Journal of Plant Process and Function, Vol. 6, No. 22, Year 2018

Effect of two irrigation regimes on crop water stress index and yield and yield components of Triticale (X *Triticosecale* Wittmack) Cultivars

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(Received: 04/02/2017-Accepted: 25/10/2017)

Abstract:

A field experiment was conducted to evaluate the crop water stress index (CWSI), grain yield and canopy temperature of triticale under two irrigation regimes at Research Station of College of Agriculture and Natural Resources of Darab, Shiraz University, in 2013. A split plot design was used with three triticale cultivars (Sanabad, ET-83-3, and ET-84-5), as sub-plots and four levels of irrigation regimes including well watered, cutting off irrigation at flowering, milk development, and dough development stages as main plots replicated three times. Results showed that Sanabad (6.31 °C) and ET-83-3 (6.89 °C) cultivars had the higher canopy-air temperature differences, while in ET-84-5 this difference reached to 2.66 °C. In all cultivars, high amount of variation (0.18 to 0.91) was observed for monthly CWSI and decreased by cutting off irrigation from flowering to dough development. Under cutting off irrigation at flowering, ET-83-3 with 0.67 had the highest mean seasonal CWSI, while in ET-84-5 reached to 0.50. In cutting off irrigation at flowering, the highest triticale grain yield was obtained in Et-84-5 (354.3 g) and it might be attributed to higher grain number per spike and spike number per square meter compared to Sanabad and ET-83-3. Polynomial regression showed that with increasing CWSI, triticale grain yield decreased and the slope of regression between 237 to 284 g/m^2 grain yield was more than the other spots (R^2=0.79). The highest grain yield (476.2 g/m^2) was obtained in ET-84-5 under well watered and CWSI in this cultivar ranged from 0.18 to 0.33. By cutting off irrigation at flowering and increasing CWSI compared to cutting off irrigation at milk and dough development stages, grain yield decreased significantly especially in Sanabad and ET-83-3,. Overall, ET-84-5 with lower canopy and air temperature differences (T*c*-T*a*) and mean CWSI, had better performance when exposed to cutting off irrigation.

Keywords: Cutting off irrigation, Drought, Flowering, Grain yield.

Introduction

After a decade of genetic manipulation and breeding, triticale (*X Triticosecale* Wittmack) stands out as a crop of high grain yield potential which generally surpasses wheat under stress conditions. Its high productivity is most likely derived from high rates of carbon assimilation linked to stomatal physiology and probably low respiration rate. As a derivative of rye, triticale has always been assumed to be relatively resistant to abiotic stresses such as drought (Blum, 2014).Triticale seems to be an interesting alternative to other cereals, particularly bread wheat, in environments where growing conditions are unfavorable or in low-input systems. Akbarian *et al.*, (2011) declared that triticale lines performed superior than wheat cultivars for drought tolerance considering both grain yield and majority of physiological traits. Lonbani and Arzani (2011) declared that triticale cultivars 'Moreno', 'Zoro','Lasko' and 'Prego' produced superior grain yield under non-stress conditions while under water-deficit conditions, Alamos 83, 'Lasko and 'Moreno triticale cultivars ranked as the superior group for grain yield production.

In arid and semi-arid areas where the amount of water is a major limiting factor, the lower amount of irrigation water, without the decrease in crop yield is worthy for irrigation scheduling**.** When a plant closes its stomata following water stress, stomatal conductivity, heat flux, transpiration and the cooling effects of evaporation decrease and the canopy temperature increases (Panda *et al.*, 2003). This is the basis for the use of canopy temperature to determine plant water status (Emekli *et al.*, 2007). The canopy temperature (Tc) has provided an efficient method for rapid and non-destructive monitoring of whole plant response to drought stress (Idso *et al.*, 1981; Jackson *et al.*, 1981). It is also argued that variation in Tc, under stress and nonstress conditions, provides clues for crop water status and yield performance during drought seasons. The crop water stress index (CWSI), derived from canopy±air temperature differences (Tc-Ta) versus the air vapor pressure deficit (AVPD), was found to be a promising tool for quantifying crop water stress (Idso *et al.*, 1981; Alderfasi and Nielsen, 2001).

