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Quantifying water stress in canola (*Brassica napus* L.) using crop water stress index

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ABSTRACT- The relationship between canopy temperature and soil moisture is particularly important because of using canopy temperature as an indicator of crop water stress. A field experiment was conducted to calculate crop water stress index (CWSI) of two canola cultivars including RGS and Sarigol at College of Agriculture and Natural Resources of Darab, Shiraz University, Iran during 2013-2014 growing season. Irrigation regimes consisted of well watered [Irrigation equal to 100% field capacity (FC)], light drought (75% FC), moderate drought (50% FC), and severe drought (25% FC) stresses which were arranged in a randomized complete block design (RCBD) with three replications. In RGS and Sarigol, CWSI values showed an increasing trend from March (0.066 and 0.093 in well watered) to June (0.711 and 0.821 in severe drought) respectively, as a result of higher vapor pressure deficit (VPD) and increase in canopy-air temperature differences (Tc-Ta). In both cultivars, when the air temperature increased from March to June, Tc-Ta increased. The highest monthly average value of CWSI for all treatments was obtained in June. By increasing the drought stress, the color grading score decreased from 6 to 2 sharply in May and June**.** An acceptable color quality (6 -5) was sustained in May, under light drought condition. Also, a negative relationship was observed between CWSI with color quality (R^2=0.94**) and grain yield (R^2=0.97**). It could be concluded that in semi-arid areas, light drought is the best option for canola production while mean seasonal CWSI being ranged about 0.198 to 0.294 without any loss in visual color quality of canola.

Abbreviations: CWSI_crop water stress index; FC_field capacity; Tc-Ta_canopy-air temperature differences; VPD_ vapor pressure deficit.

INTRODUCTION

Canola is a useful break crop from a continuous run of cereal production. It is becoming popular in Iran, including in Fars province, due to its high oil and protein content, market demand (Naderi and Ghadiri, 2011) and purchase guaranteed scheme by government in the province (Miri and Rahimi, 2009). In the world, almost 60% of freshwater usage belongs to irrigation and water stress is one of the most important stresses limiting canola growth (Sneha et al., 2013; Heydari et al., 2015). An actively transpiring leaf with no water stress is able to loose energy and lower the temperature than surrounding air due to evaporative cooling. As water becomes limiting, transpiration is reduced and the leaf temperature increases. If little water is transpired, leaves will warm above air temperature because of absorbed radiation. Therefore, the canopy-air temperature differences (Tc-Ta) give an ideal representation of crop water stress levels (Jackson et al., 1981). Canopy temperature measured with infrared thermometer is often promoted as a basis for irrigation scheduling in different plants (Wanjura et al., 2000; Bockhold et al., 2003; Clarke et al., 2003).

Jalali-Farahani et al. (1993) found that the theoretical crop water stress index (CWSI) was the most promising approach for irrigation scheduling compared with the empirical CWSI of Idso et al., (1981) and with an empirical model that included net radiation as an independent variable. Because of the difficulty of using the theoretical CWSI, however, most researchers have preferred to use the empirical approach of Idso et al., (1981), which has been shown to work relatively well for a given location as long as locally calibrated baselines are available (Irmak et al., 2000; Sneha et al., 2013).

To establish the lower and upper baselines, however, most researchers have only included air vapor pressure deficit (VPD) and Tc-Ta and have assumed that other factors affecting Tc- Ta, such as wind speed and available energy, are constant if measurements are made close to noon and under clear-sky conditions. It is also argued that changes in canopy temperature (Tc), under stress and non-stress conditions, provide clues for crop water status and yield performance during drought seasons. The crop water stress index (CWSI) derived from Tc- Ta versus VPD was found to be a promising tool for quantifying crop water stress (Idso and Reginato, 1982; Jackson, 1982; Alderfasi and Nielsen, 2001). Al-Faraj et al. (2001) reported that the Tc-Ta increased with a decrease in soil water content in tall fescue (*Festuca arundinacea* Schreb.).

