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Effects of Different Irrigation Levels on Sugar Beet and Potential Use of Crop Water Stress Index in Irrigation Scheduling

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ABSTRACT

With the increasing world population, global warming, and climate change, water scarcity significantly limits water use in crop production. Therefore, timely and accurate determination of water stress is very important for the correct and effective management of existing water resources and minimizing harmful effects on crop production. Two years of experiments were conducted in the water-limited region in Türkiye to investigate the possible use of the Crop Water Stress Index (CWSI) as a remote sensing technology in sugar beet irrigation scheduling. Four different Irrigation levels (I_{50}: 50% deficit, I_{75}: 25% deficit, I_{100}: full irrigation, and I_{125}: 25% excess irrigation) were applied to sugar beet by drip irrigation system. The amount of applied irrigation water and crop evapotranspiration varied between 238-540 and 350-580 mm in 2021, and between 324-807 and 502-829 mm in 2022. In both years, the highest beed yields were obtained from I_{100} treatments (83 and 130 t ha^{-1}) and the lowest from I_{50} treatments (66.7 and 67.4 t ha^{-1}). Water Productivity (WP) and Irrigation Water Productivity (IWP) in both years decreased significantly by excessive irrigation. CWSI values ranged between 0.16-0.98 in 2021 and between 0.02-0.71 in 2022. CWSI was significantly related to yield and Leaf Area Index (LAI). According to the results, CWSI could be used successfully in sugar beet irrigation scheduling and yield estimation.

Keywords: Deficit irrigation, Irrigation water productivity, Leaf area index, CWSI.

INTRODUCTION

Agriculture should be developed to meet the food demands of growing populations. Currently, ongoing global warming and climate change have made it the biggest challenge of the 21st century. Rising air temperatures, decreasing precipitations or irregular distribution of precipitations and deficit water resources pose serious threats on agricultural production. Such a case shows that agricultural sector will be most affected by climate change (Stricevic *et al*., 2020; Lipovac *et al*., 2022). In this sense, various innovations, especially irrigation strategies and techniques, fertilization, and field management practices have been developed to mitigate the negative impacts of climate change on agriculture. These technological developments not only increase productivity in agriculture, but also protect soil and water resources. To improve crop productivity and use of natural resources, principles of precision agriculture should also be closely and widely followed (Cosic *et al*., 2018; Comas *et al*., 2019; Guerrero *et al*., 2021; Zhang *et al*., 2021).

Plants are exposed to greater water stress levels because of climate change-induced irregular precipitation patterns (Lobell *et al*., 2011). Water scarcity causes physiological, biochemical and morphological changes in plants that ultimately reduce photosynthesis rates. Therefore, water scarcity is an important abiotic stress that limits plant

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growth and yield (Lesk *et al*., 2016). Timely and accurate detection of water stress is a vital issue for minimizing the harmful effects on crop production and for better water management (Wang *et al*., 2022).

Remote sensing technologies provide spatial and temporal monitoring of water stress-induced structural, biochemical, and physiological changes in plants (Atzberg, 2013). Therefore, it would be more advantageous to make irrigation scheduling based on monitoring of plant water status, because the plant reflects both soil water content and air evaporative demand (Yazar *et al*., 1999). For this reason, some techniques have been developed to determine the water stress in plants. Of these techniques, Crop Water Stress Index (CWSI) is calculated with the use of vapor pressure deficit and the difference between plant surface and air temperature. Studies conducted in the last 20-25 years show that CWSI can be used successfully in irrigation scheduling (Kanemasu *et al*., 1983; William *et al*., 1989; Sezen *et al*., 2014).

Infrared thermometer technique is commonly used in irrigation scheduling. The technique relates atmospheric vapor pressure deficit and temperature difference between plant cover and air temperature to crop water stress. When there is sufficient moisture in the root zone, plants potentially begin to sweat. In this way, the leaf temperature will be lower than the air temperature, as transpiration will have a cooling effect. However, when soil moisture falls below a certain level, transpiration will decrease, in which case the leaf temperature will increase and rise above the air temperature (Idso *et al*., 1981).

Water scarcity improves sugar beet water productivity but decreases root and sugar yields. Digestion and extractable sugar contents are very important for sugar beet processing and sugar cost. Extractable sugar content is negatively affected by root amino acid, sodium, and potassium contents. Generally, some researchers have reported that water scarcity did not exacerbate these ingredients (Masri *et al*. 2015; Kiymaz and Ertek, 2015; Unlukara, 2019).

Previous studies revealed that deficit irrigations could offer water savings and improve water use efficiency. Root development is the most important factor in sugar beet production and such a development is directly affected by irrigation (Yetik and Candogan, 2022). When sugar beet is exposed to drought stress, it can develop an extensive root system to use water from the deep soil layer (Fabeiro *et al*., 2003). Therefore, response of sugar beet to water deficits should be investigated for crop production under limited water resources.

There are many studies on the effects of water stress on sugar beet yield and quality. However, in recent years, it is extremely important to determine the stress level caused by water stress with CWSI, which is one of the remote sensing techniques. However, there are few studies on the change of CWSI with water stress in sugar beet. Köksal *et al*. (2011) used CWSI for sugar beet irrigated by border method and also Yetik and Candoğan (2022) investigated CWSI under water stress conditions. In Turkey, the farmers generally tend to use excess water in sugar beet cultivation. This behavior causes inefficiency in limited water resources and causes drainage problems.

Therefore, this study aimed to investigate the effects of excess and deficit irrigation applications on the yield and quality of drip-irrigated sugar beet and to investigate potential use of CWSI in irrigation scheduling.

