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ORIGINAL PAPER

Evaluation of plant-based measurements during the flowering period for purposes of the management of irrigation of sunflower (*Helianthus annuus* L.)*

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Abstract

In this study, effects of different applications of irrigation on yield of sunflower (*Helianthus annuus* L.) and usability of plant-based measurement techniques in irrigation applications were investigated. As a result of the study, the evapotranspiration values measured in the experimental subjects during the plant growing season changed, depending on the amount of irrigation water applied, between 375.2 and 655.0 mm in 2018 and between 278.2 and 801.3 mm in 2019. The seed yields obtained from treatments in both years changed depending on the amount of water entering the soil (precipitation + irrigation). Linear relationships were calculated between applied irrigation water, measured seasonal evapotranspiration and seed yields of sunflower. The IWUE (Irrigation Water Use Efficiency) and WUE (Water Use Efficiency) values were found to be high in the experimental treatments with less irrigation water. As a result of the study, it can be suggested that 25 and 50% of the evaporation values measured from class A pan evaporation is applied under limited water supply conditions. In the under-limited water conditions, the leaf area index value of 2.83-3.95 $m^2\ m^{-2}$, leaf water potential value of -13 and -14 bar, chlorophyll content of 45-50, stomatal conductance value of 35-70 mmol $m^{-2}\ s^{-1}$, photosynthesis rate value of 25-30 µmol $CO_2\ m^{-2}\ s^{-1}$ and transpiration rate of 5-8 mmol $H_2O\ m^{-2}\ s^{-1}$ can be used for irrigation applications, especially in the flowering period of sunflower. It is important to determine the irrigation data required for sunflower in terms of protection of soil and water resources in conditions where irrigation practices are not very intensive and drip irrigation applications are new.

Keywords: supplemental irrigation, drought tolerance, yield, drip irrigation, water use efficiency (WUE)

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INTRODUCTION

In Türkiye, sunflower plants are generally grown under rainfed conditions in Thrace Region. Although the plant with its deep root system is resistant to drought, droughts that occur especially during the flowering period in the summer months affect the yield significantly. As a result of previous studies conducted in the region and world conditions, it has been stated that the sunflower yield increased significantly with irrigation applications (Sener et al. 2007, Azevedo et al. 2016, Garcia-Lopez et al. 2016, Mahmoud, Ahmed 2016, Ismail, El-Nakhlawy 2018, Liu et al. 2018, Jing et al. 2020) Water stress, particularly at the flowering stage, reduces fertilization impact and seed set due to dehydration of pollen grains (Elsheikh et al. 2015). Water stress at the flowering stage was observed to be a limiting factor for seed filling, hence a significant increase in unfilled seeds was observed as a result of irrigation deficit. Pejic et al. (2009) summarized that the period from flowering to maturity was the most sensitive towards water deficit. Yawson et al. (2011) reported that, sunflower is to some extent tolerant to water deficit. According to Casadebaig et al. (2008), minimizing water loss in response to water deficit is a major aspect of drought tolerance, and can be achieved by decreasing either the leaf area expansion rate or transpiration per unit leaf area (stomatal conductance). Pekcan and Erdem (2005) reported in their research conducted under conditions prevalent in Thrace, Türkiye, that the sunflower seed yield values obtained by supplemental irrigation applied during the flowering period of the plant increased statistically relative to rain-fed conditions. Therefore, knowledge of the effects of an irrigation schedule on sunflower production and water productivity under water stress conditions is becoming increasingly important. Irrigation scheduling is particularly important since many field crops are more sensitive to water deficit at specific phenological stages. In the season where there is insufficient water for crop demand, the optimum use of irrigation water is essential for water resources management (Elsheikh et al. 2015).

Irrigation scheduling is generally based on management of soil water content or meteorological parameters for modelling or computing evapotranspiration. But in the recent years, plant-based indicators have been used to quantity crop water stress levels. Of these, the photosynthesis rate, leaf area index, chlorophyll content, leaf water potential, stomatal conductance and transpiration rate are accepted as most stable, reliable and accurate indicators for irrigation scheduling (Balanco et al. 2018).

