Research Article
Ziraat Mühendisliği (381), 66-80
DOI: 10.33724/zm.1699791

Determining the Crop Water Stress Index for Scheduling Sesame Irrigation with Subsurface Drip Systems under Mediterranean Conditions

Yüzeyaltı Damla Sulama Yöntemi ile Sulanan Susamın Akdeniz İklim Koşullarında Bitki Su Stres İndeksinin Belirlenmesi

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Gönderilme Tarihi : 15 Mayıs 2025
Kabul Tarihi : 16 Haziran 2025

Abstract

Investigating how plants respond to water stress is extremely important for effective irrigation management under changing climatic conditions and diminishing water resources. This study aimed to determine the crop water stress index (CWSI) values of sesame grown in semiarid climate conditions in Antalya province. In the study, the leaf crown temperature of the plant was determined by infrared thermometer (IRT) measurements. In addition, the relationships between yield, irrigation time, and CWSI were determined using these index values. In this study, four different irrigation rates (I100, I70, I40, and I0) were created with the subsurface drip irrigation method established at 40 cm lateral depths. Thus, full irrigation (I100), irrigation at two different stress levels (I70 and I40), and no irrigation (I0) were included. In the research, a total of 266 mm and 248 mm of irrigation water were given in the first and subsequent years, respectively, under I100 (control) irrigation. Plant water consumption values of control subjects were determined as 288 mm in the first year and 273 mm in the second year. In the mentioned irrigation, the yield per hectare was determined as 1840 kg in the first year and 1800 kg in the second year of the research. By combining the data from the first and second years of the study, the lower limit (LL) values for the case without water stress were calculated with the equation Tc-Ta= 4.67-2.43VPD (r^2=0.86, P<0.01).

The upper limit (UL) value at which the plant is completely under water stress is 5.9 °C. The threshold CWSI value at which sesame yield begins to decrease was calculated as 0.27 from infrared thermometer measurements taken at irrigation time. Additionally, a negative linear relationship was found between yield and CWSI values.

Keywords: Sesame, Canopy temperature, Crop Water Stress Index, Subsurface drip irrigation.

Özet

Değişen iklim koşulları ve azalan su kaynakları altında etkili sulama yönetimi için bitkilerin su stresine nasıl yanıt verdiklerinin araştırılması son derece önemlidir. Bu çalışmada, Antalya ilinde yarı kurak iklim koşullarında yetiştirilen susamın bitki su stres indeksi (CWSI) değerlerinin belirlenmesi amaçlanmıştır. Çalışmada, bitkinin yaprak taç sıcaklığı kızılötesi termometre (IRT) ölçümleri ile belirlenmiştir. Ayrıca bu indeks değerleri kullanılarak verim, sulama zamanı ve CWSI arasındaki ilişkiler belirlenmiştir. Bu çalışmada, 40 cm lateral derinliğinde kurulan yüzeyaltı damla sulama yöntemi ile dört farklı sulama oranı (I100, I70, I40 ve I0) oluşturulmuştur. Böylece tam sulama (I100), iki farklı stres seviyesinde sulama (I70 ve I40) ve hiç sulama yapılmaması (I0) uygulamasına yer verilmiştir. Araştırmada, I100 (kontrol) sulaması altında ilk ve sonraki yıllarda sırasıyla toplam 266 mm ve 248 mm sulama suyu verilmiştir. Kontrol deneklerinin bitki su tüketim değerleri birinci yıl 288 mm, ikinci yıl 273 mm olarak belirlenmiştir. Söz konusu sulamada hektar başına verim birinci yıl 1840 kg, ikinci yıl 1800 kg olarak belirlenmiştir. Çalışmanın birinci ve ikinci yılına ait veriler birleştirilerek su stresi olmayan durum için alt sınır (LL) değerleri Tc-Ta= 4.67-2.43VPD ($r2=0.86$, $P<0.01$) denklemi ile hesaplanmıştır. Bitkinin tamamen su stresi altında kaldığı üst sınır (UL) değeri 5.9 °C'dir. Susam veriminin azalmaya başladığı eşik CWSI değeri sulama zamanında alınan kızılötesi termometre ölçümlerinden 0.27 olarak hesaplanmıştır. Ayrıca verim ile CWSI değerleri arasında negatif doğrusal bir ilişki bulunmuştur.

Anahtar Kelimeler: Susam, Kanopi sıcaklığı, Bitki su stresi indeksi, Yüzeyaltı damla sulama.

Symbols and Abbreviations

Symbol	Meaning	Dimension
CWSI	Crop Water Stress Index	[-]
IRT	Infrared Thermometer	-
LL	Lower base line	-
UL	Upper base line	-
ETc	Plant Water Consumption	[mm]
I	Irrigation Water	[mm]
ΔS	Soil Water Within The Effective Root Zone	[mm]
DP	Deep Percolation	[mm]
RO	Surface Runoff	[mm]
SDI	Subsurface drip irrigation	-
VPD	Vapor pressure deficit	[kPa]
Ta	Air temperature	[°C]
Tc	Plant canopy temperature	[°C]
ea	Actual Vapor Pressure	[kPa]
es	Saturated Vapor Pressure	[kPa]
RH	Relative Humidity	[%]
r	Correlation Coefficient	-
Pc	Canopy percentage	[°C]
ETa	Actual evapotranspiration	[mm]
MAD	Maximum allowable depletion	[cm^3]

Introduction

Optimization of consumer and beneficial water use in agriculture is an important issue to maximize irrigation efficiency, especially considering the scarcity of water resources (Burt et al., 1997). Due to frequent droughts and increasing competition from other industries around the world, water supply for irrigation is expected to decrease (Alvino and Marino, 2017). Therefore, improved irrigation management is needed to optimize irrigation water use while maximizing crop yields (Cohen et al., 2017, Han et al., 2018). Although soil-based methods are more commonly used to assess crop water status, interest in plant-based methods is increasing (Jones and Vaughan, 2010), because they serve as a direct proxy of true crop water status, while soil water content measurements provide only an indirect link.

