Determination of Irrigation Time by Utilizing Plant Water Stress Index (CWSI) Values of II. Crop Sesame Genotype in Siirt Conditions

Ali Beyhan UÇAK[1*], Hüseyin ARSLAN[2], Aynur Bilmez ÖZÇINAR[3], Doğan ARSLAN[4]

[1]Siirt University, Faculty of Agriculture, Department of Biosystems Engineering, Siirt, Turkey
[2,3,4]Siirt University, Faculty of Agriculture, Department of Field Crops – Siirt, Turkey
*Corresponding Author

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Abstract— *This research was carried out to determine the plant water stress index (CWSI) by using infrared thermometer (IRT) data calculated as a result of leaf crown temperature measurements of the second crop sesame plant grown in semi-arid climate conditions in Siirt, and to determine the relationships between irrigation time and seed yield of sesame plant and CWSI by using these index values. In this study, the irrigation program was established to reintroduce 100 % (I_{100}), 70% (I_{70}), %35 (I_{35}) of the decreased water through the effective root depth of 90 cm every 7 days. Thus, a full irrigation (I_{100}) and irrigation with 2 different levels of stress (I_{70} and I_{35}) were created. In the research, a total of 575.00 and 576.66 mm of irrigation water was given to I100 (control) irrigation in the first and following years, respectively. The water consumption of the above-mentioned subject was determined as 606.00 mm in the first year and 646.33 mm in the second year of the study. The yield per hectare in the first year of the research on the aforementioned irrigation was 1110.34 kg; In its second year, it was determined as 1319.00 kg. In the first and second years of the study, the lower limit (LL) values for the absence of water stress needed to determine the plant water stress index were Tc-Ta=0.373-2.42 VPD and Tc-Ta=0.74-2.52 VPD, respectively; The upper limit (UL) values, where the plant is completely water stressed, were determined as 2.04 °C and 1.77 °C, respectively. From the infrared thermometer measurements at the time of irrigation, the threshold plant water stress index value, where sesame seed yield starts to decrease, was calculated as 0.31. On the other hand, it was determined that there is a negative linear proportionality between sesame seed yield and plant water stress index values.*

Keywords— Sesame, Crop water stress index, Irrigation time.

I. INTRODUCTION

Jackson et al. (1982), explained how to make leaf crown temperature (vegetation temperature) measurements with infrared thermometer device, which is accepted as an indicator of plant water stress index, and what should be consideredIt is stated that the temperature of the plant leaf crown can be measured with a portable infrared thermometer and the device should be held at an angle of 30 °C from the ground at the time of reading and it should be covered with 80% vegetation in order to make accurate measurements. The internal water status of plants; It has been reported that neither soil water content nor atmospheric demand can be determined as accurately as the plant water stress index (CWSI) (Reginato and Howe, 1985). Therefore, methods aiming to determine the internal water status of plants are used by many researchers in making irrigation plans (Reginato and Howe, 1985; Yazar, 1993). In a study, it was determined that the slope and intersection of the lower limit threshold without water stress increased until the vegetation reached 70 %. It was found that the slope of the lower boundary line without water stress and the correlation coefficient obtained from measurements under conditions where the crown temperature was greater than 27.4 °C were greater than that obtained from daily measurements (Wanjura et al., 1990). Gençoğlan (1996), in his study to prepare an irrigation program by using the CWSI determined from infrared thermometer (IRT) and porometer observations in Çukurova conditions, found that the grain yield started to decrease and the threshold CWSI value determined from infrared observations before irrigation was 0.19 and the threshold value determined from porometer observations was 0.26 reported that there will be no yield loss in irrigated corn under these conditions. Fischer (2001) reported that the leaf crown temperature (cover temperature) of the plant is an important criterion determining the difference from the ambient air temperature and that the leaf crown temperature is lower than the air temperature. The plant water stress index was developed from the relationship between the crown temperature and the air temperature difference versus the vapor pressure gap of the air. When the plant reaches a certain water stress index value, it should be watered. This threshold value varies from plant to plant, climate and cultivation techniques (Çolak et al., 2012). Gençel (2009), in his study to prepare an irrigation program by making use of the CWSI values. It was determined that the grain yield started to decrease, the threshold CWSI value determined from infrared observations before irrigation decreased to 0.35-0.40 (just before irrigation) in the most frequently irrigated I40 subject and to 0, which was the lowest value approximately two days after irrigation. Tanriverdi (2010) reported that Water Stress Index (WSI), or WSI and Water Deficiency Index (ADI), are useful tools that can be used to optimize irrigation time. It has been reported that the water stress present in the plant can be determined quantitatively by using some measurement and observational criteria. It can be said that these parameters are the difference between the plant crown and the air temperature and the vapor pressure gap of the air (Jackson, 1981). Moroni et al. (2012) emphasized that the fastest and most accurate method for measuring water stress is the canopy (leaf-crown) temperature (CWSI). In general, the decrease in soil moisture before irrigation has an effect on increasing the plant crown temperature values, and the CWSI values are higher with the decreasing moisture in the soil (Kırnak and Gençoğlan, 2001). It has been reported that the CWSI value determined by using the lower (LL) and upper limit (UL) lines, which are found theoretically and experimentally, varies between zero and one (Gençoğlan and Yazar, 1999). Çamoğlu et al. (2011) stated that leaf water content values can be used in the instant determination of plant water stress. Some researchers stated that the leaf crown temperature determined as a result of IRT measurements and the plant water stress index calculated by using these values can be used in the preparation of irrigation plans (Clawson and Blad, 1982). On the other hand, Nielsen and Gardner (1987) reported that the irrigation time can be determined by using the plant water stress index values, but the amount of irrigation water to be applied cannot be determined with the aforementioned method. The aim of this study is to determine the CWSI by using the leaf crown temperature values measured in the second crop sesame plant grown in Siirt conditions in 2016 and 2017, to determine the stress threshold line (watering time of sesame) where the decrease in yield begins, and to determine the relationship between grain yield and plant water stress index.