Canola producers in the southern Iran are particularly interested in studies concerning the conservation and management of water due to decreasing the precipitation and drought stress conditions in the field. Little information has been published about quantifying water stress index in canola using crop water stress index under different irrigation regimes. The main aim of this study was to develop a baseline equation, which could be applied to determine CWSI for monitoring water status and irrigation scheduling of canola under water shortage conditions.

MATERIALS AND METHODS

A field experiment was conducted to calculate crop water stress index (CWSI) of two canola cultivars including RGS and Sarigol at the Research Station of College of Agriculture and Natural Resources of Darab (28°29´ N, 54°55´ E), Shiraz University, Iran during 2013-2014 growing season. The soil was a loam (fine, loamy, carbonatic, hyperthermic, typic Torriorthents) with soil properties given in Table 1. The research area has semi-arid climate with hot and dry summers and cool and rainy winters. Ten-day average of some meteorological data shown in the study area during March to June 2014 are given in Table 2. Also, rainfall during March to June was negligible (about 1-3 mm).

Table 1. Soil physicochemical properties of the experimental site

Properties	
Soil texture	Loamy
Sand (%)	36.33
Silt (%)	40.27
Clay (%)	23.40
Soil pH	7.56

Irrigation regimes included well watered [Irrigation according to 100% field capacity (FC)], light drought stress (75% FC), moderate drought (50% FC), and severe drought (25% FC) stresses were arranged in a randomized completely block design with four replications. Likewise, there was an unirrigated plot to determine the upper baseline required for determination of CWSI. The size of each plot was 3 m×5 m and it was surrounded with a 20 cm high earth berm, with a 1 m wide buffer space between the plots. On November17th 2013, canola seeds were sown. Drought stress treatments started at flowering stage of canola to the end of growing season. The soil water content was monitored in each plot by using the gravimetric method at 30 cm intervals down to 120 cm. Time-volume technique was used. This technique is an irrigation technique in which irrigation water is applied by polyethylene pipes set in each plot and the time of each plot irrigation is calibrated by a timer and a standard container (Grimes et al., 1987). Then, irrigation water amount of each plot (measured by gravimetric method) was converted to time (min) and the data was applied in analysis.

Table 2. Ten-day means of climatic data measured daily at the experimental site in 2014

Month	Relative humidity (%)	Evaporation (mm)	Temperature (°C)	Wind speed (m s^{-1})
March				
1-10	27.2	9.8	36.2	2.1
11-20	26.1	10.1	36.9	2.2
21-31	25.1	11.3	37.1	2.4
April				
1-10	26.0	11.6	38.4	2.6
11-20	26.1	11.9	38.8	1.9
21-30	26.3	12.0	39.2	1.8
May				
1-10	23.4	12.7	40.1	1.9
11-20	23.3	12.0	38.2	2.3
21-31	24.1	11.2	36.8	2.2
June				
1-10	24.2	12.8	40.3	1.7
11-20	23.2	13.2	41.8	1.5
21-30	22.1	13.3	42.1	1.1

Infrared thermometer (LT Lutron, Model TM-958, Taiwan) was used to measure the canopy temperature (3, 6 and 9 days after each irrigation) from the 1st of March to the 30th of June 2014. To ensure the collection of accurate data, the infrared thermometer was held with a horizontal angle of 45° during measurements. Temperature measurement was 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. In each plot, the measurements were carried out from four directions (east, west, north and south).

Air temperature and relative humidity were recorded using thermo hygrograph (Lambrecht, Model 252, Germany) and psychrometer, simultaneously (Lambrecht, Model 1030, Germany) as the basis for calculating vapor pressure deficit (VPD) (Monteith and Unsworth, 1990). VPD was calculated 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 plotted under stressed and non-stressed conditions (Fig. 1). In this graph, the non-stressed baseline was determined from the data collected three days after irrigation in well watered treatment between 08:00 and 17:00 with 30-min intervals.

