The Effect of Water Stress on Yield and Canopy-air Temperature Difference for Spring Corn

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Abstract: This study describes the relationship of irrigation water application, water stress, CWSI and crop yield for the spring corn, hybrid SC704. Irrigation was scheduled using accumulative pan evaporation. Five treatments including 50, 70, 90, 110 and 130 mm based on the accumulative pan evaporation were used as the main plots. Crop Water Stress Index (CWSI) were calculated using two different methods described by Idso and Jackson in the literature. A good linear equation was developed using the least square method between the grain yield and the crop water stress index (Jackson method) in the form of $Y = -10.295CWSI + 13.196$ with a correlation coefficient of $R^2 = 0.97$. Another equation was also developed, in which the relative humidity, the net receiving solar radiation, the depleted soil moisture from the root zone and the wind speed were related to the canopy-air temperature difference.

Key words: Infrared thermometer, crop water stress index, corn, crop canopy temperature

INTRODUCTION

Corn is one of the most important and strategic agricultural productions for developing countries. Khoozestan province located in the south west of Iran has a high potential of producing spring and autumn corn. Since the main problem of the arid and semi-arid regions such as Khoozestan is the scarce of supply waters, it seems that being able to optimise the irrigation programme is the only way to have the high water productivity. In recent years crop canopy-air temperature difference has been widely used as a tool to relate the crop yield and water stress index and even to schedule the irrigation programme.

The main aims of this study are to formulize the effect of the water stress on yield and canopy temperature of spring corn and making the relationship of some environmental conditions with canopy-air temperature difference. Therefore, one can estimate the corn grain yield using the measured climatic conditions.

Previous studies have shown that the temperature of crop canopy may be a suitable index to evaluate the crop water stress (Tramer, 1996). Idso et al. (1977) and Jackson et al. (1981) indicated that the Stress Degree Day (SDD), which is calculated using the canopy-air temperature difference ($T_c-T_a$) for the maximum daily stress, may be applied as an index to determine the irrigation start time. They introduced two different methods to calculate the Crop Water Stress Index (CWSI) for irrigation programming.

The definition of Idso et al. (1981) from the crop water stress index may be formulised as:

$$CWSI = \frac{(T_c - T_a)_m - (T_c - T_a)_l}{(T_c - T_a)_u - (T_c - T_a)_l}$$

where, $(T_c-T_a)_m$=canopy-air temperature difference for the maximum daily stress before irrigation, $(T_c-T_a)_l$=lower baseline limit which shows the potential plant transpiration and $(T_c-T_a)_u$=upper baseline limit which shows no plant transpiration conditions and may calculated by the following equation:

$$(T_c - T_a)_l = a + b|\text{VPG}|$$

where, VPG = vapour pressure gradient and $a, b$ = experimental coefficients that can be obtained using the relationship of the saturated vapour pressure deficit and the canopy-air temperature difference for the potential transpiration as:

$$(T_c-T_a)_u = a + b\text{VPD}_m$$

$\text{VPD}_m$ = saturated vapour pressure deficit for the maximum daily stress. $(T_c-T_a)$ and VPD are expressed as centigrade degree and mbars respectively.

Jackson et al. (1981) described another method to calculate the crop water stress index based on the energy balance and presented their equation as:

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MATERIALS AND METHODS

The experiments were conducted with spring corn (hybrid 7045C) in a 50 x 50 m field area located in the Dezful Safi-Abad research site, north of Khuzestan province, Iran. The soil texture within the root zone was classified as Silty Clay Loam (SCL) with an average of bulk density of 1.53 g cm\(^{-3}\) and Field Capacity (FC) and Wilting Point (WP) of 23 and 11% based on the dry weight, respectively. Furrow irrigation system with 11 end closed furrows was applied for each treatment. Furrows' spacing were 75 cm with north-south direction. The furrows were supplied using the hydro-flume pipes containing the measurement equipments. Five irrigation treatments based on the accumulative pan evaporation, including: 50 (T\(_1\)), 70 (T\(_2\)), 90 (T\(_3\)), 110 (T\(_4\)) and 130 (T\(_5\)) mm were planned as the main plots with four replications for each plot. The irrigation start time and amount of applied water to the treatments were designed according to the corresponding accumulative pan evaporation for each treatment. A schematic figure of the treatments and replications is shown in Fig. 1.

Fig. 1: Schematic picture from the situation of treatments and climatology station
stresses to the treatments for April. Canopy temperature was measured using an infrared thermometer model KM823. The instrument was taken towards the green canopy making an angle of 45° with the horizontal line and with a distance of about 0.5 m. The angle and distance were chosen according to the user manual of the infrared thermometer.