MATERIALS AND METHODS

Experiments were conducted over the experimental fields of Kayseri Sugar Factory (38° 44' N, 35° 25' E, altitude 1050 m) for two years: 2021 and 2022. Terrestrial climate (hot and dry summers, cold and snowy winters) is dominant in Kayseri Province. According to long-terms records, annual average

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temperature is 10.7°C, average temperature of January, the coldest month, is -1.7°C and the Temperature difference (T_{max}-T_{min}) is 28.9°C. The hottest month is July with an average temperature of 30.6°C and the temperature difference in July is 18.7°C. Meteorological data for 2021 and 2022 are given in Table 1. Total precipitations were 115.1 and 223.8 mm, respectively.

Experimental soils had a loamy fine sand texture (0-100 cm soil profile with 85% sand, 8% clay and 7% silt). Soil bulk density was 1.42 g cm^{-3}, field capacity as 32% and permanent wilting point as 15.8% (0-60 cm soil profile). Soil infiltration rate was measured as 23 mm h^{-1} by infiltrometer.

Experiments were conducted in completely randomized blocks design with three replications. Sowing was performed at 45 cm row spacing and 20 cm on-row plant spacing. Each plot had 8 rows (each plot size was 3.6×5 m). Side rows and two plants from the top and bottom of the plots were omitted as to consider side effects and observations, and harvests were made on middle four plant rows (10 m^2). Experimental fields were deep-plowed in autumn. Considering the results of soil analysis in spring; fertilizers were applied as 150 kg ha^{-1} N, 150 kg ha^{-1} P_2O_5 and 100 kg ha^{-1} K_2O. Just before sowing, half of the nitrogen and all the phosphorus were applied while the other half of nitrogen was applied at the first hoeing. Dressing fertilizers were applied only in the second year of the experiment (120 kg ha^{-1} of urea). Salamo sugar beet cultivar was used as the plant material of the study. In 2021, sowing was performed on April 23. Since the emergence was not sufficient, re-sowing was practiced on May 10 (Due to the frost event that occurred between the 10th and 14th days of May, the emergence of the seeds was adversely affected.). Emergence was not sufficient again, then, sowing was done again on June 8 and after this date, no problems were experienced in emergence. In 2022, sowing was performed on April 25. Harvest was done on October 28 in the first year and on October 27 in the second year. For Cercospora disease, 300 mL ha^{-1} of Azoxystrobin+Flutriafol mixtures were applied in both years. Manual weed control was practiced twice.

Drip irrigation system was used for irrigation of sugar beet. The dripper spacing was 0.33 m, discharge rate was 4 L h^{-1}, lateral diameter was 20 mm, manifold pipe diameter was 40 mm and main pipe diameter was 63 mm. Lateral spacing was 90 cm (with a lateral between two plants row). Irrigation schedules were made based on the principle of re-supplying depleted available moisture within the root zone at different ratios. Irrigations for control treatment (I_{100}) were initiated when 40% (±5) of the Total Available Water (TAW) of effective root zone was depleted. The effective root depth was considered as 60 cm (Unlukara, 2019). Irrigation treatments included the followings:

1- I_{100} (control treatment, full irrigation)
2- I_{75} (supplying 75% of the full irrigation)
3- I_{50} (supplying 50% of the full irrigation)
4- I_{125} (125%)

Soil moisture was measured gravimetrically and irrigation water was calculated with the following equation:

$$d = \frac{(P_{FC} - P_{AM})}{100} \times D$$

Where, d: Irrigation water quantity to be applied (mm); P_{FC}: Field Capacity (%); P_{AM}: Available Moisture in the soil (%); D: Depth of soil to be wetted (mm). Calculated value (mm) is multiplied by the area to be irrigated (m^2) to get the amount of irrigation water to be applied (L). Irrigation water was applied to experimental plots through water meters. Wetted area percentage of drip irrigation system was determined as 67% according to Keller and Bliesner (1990).

Plant water consumptions were determined with the use of the water-budget equation supplied by James (1993):

$$ET = I + R + Cr - Dp - Rf \pm \Delta s$$

Where, ET= Plant water consumption (mm), I= Irrigation water quantity (mm), R= Effective precipitation (mm), Cr= Capillary rise (mm), Dp= Deep percolation (mm), Rf=

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Surface runoff (mm), Δs= Change in soil moisture of soil profile (mm).

Since sufficient water was applied to bring the depleted moisture to field capacity, deep percolation was assumed to be zero. Since buffer zones were provided between the plots and drip irrigation system was used, surface runoff was also assumed to be zero. Since ground water was not encountered up to 5-6 m depth of soil profile, capillary rise was not taken into consideration. After each irrigation, change in moisture within 60-90 cm soil profile was monitored to see if there was any deep percolation.

Water Productivity (WP) and Irrigation Water Productivity (IWP) values were calculated with the following equations (Howell *et al*., 1990):

$$WP = \frac{E_Y}{ET}\,;\ IWP = \frac{E_y}{I}$$

Where, WP= Water Productivity (kg m^{-3}); Ey= Root yield (kg ha^{-1}); ET= Plant water consumption (m^3 ha^{-1}), IWP= Irrigation Water Productivity (kg m^{-3}); I= Irrigation water (m^3 ha^{-1}).

A leaf area meter (LI-3100 C) was used to measure Leaf Area Index (LAI) values. The device was calibrated with the use of an object with a known area. Leaf area measurements were made on 5 plants randomly selected from each treatment in harvest. Plant total leaf area was divided by canopy projection to get leaf area index (Ma *et al*., 2022).

Sodium, potassium, amino nitrogen, sugar content and extractable sugar content in sugar beet were analyzed in the Kayseri Sugar Beet Factory laboratory using the Icumsa method GS6-5 (2007). The sugar beet root sample was washed and chopped, approximately 25 kg from each treatment. Sodium and potassium contents were determined using the FP-5 flame photometer (Betalyser Anton Paar). The amino-nitrogen contents of the samples were determined by double beam spectrophotometer (Testamin 5).