(a)

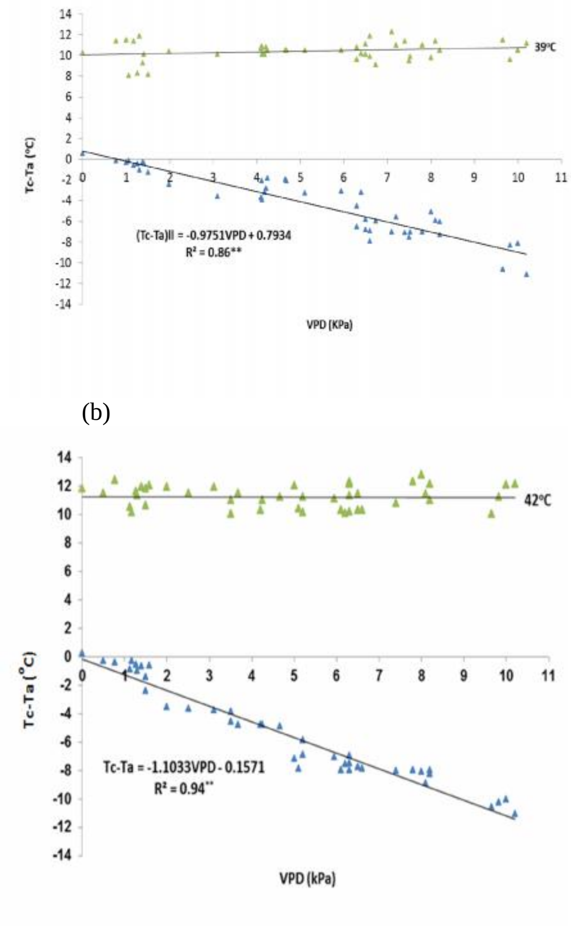

Fig. 1. The upper and lower baselines used to calculate CWSI , of canola cultivars including RGS (a) and Sarigol (b) under stressed and non-stressed conditions, respectively. VPD = vapor pressure deficit, Tc-Ta= canopy-air temperature differences.

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

$$Tc–Ta = aVPD + b$$

where T*c*–T*a* is the measured canopy and air temperature differences for non- stressed treatment (°C) 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 before each irrigation. Using the upper and lower limit estimates, a CWSI can be defined by the following Equation (2) (Idso et al., 1981):

$$(\mathrm{CWSI}) = \frac{(Tc - Ta)m - (Tc - Ta)ll}{(Tc - Ta)ul - (Tc - Ta)ll}$$

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 (°C), respectively. Water productivity (WP) was calculated by the following equation (3) (Doorenbos and Kassam, 1979).

$$\mathrm{WP} = \frac{\mathrm{Y}}{\mathrm{I} + \mathrm{P}}$$

where Y, I and P were canola grain yield (kg), irrigation water applied (m^3), and precipitation (m^3), respectively.

The canola color during the experiment was compared with the one given in the scale at 10-day intervals. After comparing color grades, the color and page numbers were found out. The page numbers, color names, and color numbers as appeared in the Munsell Color Scale as well as grading score in the experiment are given in Table 3. The observed grass colors were scored in such a way that dark green color corresponded to 9 and yellow color to 1. As the scores change from 9 to 1, the corresponding colors turn from dark green to yellow color representing that the plant is dead or it is at dormancy. Finally, the collected data were analyzed using SAS software (2003) and the means were compared using LSD test ($p \leq 0.05$).

Table 3. Page numbers of Munsell Color Chart, color numbers and visual quality values (Wilde and Voigt, 1977).

