Response of maize and black gram yield and water productivity to variations in canopy temperature and crop water stress index**

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Abstract. In order to evaluate the ability of the crop water stress index to estimate grain yield and water productivity of maize and black gram in the climatic conditions of Urmia (Iran), research was conducted under the conditions of single-row drip irrigation. This study was conducted in a randomized complete block design with four irrigation levels including 50 (I1), 75 (I2), 100 (I3) and 125 (I4) percent of the water requirements of the plants with three replications. The mean crop water stress index values for the I1, I2 and I3 treatments were 0.53, 0.44, and 0.28, respectively during the growth period of maize, and 0.37, 0.23, and 0.15 for black gram, respectively. In the present study, the correlation between the crop water stress index and the grain yield and also the water productivity of maize and black gram was high. According to the results, the highest grain yield for maize and black gram was obtained at crop water stress index values of 0.28 and 0.15, respectively. Therefore, these values are recommended for the irrigation scheduling of the plants. It should be noted that the maximum water productivity index for maize and black gram was obtained at crop water stress index values of 0.44 (I1) and 0.37 (I1), respectively, which are the values recommended for irrigation scheduling under restricted access to water.

Keywords: canopy temperature, crop yield, CWSI, phenolic and flavonoid compounds, water stress

INTRODUCTION

Water shortages in arid and semiarid regions threaten the food security of millions of people. Since most parts of Iran are located in the arid and semi-arid belt, crop production is not possible without irrigation. In areas where crops are irrigated, proper management and planning for the optimal use of water may be necessary. Iran is in dire straits with regard to water resources; therefore, it is necessary to help conserve limited water resources by optimally using, maintaining and even increasing irrigation efficiency. In a situation where irrigation water shortage prevents the development of a cultivation area, the optimum and economical use of water can increase the profit per unit area (Ahmadi et al., 2018). Water productivity actually represents the amount of product or benefit gained from water consumption and includes various aspects of water management (Ahmadi et al., 2018). The issue of irrigation management and scheduling is very important because if the irrigation scheduling methods and tools (plant and soil indices) are properly used, a significant increase in water use efficiency may be achieved (Khorsand et al., 2019).

One of the established methods of irrigation scheduling is to measure the canopy temperature, which indicates the water status of plants and is the basis of the crop water stress index (CWSI) calculation which is one of the most effective non-destructive methods (Fitzgerald et al., 2006). CWSI is a valuable indicator for quantifying water stress and predicting crop yields, using CWSI for irrigation management under water stress conditions is very important (Edalat et al., 2010). CWSI is also used to estimate grain yield (GY), plant evapotranspiration and water productivity (WP).

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In North America, two CWSI values of 0.2 and 0.4 were used for maize irrigation. Due to the use of irrigation scheduling based on a CWSI of 0.4, the WP of this crop increased from 2.3 to 2.5 kg m\(^{-3}\) (Stegman, 1986). Soybean irrigation scheduling with different CWSI values (0.2, 0.3, 0.4 and 0.5) for the initiation of irrigation in a semi-arid climate was investigated and a value of 0.2 was reported as the benchmark for irrigation scheduling to achieve maximum crop yield (Nielsen, 1990). Another study in North America used 0.2, 0.4, and 0.6 water stress indices for maize, which reduced water use by 28, 43, and 54%, respectively, and at a CWSI value of 0.2, crop yield does not experience a significant decrease (Steele et al., 1994).

For the irrigation scheduling of cowpea, the relationships between CWSI with evapotranspiration and crop yield were used in research. The irrigation time of the plant between 13 and 14 hours was estimated using CWSI at 0.11 (Sepaskhah and Ilampour, 1996). In another study, the efficiency of CWSI in watermelon irrigation scheduling was investigated. Five drip irrigation levels including 100, 75, 50, 25 and 0% soil moisture reduction were considered. Finally, the relationship between CWSI and crop performance was presented (Orta et al., 2003). The canopy temperature in different moisture conditions is affected by changes in nitrogen status, because nitrogen significantly affects the correlation between CWSI and crop yield (Meijer, 2005; Chen et al., 2010).