II. MATERIAL AND METHOD

Hatipoğlu sesame genotype was used as plant material in the research. The experiment was set up according to the randomized blocks design and was carried out in triplicate. The distance between rows was adjusted to be 70 cm, 4 rows were planted in each plot, and the plot dimensions were arranged as 6 m x 2.8 m. In the study, hand sowing was done on 1 July 2016 in the first year and on 18 June 2017 in the second year. Before planting, di-ammonium phosphate and urea fertilizers were applied homogeneously to each plot, with 8 kg of phosphorus and 4 kg of nitrogen per decare over pure matter (Arslan, 2003). In the harvest of sesame plants, one row from the parcel edges and 50 cm from the beginning and end of the parcel were taken as edge effect, and the parcel seed yield was determined on the remaining two rows (Arslan, 2014). The harvest date was made on 07 November 2016 in the first year and on 29 October 2017 in the second year. The research was carried out in Siirt University, Faculty of Agriculture, during the growing season of the second crop sesame plant in 2016 and 2017. In the study, different irrigation levels were applied with 100% (I_{100}, control subject) of the water consumed in a soil profile of 90 cm every seven days, full irrigation, and 70% (I_{70}) and 35% (I_{35}) of full irrigation applied. It was created from limited irrigation issues. Thus, 1 full irrigation (I_{100}) and 2 different levels of limited irrigation (I_{70}, I_{35}) were formed from a total of 3 irrigation subjects. Irrigation applications were made by drip irrigation method. In the year the research was conducted, 7 irrigation applications were carried out and the soil water content change was followed by the gravimetric method. Data on climate are given in Table 1. The region is mostly under the influence of dry and hot tropical air masses settled in the Basra low pressure center during the summer season. The highest temperature during the day is above 40 ºC. In the winter season, the region is under the influence of the fronts coming from the Central Mediterranean. The front activities that cause these precipitations continue until April (Atalay and Mortan, 2013). In the study area, it is observed that the average temperatures do not fall below 26 ºC in the summer period (June, July, August) and 2.7 ºC in the winter period (December, January, February). In the area subject to the research, the long-term relative humidity average is highest in January with 70.2 %, and the lowest in August with 26.9 %. The water holding capacities of soils at field capacity (33 kPa) and wilting point (1500 kPa) were determined according to the bulk weight Blake and Hartge (1986) (in intact soil samples). The soil of the trial field has a low electrical conductivity, lime rate does not pose a problem for plant cultivation, does not have salinity problems, and has a clayey textured soil structure. In the analysis of irrigation water, the method specified by (Tüzüner, 1990) was used to determine the electrical conductivity and pH values, and anions and cations. Irrigation water quality class used in the study area; As a result of the samples taken, it was determined as C2S1. The electrical conductivity of the irrigation water was determined as 0.34 dS m-1 and pH 7.20. The irrigation water used in the experiment does not pose a problem in terms of irrigation of the sesame plant.