The crop water stress index (CWSI) calculation is based on three main environmental variables: plant canopy temperature (T*c*), air temperature (T*a*) and

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atmospheric vapor pressure deficiency (VPD). These three variables have much influence on water used by plants (Braunworth, 1989). An infrared thermo meter measures the surface temperature of a crop canopy without making direct physical contact (Howell *et al.*, 1986). Idso *et al.*, (1981) defined CWSI based on the empirical linear relationship between midday T*c*-T*a* and VPD under high net radiation and well watered conditions. The CWSI has been used to quantify water status in the field based on canopy temperature (Yuan *et al.* 2004; Emekli *et al.*, 2007) and irrigation scheduling of wheat in many places (Alves and Pereira, 2000; Alderfarsi and Nielsen, 2001; Orta *et al.*, 2004; Bijanzadeh and Emam, 2012).

Many studies have been done to evaluate the application of CWSI in irrigation scheduling for different plants such as tall fescue [(*Festuca arundinacea* Schreb.); Al-faraj *et al.*, (2001)], and turfgrass [(*Cynodon dactylon* L.); Bijanzadeh *et al.*, 2013]. Furthermore, Jalali-Farahani *et al.*, (1993) concluded that the changes in CWSI values depended on the applied irrigation level. Al-Faraj *et al.*, (2001) reported that T*c*-T*a* was increased with a decrease in soil water content for tall fescue (*Festuca arundinacea* Schreb.). They suggested that CWSI could be used for irrigation timing in turfgrass. Feng *et al.*, (2001) declared that wheat cultivars with low canopy temperature could maintain superiority to cultivars with high canopy temperature and low canopy temperature in wheat could be used as an index to evaluate physiological capacities of wheat under drought stress and also as a useful marker in wheat breeding for drought tolerance.

Little research has been done to quantify the CWSI of triticale cultivars especially in Middle East, where water stress in cereals is pervasive and frequent during grain filling period. The aim of the present study was to develop a baseline equation which can be used to calculate CWSI for monitoring water status of triticale genotypes and evaluate the relationship of CWSI with water applied and grain yield of triticale cultivars under different cutting off irrigation scheduling.

Materials and Methods

Field experiment was laid out during November 2013-June 2014 at the Research Station of College of Agriculture and Natural Resources of Darab, Shiraz University, Iran (28°29´ N, 54°55´ E and 1180 m above mean sea level), for determination of the crop water stress index of triticale cultivars. Ten-day averages of some meteorological data measured daily in the study area during April to June 2014 are shown in Table 1. Three triticale cultivars including Sanabad, ET-83-3, and ET-84-5, were arranged in sub-plots and four levels of irrigation regimes including well watered, cutting off irrigation at flowering, cutting off irrigation at milk development, and cutting off irrigation at dough development were as main plots of a split plot experimental arrangement with three replications.

On November 23th 2013, triticale genotypes were sown in rows 30 cm apart with 250 plants/m^2 in plots of 2×4 m. According to soil test, before planting, 60 kg P/ha, as super phosphate, and 60 kg N/ha, as urea, were applied. Another 60 kg N/ha was added at the end of tillering stage. The soil water status was monitored in each plot by gravimetric method at 30 cm intervals down to 120 cm. The amount of water applied was measured by time-volume technique according to Grimes *et al.*, (1987) and is presented in Figure 1 for each cultivar under different irrigation regimes. In well water, irrigation continued up to late season while in cutting off irrigation at flowering, milk development, and dough development irrigation interrupted at ZGS 60, 70 and 80 (Zadoks *et al.*, 1974) up to late season, respectively.

To measure CWSI of triticale cultivars, an infrared thermometer (LT Lutron, Model TM-958, Taiwan) was used and the canopy temperature was measured (3, 6 and 9 days after each irrigation) from 4 April to 21 June 2010 (151- 233 days after planting). To ensure collection of accurate data, the infrared thermometer was held with a horizontal angle of 45° during measurements. Temperature measurements were done when there was no cloud. According to Idso *et al.*, (1981), midday canopy temperature is the best indicator to detect the crop water stress. The measurements were carried out from four directions (east, west, north and south) in each experimental plot.