The measured canopy temperatures in the day after irrigation at the noon time (12:00 to 14:00 h) for the treatments T_1 and T_2 were used to determine the lower limit baseline position. At the time of canopy temperature measurements, air temperature, relative humidity and vapour pressure deficit were also measured from 8 am till 2 pm with 0.5 to 1 h intervals on 24th April, 6th, 11th and 19th May and 8th June.

Crop Water Stress Index (CWSI) for all of the treatments were determined using Equations 1 and 4 for Idso and Jackson’s methods respectively with the air-canopy temperature difference and vapour pressure deficit being measured a day before irrigation from 12.5 to 14 h in April and May. Irrigation depths and volumes were calculated using the measured soil moisture within the root zone. Water applied for all treatments was measured using the water meters installed on the hydro-flumes. In addition to all mentioned parameters, wind speed and the net receiving radiance were obtained using the climatology station close to the research site. All measurements were carried out up to 14th of June and three weeks after the last irrigation, corn was harvested and the grain yields were measured for all treatments.

RESULTS AND DISCUSSION

Lower baseline equations for April and May were determined as two separate equations using the measured air-canopy temperature difference and vapour pressure deficit as:

$$T_c - T_s = 1.1 - 0.216 VPD \quad R^2 = 0.86 \quad n = 22 \quad (7)$$

$$T_c - T_s = 2.28 - 0.207 VPD \quad R^2 = 0.81 \quad n = 1 \quad (8)$$

These two lower baselines were also shown in Fig. 2 and 3. As can be seen from these two equations the line slopes are relatively similar but the line intercepts are different. This is due to higher transpiration in May in comparison with April and thus it is recommended to introduce different lower baselines for different plant seasons. Using different lower baseline equations for different months or different growing stages is recommended by the researchers. For instance, Yuan et al. (2004) proposed four lower baseline equations for different growing stages of winter wheat. According to their results the slope of the equations are relatively similar, whereas the intercept for the first stage of growing season is almost one third of the last stage. Equation 2 was applied to calculate the upper baselines using the experimental coefficients (a, b) in Eq. 7 and 8. These two baselines which are generally horizontal lines were calculated as 2.0 and 4.5°C for April and May, respectively. Crop water stress indexes were calculated using the Idso method (Eq. 1) with the averages being 0.1, 0.2, 0.4, 0.46 and 0.54 for T_1 to T_6 treatments, respectively. Aerodynamic resistance was calculated equal to 11 s m^{-1} using the upper baseline and Eq. 5. With this coefficient and using the Jackson’s balance energy method (Eq. 6), canopy resistance and crop water stress indexes were then calculated for all treatments. The average CWSI using Jackson’s method were calculated equal to 0.05, 0.15, 0.36, 0.43 and 0.50 for T_1 to T_6 treatments, respectively.

The applied depth of irrigation, the average grain yield, CWSI using Idso and Jackson methods for all treatments are shown in Table 1. The water productivity for all treatments were also calculated and appended to this table. Water productivity is defined as the corn yield for a unit of applied water. Table 1 shows that with increasing water application the grain yield was increased. However, the maximum water productivity was obtained for the T_1 treatment. This treatment was irrigated 15% less than the full irrigated treatment (T_6).
Table 1: Depth of irrigation, grain yield, CWSI, CWSI, and water productivity for all treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth of Irrigation (cm)</th>
<th>Grain yield (kg/ha)</th>
<th>CWSI</th>
<th>CWSI</th>
<th>Water Productivity (kg cm⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>70.50</td>
<td>12.40</td>
<td>0.05</td>
<td>0.10</td>
<td>17.60</td>
</tr>
<tr>
<td>T₂</td>
<td>60.00</td>
<td>11.90</td>
<td>0.15</td>
<td>0.20</td>
<td>19.80</td>
</tr>
<tr>
<td>T₃</td>
<td>49.65</td>
<td>9.11</td>
<td>0.36</td>
<td>0.40</td>
<td>19.70</td>
</tr>
<tr>
<td>T₄</td>
<td>45.20</td>
<td>8.69</td>
<td>0.43</td>
<td>0.46</td>
<td>19.20</td>
</tr>
<tr>
<td>T₅</td>
<td>39.70</td>
<td>7.60</td>
<td>0.50</td>
<td>0.54</td>
<td>19.10</td>
</tr>
</tbody>
</table>

The values of CWSI obtained from Jackson method were correlated with the corresponding values obtained using Idso method with a correlation coefficient of 0.999 (CWSI = 1.37 CWSI - 0.055 R² = 0.999)

The relationships between CWSI, with the relative yield and the relative accumulative irrigation depth were individually investigated and the results are illustrated by Eq. 9 to 11.

\[ CWSI = 0.076 + 1.119 \left( 1 - \frac{Y_g}{Y_m} \right) \quad R² = 0.98 \quad (9) \]

\[ CWSI = 0.029 + 1.085 \left( 1 - \frac{1}{I_m} \right) \quad R² = 0.99 \quad (10) \]

\[ Y_g - 13.196 - 10.925 CWSI \quad R² = 0.99 \quad (11) \]

where, \( Y_g \) = grain yield; \( Y_m \) = maximum grain yield; \( I \) = accumulative depth of irrigation; \( I_m \) = maximum value of accumulative depth of irrigation.