TABLE 1
CLIMATE DATA FOR MANY YEARS AND RESEARCH YEARS (2016-2017)

Years	Months	Maximum temperature average (°C)	Average temperature (°C)	Minimum temperature average (°C)	Average humidity (%)	Average wind speed (m s^{-1})	Average sunny days (h)	Total rainfall (mm)
Everage 1962 - 2018	May	25.2	19.4	9.0	49.3	1.0	9.1	36.9
	June	27.2	26.0	17.8	34.9	1.1	11.6	11.5
	July	35.1	30.5	23.4	30.3	1.1	12.3	0.6
	August	34.5	30.3	27.0	29.5	1.0	11.4	2.7
	September	30.0	25.1	14.7	37.4	1.0	10.1	7.0
	October	24.5	17.9	12.7	42.0	1.0	7.2	50.9
2019	May	26.62	19.29	14.52	50.87	1.0	8.7	39.6
	June	26.09	28.16	20.0	35.50	1.1	11.5	10.6
	July	34.13	31.45	24.35	32.69	1.0	12.4	0.1
	August	33.92	31.19	24.23	32.95	1.0	11.3	0.4
	September	31.23	25.43	21.5	39.90	1.1	10.0	9.2
	October	24.3	16.8	11.5	42.3	1.1	7.0	55.1
2020	May	24.69	21.29	14.59	51.77	1.0	9.3	37.7
	June	28.19	28.41	20.25	34.40	1.1	12.0	9.3
	July	36.24	33.19	25.35	29.69	1.0	12.5	0.1
	August	35.92	32.45	24.73	29.95	1.0	11.5	0.0
	September	32.23	27.43	21.65	36.79	1.1	10.0	12.2
	October	21.1	19.7	12.0	44.2	1.0	7.3	69.20

The moisture content of the soil profile at a depth of 90 cm was determined by gravimetric method before each irrigation. In finding the amount of irrigation water to be given to the subjects, the amount of irrigation water that will bring the missing moisture in the soil depth of 90 cm to the field capacity for full irrigation (I_{100}) was used. The moisture content (%) determined for each layer was converted to moisture content in depth using the equation below

$$d = \frac{PwxAsxD}{10} \quad (1)$$

In the equation d; water content of soil moisture in depth (mm), Pw; moisture content (%), As determined for each layer; bulk weight of soil (g cm^{-3}) and D; layer depth (cm). The total water (d_T) amount for the 90 cm soil profile was found by summing the water depth calculated for each layer.

$$d_T = d_{(0\text{-}30)} + d_{(30\text{-}60)} + d_{(60\text{-}90)} \quad (2)$$

The volume of water to be given to the parcels was calculated from Equation 3 by multiplying the total water amount, the parcel area, the percentage of curtailment (1, 0.70, 0.35) and the percentage of cover.

$$V = d_T x A x U_o x P \quad (3)$$

V in equality; the volume of water (L) and A to be given to the plots; parcel (m^2), Uo; cut percentage (%) and P: cover percentage (%) Cover percentage was calculated by dividing the plant crown width by the plant row spacing. Its true value is fixed at 0.30 until the ÖY is 30 %, and then at 80% until it reaches 80% thereafter. The lateral lines of the drip irrigation system to be used in the experiment have an outer diameter of 16 mm, and the drippers to be used are internally permeable and with constant flow. 1 lateral is laid on each plant row. After calculating the amount of water to be given to the plots, the irrigation water to be applied was given by passing through the meters.

CWSI measurements were started with infrared thermometers, before and after irrigation, from the date when the plants covered the soil surface by approximately 80 %, and the measurements continued until the date of physiological maturity. Crown temperature (Tc) measurements were made between $12{:}^{00}$ and $14{:}^{00}$ in conditions where the weather was completely clear or the clouds did not block the sun. The average crown temperature of that parcel was found by taking the average of 12 measurements in total, in the direction of the diagonals of the parcels (from 4 corners) and with 3 replications from each of them. At the beginning and end of the plant crown temperature measurements, wet and dry thermometer values were read with a digital psychrometer.