Simultaneously, air temperature and relative humidity were recorded using thermo hygrograph (Lambrecht, Model 252, Germany) and psychrometer (Lambrecht, Model 1030, Germany) as basis for calculating vapour pressure deficit (VPD) (Monteith and Unsworth 1990). VPD was computed from standard psychrometer equation (Allen *et al.*, 1998). Then, CWSI values were calculated using the empirical method of Idso *et al.*, (1981). The relationship between canopy-air temperature differences (T*c*-T*a*) and VPD were computed under stressed and non- stressed conditions (Fig. 2). In this graph, the non-stressed baseline for each triticale cultivar was determined from the data collected three days after irrigation in well watered treatment between 08:00 and 17:00 h with 30-min intervals.

The Idso’s empirical non-stressed baseline can be expressed as Equation (1):

$$Tc - Ta = aVPD + b \quad (1)$$

Where T*c*–T*a* is the measured canopy and air temperature differences for non- stressed treatment (ºC) and VPD is vapor pressure deficit (kPa) and *a* (slope) and *b* (intercept) are the linear regression coefficients of *Tc*–*Ta* on *VPD*. The upper baseline was determined using the average T*c*–T*a* values measured at 13:00, 14:00 and 15:00 h before each irrigation. Using the upper and lower limit estimates, a CWSI can be defined by the following Equation (2) (Idso *et al.*, 1981):

$$CWSI=[(Tc\text{-}Ta)m\text{-}(Tc\text{-}Ta)ll]/[(Tc\text{-}Ta)ul\text{-}(Tc\text{-}Ta)ll] \quad (2)$$

Table 1. Ten-day means of climatic data measured daily at experimental site.

	Mean			
Month	Temperature(°C)	Evaporation (mm)	Relative humidity (%)	Wind speed (m/s)
April				
1-10	19.3	11.8	27.8	2.1
11-20	19.8	12.6	28.3	2.0
21-30	20.5	13.2	29.3	2.2
May				
1-10	24.6	14.2	30.2	2.5
11-20	25.9	14.7	31.3	1.5
21-31	27.3	14.9	32.4	1.6
June				
1-10	30.2	15.7	33.4	1.1
11-20	32.1	16.3	34.3	1.6
21-30	34.5	17.6	36.8	1.3

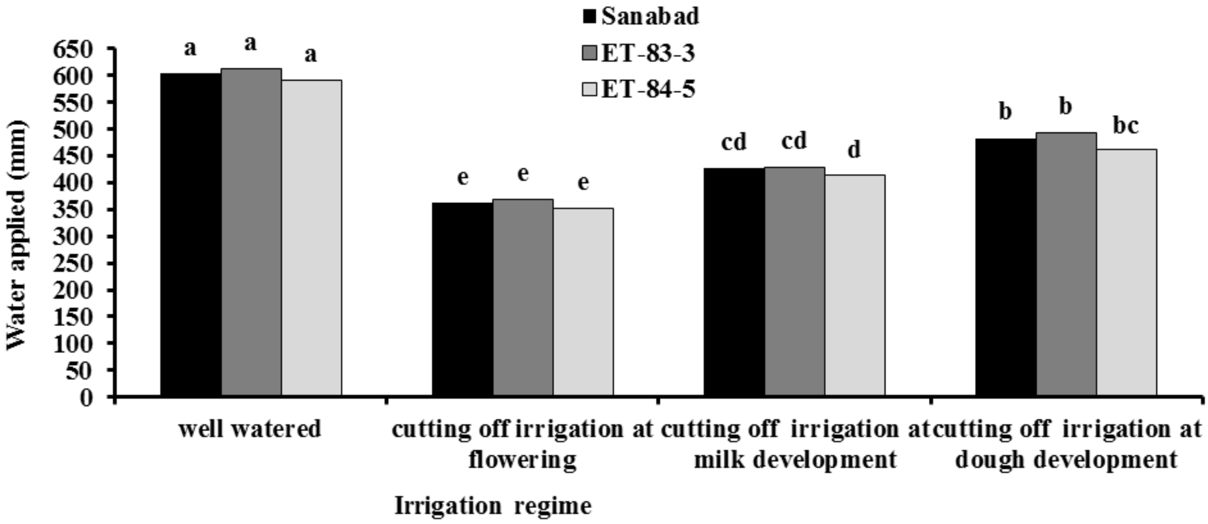

Figure 1. Total water applied (mm) in each irrigation regime and triticale cultivars. Means in each column by the same letters are not significantly different at 5% probability level using Duncan's multiple range test.

where (T*c*–T*a*)*m*, (T*c*–T*a*)*ll* and (T*c*–T*a*)*ul* are the measured canopy and air temperature differences at the moment and the lower and upper limit values (ºC), respectively. Grain yield measured from center of 1 m^2 final harvest area in each plot. The data were analyzed using SAS (2003) software and means were compared by Duncan's multiple range test at 0.05 probability level.