Canopy temperature (Tc) has been a useful tool for monitoring water stress (Alvino and Marino, 2017, Han et al., 2018, Bian et al., 2019). However, the sensitivity of Tc to changing weather conditions has led to the development of the crop water stress index (CWSI), which takes into account the effects of air temperature (Ta) and other meteorological variables such as vapor pressure deficit (VPD), wind speed (WS), and available energy. The Crop Water Stress Index (CWSI) has been proven to be effective in irrigation management (DeJonge et al., 2015, Alvino and Marino, 2017). The applicability of CWSI for water stress monitoring depends on the demonstration that it can accurately and reliably replace soil and plant-based water status indicators in agricultural fields and is suitable for stress detection in various crops in different climatic zones (Cohen et al., 2017). To accurately translate CWSI into water stress estimates, appropriate relationships between CWSI and other indicators are required, which can then be used in irrigation decision support (Möller et al., 2006). CWSI has been shown to correlate well with direct in situ plant and soil-based measurements such as soil water content (Padhi et al., 2012, DeJonge et al., 2015, Taghvaeian et al., 2014), leaf water potential, stomatal conductance, and transpiration (Gonzalez-Dugo et al., 2013, Cohen et al., 2017, Bian et al., 2019). CWSI was developed to provide a universal water stress monitoring method for agricultural crops in different climatic zones (Jackson et al., 1988) and has so far proven robust in many arid and semiarid regions around the world and for different agricultural crops (Meron et al., 2013, DeJonge et al., 2015, Liu et al., 2020).In the field experiment conducted by Wanjura et al. (1992), an infrared thermometer was connected to a drip irrigation system, and the system was managed according to the canopy temperature. The drip irrigation system operated when the canopy temperature fell to the determined threshold value. The threshold temperature degree was between 26 ^{0}C and 32 ^{0}C with 2 ^{0}C intervals. Irrigation periods varied from short to long. According to the study results, the highest yield was obtained from the trial subjects that started irrigation at the threshold values of 28 ^{0}C and 30 ^{0}C. In a study conducted by Ödemiş and Baştuğ (1999) in Antalya, it was determined that CWSI values could be used to determine the irrigation time and that the value of CWSI=0.45 could be taken as a criterion for this purpose. It was also determined that there was a linear relationship between the average CWSI and yield. It was stated in the study that cotton yield could be estimated using CWSI values with this relationship.

Jones (1999) conducted a study to develop an approach for the use of infrared thermometers in determining stomatal closure as an indicator of crop water stress in humid conditions. In this study, CWSI calculated with the approach of Idso et al. (1981) and the approach developed based on stomatal closure were compared. It was determined that both indices were compatible with each other. Gençoğlan (1996) prepared an irrigation program using CWSI values determined for corn by IRT and porometer observations in Çukurova conditions and found that the CWSI threshold value determined from pre-irrigation measurements was 0.19 and the threshold value determined from porometer observations was 0.26. They also reported that there would be no yield loss in irrigated corn under these conditions. The crop water stress index was developed based on the difference between canopy temperature and air temperature. Plants should be irrigated when they reach a certain water stress index value. The threshold value varies according to climatic conditions, plant species, and cultivation techniques (Çolak et al., 2012). Moroni et al. (2012) stated that measuring canopy temperature is the fastest and most accurate method for determining water stress. In general, the decrease in soil moisture before irrigation is effective in increasing plant crown temperature values, and CWSI values become higher as soil moisture decreases (Kırnak and Gençoğlan, 2001). Some researchers reported that CWSI values calculated using canopy temperature can be used in irrigation planning (Clawson and Blad, 1982). However, Nielsen and Gardner (1987) emphasized in their study that irrigation timing can be determined, but the amount of irrigation water cannot be determined.

Accurately measuring plant water status and knowing the plant's response to water stress are extremely important for managing irrigation systems and saving water (Yazar et al., 1999; Gu et al., 2021). Methods such as leaf water potential, photosynthesis rate, stomatal conductance, and stem water potential are widely used to determine plant water status. However, these methods can damage plants and take a long time to measure (Khorsandi et al., 2018; Gu et al., 2021). In addition, these methods cannot be applied to spatial and temporal monitoring of crop water stress in large areas (Ballester et al., 2013).

Remote sensing can be used in three categories: ground-based, air-based, and satellite-based. In this study, ground-based laboratory devices were used. However, other remote sensing platforms should be used by mounting thermal cameras on airplanes, drones, or satellites to monitor the water status of plants in large areas in a short time. Low-altitude aircraft/drones are good for obtaining high spatial resolution data. The most stable platform in the air is space-based satellites. However, for satellite data, an atmospheric correction factor may be required to estimate the correct surface temperature (Ramírez-Cuesta et al., 2017). This study aims to evaluate CWSI using infrared thermometry and to evaluate its potential for optimizing irrigation schedules in sesame cultivation in Antalya Province, a region with a Mediterranean climate.