An Infrared Thermometer (IRT) device (Everest 100L model with 8-14 μm spectral band range and 4 degrees viewing angle) was used to determine the vegetation temperature. Black objects, whose surface temperature can be determined, were used in the calibration of the IRT device (Fucs and Tanner, 1966).

Canopy temperature measurements were made between the hours 13:00 and 14:00 when the weather was completely clear or the clouds did not block the sun. Measurements were taken at least 3 times a week. Canopy temperature measurements were made before and after irrigation, every day when the above-mentioned conditions were met. The average canopy temperature of a plot was found by taking the average of 12 measurements, 3 replicates in each plot in the direction of the diagonals of the plots. Plant canopy temperatures were measured with a portable Infrared Thermometer (IRT). To keep the soil surface out of the field of view, IRT was directed to the plant surface at an angle of 30-40^o from the horizontal plane. During the measurement of plant canopy temperatures, air temperature and relative humidity values were also recorded. Air vapor pressure deficit was calculated according to Ward and Elliot (1995).

Crop Water Stress Index (CWSI) was empirically determined as recommended in Idso *et al.* (1981):

$$CWSI = \frac{\left[\left(T_c - T_a\right) - LL\right]}{UL - LL}$$

Where, Tc is plant cover Temperature; Ta is air Temperature; LL is Lower Limit of non-water stress and UL is Upper Limit of water stress. LL was obtained from treatment I_{100} without water stress, while UL was obtained from I_{50} with water stress.

Analysis Of Variance (ANOVA) of the data was obtained using the SAS program. Analysis of variance was performed at 0.01 and 0.05 probability levels to determine the effects of irrigation practices on yield, quality, IWP and WP. Least Significance Test (LSD) at 0.05 significance level was used to identify statistically different groups. Regression analysis was performed to determine the relationships between CWSI versus ET, yield, and LAI.

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RESULTS AND DISCUSSION

Effects of Different Irrigation Levels on ET, Yield, and Quality Parameters

Effects of different irrigation water levels on yield, I, ET, WP, IWP and quality parameters of sugar beet are in Table 2.

To have sufficient emergence, 35 mm emergence irrigation was carried out in 2021 and 20 mm in 2022. In 2021, scheduled irrigations were started on July 2 and the last irrigation was carried out on October 13. In 2022, scheduled irrigations were started on 20 June and the last irrigation was made on 19 September. While 10 irrigations were carried out in 2021, 12 irrigations were carried out in 2022. In the first and second years of the experiment, water applied varied between 238-540 and 324-827 mm, respectively. ET values varied between 350-580 mm in 2021 and between 502-829 mm in 2022. Significant differences both in I and ET occurred between the two experimental years. These may be explained by the differences between plant growing periods, by the differences between plant growth, and by the differences between atmospheric evaporative demands. The second-year plant growing period was longer by 43 days than the first year. As seen in Table 2, root yield, which may be considered a plant growth parameter, generally was lower for all the treatments in the first than ones in the second year. Finally, mean reference evapotranspiration in the second year was 4.6 mm/day while it was 4.4 mm d^{-1} in the first year. In a previous study conducted under semi-arid climate conditions, it was reported that the irrigation water applied in sugar beet irrigation varied between 65-865 mm and ET values varied between 338.5-1009.9 mm (Köksal *et al*., 2011). Tarkalson *et al*. (2018) applied 686 mm water to sugar beet plants and reported ET value as 857 mm. Yetik and Candogan (2022) reported the water applied as between 160 - 765.7 mm and ET values as between 387.3-830 mm. Present findings comply with the findings of previous studies.

Different irrigation levels had significant effects on sugar beet yields of both growing seasons (P< 0.01) (Table 2). Water stress decreased root yield in I_{50}, which had the lowest yield in both years, but I_{75} had a

Table 1. Meteorological data for 2021 and 2022.[a]

Years	Months	T_{min} (°C)	T_{max} (°C)	T_{avr} (°C)	RH_{min} (%)	RH_{max} (%)	RH_{avr} (%)	U_2 (m/s)	Precipitation (mm)
2021	April	4.45	16.82	10.71	41.83	86.25	63.54	1.68	22.70
	May	7.40	23.59	15.93	33.5	87.09	56.44	1.63	21.30
	June	12.07	25.82	18.80	32.18	75.22	53.05	1.53	37.20
	July	14.65	31.85	23.76	25.43	70.98	44.46	1.82	0.00
	August	13.45	30.67	21.94	28.98	77.18	53.08	0.85	17.10
	September	10.35	24.29	16.90	36.07	82.69	59.27	1.26	16.70
	October	4.05	20.43	11.81	29.04	80.03	53.05	1.07	0.10
2022	April	6.45	20.78	13.61	28.25	68.40	48.32	2.59	15.20
	May	7.25	19.44	13.34	26.17	46.13	36.15	1.93	77.80
	June	13.71	27.29	20.50	36.90	82.34	59.62	1.99	54.50
	July	13.42	29.79	21.61	28.38	74.57	51.47	2.26	0.30
	August	16.90	33.95	25.42	22.85	62.29	42.57	1.84	0.00
	September	9.82	26.59	18.20	27.83	76.30	52.07	1.63	58.10
	October	4.86	19.85	12.36	37.44	95.31	66.37	0.99	17.90

[a] T_{avr}, T_{max} and T_{min}: Average, maximum and minimum Temperatures, respectively; RH_{avr}, RH_{max} and RH_{min}: Average, maximum and minimum Relative Humidity, respectively; U_2: Wind speed at 2 m height.

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Table 2. Effects of different irrigation water levels on yield, I, ET, WP, IWP, digestion, sodium, potassium, amino nitrogen, and sugar yield.