Researchers in Bursa (Turkey) conducted a study on soybean with five treatments of 100, 75, 50, 25 and zero percent of water requirement and a seven-day irrigation period for both 2005 and 2006 crop years and concluded that CWSI may be used to determine soybean irrigation time in humid climates. They determined a CWSI limit of 0.22. They also obtained statistical relationships between CWSI, grain yield and evapotranspiration (Candogan et al., 2013). In a study on olive trees, they set a value of 0.39 for CWSI to achieve maximum WP (Akkuzu et al., 2013). Also, the results showed that in order to achieve a maximum yield of grapes, irrigation should be implemented when CWSI is about 0.2 (Colak and Yazar, 2017).

Maize with the scientific name of *Zea mays* L. is a monocotyledous, annual plant from the *Geramineae* and *Poaceae* family which has a high degree phenotypic variability. Black gram is also a plant with the scientific name *Vigna mungo* L. from the Fabaceae family. The black gram used in this study was grown in a vast area in the south of the West Azerbaijan province to meet the nutritional needs of the local people. The objectives of the present study are to: (i) calculate the CWSI threshold under different drip irrigation regimes, (ii) evaluate the potential of CWSI to estimate the GY and WP levels of maize and black gram in the climatic conditions of Iran (Urmia city), and (iii) determine the relationship between the WP index and antioxidant compounds including phenol and flavonoid.

### MATERIALS AND METHODS

This research was carried out on two maize crops (cultivar SC704) and black gram at Urmia (Iran) in the crop year 2017. The location of this field has been specified at 37°39' north latitude, 44°58' east longitude and 1365 m a.s.l. (Khorsand et al., 2019). The climate of Iran is semi-arid. The dimensions of the plots for the two maize and black gram crops were 4 × 3 and 3 × 2 (m × m), respectively, and the plots have a spacing of 2 m. Soil samples were also taken to determine the physical properties of the soil (Table 1).

In this study, the effects of different irrigation treatments on two maize and black gram crops were investigated. The experimental design was a randomized complete block design with four water treatments of maize and black gram in three replications (Fig. 1). The water treatments were as follows: I\(_1\) – 50%, I\(_2\) – 75%, I\(_3\) – 100% and I\(_4\) – supplying 125% of crop water requirements, respectively. Daily meteorological parameters were obtained from a meteorological station to determine water requirements (Khorsand et al., 2019). The meteorological parameters including maximum, minimum and average temperature, maximum and minimum relative humidity, hours of sunshine, wind speed and rainfall were obtained (Table 2). Then, the reference evapotranspiration (ET\(_{0}\)) value was calculated using the ET\(_{0}\) Calculator (Raes, 2009). Finally, the ET\(_{0}\) obtained by multiplying the crop coefficient (K\(_c\)) (Farshi et al., 1997) was generalized for the potential evapotranspiration (ET\(_{p}\)) values of maize and black gram.

### Table 1. Physical properties of the experimental soil

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Clay (%)</th>
<th>Silt (%)</th>
<th>Sand (%)</th>
<th>Texture class</th>
<th>Maize FC (cm(^3) cm(^{-3}))</th>
<th>Maize PWP (g cm(^{-3}))</th>
<th>Maize BD (g cm(^{-3}))</th>
<th>Black gram FC (cm(^3) cm(^{-3}))</th>
<th>Black gram PWP (g cm(^{-3}))</th>
<th>Black gram BD (g cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-30</td>
<td>44</td>
<td>50</td>
<td>6</td>
<td>Silt Clay</td>
<td>0.349</td>
<td>0.241</td>
<td>1.328</td>
<td>0.353</td>
<td>0.241</td>
<td>1.370</td>
</tr>
<tr>
<td>30-60</td>
<td>39</td>
<td>33</td>
<td>28</td>
<td>Clay Loam</td>
<td>0.366</td>
<td>0.279</td>
<td>1.530</td>
<td>0.360</td>
<td>0.249</td>
<td>1.473</td>
</tr>
</tbody>
</table>