Results and Discussion

Canopy temperature changes of triticale cultivars: Changes in canopy-air temperature differences (T*c*-T*a*) observed among triticale cultivars, were significant at 5% probability level so that, Sanabad (Fig. 2a) and ET-83-3 (Fig. 2b) cultivars with 6.31 and 6.89 °C had the higher canopy- air temperature differences, while in ET-84-5 (Fig. 2c) this difference reached only 2.66 °C. Feng *et al.,* (2009) concluded that canopy temperature could be considered as a consistent character for each wheat genotype. They declared that the difference in canopy temperature between low temperature wheat cultivars and high temperature cultivars could be observed mainly during the grain filling period, which a key period for final wheat grain yield. Results of the present study are in agreement with the finding of Bijanzadeh and Emam (2012) where they found a significant variations in T*c*-T*a* among the five wheat cultivars.

Determination of lower base line: Comparison of the upper limit values of canopy and air temperature difference (Tc -Ta)*ul* and slopes(*a*) and intercepts(*b*) for lower limit [(T*c* -T*a*)*ll* = a VPD + b] of three triticale cultivars are given in Table 2. In all cultivars, *a* and *b* of lower base line equation between T*c*-T*a* and VPD were significantly increased due to more limitation in water and increasing VPD (Fig. 2). Our result was in agreement with Orta *et al.,* (2004) who declared that T*c*-T*a* measured above a crop was negatively related to the atmospheric VPD. The value of *a* varied from -1.35 in Sanabad to -1.00 in ET-84-5 (Table 2). It appeared that Sanabad and ET-83-3 cultivars with higher *a* value were more sensitive to increasing VPD (Table 2 and Figure 2). On the other hand, in Sanabad and ET-83-3 difference between upper base line (under stress) and lower base line (non-stress) was more than in ET-84-5 genotype (Fig. 2). The value of *b* ranged from 3.00 to