Material and Methods

Study area

The research was carried out at the Western Mediterranean Agricultural Research Institute between 2019 and 2020. The study area is located at 30º 53' 04' E longitude, 36º 56' 29' N latitude, and 11 meters above sea level. The experimental area has a Mediterranean climate, with dry and hot summers and mild and rainy winters. Monthly average climate data for the 2019-2020 growing seasons as well as long-term averages are provided in Table 1. The chemical and physical properties of the soil in the experimental area, along with the quality parameters of the irrigation water, are presented in Tables 2 and 3. The soils in the research area are clayey loamy between 0-60 cm and loamy between 60-120 cm. Lime content varies between 23.7-25.6%. The electrical conductivity of the experimental area soils varies between 0.10-0.15 dS m^{-1} (salt-free), and their pH contents vary between 8.3-8.4 (medium alkaline). Field capacity values were calculated as 23.5, 23.4, 23.1 and 23.2 g g^{-1} for 0-30, 30-60, 60-90 and 90-120 cm, respectively, while wilting point values were calculated as 10.8, 11.1, 11.7 and 10.8 g g^{-1}. Bulk density values vary between 1.31-1.43 g cm^{-3} (Table 2). The irrigation quality class used in the research is in the T_2A_1 class (Table 3). As stated in the table of irrigation water used, it can be considered as good quality water that does not cause any limitations in terms of plant production (Akın and Cemek, 2021).

Table 1. Average Monthly Climate Data for the 2009–2018 Period and the 2019–2020 Sesame Growing Seasons (MGM, 2023)

Years	Months	Precipitation (mm)	Temperature (°C)	Wind Speed (%)	Relative Humidity (%)
2009-2018	May	53.0	20.9	3.0	69.9
	June	13.0	25.5	3.0	64.8
	July	3.0	28.5	3.0	63.5
	August	2.0	28.3	3.0	66.0
	September	22.0	24.9	2.8	67.0
2019	May	0.24	21.3	1.8	66.9
	June	0.41	25.7	1.7	64.6
	July	-	27.9	1.7	60.8
	August	0.2	28.3	1.5	65.5
	September	9.5	26.7	1.8	66.0
2020	May	1.7	28.9	2.0	68.6
	June	-	23.7	1.8	70.7
	July	-	28.6	1.7	70.4
	August	-	28.3	1.7	66.2
	September	12.0	25.8	1.9	69.0

Table 2. The physical and chemical properties of the soils

Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture Class	$CaCO_3$ (%)	pH	EC (dS m^{-1})	Bulk Density (g cm^{-3})	Field Capacity (g g^{-1})	Wilting Point (g g^{-1})
0-30	32	44	24	CL	25.6	8.3	0.10	1.31	23.5	10.8
30-60	28	48	24	CL	24.8	8.3	0.11	1.38	23.4	11.1
60-90	24	40	36	L	23.7	8.4	0.16	1.43	23.1	11.7
90-120	26	48	26	L	23.9	8.3	0.15	1.41	23.2	10.8

Table 3. Some chemical properties of the irrigation water used in the experiment

pH	EC (dS m^{-1})	Cations (me L^{-1})				Anions (me L^{-1})				Class
		K^+	Na^+	Mg^+	Ca^{++}	$CO_3^=$	HCO_3^-	$SO_4α$	Cl^-	
7.30	0.56	0.05	0.49	1.85	4.23	-	5.03	1.06	0.53	C_2S_1

The sesame variety Muganlı-57, widely cultivated in the Mediterranean region and officially registered by WMARI, was used in the experiment. Some characteristics of Muganlı 57 sesame variety: yield, 60-150 kg da^{-1}; oil content, 50-60%; protein content, 18-20%; resistance to fusarium: medium. Plots were established with dimensions of 7.7 x 6.8 m (52 m²) for planting and 4.7 x 3.5 m (16.45 m²) for harvesting. The experiment was conducted in a randomized block design with three replications (Figure 1).

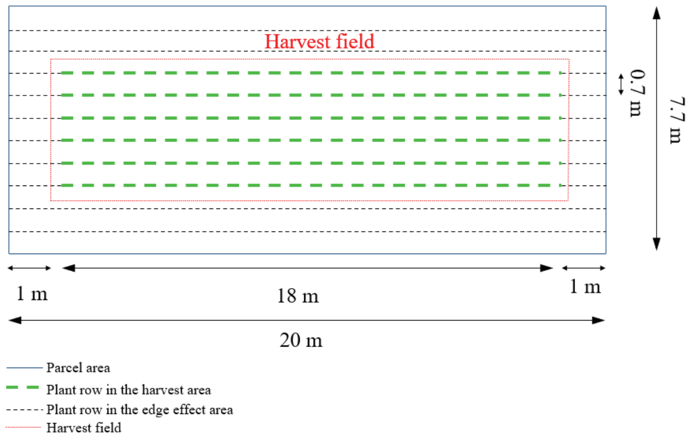

Figure 1. Harvest area and dimensions of a parcel

The subsurface drip irrigation treatments included 40 cm lateral depth and four irrigation levels (I100, I70, I40, and I0). Based on infiltration rate and emitter tests, the spacing between emitters was set at 30 cm, with one lateral line positioned per row. The emitters were calibrated to deliver 2 L hour^{-1} at a pressure of 0.1 MPa. In the control treatment (I_{100}), soil moisture content was monitored using both the gravimetric method and a neutron probe to determine optimal irrigation timing and amount. Under the full irrigation treatment (I_{100}), irrigation was applied when the top 0.90 m of soil had depleted 40% of its available water. The I00, I70, and I40 treatments received 100%, 70%, and 40% of the water applied to the control treatment, respectively (Figure 2).