The purpose of research was to identify the plant-based indicators for sunflower in the Thrace Region of Türkiye. Sunflower was grown under six different irrigation regimes during the 2018 and 2019 growing seasons. The correlations among the measurements the photosynthesis rate, leaf area index, chlorophyll content, leaf water potential, stomatal conductance and transpiration rate during the flowering period and sunflower water relations were examined.

MATERIALS AND METHODS

Experiment site and growth conditions

The experiment was carried out in Tekirdag, northern Türkiye (40°59′ N and 27°29′), at the experimental station of Tekirdag Viticulture Research Institute, during the 2018 and 2019 sunflower growing periods. The climate of the region is semi-arid, with average annual precipitation of 580.80 mm. Additionally, some meteorological factors in 2018 and in 2019 relative to the long-term data during the sunflower growing period are presented in Table 1.

Some soil properties of the field are listed in Table 2. The bulk density varied from 1.49 to 1.61 g cm^{-3}. The available water holding capacity within 90 cm of the soil profile was 152.38 mm in 2018 and 128.17 mm in 2019. Irrigation water quality was classified as C_2S_1 with 1.8 sodium absorption ratio (SAR) and 0.72 dS m^{-1} electrical conductivity (EC).

Table 1

Some meteorological data of the experimental site

Year	Month	T (°C)	RH (%)	W ($m\ s^{-1}$)	n (h)	E_p ($mm\ day^{-1}$)	R ($mm\ month^{-1}$)
2018	April[1]	17.35	70.87	2.38	10.18	5.05	-
	May	18.46	79.39	3.65	5.93	3.80	27.40
	June	22.28	72.59	3.03	8.30	4.98	75.40
	July	25.12	69.23	2.59	8.39	5.08	87.70
	August	26.05	63.12	3.83	7.84	6.38	-
	September[2]	26.67	65.67	2.10	6.50	6.35	-
2019	April[3]	17.50	67.80	3.10	11.50	4.00	-
	May	17.81	70.62	2.32	6.11	3.99	31.2
	June	24.06	64.75	2.80	7.90	6.31	7.50
	July	23.87	64.48	2.85	9.42	6.51	18.8
	August	25.23	62.25	3.66	9.47	7.11	-
	September[4]	24.68	63.40	4.32	9.18	6.54	-
Long-term	April	11.9	77.10	2.50	5.60	2.12	40.70
	May	16.8	76.00	2.30	7.70	3.70	36.90
	June	21.5	72.00	2.40	9.00	4.74	37.90
	July	24.0	68.80	2.80	9.70	5.80	22.50
	August	24.0	69.40	3.00	8.80	5.51	13.20
	September	20.0	73.40	2.80	7.20	3.83	33.90

T – average temperature, RH – average relative humidity, W – average wind speed at 2 m, n – sunshine duration, E_p – class-A pan evaporation, R – rainfall,
[1] the four-day averages (27-30 April), [2] the five-day averages (1-4 September), [3] the one-day value (30 April), [4] the six-day averages (1-5 September).

Table 2

Soil properties of the experimental site

Year	Soil depth	Texture class	Field capacity	Wilting point	Bulk density	Organic matter	pH	EC
	(cm)		(m^3 m^{-3})	(m^3 m^{-3})	(g cm^{-3})	(%)		(ds m^{-1})
2018	0-30	C	0.348	0.165	1.60	2.11	7.64	0.6
	30-60	C	0.358	0.189	1.59	2.88	7.73	0.6
	60-90	CL	0.301	0.147	1.54	2.50	7.50	0.6
2019	0-30	C	0.343	0.237	1.49	1.27	7.19	0.6
	30-60	C	0.427	0.279	1.58	1.01	6.71	0.5
	60-90	C	0.511	0.337	1.61	1.45	7.05	0.5