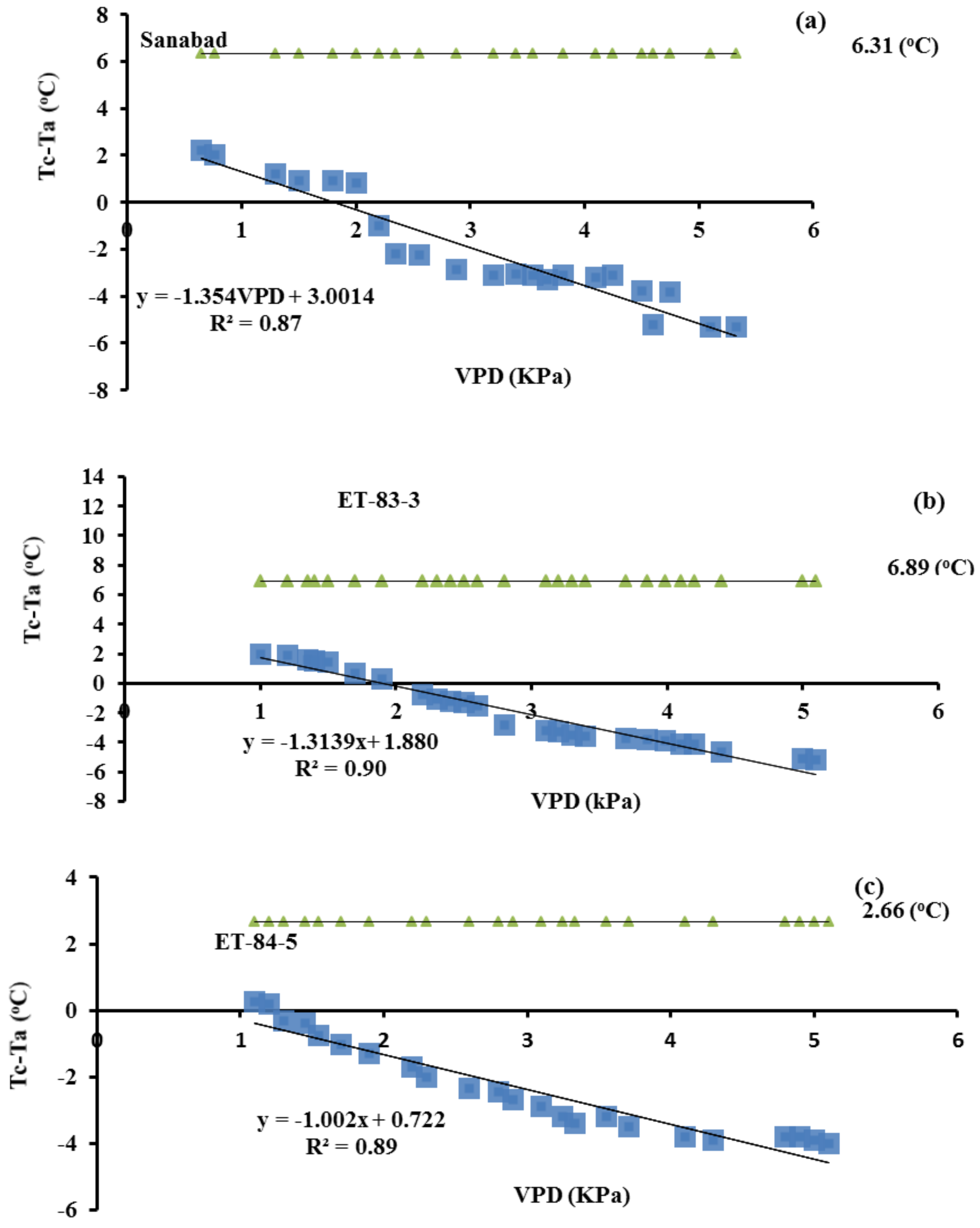

Figure 2. Stressed and non-stressed baselines for calculation of CWSI in three triticale cultivars including (a) Sanabad, (b) ET-83-3, and (c) ET-84-5.VPD = vapor pressure deficit.

Table 2. Comparison of the upper limits values of canopy and air temperature difference (Tc -Ta)*ul* and slope (a) and intercept (b) for lower limit [(T*c* -T*a*)*ll* = a VPD + b] of three triticale cultivars.

	Triticale cultivars		
	Sanabad	ET-83-3	ET-84-5
T*c*-T*a*	6.31[a]	6.89[a]	2.66[b]
Slope (*a*)	-1.35[a]	-1.31[a]	-1.00[b]
Intercept (*b*)	3.00[a]	1.88[b]	0.72[c]

T*c*–T*a* is the measured canopy and air temperature differences for non- stressed treatment (ºC) and VPD is vapor pressure deficit (kPa) and *a* (slope) and *b* (intercept) are the linear regression coefficients of *Tc–Ta* on *VPD*. Means in each row by the same letters are not significantly different at 5% probability level using Duncan's multiple range test.

Table 3. Effect of cutting off irrigation regimes on monthly and mean seasonal CWSI values of triticale cultivars.

Irrigation regime	Triticale cultivars	Monthly CWSI April	Monthly CWSI May	Monthly CWSI June	Mean seasonal CWSI
well watered	Sanabad	0.21	0.32	0.45	0.32[d]
	ET-83-3	0.23	0.34	0.48	0.35[d]
	ET-84-5	0.19	0.25	0.33	0.25[e]
cutting off irrigation at flowering	Sanabad	0.45	0.65	0.79	0.63[a]
	ET-83-3	0.45	0.66	0.91	0.67[a]
	ET-84-5	0.41	0.48	0.63	0.50[b]
cutting off irrigation at milk development	Sanabad	0.41	0.57	0.61	0.53[b]
	ET-83-3	0.44	0.58	0.63	0.55[b]
	ET-84-5	0.35	0.43	0.56	0.44[c]
cutting off irrigation at dough development	Sanabad	0.23	0.35	0.49	0.35[d]
	ET-83-3	0.25	0.37	0.51	0.37[d]
	ET-84-5	0.20	0.29	0.37	0.28[e]

Means in each column by the same letters are not significantly different at 5% probability level using Duncan's multiple range test.