FC – field capacity, PWP – permanent wilting point, BD – bulk density.
During the vegetation season of maize and black gram, irrigation was applied using a 16 mm adipose drip pipe located next to each row of crops. The 16 mm pipes had a constant pressure and a thickness of 1.15 mm. In-line emitter intervals were 20 cm and the emitter discharge was 4 l h$^{-1}$. At the start of each 16 mm pipe, a 16 x 16 mm valve was used to control the stress over time (Khorsand et al., 2019).

Table 2. Average and sum monthly weather parameters, during the 2017 growing seasons (Khorsand et al., 2019)

<table>
<thead>
<tr>
<th>Month</th>
<th>Atm $^{\circ}$ (°C)</th>
<th>RH (%)</th>
<th>HBS (h d$^{-1}$)</th>
<th>WS (m s$^{-1}$)</th>
<th>P (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>May</td>
<td>18.7</td>
<td>12.5</td>
<td>24.9</td>
<td>26</td>
<td>65</td>
</tr>
<tr>
<td>June</td>
<td>24.0</td>
<td>16.7</td>
<td>31.3</td>
<td>24</td>
<td>54</td>
</tr>
<tr>
<td>July</td>
<td>27.4</td>
<td>20.2</td>
<td>34.5</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>August</td>
<td>26.9</td>
<td>19.6</td>
<td>34.2</td>
<td>29</td>
<td>52</td>
</tr>
<tr>
<td>September</td>
<td>22.2</td>
<td>15.1</td>
<td>29.4</td>
<td>35</td>
<td>57</td>
</tr>
<tr>
<td>October</td>
<td>14.4</td>
<td>7.9</td>
<td>21.0</td>
<td>35</td>
<td>63</td>
</tr>
</tbody>
</table>


In the present study, a handheld infrared device was used to measure the canopy temperature ($T_c$). In this study, $T_c$ was not measured from treatments of maize and black gram from the time of planting until 10 July due to the small size of the shrubs. Canopy temperature was measured after the complete establishment and formation of the plants and when the sky was clear and sunny in four different directions (Erdem et al., 2005) for each water treatment with
three replications. Measurements were taken from different maize and black gram leaves at an angle of 30 to 45 degrees relative to the horizon because different plant leaves were likely to have different temperatures; therefore, the average \( T_c \) was obtained by averaging these values (12 readings) (Sezen et al., 2014). Generally, 84 \( T_c \) readings were performed in 7 h for each treatment in one day for the maize and black gram separately.

To obtain the lower baseline equation, the \( T_c \) values of maize and black gram were measured between the hours of 8:50 and 14:50 for 100% water requirement (I3) on the days after irrigation (Taghvaeian et al., 2013). Also, in order to determine \( CWSI \) and calculate \( (T_c - T_a)_{m} \), the \( T_c \) of maize and black gram were measured hourly from 11:50 to 14:50 in the days before irrigation for all three treatments (I1, I2, and I1);

\[
(T_c - T_a)_{L.L} = a - b(AVPD) = a - b \left[ \frac{16.79T_a - 16.9}{T_a + 237.3} \times (1 - \frac{RH}{100}) \right],
\]

where: \( T_c \) is the canopy temperature (\(^\circ\)C), \( T_a \) represents the air temperature (\(^\circ\)C), \( AVPD \) is the air vapour pressure deficit (mbar), \( RH \) denotes the relative humidity (%), \( a \) and \( b \) are the constant coefficients which are different for different products (crop and garden). The upper baseline also represents the maximum value that can be expected for \( (T_c - T_a) \) (Idso et al., 1981). \( CWSI \) is one of the indices that express the water status of the plant based on \( (T_c - T_a) \) and is calculated from the following formula (Idso et al., 1981):