Page numbers of the chart	Color numbers (value/chroma)	Visual quality value	Color changing
5GY	3/4	9	Dark green
5GY	4/4	8	
5GY	4/6, 8	7	
5GY	5/4, 6, 8, 10	6	Green
5GY	6/4, 6, 8, 10	5	
5GY	7/4, 6, 8, 10	4	
2.5GY	7/4, 6, 8	3	
2.5GY	8/4, 6, 8	2	Light green
2.5Y and 5Y	All colors	1	Yellow

RESULTS AND DISCUSSION

Water Productivity

In RGS, water productivity was 0.45, 0.57, 0.65, and 0.77 kg m^{-3} for well watered (100% FC), light drought (75% FC), moderate drought (50% FC), and severe drought stress (25% FC) treatments, respectively. Sarigol cultivar, consumed more water compared to RGS, so that water productivity in well watered, light drought, moderate drought, and severe drought stress were 0.38, 0.43, 0.36, and 0.36, respectively. Heydari et al., (2015) declared that 995 mm of water would be enough under normal conditions in terms of meeting quality and color standards of canola in semi-arid condition. Baladi et al., (2015) also, reported that canola could be grown successfully when 1050-1110 mm irrigation water was applied in southern Iran and canola cultivars had different water productivity when exposed to drought stress.

Determination of Lower Base Line

The upper (stressed) and lower (non-stressed) baselines to calculate CWSI are presented in Fig. 1a and Fig. 1b, respectively. In RGS and Sarigol, the upper limit [(Tc-Ta) ul], was 9.9 and 11.78 °C when the air temperature at solar noon was 39 and 42 °C, respectively. Emekli et al., (2007) determined that the upper limit for bermudagrass (*Cynodon dactylon*), was 11.22 when the air temperature was 40°C at solar noon. The equation of lower limit was found to be (Tc-Ta) ll = -0.9751VPD + 0.7934 in RGS (Fig. 1a) and (Tc-Ta) ll = -1.1033VPD - 0.1571 in Sarigol (Fig. 1b). Orta et al. (2002) reported that in sunflower the lower baseline equation for (Tc-Ta) ll was –0.25VPD – 2.9. In a study on corn (*Zea mays* L.) in southern Iran, Edalat et al. (2009) declared that (Tc-Ta) ll was equal to -0.926 VPD + 1.272.

CWSI Changes

In RGS, CWSI values showed an increasing trend from March (0.066 in well water) to June (0.711 in severe drought) as a result of higher VPD values and negatively increase in Tc-Ta differential (Table 4). Similar trend was observed in Sarigol in June, so that CWSI decreased from 0.381 in well watered to 0.821 in moderate drought stress, significantly different at $p \leq 0.05$. In both of the canola cultivars, when air warmed from March to June, Tc-Ta differential increased and the highest monthly average value of CWSI for all treatments was obtained in June (Table 4). As VPD increased, the transpiration also increased and when soil water content was not a limiting factor, plant transpires without restriction, resulting in a smaller Tc-Ta differential (Emekli et al., 2007). Overall, a decrease in VPD values in June caused an increase in CWSI and the weather conditions could be the reason for lower values of CWSI in March (Tables 2 and 4).

In RGS and Sarigol, the highest mean seasonal CWSI for severe drought treatments were 0.531 and 0.650, respectively (Table 4). In both of the cultivars, significant differences were observed between mean CWSI values of well watered and drought stress treatments. It is appeared that the CWSI values can potentially be employed as a good indicator of crop water stress index in canola. Similar results have been reported in previous studies (e.g. Irmak et al., 2000). Likewise, Jalali-Farahani et al., (1993) also found that the seasonal average of CWSI values for bermudagrass, using empirical method, were 0.02, 0.16, and 0.5 in treatments including daily irrigation as well watered, light drought, and moderate drought, respectively. Sneha et al., (2013) declared that in mahogany (*Swietenia macrophylla* King) CWSI responded to irrigation events along the whole season and clearly detected mild water stress, suggesting extreme sensitivity to variations in plant water status. They revealed the potential of CWSI for early, non-destructive and less time-consuming estimation of drought stress. Orta et al., (2002) reported a mean CWSI of 0.59 before irrigation times produced maximum yield in sunflower (*Helianthus annuus* L.).