Year	Treatments	Irrigation (mm)	ET (mm)	Yield** (t ha^{-1})	WP** (kg m^{-3})	IWP** (kg m^{-3})	Digestion %	Sodium (Mmol 100 g^{-1})	Potassium (Mmol 100 g^{-1})	Amino nitrogen (Mmol 100 g^{-1})	Sugar Ratio (%)	Sugar** yield (t ha^{-1})
2021	I_{125}	540	580	83.0a	14.31d	15.38d	16.80	1.42	5.36	2.53	14.84	12.32a
	I_{100}	437	541	83.0a	15.35c	19.00c	17.05	1.64	5.24	2.92	14.63	12.14a
	I_{75}	323	414	76.9a	18.57b	23.80b	17.27	1.4	5.55	2.93	14.53	11.17a
	I_{50}	238	350	66.7b	19.05a	28.02a	17.62	1.33	5.53	3.35	15.19	10.13b
2022	I_{125}	807	829	120.9a	14.58	14.98c	16.17	0.88	4.34	2.26	14.4	17.41a
	I_{100}	648	785	130.0a	16.56	20.05a	16.00	0.85	4.21	2.74	14.13	18.37a
	I_{75}	486	639	92.3b	14.44	18.98b	15.90	0.63	3.91	2.65	14.12	13.03b
	I_{50}	324	502	67.4c	13.42	20.79a	15.54	1.01	4.45	3.66	13.4	9.52c

*: Significant at 5% and **: Significant at 1% level.

significantly lower result only in 2022. However, yield increase was not recorded in excessive irrigation treatments (I_{125}). Excess irrigation water, especially in the second year, caused 7% yield loss as compared to full irrigation (I_{100}). Yield values varied between 66.7-83.0 t ha^{-1} in the first year and between 67.4-130 t ha^{-1} in the second year. In both growing seasons, the highest yield was obtained from I_{100} treatment, and the lowest yield from I_{50}. Significant yield losses were encountered with increasing water deficits. As compared to full irrigation treatments, 7.4 and 19.6% yield reductions were seen in, respectively, I_{75} and I_{50} treatments in 2021 and 29 and 48.2% in 2022. Re-sowings and thus delayed sowing and emergence in the first year shortened. Negative effects of deficit irrigations on sugar beet yield were also reported in previous studies. Topak *et al.* (2011) reported that the highest sugar beet yield was obtained from full irrigation (77.3 t ha^{-1}) and the lowest from 75% water deficit treatments (28.1 t ha^{-1}). Yetik and Candogan (2022) reported significant decreases in sugar beet yields with increasing water deficits and obtained the highest yield from full irrigation treatments (86.3 t/ha). Unlukara (2019), Fabeiro *et al.* (2003), and Ortiz *et al.* (2010) reported the highest sugar beet yields as 104.8, 121.33, and 135.0 t ha^{-1}, respectively.

Significant differences were in WP and IWP values of different irrigation treatments (Table 2). While different irrigation treatments had significant effects on WP values in 2021 ($P< 0.01$), differences in WP values of irrigation treatments were not significant in 2022. On the other hand, significant differences were seen in IWP values of irrigation treatments in both seasons ($P< 0.01$). WP values varied between 14.31-19.05 kg m^{-3} in 2021 and between 13.42-16.56 kg m^{-3} in 2022. The lowest WP was obtained from the I_{125} in 2021 and 2022, while the highest from I_{50} in 2021 and I_{100} in 2022. IWP values varied between 15.38-28.02 kg m^{-3} in 2021 and between 14.98-20.79 kg m^{-3} in 2022. Generally, water deficiency tends to improve WP and IWP, as found in this study for I_{50} treatment. For example, Topak *et al.* (2011) reported WP and IWP for full irrigation treatment as 7.46 and 8.18 kg m^{-3} and for I_{50} treatment as 7.91 and 10.30 kg m^{-3}, respectively. Similarly, Kassem *et al.* (2022) reported that the WP value was highest in the treatment with water restriction. Both applied irrigation water and precipitation were lower in 2021 than in 2022. Therefore, WP and IWP were found higher in the first year. Consequently, WP and IWP were found higher in 2021. Differences between the first and second years were mainly attributed to late sowings of the first year. Fabeiro *et al.* (2003) conducted a study in Spain and reported WP values of sugar beet as between 13.3 - 17.5 kg m^{-3}. Topak *et al.* (2011) reported WP values between 7.46-8.32 kg m^{-3}. Unlukara (2019) reported WP value as 16.1 kg m^{-3} in 2014 and 24.1 kg/m^3 in 2015. Süheri *et al.* (2007) reported IWP values of sugar beet as between 5.9-14.2 kg m^{-3}. Several researchers reported the highest WP values for increased water deficits (Fabeiro *et al.*, 2003; Kiziloglu *et al.*, 2006; Topak *et al.*, 2016). Present findings comply with the results of previous studies. WP and IWP values are significantly affected by irrigation schedules, cultivars, and climate parameters.

Different irrigation treatments did not have any significant effects on quality of sugar beet plants (digestion, sodium, potassium, amino nitrogen, and sugar ratio). Digestion ratios were quite close to each other in both years (Table 2). Digestion ratios varied between 16.8 - 17.62% in the first year and between 15.54 - 16.17% in the second year. Previous studies also reported insignificant differences in digestion ratios of different irrigation water levels Hassanli *et al*. (2010) used furrow, subsurface drip, and surface drip irrigation systems in sugar beet irrigation and indicated that digestion rates were not affected by irrigation methods. Digestion ratio was reported as 17% for surface drip irrigation. Kiymaz and Ertek (2015) conducted a two-year study for sugar beet irrigation and reported digestion ratios between 13.63-13.94%. They also reported the values of

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amino nitrogen ranged from 2.61 to 4.44, K values ranged from 4.19 to 5.10, Na values changed between 1.21 and 2.32 mmol 100 g^{-1}. It was also indicated that digestion ratios were not influenced by irrigations. Topak *et al*. (2011) reported digestion rates as between 15-18.68% and indicated that recoverable sugar content was obtained under full irrigation conditions. In the same study, they stated that amino nitrogen varied between 2.11-4.31, K value between 4.33-4.87 and Na value between 0.88-1.09 mmol/100 g. Masri *et al*. (2015) determined that deficit irrigations did not make a significant difference in sugar ratio of sugar beet plants irrigated with sprinkler irrigation.