\[
CWSI = \frac{dT_m - dT_L \cdot L}{dT_U \cdot L - dT_L \cdot L} = \frac{(T_c - T_a)_{m} - (T_c - T_a)_{L.L}}{(T_c - T_a)_{U \cdot L} - (T_c - T_a)_{L \cdot L}},
\]

where: \( dT_m \) is the difference between the canopy temperature and air temperature at the measurement time (\(^\circ\)C), \( dT_U \cdot L \) represents the difference between the canopy temperature and air temperature obtained from the lower baseline equation for the measured \( AVPD \), and \( dT_L \cdot L \) is a constant number for the upper baseline.

Crop harvesting was implemented at the physiological maturity stage for black gram on 09/13/2017 and maize on 03/10/2017 by eliminating the marginal effects of each plot surface area. In order to obtain the grain yield, pods were harvested from black gram and corn from maize and samples from the harvest were transferred to the laboratory for drying. The samples were dried in an oven conditioned at 70\(^\circ\)C for 48 h, the samples were then weighed to obtain grain yield using a digital scale (0.01 precision). Finally, the plant yield numbers were generalized to one hectare.

The water productivity (WP) index is one of the important indicators in the evaluation and optimal management of water consumption in irrigation projects. According to the measurement of yield and water consumption for each treatment, the WP index for different treatments of black gram and maize was calculated from the following relationship (Molden et al., 2003):

\[
WP = \frac{GY}{V_I},
\]

where: \( WP \) is the water productivity index (kg m\(^{-3}\)), \( GY \) is the grain yield (kg ha\(^{-1}\)) and \( V_I \) is the volume of irrigation water (m\(^3\) ha\(^{-1}\)).

RESULTS

The first step for estimating \( CWSI \) is the development of lower and upper baselines for maize and black gram plants. In order to calculate the lower baseline of the experimental method of Idso et al. (1981), the \( T_c \) of maize and black gram were measured from 8:50 a.m. to 02:50 p.m. The lower baseline equations from the results of this experimental method for the three growth stages of maize (vegetative phase-floral initiation, flowering-pollination and seed seating-seed filling) and the four growth stages of black gram (floral induction-flowering, pod formation, seed and pod filling and physiological maturity) are presented for different days after irrigation in Figs 2 and 3. The correlation between \( (T_c - T_a) \) and \( AVPD \) is also shown in Figs 2 and 3.

According to both sampling and field and laboratory measurements, the \( GY \) of the plants was calculated in kg per hectare and also through dividing the grain yield by the irrigation water, the \( WP \) of maize and black gram in kg m\(^{-3}\) was determined for each replicate of the tested treatments (Table 3). According to Table 3, crop yields decreased with the application of irrigation treatments and the stress applied to the plants and showed a greater decrease with increasing stress. The maximum average grain yield in the I1 treatment (100% water requirement) for maize and black gram were 10.02 and 1.87 t ha\(^{-1}\), respectively and the minimum average grain yield for the I1 treatment (50% water requirement) for maize and black gram, respectively was found to be 5.28 and 1.47 t ha\(^{-1}\), respectively.