Canola Grain Yield

In all of the irrigation regimes, RGS had higher grain yield and mean seasonal CWSI ranged from 0.128 to 0.531 so that, in light drought stress condition, RGS had a higher grain yield (501.2 g m^{-2}) compared to Sarigol (413.5 g m^{-2}) (Table 4). Interestingly, in all of the irrigation regimes by applying lower water (from flowering to the end of growing season) and increasing mean CWSI, grain yield in Sarigol cultivar decreased sharper than RGS (Table 4). This might mean that Sarigol was a more drought sensitive cultivar. Garrot & Mancino (1994) found that in wheat the highest grain yield (606 g m^{-2}) was achieved at CWSI levels between 0.3 and 0.37. These results illustrate the value of using CWSI as an indicator of crop water status and many researchers suggested that CWSI could be used to reach acceptable grain yield especially under water shortage conditions (Gardner et al., 1992; Alderfasi and Nielsen 2001; Emekli et al., 2007).

Color Quality of Canola

In both cultivars in May, by increasing the drought stress from well water to severe drought, the color grading score decreased from 6 to 2 sharply, and stayed constant at 2 in June under severe drought treatment (Table 5). Overall, in Sarigol the mean seasonal visual quality values were more affected negatively by increasing the drought stress compared to RGS. It might be due to higher air temperature and Tc-Ta differential in Sarigol compared to RGS (Table 2 and Fig. 1). Bonos and Murphy (1999) also found that drought stress caused by hot summer days would affect visual quality of Kentucky bluegrass (*Poa pratensis* L.) negatively.

In RGS and Sarigol, the color grading number in un-irrigated plot was sharply decreased (from 8 to 1) because the leaves were completely perished in this treatment by the end of April (Table 5). Bastug and Buyuktas (2003) reported that the best color quality for turfgrass (*Cynodon dactylon*) under the Mediterranean conditions could be attained when water was applied as much as 75% of Class A pan. In a similar study, Karcher and Richardson (2003) found that the color quality grading numbers ranged from 9 to 1 with an acceptable minimum visual quality number of 6. In the current study, an acceptable color quality (6 -5) was sustained in May, under well watered and light drought stress conditions, however, the mean color quality obtained in moderate and severe drought treatments was not desirable (4.25 to 2.5) for canola.

Relationship Between CWSI With Water Applied, Color Quality and Grain Yield

Linear regression showed that with decreasing water supply under stress from 969 mm to 295 mm, CWSI was increased and water supply in canola correlated with CWSI negatively (R^2=0.83** ; Fig. 2). Stokcle and Dugas (1992) reported that as plants closed their stomata due to water shortage, and hence stomatal conductivity, heat flux, transpiration and the cooling effects of evaporation were decreased, the canopy temperature and CWSI were increased, compared to well watered conditions. In the current study, canola consumed more water and had more CWSI when exposed to moderate drought and severe drought stress conditions, especially under hot weather in the study area. A negative relationship was observed between CWSI and color quality (R^2=0.94**; Fig. 3). This relation could be used as a suitable tool by canola producers to maintain required seasonal color quality based on the crop water stress index under semi-arid condition [Bonos and Murphy, (1999); Al-Faraj et al., (2001); Emekli et al., (2007)]. Similarly, grain yield was correlated with mean seasonal CWSI values, nagatively (R^2=0.97**) (Fig. 4) by the following polynomial Equation (3):

Grain yield (g m^{-2})= -573.68 $(CWSI)^2$-373.25 (CWSI)+594.03

This equation could be used for yield prediction under different CWSI value in canola. 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).

Table 4. Monthly and mean seasonal CWSI and grain yield of canola under different irrigation regimes in RGS and Sarigol cultivars.

Irrigation regimes	Mean CWSI								Mean Seasonal CWSI		Grain yield (g m^{-2})	
	March		April		May		June					
	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol
Well watered	0.066	0.093	0.118	0.217	0.133	0.166	0.196	0.381	0.128	0.214	535.4	491.3
Light drought	0.011	0.130	0.289	0.343	0.208	0.297	0.283	0.407	0.198	0.294	501.2	413.5
Moderate drought	0.291	0.309	0.473	0.503	0.303	0.378	0.621	0.792	0.422	0.496	386.2	230.2
Severe drought	0.322	0.476	0.677	0.731	0.412	0.573	0.711	0.821	0.531	0.650	227.1	117.4
LSD (0.05)	0.03	0.04	0.17	0.11	0.19	0.12	0.15	0.09	0.15	0.17	101.6	71.1

Table 5. Visual color quality values of canola during the experiment under different irrigation regimes in RGS and Sarigol cultivars.