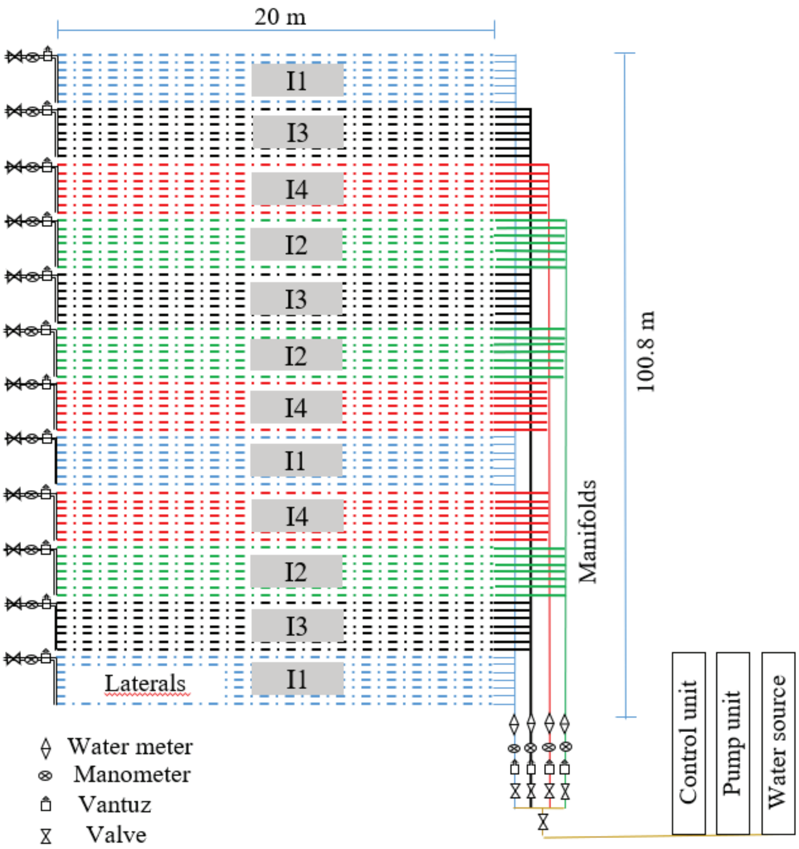

Figure 2. Installation of subsurface drip irrigation system

Plant evapotranspiration was calculated according to the soil water budget method (Equation 1) developed by Jensen et al. (1990), Allen et al. (1998), and Evett (2002).

$$ETc = I + P \pm \Delta S - DP - RO \quad (1)$$

In the equation, ETc represents crop water consumption (mm); I denotes applied irrigation water (mm); P refers to precipitation (mm); ΔS indicates the change in soil water within the effective root zone (mm); DP shows deep percolation (mm); and RO refers to surface runoff (mm). To determine deep infiltration loss, soil moisture in the 90-120 cm soil layer below the root zone was determined.

According to the results of the fertility analysis of the experimental area soils in the laboratory, a 10 kg da^{-1} N and 6 kg da^{-1} P_2O_5 fertilization program was applied to the experimental area. The seeds were planted in rows with a 70 cm row spacing and 10 cm row spacing with a seeder on May 19, 2020. Harvesting was done on different dates. The thirsty subjects were harvested first. As the amount of water application increased, the vegetation and harvesting time of the plant increased. The harvest dates of the I1, I2, I3 and I4 subjects are September 28, September 23, September 16 and September 13, respectively.

Crop Water Stress Index (CWSI)

A Testo 871 model thermal camera (IRT) was used to determine plant canopy temperature. This camera operates in the 8-14 μm spectral range and is equipped with a 32° x 23°/0.1 m lens, a detector with a resolution of 160x120 pixels, a geometric resolution of 3.3 mrad, and a thermal sensitivity of ≤0.08 °C. Calibration of the IRT was performed using black objects with known surface temperatures (Fuchs et al., 1996). Meteorological information was obtained from the meteorological station in the study area. Vapor pressure deficit calculation was made by taking the difference between the saturated vapor pressure at the measured air temperature and the actual vapor pressure at the dew point temperature.

Plant canopy temperature was measured between 11:00 a.m. and 2:00 p.m. before each irrigation, using three selected plants per plot. The thermal camera was positioned at four orientations (perpendicular and parallel to the plant rows) to capture both plant and soil temperatures. Plants in the I100 treatment served as wet references, while dried plants provided dry reference temperatures for canopy temperature calculations. Measurements were conducted separately for each replication of every irrigation treatment. The average canopy temperature was calculated by isolating plant pixels from soil pixels in the thermal images. In the measurements, the emissivity value of the instrument was set to 0.95, reflecting the plant surface (Jones et al., 2002). Dry and wet soil surfaces served as reference surfaces for calculating CWSI (Leinonen and Jones, 2004). The CWSI was calculated using the equation proposed by Idso et al. (1981) (Equation 2).

$$CWSI=[(T_c-T_a) – (LL)] / [(UL) – (LL)] \quad (2)$$

In the CWSI equation, Tc represents canopy temperature, Ta represents air temperature, LL denotes the lower limit of the fundamental graph relating Tc and vapor pressure deficit (VPD), and UL indicates the upper limit. Relative humidity and air temperature measurements were used to calculate VPD using the equations provided by Ward and Elliot (1995) and Allen et al. (1998) (Equations 3, 4, and 5).

$$VPD = e_s - e_a \quad (3)$$

$$e_s = \exp\frac{16.78T-116.9}{T+273.3} \quad (4)$$

$$e_a = e_s\frac{RH}{100} \quad (5)$$

In the equation, es represents the saturated vapor pressure (kPa), ea denotes the actual vapor pressure (kPa), T refers to air temperature (°C), and RH indicates relative humidity (%). The data obtained from the study were evaluated using variance analysis (ANOVA). Statistical analyses were performed using SPSS (version 21.0, SPSS Inc.) software. According to the results of variance analysis, statistically significant applications were compared using the LSD test. Correlation analysis was performed to determine the relationship between the features (Der and Everitt, 2002).