The lower baseline equation for the experimental method Idso et al. (1981) was based on the non-stress treatment. In this study, the non-stress treatment is the I1 treatment, which is the same as the lower baseline equation for the under-stress treatments (I1 and I2). In this experimental method, the basis of the calculations for the lower baseline equation of all treatments is the non-stress treatment. It should be noted that sometimes the measurement of canopy temperature is conducted after irrigation, this does not mean non-stress conditions exist and then the treatment data that received the most water can be used for the rest of the treatments. By examining the data and calculating the \( CWSI \) for the I1 treatment, we found that the treatment had non-stress conditions; therefore, the \( CWSI \) calculation for treatment I1 was not performed.
The relationship of maize and black gram with CWSI may be observed from the results obtained in Fig. 4. According to these figures, the relationship between GY and CWSI is inverse, that is, the lower CWSI leads to the more favourable water conditions of the plant and higher GY; therefore, CWSI can be used to estimate GY under water stress conditions (Ahmadi et al., 2018). The regression relationship between the GY of maize and black gram with CWSI may be determined as follows (Fig. 4):

\[
G_{Y_{\text{maize}}} = -17.53 \times \text{CWSI} + 15.39 \quad R^2 = 0.79, \quad (5)
\]

\[
G_{Y_{\text{black gram}}} = -1.824 \times \text{CWSI} + 2.144 \quad R^2 = 0.99, \quad (6)
\]

According to Fig. 4a, the maximum GY of maize for the I3 treatment (100% water requirement) with an average water stress index of 0.28 is equal to 10.02 t ha\(^{-1}\) and the minimum GY for the I1 treatment (50% water requirement) with an average water stress index of 0.53 was 5.28 t ha\(^{-1}\). Also, according to Fig. 4b, the maximum GY of black gram for I1 or the control treatment with an average water stress index of 0.15 is 1.88 t ha\(^{-1}\) and the minimum GY for the I1 treatment with an average water stress index of 0.37 was found to be 1.47 t ha\(^{-1}\). The higher degree of water stress in the plant causes the lower GY value of the crop.

According to the results, the highest GY values of maize and black gram were obtained at a water stress level of 0.28 and 0.15, respectively. These values are recommended for the irrigation scheduling of maize and black gram in Iran (Urmia). Given the high degree of accuracy of the regression models obtained between the GY values of the crops and CWSI, one can predict the GY value of crops through these relationships by calculating CWSI and the aforementioned models can also be used for better water management on the farm.

An examination of the relationship between WP and the CWSI index for maize and black gram showed that there is a respectively nonlinear (uni-variate) and linear (uni-variate) relationship between them, as presented in Fig. 5. According to Fig. 5, the WP range for maize is between 1.5 and 1.9 kg m\(^{-3}\) and for black gram it is between 0.3 and 0.6 kg m\(^{-3}\). The highest WP value in maize was related to the I2 treatment (75% water requirement) with a value of 1.88 kg m\(^{-3}\) and at a CWSI value of 0.44 (Fig. 5a). Also, the highest WP value in black gram was related to the I1 treatment (50% water requirement) with a value of 0.53 kg m\(^{-3}\) and at a CWSI value of 0.37 (Fig. 5b).

According to the above, the highest WP value for maize and black gram were obtained respectively at a water stress index of 0.44 (I3 treatment) and 0.37 (I1 treatment), which are the values recommended for irrigation scheduling under access restriction conditions with high water prices. The WP vs. CWSI relationship for maize and black gram includes Eqs (11) and (12), respectively:

\[
WP_{\text{maize}} = -17.17 \times (\text{CWSI})^2 + 14.25 \times (\text{CWSI}) -1.067 \quad R^2 = 1.0, \quad (7)
\]

\[
WP_{\text{black gram}} = -0.868 \times (\text{CWSI}) + 0.207 \quad R^2 = 0.99. \quad (8)
\]

In the present study, antioxidant activity was determined using the total phenol and flavonoid content in four water treatments with three replications for black gram and maize. According to the results obtained for black gram, the highest total phenol content (22.6 mg of gallic acid per 100 g of seed dry matter) was observed for the I1 treatment and the lowest amount (17.82 mg of gallic acid per 100 g of seed dry matter) was observed for the I4 treatment (Fig. 6a). Also, according to Fig. 6b for maize, the maximum total phenolic content (7.68 mg of gallic acid per 100 g...
of seed dry matter) was observed for the I2 treatment and its minimum amount (5.47 mg of gallic acid per 100 g of seed dry matter) was observed for treatment I4.