The Sanay MR variety of sunflower (*Helianthus annuus* L.) was planted on 27 April (DOY 117) in 2018 and 30 April (DOY 120) in 2019. Trifluralin at a rate of 0.2 kg da^{-1} was applied to control weeds. The preceding crop in both years was wheat. Composite fertilizer including 50 kg ha^{-1} N and 22 kg ha^{-1} P was applied to all plots, according to soil analysis recommendations. Each plot was 25.20 m^2 (4.20 m x 6.00 m) and was seeded with 120 plants at 0.70 m x 0.30 m spacing. There was a gap of 3 m width between the plots.

Irrigation management and experimental design

Sunflower was grown under a drip irrigation technology. The diameters of polyethylene (PE) laterals were 16 mm, and each lateral irrigated two plant rows. The pressure compensating dripper discharge rate was 4 L $h^{-}1$ above 10 m operating pressure. The dripper and lateral spacing were calculated as 0.50 m and 1.40 m, and the percentage of the wetted area (P) was calculated as 36%, according to the methods described by Keller, Bliesner (1990).

The experiment was designed as completely randomized blocks replicated three times. The irrigation regime treatments consisted of six levels of cumulative pan evaporation (Ep) and water quantities applied were: 0.00 (I_1 rainfed treatment), 0.25 (I_2), 0.50 (I_3), 0.75 (I_4), 1.00 (I_5) and 1.25 (I_6) times of pan evaporation measured at seven days interval with a Class A Pan. The amount of irrigation water was calculated from equation given below:

$$I = E_p \text{ x } k_{pc} \text{ x } P,$$

where: E_p – the cumulative pan evaporation for a 7-day irrigation interval (mm), k_{pc} – the coefficient of pan evaporation (0.00, 0.25, 0.50, 0.75, 1.00 and 1.25) and P – the percentage of wetted area.

Soil water content was gravimetrically calculated every week in the 30 cm depth to 90 cm. Evapotranspiration was determined using the soil water balance equation (Li et al. 2017). Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were determined as total marketable sunflower yield divided by the seasonal ET and seasonal irrigation water applied, respectively (Kilemo 2022).

Plant-based measurements

The leaf water potential, stomatal conductance, leaf area index, photosynthesis rate, chlorophyll content and transpiration rate during the flowering period were measured as plant-based indicators for sunflower. Leaf area index (LAI) was measured with a plant canopy analyser (LAI-2200 C, LI-COR, USA). The leaf water potential was monitored before the irrigation applications at 12:00-14:00 h (midday time) with a Scholander pressure chamber (Model 3115 Soil Moisture Equipment Corp., USA) according to Hisio (1993). In the leaf water potential measurements, young and fully developed leaves of the sunflower plant facing the top sun were used. The chlorophyll content was monitored before the irrigation applications at 12:00-14:00 h (solar time) with a Chlorophyll Meter (SPAD-502 Plus, Konica Minolta, Japan). The photosynthesis rate, transpiration rate and stomatal conductance were measured for the youngest and fully expanded leaves between 12:00-14:00 with an infrared gas analyser (LI-6400 Portable Photosynthesis System, LI-COR, USA).

Yield measurement and statistical analysis

After physiological maturity, head samples for seed yield were harvested from four rows in each plot on 4 September 2018 (DOY 247) and 5 September 2019 (DOY 248). The seeds were separated from the heads, oven dried at 65°C and adjusted to 9% moisture content (Unger 1982). Analysis of variance (ANOVA) and the Least Significant Difference (LSD) Test were used for effects of yield, WUE and IWUE. Differences were evaluated at $p<0.05$ or $p<0.01$ levels. Relationships between plant-based measurements, evapotranspiration and irrigation water were determined according to regression analyses.

