
<td>1.28(^{b})</td>
</tr>
</tbody>
</table>

Means in the same columns followed by the same letters are not significantly different statistically. Duncan grouping at 1% level.
less water for every carbon molecule fixed (Bloch et al. 2006). According to some research results, the IWUE values under increasing water deficit conditions are generally high (Esmaeili 2011; Ghamarnia et al. 2012).

According to Figure 2, the value of \((\frac{T_c - T_a}{C_0})_{ul}\) was calculated as 5.3°C \((n = 78)\). Also, the linear equation for the non-water stressed baselines was defined as \((\frac{T_c - T_a}{C_0})_{ll} = -0.832\text{VPD} + 2.1811\) with \(R^2 = 0.6508\). Gardner et al. (1992) indicated this value of \(R^2\) is typical of baseline equations defined using data obtained during the growing season.

The intercept and slope of the lower baseline in this study were somewhat different from other published values for sugar beet. Koksal & Yildirim (2011) found the \((\frac{T_c - T_a}{C_0})_{ll} = -2.75\ \text{VPD} + 3.17\) upper limit as 3.5°C for Turkey. These differences may be due to differences in climatic conditions or plant varieties.

As shown in Figures 3 and 4, the CWSI values increased with increasing water stress. Zero or negative values of CWSI show that crop transpiration is at a potential rate with no moisture stresses. CWSI was highly sensitive to changes in weather conditions. In all treatments, there were daily variations of CWSI. In the irrigation treatments, CWSI values ranged between 0.08 and 0.42 in 2013 and ranged between 0.1 and 0.44 in the 2014 growing season. The I70 treatment had higher CWSI values than other treatments in both growing seasons (0.44 in 2013 and 0.42 in 2014).

Experimental results indicated that irrigating at the seasonal mean CWSI of 0.1 and 0.08 values for 2013 and 2014 would result in maximum sugar beet yields for irrigation treatments.

Figure 5 shows the comparison statistics between the mean CWSI values and sugar beet root yield, sugar yield, IWUE(R) and IWUE(S). All relationships were significant at the 0.01 probability level. In order to define the highest coefficient of determination, all types of regression analyses were conducted. The result indicated that the highest determination coefficients were calculated for a polynomial relationship between root yield and mean CWSI \((R^2 = 0.99)\), the polynomial relationship between sugar yield and mean CWSI \((R^2 = 0.94)\) and the linear relationship between IWUE (R) and IWUE (S) mean with CWSI \((R^2 = 0.74\) and \(R^2 = 0.79))\). Irmak et al. (2000) have suggested a non-linear relationship (quadratic) between corn yield and CWSI. Results show that there was a significant inverse relationship between the CWSI values and sugar beet yields (Figure 5 and Table 2). The sugar beet root yield
with mean CWSI relationship can be described by the equation 
\[ Y = -179497 \text{CWSI}^2 + 59209 \text{CWSI} + 59740 \]
and can be used for root yield prediction. O’Shaughnessy et al. (2011) calculated the average seasonal CWSI values for soybean seed, protein and oil yields and indicated as CWSI values increased these parameters decreased.

The linear relationship between IWUE and CWSI demonstrated that higher values of IWUE (R), IWUE (S) could be obtained under CWSI close to 0.42 (Figure 5).

With a decrease in the applied irrigation water, the transpiration rates of the crop decreased, thus increasing the plant canopy temperatures increases the amount of CWSI, resulting in a reduction of yield and growth. A similar result was indicated by Erdem et al. (2010).

Other studies under different local conditions and crop types have reported the high correlations between the mean of CWSI and yield that were also obtained in this study (Erdem et al. 2010; Al-Kayssi et al. 2011). According to these results, it can be said that the CWSI values can potentially be used to quantify water stress for sugar beets.

Figure 6 shows that there were no significant differences between CWSI in similar treatments in 2013 and 2014, but between the treatments the differences were significant.

**CONCLUSION**

The results of this study demonstrate that the effects of deficit irrigation levels had a significant effect on total yield of sugar beet, sugar yield and IWUE. Water use is significantly important in order to obtain higher yields of field-grown sugar beet under the climatic conditions in Iran. Full irrigation treatment (I100) produced the highest root yield (two-year averages, 63.5 t ha⁻¹), the lowest root yield was obtained with the 170 treatment (two-year averages 51.9 t ha⁻¹).
ha\(^{-1}\)). Higher IWUE was obtained with the lowest irrigation level (I70). It is suggested that a high IWUE should be associated with high yield, particularly in water-scarce areas. The lowest irrigation level resulted in the lowest total yield of sugar beet, but increased the sugar rate.

This study shows that in the semiarid region, a CWSI value of 0.5 or smaller could be taken as a threshold value to start irrigation for sugar beet grown under the water scarcity conditions that are described in this study. Between the sugar beet yield and CWSI, a significant nonlinear relation was found that can be used for root yield prediction. It is important for prediction of the yield reaction to crop water stress in developing programs, and decision making for use by farmers and researchers for irrigation management under water scarcity conditions.

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