In the determination of CWSI, The empirical method developed by. (1981) was used. According to the method developed by Idso et al (1981), CWSI was calculated with the following equation.

$$CWSI = \frac{[(T_c - T_a) - LL}{UL - LL} \quad (4)$$

Eq. Tc; crown temperature (°C), Ta; air temperature (°C), LL; lower limit of plants free of water stress, UL; refers to the upper limit values at which the plants are completely under stress. The lower limit (LL) at which plants experience no water stress, Idso et al. (1982) and obtained as a result of the regression analysis between the crown-air temperature difference and the vapor pressure gap (VPD, kPa) were calculated with the help of the following equation.

$$T_c\text{-}T_a = a\text{-}b * VPD \quad (5)$$

In the equation, as is the cross-sectional value of the line (°C); b shows the slope of the line (°C kPa^{-1}). Vapor pressure gap Howell et al. (1992) using the basic psychrometer equations. These equations are given below.

$$e_w = 0.61078 \exp\left[\frac{17.27 T_w}{237.3 + T_w}\right] \quad (6)$$

$$e_a = e_w - [(AP)(T_a - T_w)] \quad (7)$$

In equations; e_w, saturated vapor pressure (kPa) at wet bulb temperature; e_a, actual vapor pressure at air temperature (kPa), Tw, wet bulb temperature (°C); A is the psychrometric constant (kPa°C^{-1}); P is the barometric pressure, (kPa).

The psychometric constant (A) was calculated from the equation given below.

$$A = [0.00066(1 + 0.00115 T_w)]$$

The saturated vapor pressure was determined from the equation given below.

$$e_a * (T_a) = 0.61078 \exp\left[\frac{17.27 T_a}{237.3 + T_a}\right] \quad (8)$$

The vapor pressure gap (VPD) is found by taking the difference between the saturated vapor pressure at the dry bulb temperature and the actual vapor pressure at the same temperature.

$$VPD = [(e_a * (T_a) - e_a)]$$

In the equation: $ea * (T_a)$, is the saturated vapor pressure (kPa) calculated at dry bulb temperature, The upper limit (UL) where plants are assumed to experience complete water stress, Idso et al. (1982) with the help of the methods suggested.

$$T_c\text{-}T_a = a\text{-}b \; VPG \quad (9)$$

$$VPG = [(e_a * (T_a) - e_a * (T_a + a))] \quad (10)$$

where: a and b; The regression coefficients in the lower bound (LL) equation without water stress, VPG, are the negative atmospheric vapor pressure slope required for zero crown-air vapor pressure training.

The findings obtained from the study were subjected to analysis of variance and statistically significant applications according to the results of analysis of variance were compared with the LSD test. Correlation analysis was performed to determine the relationship between the features. (Der and Everitt, 2002).

III. RESULTS AND DISCUSSION

Seasonal water consumption (ETa) of the sesame genotype was 606.00 mm and 646.33 mm, respectively, during the research years, throughout the soil effective root depth of 90 cm in I100 irrigation, where water stress was determined at a minimum level; In the case of I35 irrigation, where water stress is applied excessively, it was determined as 171.00 mm and 212.00 mm in the first and second years of the study, respectively. In order to determine the plant water stress index in the sesame genotype in the years of the study, the lower limit (LL) formulas to define the situation where the genotype potentially transpiration and the upper limit (UL) equations, which define the situation where the plant is under extreme water stress, are given in Figure 1.