RESULTS AND DISCUSSION

Irrigation water use and evapotranspiration

The daily rain, irrigation water amounts, measured soil water content before irrigation applications, and measured evapotranspiration are shown in Figure 1 for 2018 and Figure 2 for 2019. The total sunflower period after planting was determined as 131 days in the first year and 129 days in the second year. Irrigation applications were started in both years of the study when the spring precipitation decreased and the soil moisture at the 90 cm depth fell to around 50% of the available water holding capacity. As shown in Figures 1 and 2, seven irrigation applications were applied in 2018 and

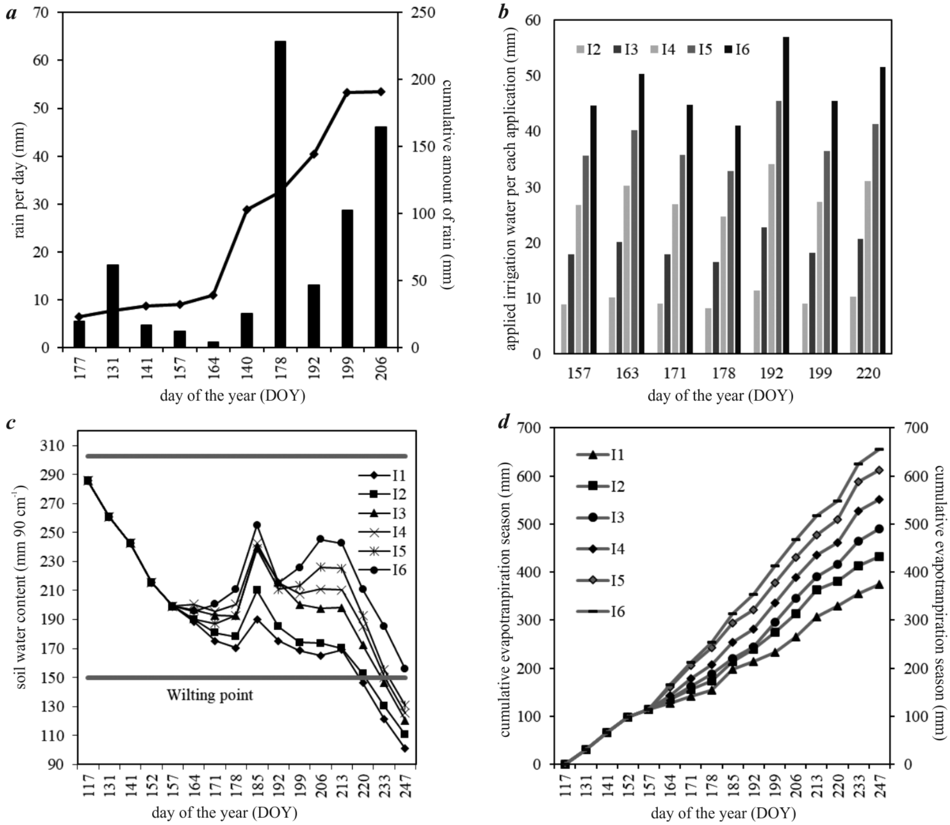

Fig 1. Daily and cumulative amounts of rain – *a*, irrigation water applied per irrigation – *b*, soil water content variations before irrigation – *c*, cumulative measured evapotranspiration for treatments for 2018 – *d*

twelve ones in 2019. Although the irrigation applications were planned to be carried out on 7 days during the research, daily excessive rainfall amounts of 50.5 mm on June 28, 28.2 mm on July 24 and 29.9 mm on July 30 in 2018 affected irrigation applications in the first year. The cumulative rainfall was 190.5 mm in 2018 and 57.5 mm in 2019. The total irrigation water applied varied between 67.0 and 334.8 mm in 2018 and between 133.7 and 668.1 mm in 2019, depending on the experimental treatments. The difference between the total rainfall in the two years resulted in the total number of applications and amounts of irrigation water being lower in 2018 than in 2019. The soil moisture values measured at 90 cm soil depth before irrigation applications differed depending on the treatment. The moisture values before irrigation differed due to excessive rainfall in 2018. In the second year of the experiment, it was determined that the soil moisture values measured before the irrigation season in I_5 treatment, where 100% of the open water surface evaporation amount measured from the A class pan was applied, were around 60% of the available soil water capacity. Especially in the second