RESULTS AND DISCUSSION

Surface Temperature and Vapor Pressure

Canopy temperature exhibited significant variations throughout the plant growth season in both years. In the first year, vegetation temperatures were recorded over a total of seven days: July 3, 6, 14, 21, and 27, and August 6 and 13. In the second year, eight measurements were taken on June 10, 21, and 28, July 14, and August 12, 18, 27, and September 6. The results of the difference between canopy temperature and air temperature (Tc-Ta) for the years in which the research was conducted are presented in Figure 5. In the I0 treatment, the Tc-Ta values were predominantly positive, while in the full irrigation treatment (I100), these values tended to be negative or close to zero. Generally, these values represent the variations of both canopy and soil surface temperatures in comparison to the air temperature (Ta), and they are primarily positive. Moreover, the Tc-Ta values are consistent with the amounts of irrigation water applied in the irrigation treatments. In particular, the Tc-Ta values were lowest in the I100 treatment and highest in the I0 treatment. The difference of the Tc-Ta values was used to calculate the CWSI.

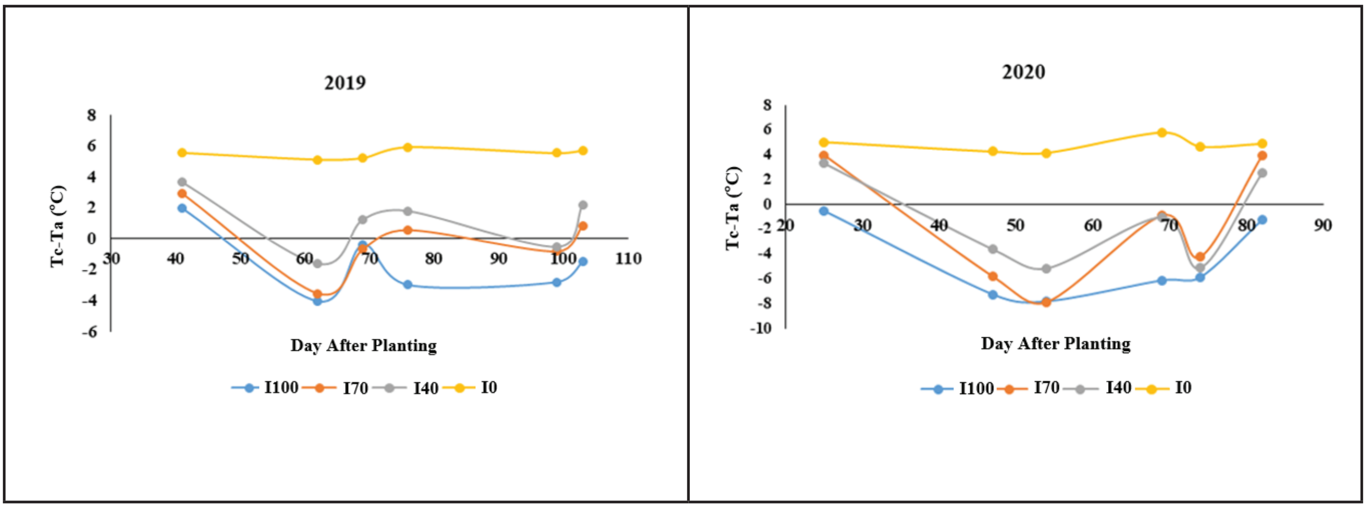

Figure 5. The changes in the canopy temperature (Tc) relative to the air temperature (Ta) during the growth period of sesame in 2019 and 2020

The variations in the VPD values calculated for both years were determined using the measured air temperature and relative humidity throughout the plant growth period, and these changes are illustrated in Figure 4. Additionally, the changes in air temperature and VPD during the sesame growing seasons of 2019 and 2020 are depicted in Figure 5, highlighting the differences between Tc and Ta. When the graph is examined, it is clearly seen that the VPD range for the lower limit is between 1.0 and 3.73. Gardner and Shock (1989) suggested that the VPD range should be between 1 and 6 so that it can be used better in other studies. In our study, measurements were taken at a wider VPD than in other studies, although not between 1 and 6. As can be seen in Figure 6, the lower baseline changes depending on the VPD, while the upper baselines do not depend on the VPD.