Irrigation regimes	Visual quality values											
	At flowering (before stress)		March		April		May		June		Mean Seasonal	
	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol	RGS	Sarigol
Well watered	8	8	7	7	6	6	6	6	5	5	6.00	6.00
Mild drought	8	8	7	6	6	5	6	5	4	4	5.75	5.00
Severe drought	8	8	5	5	5	4	4	3	3	2	4.25	3.50
Most severe drought	8	8	3	3	3	3	2	2	2	2	2.50	2.50
Unirrigated	8	8	2	2	1	1	1	1	1	1	1.25	1.25

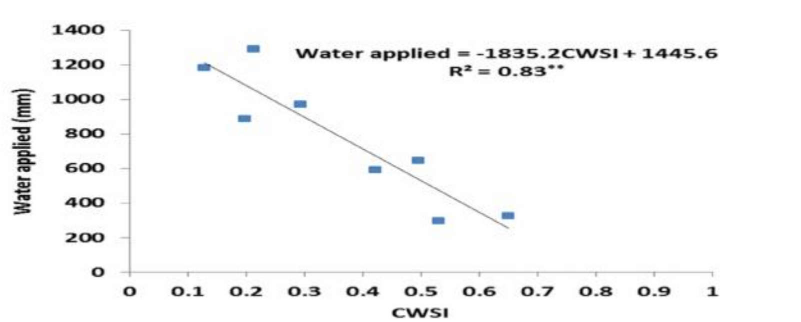

Fig. 2. Relationship between water applied and CWSI of canola during 2013-2014 growing season

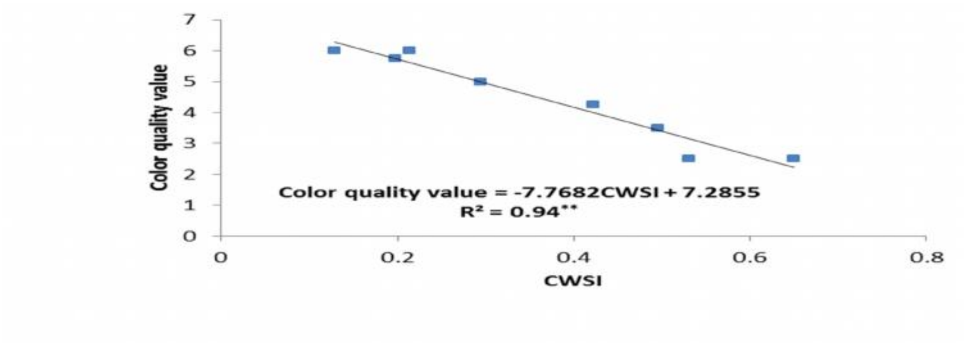

Fig. 3. Relationship between visual color quality values and CWSI of canola during 2013-2014 growing season

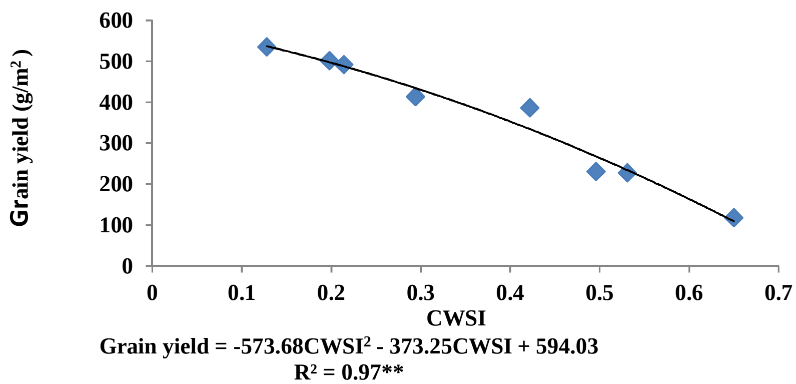

Fig. 4. Relationship between canola grain yield and CWSI during 2013-2014 growing season