Different irrigation water levels had a significant effect on sugar yields (Table 2). Sugar yields varied between 10.13-12.32 t ha^{-1} in the first year and between 9.52-18.37 t ha^{-1} in the second year. Significant increases were observed in sugar yield with increasing irrigation water levels. However, there was no significant difference between I_{100} and I_{125} treatments. Mahmoodi *et al*. (2008) and Topak *et al*. (2016) indicated that the highest sugar yield was directly proportional to irrigation water applied.

Effects of Irrigation Water on Leaf Area Index (LAI)

LAI designates photosynthesis, thus plays a great role in yields. Dry matter production of a plant through photosynthesis is directly related to leaf area of the plant (Abu-Shahba *et al*., 2021). Leaf area also designates chlorophyll content, an indicator of regular water and nutrient uptake of the plants (Surendran *et al*. 2017). Effect of water deficits on LAI of sugar beet are presented in Figure 1.

The highest LAI values were obtained from I_{125} treatments in both growing seasons (11.83 and 12.32 cm^2 cm^{-2}, respectively). The lowest LAI values were obtained from I_{50} (3.5 and 7.8 cm^2 cm^{-2}, respectively). Water stress negatively affected LAI values. El-All *et al.* (2017) stated that LAI in sugar beet is adversely affected by water scarcity. Similarly, negative effects of water stress on LAI were reported for several plants (Yavuz *et al*., 2023; Kirnak *et al*., 2019; Aladenola and Madramotoo, 2012).

Crop Water Stress Index (CWSI) and Lower Limit Equations

In the first year, Tc measurements were started on August 24 and ended on October 8. In the second year, measurements were started on July 6 and ended on September 19. The Tc-Ta graph for different irrigation treatments is presented in Figure 2. Tc-Ta values increased with decreasing irrigation water quantities. In both growing seasons, the highest Tc values were obtained from I_{50}. Change in Tc-Ta values were similar in full

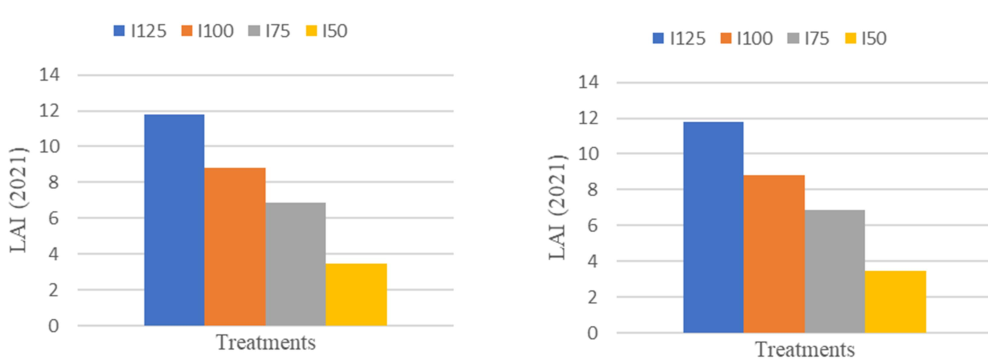

Figure 1. Change in LAI of sugar beet.