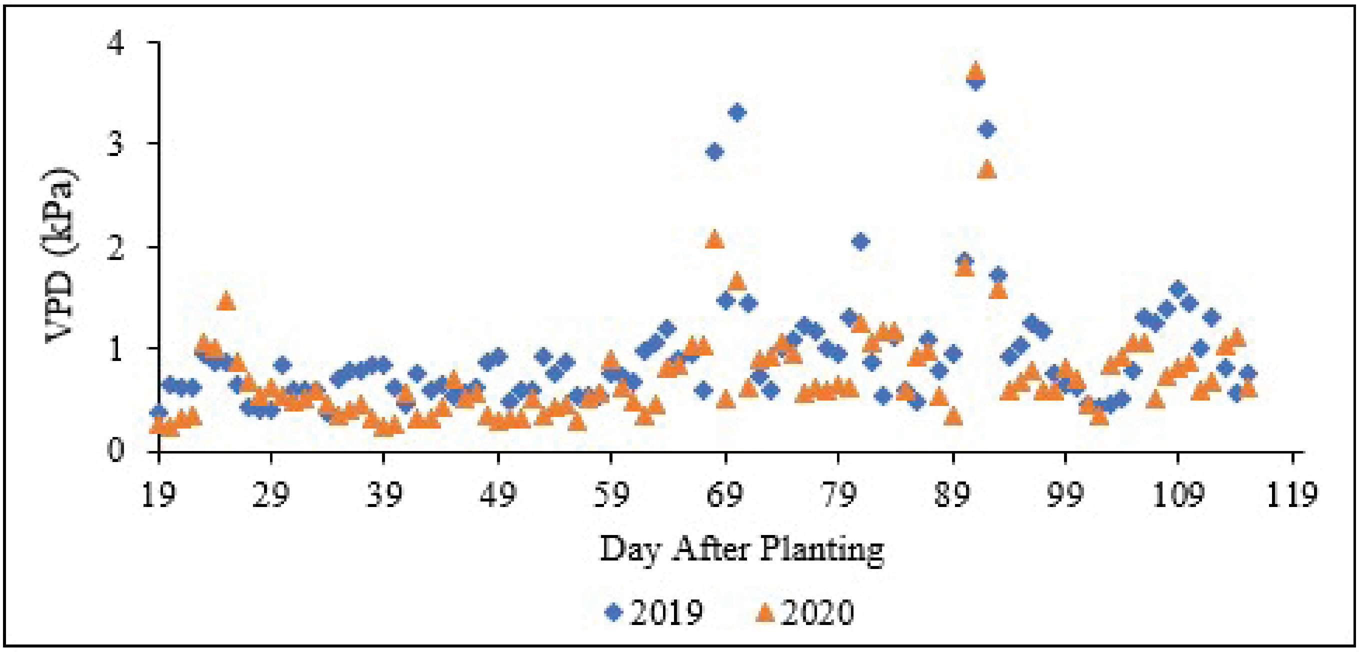

Figure 6. The changes in the vapor pressure deficit (VPD) during the growth period of sesame in 2019 and 2020

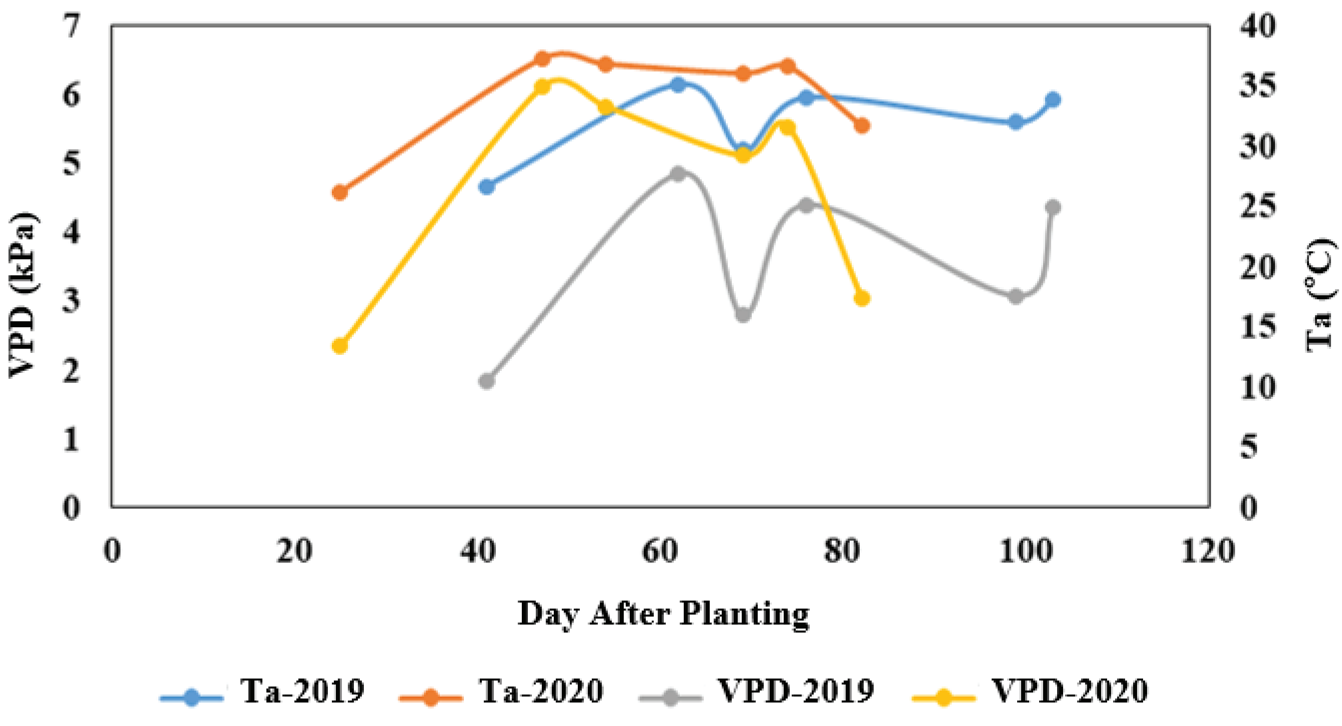

Figure 5. The changes in the air temperature (Ta) and vapor pressure deficit (VPD) during the growth period of sesame in 2019 and 2020