Equations 9 and 10 have shown the excellent correlations between the relative decreased yield and the relative deficit of irrigation with CWSI. Moreover, Eq. 11 illustrates a good linear relationship between yield and crop water stress index, as by increasing CWSI from 0.05 to 0.5, the yield decreased about 40%. This equation may also be applied for predicting grain yield. Equation 9 shows a similar result, by changing CWSI from 0.05 to 0.5 the relative decreased yield varies from about 1 to 0.62, which shows a decreased yield of about 38%.

By substituting CWSI from Eq. 10 in Eq. 9 the following equation may be obtained which shows the relationship of the relative decreased yield with the relative irrigation deficit. The results of this equation shows that corn is relatively sensitive to water stress, for instance, with each 1% irrigation deficit the yield decreased about 1%.

\[ 1 - \frac{Y_g}{Y_m} = -0.042 + 0.97 \left( 1 - \frac{1}{I_m} \right) \quad \text{or} \]

\[ \left( 1 - \frac{Y_g}{Y_m} \right) = \left( 1 - \frac{1}{I_m} \right) \quad (12) \]

Table 2: statistic analysing results for the split plots

<table>
<thead>
<tr>
<th>Variable</th>
<th>df</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>5%</th>
<th>1%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>4</td>
<td>89.22</td>
<td>22.30</td>
<td>5.92</td>
<td>3.26</td>
<td>5.14</td>
</tr>
<tr>
<td>Replication</td>
<td>3</td>
<td>4.91</td>
<td>1.64</td>
<td>0.44</td>
<td>0.49</td>
<td>5.95</td>
</tr>
</tbody>
</table>

The average slope of the line defined in the form of Eq. 12 for three stages of the corn growing season, including: vegetative, flowering and yield formation is measured and reported equal to 0.97, which is similar to what was obtained in this research study (Dorrenbos et al., 1988).

The statistic analysing results of the split plots, including: degree of freedom (df), Sum of Square (SS), Mean of Squares (MS) and F test for 5 and 1% levels of confidence are summarised in Table 2. As can be seen from this table the difference between the results of treatments at 5 and 1% levels of confidence are meaningful.

In this research study another equation was developed to describe the relationship of \( T_2 - T_1 \) \(^{\circ}C\) as the dependent variable and the net receiving radiation \( R_n \) (lg/min), the relative soil water depleted from the root zone (MD), the Relative Humidity (RH) and the wind speed \( V \) (m/s) as the independent variables. These parameters were simultaneously measured a day before irrigation and for the maximum daily stress. A linear multiple variables was developed using the computer SPSS programme as the following equation with a correlation coefficient of 0.71.

\[ T_2 - T_1 = -15 + 3.886R_n + 0.143RH + 7.392MD - 0.184V \quad R² = 0.71 \quad (13) \]

Since the maximum allowable depleted soil moisture for corn is about 0.6 and the average wind speed in the research region was 5 m s⁻¹ Eq. 13 may be reduced to Eq. 14 as:

\[ (T_2 - T_1)_{max} = -11.5 + 3.886R_n + 0.143RH \quad (14) \]

where, \( (T_2 - T_1)_{max} \) = the maximum allowable canopy and air temperature difference. This equation may be applied to schedule the irrigation programme without measuring the soil moisture. The allowable canopy and air temperature difference can be calculated using the recorded net receiving radiation and the relative humidity for the maximum daily stress. The values obtained using Eq. 14 are compared with the measured canopy and air temperature difference and the irrigation should be started when the measured values are equal or more than the corresponding values obtained from this equation.
CONCLUSIONS

Details are given of the experimental field research study to relate the crop water stress index with grain yield for spring corn. In this study the lower and upper baselines which related vapour pressure deficit to the canopy-air temperature difference were determined in the form of the separate equations for April and May. The results showed higher grain yield but lower water use efficiency with increasing water application. The maximum grain yield was obtained 12.4 t ha$^{-1}$, with the corresponding being 0.05. The maximum water productivity (19.8 kg mm$^{-1}$) was obtained for the treatment with 60 cm depth of irrigation which this amount of water application was 15% less than the fully irrigated treatment. The maximum allowable canopy-air temperature differences were also correlated with some environmental parameters.

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