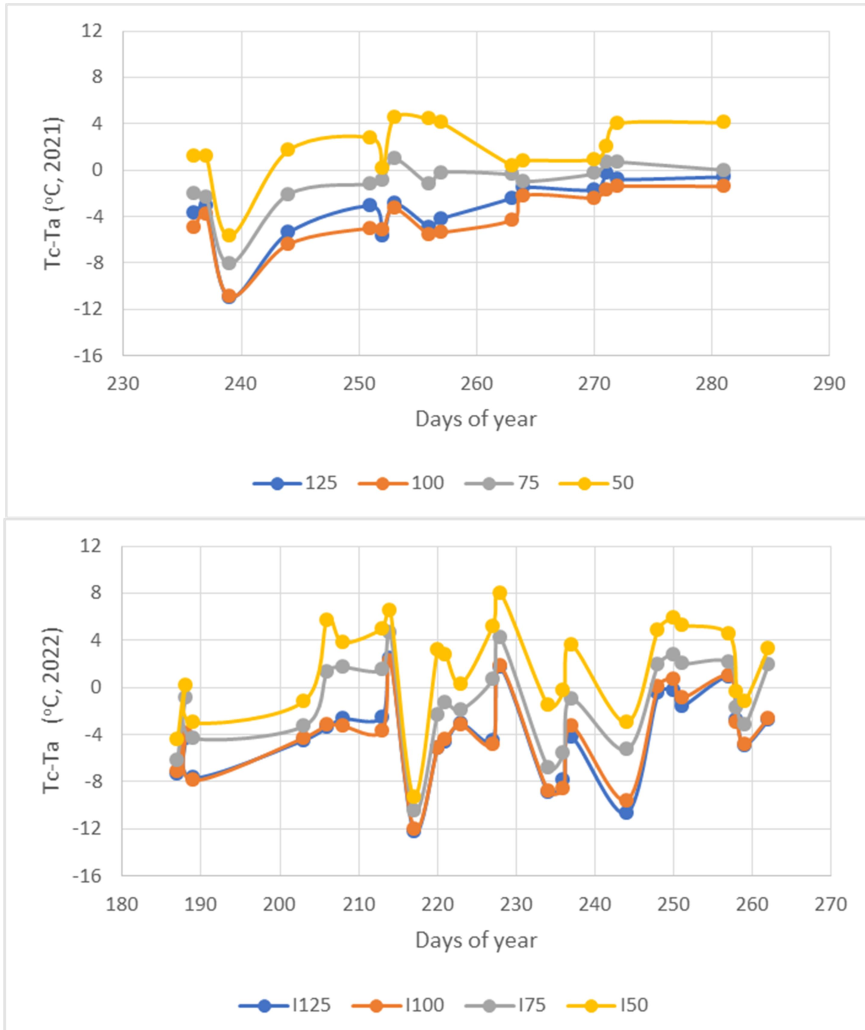

Figure 2. Tc-Ta values for 2021 and 2022 growing seasons in sugar beet.

Irrigation (I_{100}) and excessive Irrigation (I_{125}) treatments.

The lower and upper limits created by using Tc-Ta and VPD values is shown in Figure 3. The Lower Limit (LL) was obtained from I_{100} treatment without a water deficit, and Upper Limit (UL) was obtained from I_{50} treatment. The LL equation was found to be Tc-Ta= -1.468×VPD+1.4075 (R^2= 0.56) in 2021 and as Tc-Ta= -0.8663×VPD+0.2363 (R^2= 0.51) in 2022. UL values were 2.3 and 4.8°C, respectively, As the combination of two years, LL equation was found to be Tc-Ta= -1.0876×VPD+0.6625 (R^2= 0.56) and UL as 4.7°C. Bahmani *et al*. (2017) reported for sugar beet upper limit as 5.3°C and lower limit as Tc-Ta= 0.832×VPD+2.1811 (R^2= 0.65). Also, Yetik an Candogan (2023) reported the upper limits for sugar beet as 2.73 and 3.06°C, respectively, lower limits as Tc-Ta= -1.9861×VPD+0.4488 (R^2= 0.91) and Tc-Ta= -2.0395×VPD-0.8063 (R^2= 0.82). The differences between the studies can be explained with changes in climatic factors, crop cultivars, and applied irrigation scheduling.

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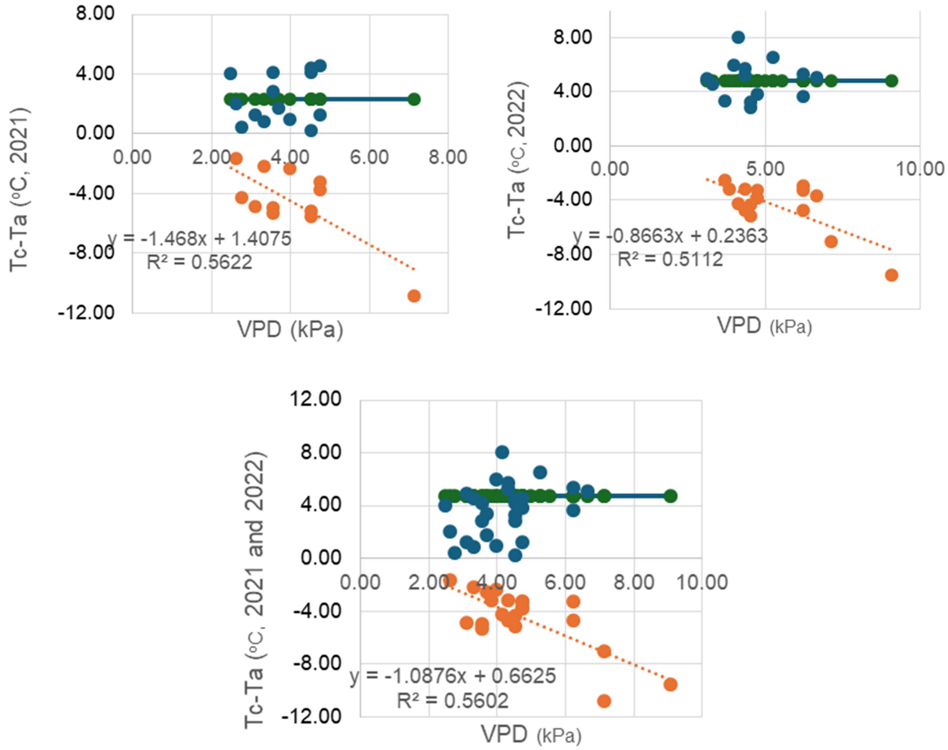

Figure 3. Lower and upper limits used in calculation of CWSI.

CWSI values increased with increasing water deficits. Plants close stomata when they cannot transpirate sufficiently, then, Tc values increase accordingly. The increase in Tc value caused an increase in Tc-Ta values, then, CWSI values increase accordingly. Therefore, Tc-Ta value reached negative values in plants that potentially transpirated and did not experience a water stress and CWSI values decreased in these plants. In 2021, seasonal CWSI values for I_{125}, I_{100}, I_{75} and I_{50} treatments were 0.16, 0.12, 0.50 and 0.98, respectively. In 2022, they were 0.02, 0.03, 0.34 and 0.71, respectively (Figure 4). While the CWSI value may fall below zero under excessive irrigation conditions, it may rise above 1 as drought increases (Köksal and Yildirim, 2011; King *et al*., 2020). Yetik and Candogan (2023) reported the range of seasonal CWSI value were -0.07-1.14 in 2019 and -0.04 -1.09 in 2021 growing season.