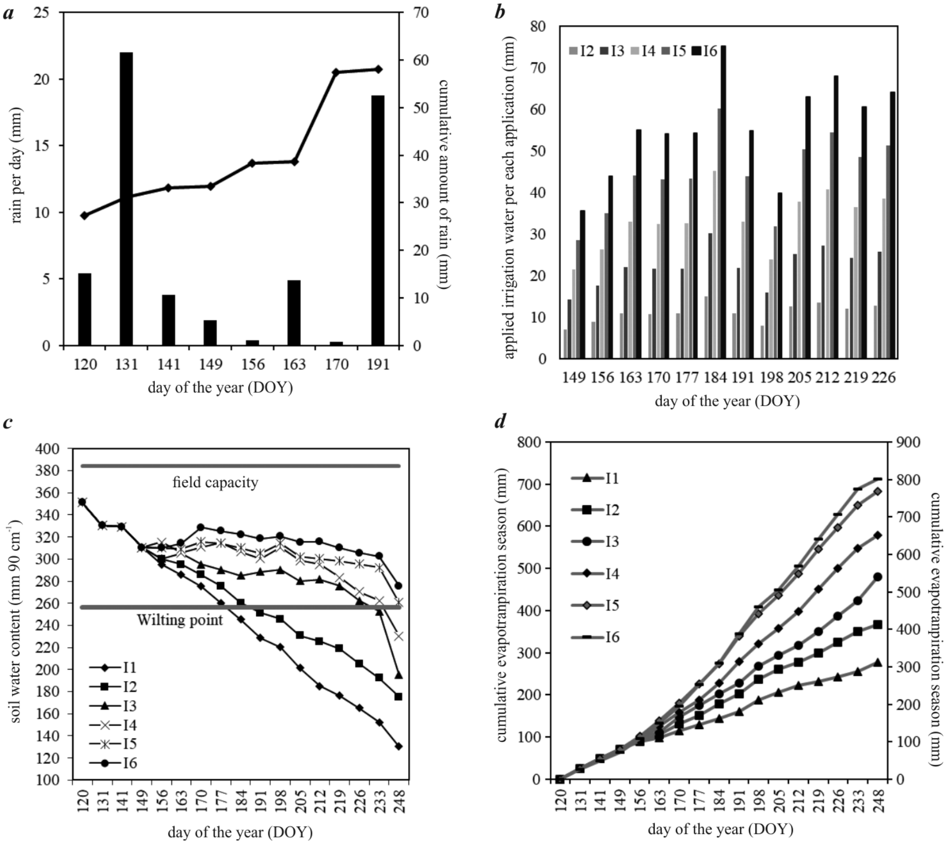

Fig 2. Daily and cumulative amounts of rain – *a*, irrigation water applied per irrigation – *b*, soil water content variations before irrigation – *c*, cumulative measured evapotranspiration for treatments for 2019 – *d*

year, it was observed that the existing moisture before irrigation fell to the wilting point and below in I_1 and I_2 treatments, i.e. without irrigation water and with the amount of irrigation water equal 25% of the evaporation amount, respectively.

The evapotranspiration (ET_c) measured from treatments during the total growing season varied between 375.2 mm and 655.0 mm in 2018 and between 278.2 mm and 801.3 mm in 2019. The sunflower seasonal ET_C increased with the depth of irrigation water applied. Excessive rainfall in 2018 and high irrigation water amounts in 2019 affected the sunflower seasonal ET_c. The total seasonal evapotranspiration (ETc) obtained in the current study corresponds well with the values obtained from previous studies conducted in Thrace Region, Türkiye, and elsewhere in the world (Pekcan, Erdem 2005, Sezen et al. 2011, Sullu, Dagdelen 2015, Azevedo et al. 2016, Garcia-Lopez et al. 2016, Mahmoud, Ahmed 2016, Yavuz 2016, Ismail, El-Nakhlawy 2018, Liu et al. 2018, Jing et al. 2020,).