According to the results obtained for black gram, the highest flavonoid content (15.07 mg of quercetin per 100 g of seed dry matter) was observed for the I1 treatment and the lowest amount (8.39 mg of quercetin per 100 g of seed dry matter) was associated with the I4 treatment (Fig. 7a). Also according to Fig. 7b for maize, the maximum flavonoid content (3.08 mg of quercetin per 100 g of seed dry matter) was associated with the I1 treatment and its minimum value (1.82 mg of quercetin per 100 g of seed dry matter) was observed for the treatment I4.

DISCUSSION

Using the experimental method proposed by Idso et al. (1981), the values of \((T_e - T_a)\) were plotted versus AVPD and, regression relationships were obtained for the growth stages of maize (three stages) and black gram (four stages) (Figs 2 and 3). In deriving regression relationships, it was assumed that the plants did not tolerate environmental stress other than water stress. According to Figs 2 and 3, the range of AVPD and \((T_e - T_a)\) for the three stages of maize growth is 4 to 45 mbar and 3 to \(-5^\circ C\), respectively, and for the four stages of black gram growth it is 4 to 46 mbar and 3 to \(-7^\circ C\), respectively. The equations of the low base

---

**Table 3.** Quantities of irrigation volume, grain yield and water productivity of crops for different irrigation treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant</th>
<th>Maize</th>
<th>Black gram</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I1</td>
<td>I2</td>
<td>I3</td>
</tr>
<tr>
<td><strong>CWSI ((-)</strong></td>
<td>0.53</td>
<td>0.44</td>
<td>0.28</td>
</tr>
<tr>
<td><strong>VI (m³ ha⁻¹)</strong></td>
<td>3177.80</td>
<td>4766.60</td>
<td>6355.50</td>
</tr>
<tr>
<td><strong>GY (kg ha⁻¹)</strong></td>
<td>5281.11</td>
<td>8954.07</td>
<td>10021.33</td>
</tr>
<tr>
<td><strong>WP (kg m⁻³)</strong></td>
<td>1.66</td>
<td>1.88</td>
<td>1.58</td>
</tr>
</tbody>
</table>

Fig. 4. Relationship between grain yield and crop water stress index of maize (a) and black gram (b).

Fig. 5. Relationship between the water productivity index and crop water stress index of maize (a) and black gram (b).

Fig. 6. Comparison of mean total phenolic content of black gram seeds (a) and maize (b) in the different irrigation treatments.

Fig. 7. Comparison of flavonoid content of black gram seeds (a) and maize (b) for the different irrigation treatments.
lines fitted in the plant growth stages may be used in different places for maize and black gram, provided that the range of AVPD is wide (Gardner and Shock, 1989). With different places for maize and black gram, provided that the -lines fitted in the plant growth stages may be used in different stages. The negative slope of the line was obtained for all three stages of maize growth and the four stages of negative black gram growth (Figs 2 and 3). The reasons for the different values of coefficients a and b include the difference in water absorption potential as well as transpiration during the plant growth stages (Khorsand et al., 2019). Using the method of Idso et al. (1981) and according to Figs 2 and 3, the values of the upper baseline for the three stages of maize growth were found to be 4.69, 2.83 and 10.01°C (Fig. 2), respectively, and for the four stages of growth of black gram, they were found to be 2.63, 6.25, 2.79 and 7.73°C (Fig. 3).

In the present study, the values of coefficients a and b of the baseline for maize were different from the results of Taghvaeian et al. (2000; Chen et al., 2010) and its value is a variable between zero and one (DeJonge et al., 2015). The mean CWSI values during the growing periods of maize and black gram for the three treatments are presented in Table 3. The maximum CWSI of both plants is related to treatment I1 (severe deficit irrigation). The factor that increased CWSI for the I1 treatment was Tc; because the plant closed its stomas due to water stress and the Tc of the plant increased (Taghvaeian et al., 2013).