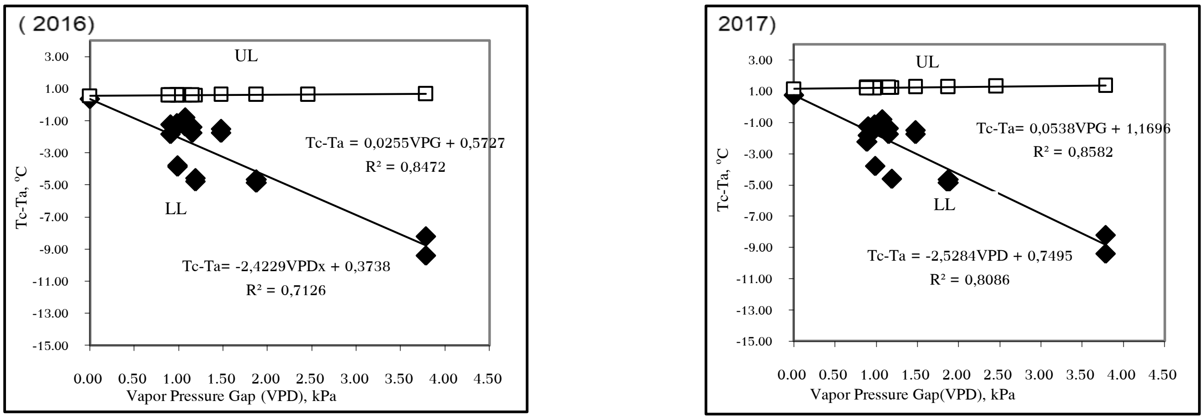


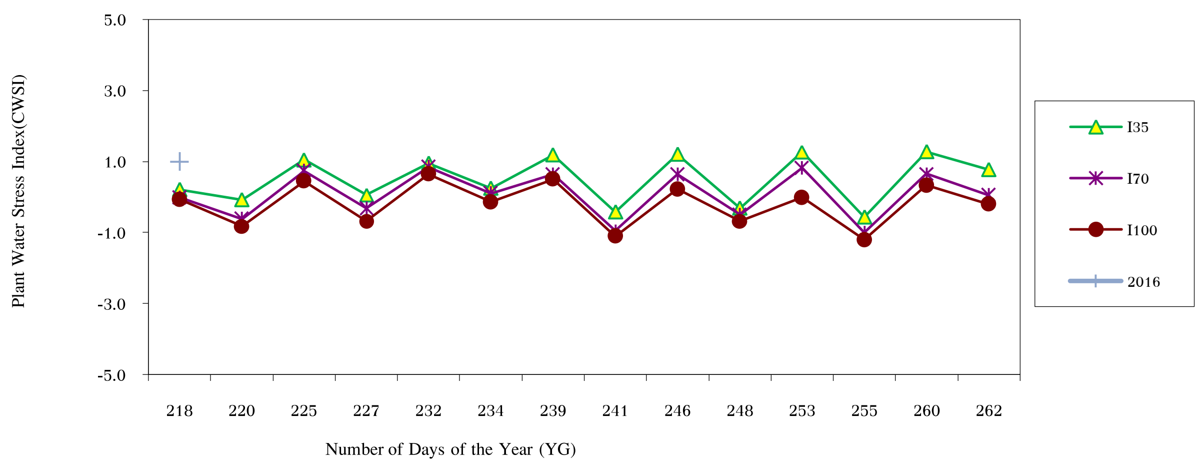
FIGURE 1: The lower and upper bound relationship values of sesame plant during the research years