Relationship of CWSI with ET, Yield and LAI

The relationship between ET and CWSI resulting from the irrigation water applied to the sugar beet plant is shown in Figure 5. Decreased transpiration with decreasing irrigation water increases plant leaf temperature. The leaf cnopy temperature becomes warmer than the air temperature then CWSI value increases. In both growing seasons, there were significant linear relationships between CWSI and ET (Figure 5). Present findings are consistent with the results of previous studies (Köksal, 2006; Gencel, 2009).

The relationship between sugar beet yields of different irrigation treatments and CWSI is shown in Figure 6. There were significant relationships between sugar beet yield and

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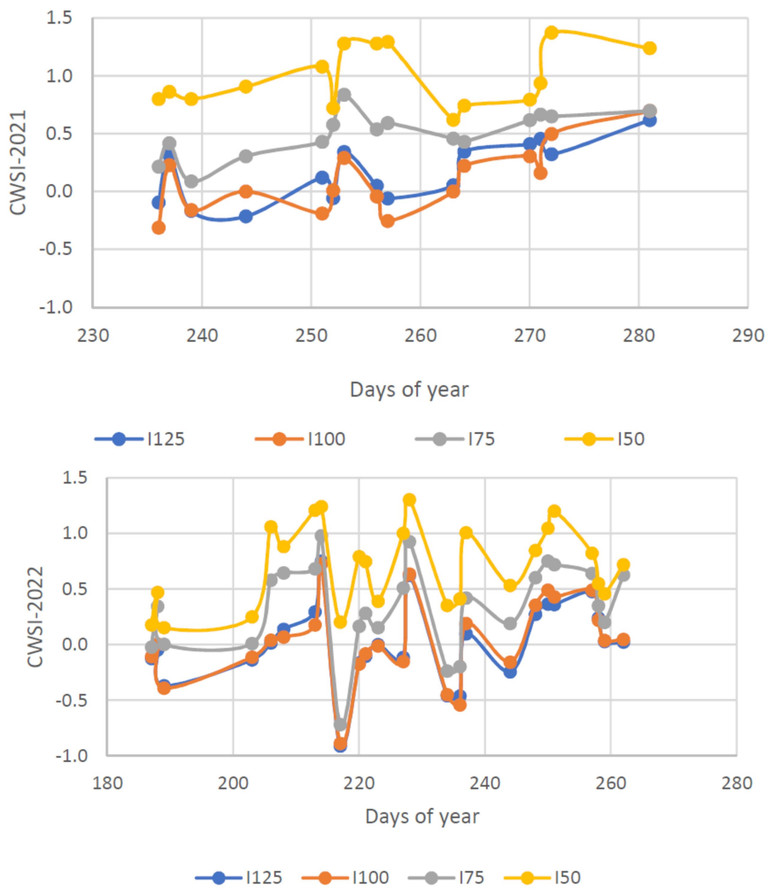

Figure 4. Change in CWSI of irrigatino treatments in sugar beet.

CWSI. The CWSI values decrease and the yields increase when sugar beet plants potentially transpire. On the other hand, as the water deficit increased, CWSI values increased and yields decreased significantly. The relationship between CWSI and yield was formulated as Y= -19317×CWSI+85902 ($P< 0.01$, $R^2= 0.99$) in 2021 and as Y= 85870×CWSI+126436 ($P< 0.01$, $R^2= 0.97$) in 2022.

Bahmani *et al*. (2017) reported a highly significant relationship between sugar beet yield and CWSI ($R^2= 0.99$) ($P< 0.01$). It was reported that CWSI values varied between 0.1-0.8 in full irrigation treatments and between 0.42-0.44 in 30% water deficit treatments. Kovar and Cerny (2016) indicated that CWSI values could be used to monitor the stress level in sugar beet. Köksal and Yildirim (2011) reported significant correlations between sugar beet yield and CWSI (r= 0.82 and r= 0.87). Yetik and Candogan (2023) reported a polynomial relationship between sugar beet yield and CWSI and indicated that CWSI values could be used in yield estimation. Significant relationships between CWSI and yield were also reported by Kirnak *et al.* (2019) for pumpkin seed, by Golgul *et al*. (2023) for mung bean, by Çolak *et al.* (2021) for quinoa, and Han *et al*. (2018) for maize.

The relationship between LAI and CWSI is shown in Figure 7. There were significant linear relationships between CWSI and LAI in both growing seasons ($P< 0.05$, $R^2= 0.84$ and $P< 0.01$, 0.92, respectively). LAI and

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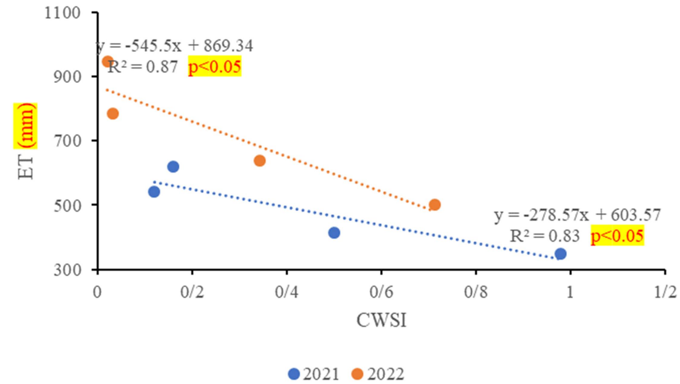

Figure 5. Relationships between seasonal CWSI and ET in sugar beet.

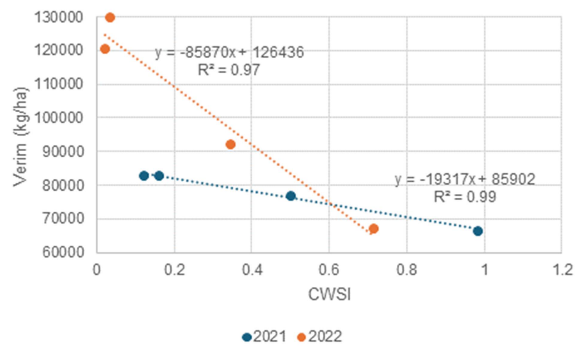

Figure 6. Relationship between CWSI and sugar beet yield.