CONCLUSIONS

In the current study, canola Sarigol cultivar consumed more water and had more CWSI when exposed to moderate drought and severe drought stress conditions, especially under hot months such as May and June in the study area. A negative relationship was observed between CWSI with color quality and grain yield. It concluded that light drought is the best option for canola production especially in RGS while mean seasonal CWSI being ranged about 0.198 to 0.294 without any loss in visual color quality of canola under semi-arid areas, however, no acceptable quality was observed in severer drought and most moderate drought stress treatments. It revealed the potential of CWSI for early, non-destructive and less time-consuming estimation of drought stress in canola.

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کمی سازی تنش خشکی در کلزا (*Brassica napus* L.) با استفاده از شاخص تنش خشکی گیاه زراعی

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دمای سایه انداز
کیفیت رنگ
تنش خشکی
برنامه آبیاری

چکیده- رابطه بین دمای سایه انداز و رطوبت خاک از زمانی که پتانسیل استفاده از دمای سایه‌انداز به عنوان یک شاخصی از تنش خشکی شناسایی شد بسیار مهم شده است. یک آزمایش مزرعه‌ای در سال زراعی ۱۳۹۲-۱۳۹۳ در دانشگاه شیراز، ایران برای محاسبه شاخص تنش خشکی گیاه زراعی در دو رقم کلزای روغنی شامل آرجی‌اس و ساری‌گل اجرا شد. رژیم‌های آبیاری شامل آبیاری مطلوب (آبیاری برابر با ۱۰۰٪ ظرفیت مزرعه)، تنش خشکی ملایم (۷۵٪ ظرفیت مزرعه)، تنش خشکی شدید (۵۰٪ ظرفیت مزرعه) و تنش خشکی خیلی شدید (۲۵٪ ظرفیت مزرعه) بودند که در قالب یک طرح بلوک کامل تصادفی اجرا شد. در رقم آرجی‌اس، مقدار شاخص تنش خشکی گیاه زراعی از ماه فروردین (۰/۰۶۶ در آبیاری مطلوب) تا تیر ماه (۰/۷۱۱ در تنش خشکی شدید) روند افزایشی داشت که دلیل آن بالاتر بودن کمبود فشار بخار آب و افزایش تفاوت دمای سایه‌انداز و هوای اتمسفر بود. چنین روند مشابهی در رقم ساری‌گل نیز مشاهده شد. در هر دو رقم زمانیکه دمای هوا از فروردین تا تیر افزایش یافت تفاوت دمای سایه‌انداز با هوا افزایش یافت و بالاترین مقدار ماهیانه شاخص تنش خشکی گیاه زراعی برای همه تیمارها در تیر ماه بدست آمد. با افزایش تنش خشکی، میزان نمره درجه بندی رنگ که نشان دهنده کیفیت رنگ گیاه است به سرعت از ۶ به ۳ کاهش یافت و در عدد ۲ در ماه های خرداد و تیر ثابت باقی ماند. در تیمار تنش خشکی ملایم یک کیفیت رنگ قابل قبول (با نمره درجه بندی رنگ ۵ تا ۶) در خرداد ماه بدست آمد. همچنین یک رابطه منفی بین شاخص تنش خشکی گیاه زراعی با کیفیت رنگ گیاه (R^2=0.94**) و عملکرد کلزا (R^2= 0.97**) بدست آمد. می‌توان نتیجه گرفت در نواحی نیمه خشک، تنش خشکی ملایم می‌تواند بدون از دست دادن کیفیت رنگ در کلزا بهترین گزینه برای تولید کلزا باشد وقتی که میانگین فصلی شاخص تنش خشکی در کلزا در دامنه ای بین ۰/۱۹۸ تا ۰/۲۹۴ باشد.