The CWSI method has been used in various studies to manage plant irrigation. The CWSI threshold values in this study for maize and black gram undergoing the non-stress treatment were 0.28 and 0.15, respectively, these values were the basis of irrigation scheduling. Stegman (1986) conducted a study in the United States concerning the timing of maize irrigation and used two CWSI values (0.2 and 0.4). Plant WP was increased to 2.5 kg m⁻³ using irrigation scheduling based on CWSI (with a threshold of 0.4).

In the present study, the maximum maize WP (1.88 kg m⁻³) was observed to have a CWSI value of 0.44. It is true that the CWSI of this study is close to the CWSI obtained by Stegman (1986), but the WP of maize in this study was approximately 0.62 kg m⁻³ (24.8% decrease in WP) less than the WP obtained by Stegman (1986). Steele et al. (1994) conducted a similar study with maize for three years in the region where Stegman (1986) conducted a study in the United States. In this study, CWSI values of 0.2, 0.4 and 0.6 were used, which reduced water consumption by 28, 43 and 54%, and no significant GY reduction occurred for the product at a CWSI threshold of 0.2. Irmak et al. (2000) conducted a study on maize in Turkey and concluded that the mean CWSI should be below 0.22 to prevent a reduction in maize GY. In the present study, the difference between the mean value of CWSI and the result produced by Irmak et al. (2000) is 0.06, which is about 21.4% higher, and the mean value of CWSI in this research with maize should be below 0.28 so that the GY of the plant does not decrease.

In a study with different plants, the threshold value of CWSI for red pepper was 0.20 (Sezen et al., 2014), for eggplant it was 0.26 (Colak et al., 2015) and for soybean it was 0.18 (Ahmadi et al., 2018). The existence of a linear regression relationship between GY and CWSI and its use to predict performance has been confirmed by other researchers (Idso et al., 1981; Orta et al., 2003; Erdem et al., 2010; Sezen et al., 2014; Colak et al., 2015). The following regression relationships were found between GY (kg ha⁻¹) and CWSI for red pepper under drip irrigation and furrow irrigation under different irrigation regimes in Turkey in 2010 and 2011 (Sezen et al., 2014):

**Drip irrigation:**

\( GY_{2010} = -23.77 \times 10^{-3} \) \( (CWSI) + 48.84 \times 10^{-3} \) \( R^2 = 0.88 \) \( , \)

\( GY_{2011} = -43.52 \times 10^{-3} \) \( (CWSI) + 60.61 \times 10^{-3} \) \( R^2 = 0.90 \) \( , \)

**Furrow irrigation:**

\( GY_{2010} = -94.80 \times 10^{-3} \) \( (CWSI) + 38.87 \times 10^{-3} \) \( R^2 = 0.75 \) \( , \)

\( GY_{2011} = -35.07 \times 10^{-3} \) \( (CWSI) + 52.97 \times 10^{-3} \) \( R^2 = 0.66 \) \( . \)

In another study carried out for eggplants under different irrigation regimes using surface and subsurface drip irrigation systems in Turkey in 2013, the following regression relationships were obtained between GY (kg ha⁻¹) and CWSI (Çolak et al., 2015):

\( GY_{2010} = -23.77 \times 10^{-3} \) \( (CWSI) + 48.84 \times 10^{-3} \) \( R^2 = 0.88 \) \( , \)

\( GY_{2011} = -43.52 \times 10^{-3} \) \( (CWSI) + 60.61 \times 10^{-3} \) \( R^2 = 0.90 \) \( , \)

\( GY_{2010} = -94.80 \times 10^{-3} \) \( (CWSI) + 38.87 \times 10^{-3} \) \( R^2 = 0.75 \) \( , \)