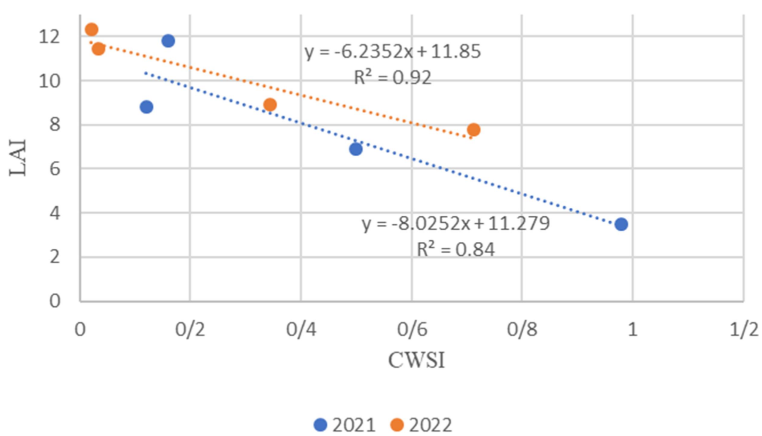

Figure 7. Relationship between LAI and CWSI in sugar beet.

yield values decreased with increasing canopy temperatures and decreasing transpiration rates. LAI increased with decreasing CWSI values. Sezen *et al*. (2014) reported a significant relationship between LAI and CWSI for red pepper (R^2= 0.81). Colak and Yazar (2017) reported a significant relationship between CWSI and LAI for grapevine. Kirnak *et al.* (2019) reported significant relationships between CWSI and LAI for pumpkin seeds and indicated that CWSI could be used for estimation of LAI.

CONCLUSIONS

Present findings revealed that irrigation was the most significant input to ensure reliable yields in sugar beet farming. Irrigation has a direct effect on root growth, which is the essential factor in sugar production. Therefore, appropriate irrigation scheduling is extremely important to achieve both higher root and sugar yield in sugar beet cultivation. Excessive irrigation caused water loss in both years of the experiment and sugar beet yield loss in only the second year. Furthermore, excessive irrigation considerably decreased water productivities.

Amount of irrigation water applied in different treatments varied between 238 and 540 mm in 2021and between 324 and 807 mm in 2022. ET values were between 350 and 619 mm in 2021 and between 502 and 946 mm in 2022. On the other hand, root yields varied between 66.7 and 83.0 t/ha in the first year and 67.4-130.0 t/ha in the second year. The highest yield was obtained from I_{100} treatments in both years.

According to the results of the study, it was concluded that CWSI values can be effective in determining water stress, yield, and irrigation scheduling in sugar beet. Lower limit equation to be used in CWSI calculation was identified as Tc-Ta= -1.468×VPD+1.4075 in 2021, and Tc-Ta= -0.8663×VPD+0.2363 in 2022. CWSI values varied between 0.16 and 0.98 in 2021 and between 0.02 and 0.71 in 2022. It is recommended to start irrigation when the CWSI value for sugar beet is 0.10. It can be suggested that in the regions with enough water resources, sugar beet water requirement should be completely supplied, while in water scares regions, a mild water stress could be recommended.

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اثرات سطوح مختلف آبیاری بر چغندرقند و استفاده بالقوه از شاخص تنش آبی محصول در برنامه ریزی آبیاری

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چکیده

با افزایش جمعیت جهان، گرم شدن کره زمین و تغییرات آب و هوایی، کمبود آب به طور قابل توجهی مصرف آب در تولید محصولات را محدود می کند. بنابراین تعیین به موقع و دقیق تنش آبی برای مدیریت صحیح و موثر منابع آبی موجود و کمینه کردن اثرهای مضر بر تولید محصول بسیار مهم است. دو سال آزمایش در منطقه‌ای با محدودیت آب در ترکیه برای بررسی امکان استفاده از شاخص تنش آبی محصول (CWSI) به عنوان یک فناوری سنجش از دور در برنامه‌ریزی آبیاری چغندرقند انجام شد. چهار سطح آبیاری مختلف (I_{125}، I_{100}، I_{75}، I_{50}) به روش آبیاری قطره‌ای برای چغندرقند اعمال شد. مقدار آب آبیاری مصرفی و تبخیر تعرق محصول بین ۵۴۰- ۲۳۸میلی متر و۵۸۰- ۳۵۰میلی متر در سال ۲۰۲۱ و بین ۸۰۷- ۳۲۴میلی متر و

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۸۲۹ -۵۰۲ میلی متر در سال ۲۰۲۲ بود. در هر دو سال بیشترین عملکرد دانه از تیمار I_{100} (۸۳ و ۱۳۰ تن در هکتار) و کمترین از تیمارهای I_{50} (۶۶.۷ و ۶۷.۴ تن در هکتار) بدست آمد. بهره وری آب (WP) و بهره وری آب آبیاری (IWP) در هر دو سال با آبیاری بیش از حد به طور قابل توجهی کاهش یافت. مقادیر CWSI بین ۰.۹۸ – ۰.۱۶ در سال ۲۰۲۱ و بین ۰.۷۱ – ۰.۰۲در سال ۲۰۲۲ متغیر بود. CWSI به طور قابل توجهی با عملکرد و شاخص سطح برگ (LAI) مرتبط بود. با توجه به نتایج، CWSI می تواند با موفقیت در برنامه ریزی آبیاری و تخمین عملکرد چغندرقند استفاده شود.