As can be seen in Figure 1, the condition of no water stress in the plant for the first year of the study, that is, the lower limit (LL) equation assumed to potentially evapotranspiration Tc - Ta = 0.373 - 2.422 VPD (R2 = 0.71) and Tc - Ta = for the second year of the study 0.74 - 2.52 VPD (R2 = 0.80). In the equation, the intersection values of the LL line are determined as positive. Idso et al. (1982) reported that the intersection value could not be less than 0 and that this value occurred due to the formation of a positive water vapor flow from the leaves to the atmosphere, even if the VPD was reduced to zero by saturating the atmosphere. In the light of these data, according to the LL equation, it can be concluded that a positive water vapor flux towards the atmosphere occurs during the whole growing season, as mentioned in previous studies on this subject (Köksal, 1995; Gençel, 2009). The upper limit (UL) equation, which is assumed to be completely under water stress, was determined as Tc - Ta = 0.572 + 0.025 VPG for the first year of the study, and Tc - Ta = 1.169 + 0.0538 VPG for the second year of the study. The differences between the crown temperature and the air temperature in UL were determined as 1.169-0.572 ºC for the first and second years of the study, with the slope being neglected in the UL formula due to its minimum level. Although the CWSI values measured at different levels of irrigation were mostly between 0 (no water stress) and 1 (maximum stress state), some of these values were negative. It can be said that the negative CWSI values obtained are due to the fact that the measurement values used in the calculation are lower than the LL line shown in Figure 1. The average CWSI values determined in irrigation subjects during the research years are given in Table 2. As can be seen from Table 2, the average CWSI values determined in irrigation subjects were obtained as 0.62 for the highest I35 irrigation in the first year and 0.21 for the lowest I_{100} irrigation, respectively. In the second year of the study, the highest I_0 was 0.60 in irrigation; the lowest I_{100} irrigation was determined as 0.20. In other irrigation issues, it changed between these two values. It is seen that the CWSI values determined in all irrigation subjects in the first year are slightly higher than the CWSI values obtained in the second year. This can be related to the fact that the temperature values in the first year, especially in July and August, when the second crop sesame plant grows, are higher than the second year. The CWSI values determined according to the days measured during the growing season are given in Figure 2 for the first and second years of the study, respectively. As can be seen from the aforementioned figures, CWSI values, which show an increase depending on the severity (excess) and duration of the applied water restriction, generally showed a tendency towards maximum before irrigation and decreasing after irrigation. Köksal (1995), CWSI values of 0.13-0.43 in the subject that receives the most water in Çukurova runners; He found that it varies between 0.42-073 in the subject that receives the least amount of water. Ödemiş and Baştuğ (1999) reported that a time period is needed for the CWSI value to decrease after irrigation and this period varies between 4-5 days. The researchers emphasized that as the amount of water in the soil decreases, the plant suffers from water stress and therefore there is an increase in the CWSI value. Simsek et al. (2005) stated that the CWSI value changes depending on the amount of water applied and in general, high CWSI values cause yield loss in plants. Gençel (2009) found the CWSI value of 0.35-0.40 for the most frequently irrigated I_{40}, 0 to 0.55 for I_{60} irrigation, which is similar to the irrigation program applied by the producers, and 1.0 for I_{80}, which represents extremely stressful conditions in the plant. In short, depending on the amount of water stress applied, it was observed that there was a change in the CWSI values between the irrigation subjects as expected, as expected. The CWSI threshold values, where the efficiency determined from the IRT observations began to decrease, were found to be 0.32 for the first year of the study, 0.31 for the second year of the study, and approximately 0.31 when the results of both years were evaluated together. Köksal (1995) found the threshold value as 0.33 for grain yield and 0.32 for dry matter in the second crop corn plant. Gençoğlan and Yazar (1999) determined the threshold CWSI value determined from infrared observations as 0.19 and the threshold value determined from porometer observations as 0.26 in Çukurova conditions. Reginato (1983) stated that little or no effects of water stress on plants are observed in conditions where the CWSI value is less than or equal to 0.2. There is a similarity between the threshold CWSI values obtained in this study and those obtained by Gençoğlan and Yazar (1999), whereas there is a partial difference between the threshold CWSI values obtained by Köksal (1995). We can attribute this situation to the fact that the responses of genotypes obtained through breeding in recent years to the decrease in moisture in the soil are different from each other. From this, it can be said that the CWSI (thus the threshold at which the yield starts to decrease) may vary depending on the irrigation program, the soil type in which the experiment is carried out, the climatic values of the trial years, the cultivar that forms the plant material in the trial and the cultivar cultivated as the main or second crop.

TABLE 2
PLANT WATER STRESS INDEX, IRRIGATION WATER AND PLANT WATER CONSUMPTION VALUES DURING THE RESEARCH YEARS

Irigation considerations	Yield (kg ha^{-1}	Plant water stress index	Irrigation water (mm)	Plant water consumption (mm)	Water Usage Efficiency (kg da^{-1} mm)
2016 (first year)					
I100	1110.34 a	0.21 c	575.00	606.00	1.82 c
I70	857.05 b	0.43 b	403.00	435.00	1.96 b
I35	654.54 c	0.62 a	141.00	171.00	3.82 a
LSD	181.82	0.015			0.32
2017 (Second year)					
I100	1319.0 a	0.20 c	576.66	646.33	2.04 b
I70	910.0 b	0.42 b	404.50	474.00	1.92 c
I35	711.0 c	0.60 a	141.33	212.00	3.35 a
LSD	83.10	0.013			0.20