0.72 and was significantly different among triticale cultivars (Table 2) Bijanzadeh and Emam (2012) showed that the lower baseline equation obtained for wheat crop was (T*c*-T*a*)*ll*= - 1.0001(VPD)+1.8934 during flowering to maturity and *a* and *b* parameters in the following equation were close to parameter of ET-84-5 (Fig. 2). On the other hand, in ET-83-3 and Sanabad cultivars the value of *a* was very close to that reported by Alderfarsi and Nielsen (2001) for winter wheat in Colorado [(T*c*-T*a*)*ll*= -1.35VPD+0.41], however, *b* in this equation was smaller than that for ET-83-3 and Sanabad cultivars of our study. This might be attributed to higher temperature in our experimental site, i.e. ET-83-3, from April to June (Fig. 1), compared to Colorado. Overall, many researchers pointed out that cultivar type and environmental conditions could influence the baseline equation causing differences in slopes(*a*) and intercepts(*b*) (Panda *et al.*, 2003; Yuan *et al.*, 2004; Bijanzadeh *et al.*, 2013).

Crop water stress (CWSI) changes of triticale cultivars: In all cultivars and cutting off irrigation regimes, high amount of variation (0.18 to 0.91) was observed from April to June for monthly CWSI and increased by progressing drought stress from cutting off irrigation at flowering to milk development (Table 3). When plant exposed to cutting off irrigation at flowering, ET-83-3 and Sanabad cultivars with 0.67 and 0.63 had the highest mean seasonal CWSI, respectively, while in ET-84-5 reached to 0.50 and CWSI variation of these cultivars was less than ET-83-3 and Sanabad (Table 3). Garrot *et al.*, (1994) reported that in durum wheat (CV. Aldura) mean CWSI varied from 0.11 under well watered to 0.82 under severe drought sress. Gontia and Tiwari (2008) reported that the maximum CWSI of 0.52, 0.58, 0.68 and 0.89 were found under irrigation according to 100, 60, 40 and 20% of field capacity, respectively.

Yield and yield components of triticale cultivars: In all of the irrigation regimes, ET-84-5 triticale cultivars had the highest grain number per spike compared to the other cultivars (Table 4). Also, by improving the drought stress from cutting off irrigation from dough development to flowering, grain number per spike in Et-84-5 from 39.8 g decreased to 33.1 g in Sanabad triticale cultivar, sharply. As was shown in Table 4, spike number per square meter affected by cutting off irrigation so that, the lowest spike number per square meter was observed in cutting off irrigation at flowering and milk development, especially in ET-83-3 and Sanabad. At cutting of irrigation at flowering, Et-84-5 with 36.1 g 1000-grain weight had the highest 1000-grain weight and decreased 8.1% compared to well watered condition (Table 4). In cutting off irrigation at flowering, the highest triticale grain yield was obtained in Et-84-5 (354.3 g) and it might be attributed to higher grain number per spike and spike number per square meter compared to Sanabad and ET-83-3 (Table 4). Royo *et al.*, reported that grain yield of triticale decreased 42% under drought stress condition compared to well water so that grain number per spike and spike number per unit area had the main role in grain yield decreasing under drought stress. Khazaie *et al.*, (2010) showed that in four triticale cultivars drought stress at flowering decreased grain number per spike and spike number per square meter due to decrease the assimilate amount from shoot to spike. Our findings are in agreement with Trethowen *et al.*, (2006) work who declared that drought stress from flowering to grain filling period with decreasing grain number per spike declined triticale grain yield and the lowest grain number per spike was observed in cutting off irrigation at flowering.

CWSI and grain yield relationship:

The highest grain yield (476 g/m^2) was obtained in ET-84-5 under well watered and CWSI in these cultivars ranged from 0.18 to 0.33 (Tables 3 and 4). In all cultivars, by lowering water applied (from flowering to milk development stages) and increasing CWSI, grain yield in these cultivars decreased sharply (Fig.3). Garrot *et al.*, (1994) found that the highest grain yield (606 g/m^2) was achieved at CWSI levels between 0.3 and 0.37. These results illustrated the value of using CWSI as an indicator of crop water status and many researchers suggested that CWSI could be used to

Table 4. Effect of cutting off irrigation regimes on yield and yield components of three triticale cultivars.