Crop Water Stress Index

In the study, the upper limit (UL) equation and the lower limit (LL) equation of the plant were created using two-year field measurements (Figure 6). As seen in Figure 6, in the case of no water stress in the plant, i.e., the lower limit (LL) equation, the potential evapotranspiration was assumed to be Tc-Ta=4.67-2.43VPD (r^2=0.86). The intersection values of the LL line in the equation were determined as positive. Idso et al. (1982) reported that when the atmosphere becomes saturated, the VPD will drop to zero and the intercept may be less than zero. According to the studies conducted, it can be concluded that there is a positive water vapor flux towards the atmosphere throughout the entire growing season according to the LL equation (Köksal, 1995; Gençel, 2009). The average CWSI values calculated for irrigation topics in the research years 2019 and 2020 are given in Table 4. The average CWSI values in the first year were determined as 0.271 for the highest I0 irrigation and 0.098 for the lowest I70 irrigation. In the second year of the study, the highest I0 value was determined as 0.274 for irrigation and 0.101 for the lowest I70 irrigation. It was determined that the values for other irrigation subjects were in this range. It was determined that the CWSI values determined in the first year were higher than the CWSI values determined in the second year for all irrigation subjects. As can be seen from Figure 6, CWSI is generally at maximum value before irrigation and decreasing values after irrigation. Köksal (1995) found that the CWSI values in Çukurova runners varied between 0.13 and 0.43 in the subject receiving the most water and between 0.42 and 0.73 in the subject receiving the least water. Gençel (2009) determined the CWSI value as 0-0.55 for I60, which is similar to the irrigation program applied by producers; as 1.0 for I80, which represents extreme stress conditions on the plant; and as 0.35-0.40 for I40, which is the most frequently irrigated.