***: p < 0.05 and **; p < 0.01. ns;not importent**



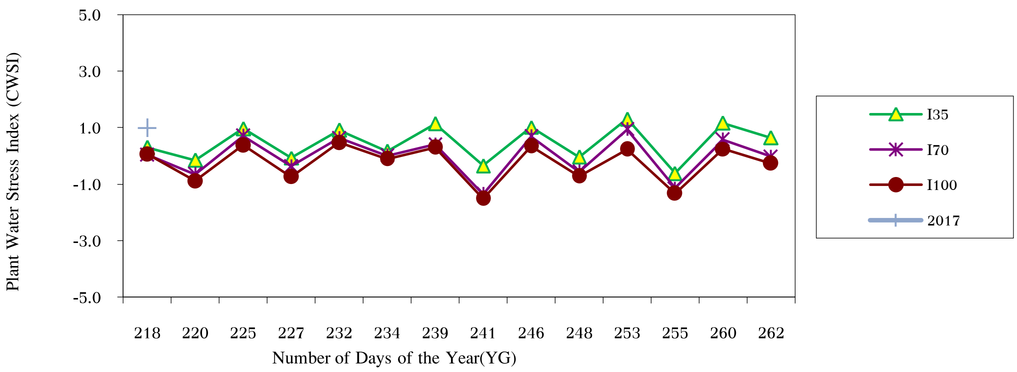


FIGURE 2: Plant water stress index values determined in irrigation subjects during the research years

3.1 Correlation analysis

Correlation coefficients (r) of the relationships between the plant water stress index (CWSI) of sesame plant and yield, water use efficiency and chlorophyll content are given in Table 3 for 2016 and 2017, respectively. When the correlation coefficients of 2016 were examined, it was determined that there were statistically significant relationships ($p \leq 0.01$) between all these features. There is a decreasing (negative) relationship as high as r = -0.85 between CWSI and yield. There is a high (positive) correlation of r = 0.74 between CWSI and water use efficiency. There is a decreasing (negative) relationship as high as r = -0.97 between CWSI and chlorophyll content. In other words, it can be said that as CWSI increases, there is a decrease in yield, an increase in water use efficiency and a decrease in chlorophyll content. When the correlation coefficients of 2017 were examined, it was determined that there were statistically significant relationships ($p \leq 0.01$) between all these features, similar to the first year. There is a high decreasing (negative) relationship such as r = -0.94 between CWSI and yield. There is an increasing (positive) relationship as high as r = 0.50 between CWSI and water use efficiency. There is a decreasing (negative) relationship as high as r = -0.96 between CWSI and chlorophyll content. In other words, it can be said that as CWSI increases, there is a decrease in yield, an increase in water use efficiency and a decrease in chlorophyll content.

TABLE 3
RELATIONSHIPS BETWEEN PLANT WATER STRESS INDEX AND OTHER PARAMETERS

a (2016)	Yield	WUE	CWSI	CC
Yield	1.00	-0.45*	-0.85**	0.86**
WUE	-0.45*	1.00	0.74**	-0.64**
CWSI	-0.85**	0.74**	1.00	-0.97**
CC	0.86**	-0.64**	-0.97**	1.00
b (2017)	**Yield**	**WUE**	**CWSI**	**CC**
Yield	1.00	-0.25ns	-0.94**	0.97**
WUE	-0.25ns	1.00	0.50**	-0.44*
CWSI	-0.94**	0.50**	1.00	-0.96**
CC	0.97**	-0.44*	-0.96**	1.00

: p < 0.05 and **; p < 0.01. ns;not important. WUE; Water usage efficiency. CWSI; plant water stress index. CC; chlorophyll content

IV. CONCLUSION AND SUGGESTIONS

This work; A field study was conducted in semi-arid climate conditions in order to determine the plant water stress index of the sesame genotype grown in water-free and water-stressed conditions and to determine the threshold value at which the economic yield reduction will start from the residual sesame plant by making use of these data. As a result of the findings obtained from the research, II. When the plant water stress index threshold value of the crop sesame plant is 0.31, it can be decided that the irrigation time has come, and when irrigation is done when it is 0.31, there will be no statistically significant loss in yield, and it has been determined that 30% water reduction can be made in conditions where irrigation water is limited. It has been determined that if the CWSI is higher than the value mentioned above, there may be a significant decrease in yield. In the light of the data obtained from the study, yield estimation can be made by making use of the linear relationships between the sesame grain yield and the plant water stress index obtained by using the leaf crown temperature measurements made at the irrigation time.

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