Irrigation regime	Triticale cultivars	Grain number per spike	Spike number per square meter	1000- grain weight (g)	Grain yield (g/m^2)
well watered	Sanabad	37.7^{c}	260.1^{b}	36.2^{bc}	355.1^{c}
	ET-83-3	38.1^{c}	258.2^{b}	35.1^{de}	344.6 ^{c}
	ET-84-5	40.1^{a}	302.2^{a}	39.3^{a}	476.2^{a}
cutting off irrigation at flowering	Sanabad	33.1^{g}	214.1^{c}	34.3^{e}	243.2^{e}
	ET-83-3	34.3^{fg}	196.2^{c}	35.2^{de}	237.8^{e}
	ET-84-5	35.5^{de}	276.3^{a}	36.1^{bc}	354.3^{c}
cutting off irrigation at milk development	Sanabad	36.1^{d}	217.6^{c}	36.8^{bc}	289.2^{d}
	ET-83-3	35.1^{ef}	214.2^{c}	37.1^{b}	279.1^{d}
	ET-84-5	38.9^{bc}	281.8^{a}	39.6^{a}	434.1^{b}
cutting off irrigation at dough development	Sanabad	37.7^{c}	261.1^{b}	36.3^{b}	357.2^{c}
	ET-83-3	36.1^{d}	265.5^{a}	35.9^{cd}	344.1^{c}
	ET-84-5	39.8^{ab}	289.6^{a}	39.3^{a}	453.6^{ab}

Means in each column by the same letters are not significantly different at 5% probability level using Duncan's multiple range test.

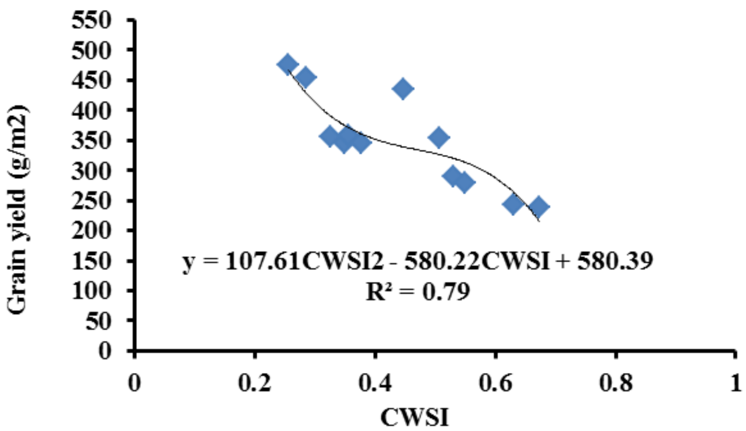

Figure 3. Relationships between CWSI and grain yield of triticale.

evaluate crop water status, and to improve irrigation scheduling and obtain optimum grain yield especially under water shortage conditions (Gardner *et al.*, 1992; Alderfarsi and Nielsen 2001; Emekli *et al.*, 2007; Bijanzadeh and Emam, 2012).

The grain yield was correlated with mean seasonal CWSI values (Figure 3b) by the following polynomial Equation (3):

$$Y= 107.61\,(CWSI)^2-580.22(CWSI)+580.39 \qquad (3)$$

where Y is grain yield (g/m^2). As was shown in Figure 3b, the seasonal mean CWSI was negatively correlated to grain yield, (R^2=0.79). This equation could be used for yield prediction under different CWSI value in triticale. Predicting the grain yield to crop water stress had a key role in developing strategies and decision-making by researchers and farmers for irrigation scheduling under water shortage conditions (Yuan *et al.*, 2004; Orta *et al.*, 2004; Bijanzadeh and Emam, 2012; Bijanzadeh *et al.*, 2013).

Conclusion

Application of canopy–air temperature difference was appropriate for crop water stress determination as it is non-destructive, non-contact, and reliable, and also provides considerably precise estimation and represents actual crop water demand. Crop canopy temperature reflects the interactions among plants, soil and atmosphere. The CWSI can be estimated using semiempirical approach with observations of T*c*-T*a* and VPD. A negative relationship was observed between CWSI and grain yield under different irrigation regimes. In all of the cutting off irrigation treatments, the decrease in the triticale grain yield might be attributed to decrease in the grain number per spike and spike number per square meter. The seasonal mean CWSI was related to triticale grain yield, negatively and a polynomial equation (Equation 3) can be used to predict the yield potential. Indeed, high CWSI values could lead to less grain yield due to more water limitation. ET-84-5, with lower T*c*-T*a*, water applied, and mean CWSI had better performances than ET-83-3 and Sanabad, especially when subjected to cutting of irrigation. Evaluation of CWSI in the field should be further investigated as potential indirect selection criteria for grain yield sustainability of triticale cultivars under late season drought stress.

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