\( GY_{2011} = -35.07 \times 10^{-3} \) \( (CWSI) + 52.97 \times 10^{-3} \) \( R^2 = 0.66 \) \( . \)
surface drip irrigation:

\[ GY = -79.71 \times 10^3 \times CWSI + 94.34 \times 10^3 \quad R^2 = 0.83, \quad (13) \]

subsurface drip irrigation:

\[ GY = -78.16 \times 10^3 \times CWSI + 86.01 \times 10^3 \quad R^2 = 0.69. \quad (14) \]

In a study conducted with soybean under different irrigation regimes using a furrow irrigation system in the climatic conditions of Khorrarambad, the CWSI values for irrigation scheduling to achieve maximum WP at the developmental, intermediate and final stages of plant growth were 0.42, 0.37 and 0.29, respectively (Ahmadi et al., 2018). It should be noted that the mean CWSI in this study for black gram should be below 0.15 so that \( GY \) does not decrease. Also, no research has been done to evaluate the CWSI of black gram to compare it with the results of the present study.

According to the results for phenol and flavonoid, the maximum values for black gram and maize where obtained for 50 and 75% water requirement treatments, respectively. We found that the maximum WP values for both plants were obtained for these treatments (I1 and I2) which were discussed in the previous section; therefore, a direct relationship between phenol and flavonoid and the WP of the plants may be considered. Phenolic compounds and flavonoids are the antioxidant compounds of plants (Lindsay and Astley, 2002) which are of great physiological and morphological importance in plants (Schijlen et al., 2004). The main reason for the high antioxidant activity of some extracts is due to the high content of phenolic compounds (Jiao et al., 2005). Various factors such as genotype, climate and weather conditions, soil type, plant growth season and storage conditions affect the antioxidant activity of plants (Asekun et al., 2006). Flavonoids have the ability to cleanse active oxygen species and prevent oxidative stress. An examination of the flavonoid content of canola under drought irrigation (water stress) showed that flavonoid content increases as a secondary metabolite in the plant (Sangtarash et al., 2009). In general, the results showed that by stimulating the factors promoting the formation of phenolic compounds and flavonoids, water stress increases its content in black gram seeds, which can also be a reason for reducing transpiration in this plant. Also, given the results for black gram, it may be concluded that this plant has a high tolerance for drought and may be used as a low water plant in arid and semi-arid climates. It should be noted that promoting the cultivation of low-water medicinal plants such as lavender, garden thyme, lemon balm among others is one of the plans for the Urmia Lake Restoration project, which aims to improve farmers’ livelihoods (income generation) and reduce pressure on resources and soil (reduce water use) in the Urmia Lake basin; therefore black gram can also be cultivated as one of the medicinal plants in this basin.

CONCLUSIONS

The present study was conducted in order to investigate the relationship between the crop water stress index, grain yield, water productivity and antioxidant compounds (phenol and flavonoid) of two maize (cultivar SC704) and black gram (native bulk) plants in Urmia (Iran).

1. Based on the results, the highest grain yield values for maize and black gram were obtained at a crop water stress index of 0.28 and 0.15, respectively; therefore, these values are recommended for the irrigation scheduling of maize and black gram in Urmia (Iran). Given the high degree of accuracy of the regression models obtained between the grain yield of crops and the crop water stress index, one may predict the grain yield of the crops through the relationships between them by calculating the crop water stress index and this can also be used for better water management in the field.

2. The maximum water productivity for maize and black gram was obtained at a water stress index of 0.44 (I2 treatment) and 0.37 (I1 treatment), respectively, which are recommended for irrigation scheduling under water restriction conditions in Urmia (Iran).

3. In general, it may be stated that the crop water stress index is capable of assessing water stress and estimating the crop produced under water stress in plants.

4. It should be noted that the direct relationship between water productivity and the antioxidant compound content of the two plants was also obtained.

Conflict of interest: The authors declare no conflict of interest.

REFERENCES