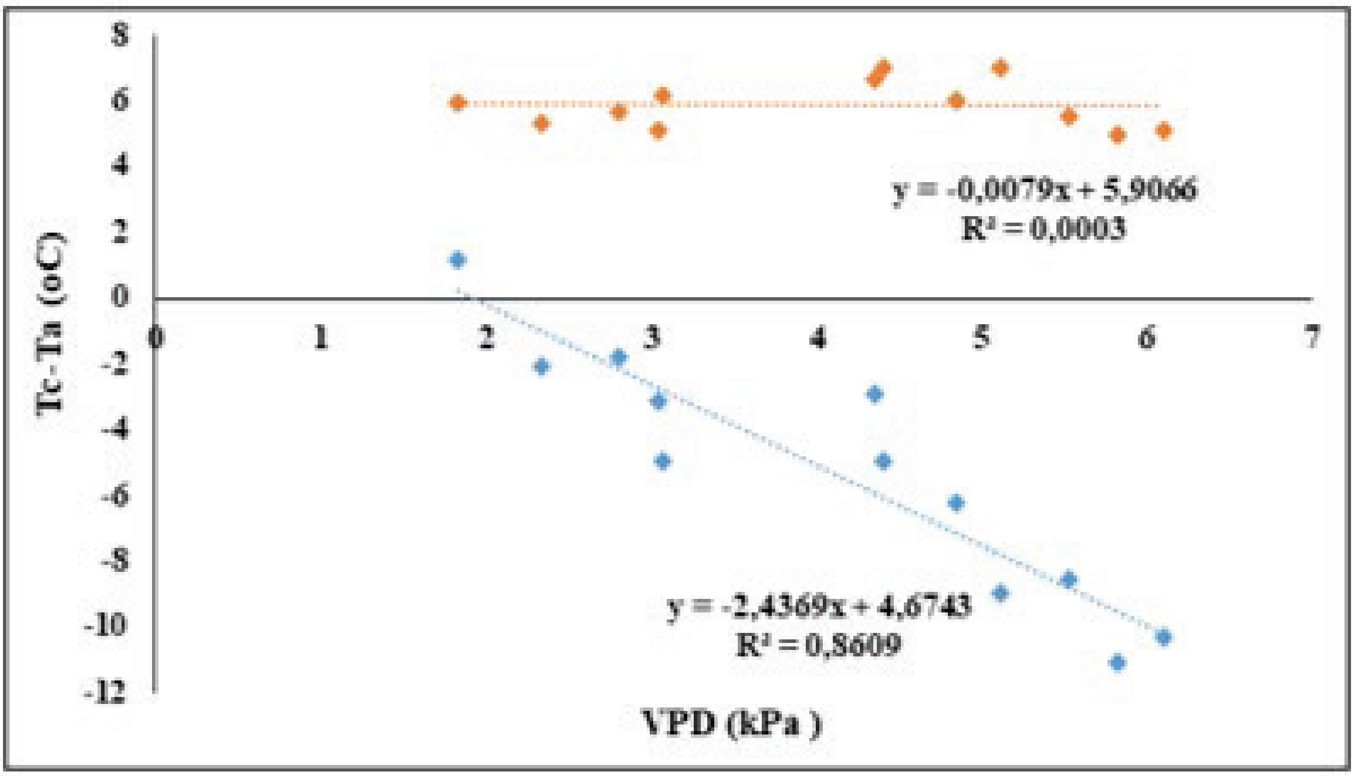

Figure 6. Basic Graph of Crop Water Stress Index (CWSI) for Sesame

Candoğan et al. (2013) suggested that the reason for the difference between the slopes and intervals obtained by Nielsen (1990) in soybean plants is due to the plant variety and climatic conditions. This difference may also be due to the difference in leaf area between the varieties. Since leaf size affects leaf temperature (Smith, 1978), it may have caused the lower limit values obtained from different genotypes to be different. In addition, the lower limit differs because the study was not conducted under similar climatic conditions, irrigation practices, and soil types (Erdem et al., 2012). For example, Khorsand et al. (2019) found that the slope and intercept values of the lower limit values obtained in different growth periods of maize were different. Gu et al. (2021) reported that the slope and intercept values of the lower line changed significantly as the growth period changed in both maize varieties. Taghvaeian et al. (2013) and De Jonge et al. (2015) obtained different slope values in the same country and city.

The upper limit (UL) values for sesame genotypes in Türkiye were determined as 2.04 °C and 1.77 °C, respectively. In the IR measurements made throughout the growing season, the threshold CWSI value at which sesame grain yield starts to decrease was determined as 0.31 (Uçak et al. 2022). Khorsandi et al. (2018) reported the UL values as 3 °C and -2.7 °C, respectively, in their study conducted in a greenhouse environment in Iran.

We can attribute the different results found in the studies to the different responses of varieties to the decrease in soil moisture (Uçak et al, 2022; Qin et al, 2021). Based on this, it has been stated in the studies that CWSI (the threshold value at which yield starts to decrease) varies depending on the irrigation method, irrigation program, soil type, plant variety, and climate values (Erdem et al, 2005; Bellvert et al, 2015; Ru et al, 2020).

In this study, unlike other studies, a subsurface drip irrigation system was used, where evaporation from the soil surface is minimal and water is delivered to the plant root zone. Another difference is that the plant stress index value is lower in the I70 subject, not in the I100 subject. The reason for this is that the water coming from the dripper from a depth of 40 cm remains in the plant root zone and can be easily used by the plant.

Table 4. Crop water stress index, irrigation water and plant water consumption values

Year	Irrigation considerations	Yield (kg ha^{-1})	Irrigation water (mm)	Plant water stress index
2019	I100	1840 b	266	0.227 c
	I70	2370 a	190	0.198 d
	I40	1390 c	114	0.368 b
	I0	860 d	12.6	0.571 a
2020	I100	1800 b	248	0.240 c
	I70	2320 a	178	0.211 d
	I40	1270 c	108	0.390 b
	I0	850 d	14.7	0.530 a

Correlation analysis

The correlation coefficient (r) values of the relationships between CWSI and yield of sesame plants are given in Table 5. When the correlation coefficients were examined, it was determined that the values of 2019 were statistically significant (p≤0.01). There was a decreasing (negative) relationship between CWSI and yield as high as r = -0.78. In other words, it can be said that there was a decrease in yield as CWSI increased. When the correlation coefficients of 2020 were examined, it was determined that there were statistically significant relationships (p≤0.01), similar to the first year. There was a decreasing (negative) relationship between CWSI and yield as high as r = -0.82. In other words, it can be said that there was a decrease in yield as CWSI increased.

Table 5. Relationship between crop water stress index and yield

Year	Parameter	Yield	CWSI
2019	Yield	1.00	-0.78**
	CWSI	-0.78**	1.00
2020	Yield	1.00	-0.82**
	CWSI	-0.82**	1.00
CV(%)	2.74		

*: p < 0.05 and **; p < 0.01. ns; not important. CWSI; crop water stress index.

Conclusion

The plant development periods between germination and the beginning of vegetative growth and between flowering and fruit formation are the periods when sesame is most sensitive to water deficit. Water restriction during these periods has led to lower quality seed production. The study was conducted to determine the CWSI of the Muganlı-57 sesame variety grown by the subsurface drip irrigation method. With this study, the CWSI value was determined for the first time in sesame plants irrigated with the subsurface drip irrigation method. As a result of the findings obtained from the study, it can be decided that irrigation time has come when the crop water stress index threshold value of the first crop sesame plant is 0.27, and it was determined that there will be a loss in yield when irrigation is made when it is 0.27, and that water can be reduced by 40% in conditions where irrigation water is limited.

It was determined that there may be a significant decrease in yield if CWSI is higher than the above-mentioned value. In the light of the data obtained from the study, yield estimation can be made by using the linear relationships between sesame grain yield obtained by using leaf crown temperature measurements made at irrigation time and crop water stress index. In addition, it has been determined that irrigation is absolutely necessary for the first crop of sesame in Antalya and that irrigation has a positive effect on the balance of soil water relations of the plant. As a method, subsurface drip irrigation has been seen to have advantages such as no plant lodging, high fertilizer use efficiency, and low weed growth in sesame irrigation.

Data availability

The manuscripts data is contained in the text.

Funding

This study is based on data obtained from project number TAGEM/TSKAD/A/19/A9/P3/1068, carried out at the Western Mediterranean Agricultural Research Institute (BATEM) and supported by the General Directorate of Agricultural Research and Policies (TAGEM).

Ethics declarations

Conflict of interests

The authors state that they have no other financial or personal affiliations or interests that would have affected the research presented in this paper.

Code availability

Not applicable.

Ethics approval

Not Applicable.

Consent to participate

Not applicable.

Content for publication

Not applicable.

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