Yield and irrigation water use efficiency (IWUE), water use efficiency (WUE)

The sunflower seed yields, irrigation water use efficiency (IWUE) and water use efficiency (WUE) for treatments are given in Table 3. The seed

Table 3

Irrigation water use efficiency (IWUE) and water use efficiency (WUE) for treatments

Year	Treatment	I (mm season^{-1})	ET_c (mm season^{-1})	Y (t ha^{-1})	IWUE (kg m^{-3})	WUE (kg m^{-3})
2018	I_1	-	375.2	2.73 *c***	-	0.73 ns
	I_2	67.0	432.6	2.94 *c*	4.39 *a***	0.68
	I_3	134.1	489.7	4.08 *b*	3.04 *b*	0.83
	I_4	201.0	551.7	3.91 *b*	1.95 *c*	0.71
	I_5	267.8	613.1	4.75 *ab*	1.77 *c*	0.77
	I_6	334.8	655.0	5.04 *a*	1.50 *c*	0.77
				$LSD_{0.01=}$0.88	$LSD_{0.01=}$0.70	
2019	I_1	-	278.2	2.22 *c***	-	0.80 ns
	I_2	133.7	367.2	2.79 *c*	2.06 *a***	0.75
	I_3	267.4	480.9	3.35 *b*	1.25 *b*	0.70
	I_4	401.1	579.5	3.73 *b*	0.93 *c*	0.64
	I_5	534.4	682.6	5.05 *a*	0.95 *c*	0.74
	I_6	668.1	801.3	5.19 *a*	0.78 *c*	0.65
				$LSD_{0.01}$=0.99	$LSD_{0.01}$=0.23	

I – applied irrigation water, ET_c – measured evapotranspiration, Y – seed yield, IWUE – irrigation water use efficiency, WUE – water use efficiency, ** numbers followed by different letters indicate statistically significant differences at P<0.01, ns – non-significant

yield varied between 2.73 t ha^{-1} and 5.04 t ha^{-1} in 2018 and between 2.22 t ha^{-1} and 5.19 t ha^{-1} in 2019. Seed yields harvested from the experimental treatments in both years changed depending on the amount of water entering the soil (rainfall + irrigation). Especially the high amount of rainfall in 2018 resulted in higher seed yield than in the second year in I_2, I_3 and I_4 treatments, when less irrigation water was applied.

Sunflower seed yield values obtained in I_1 treatment, where irrigation water is not applied, were 2.73 t ha^{-1} in 2018 and 2.22 t ha^{-1} in 2019. Similar results were obtained for sunflower seed yields under conditions where irrigation water was not applied in previous studies conducted in the same region or in the country. Yılmaz and Boyraz Erdem (2020) stated that under the same conditions, the seed yield in four different sunflower varieties in three different soils varied between 1.65 t ha^{-1} and 2.54 t ha^{-1} in rainfed conditions. The seed yields obtained in I_5 treatment, where 100% of the open water surface evaporation value measured from the A class pan was applied, was 4.75 t ha^{-1} in 2018 and 5.05 t ha^{-1} in 2019. The corresponding values were 5.04 t ha^{-1} and 5.19 t ha^{-1} for the experimental years, respectively, in I_6 treatment, where 125% of the open water surface evaporation value was applied. It is similar to the seed yield values obtained under the maximum crop evapotranspiration ($ET_c = ET_m$) in the conditions of the region, country and other parts of the world.

The IWUE values obtained from the treatments varied between 1.50 and 4.39 kg m^{-3} in 2018 and between 0.78 and 2.06 kg m^{-3} in 2019. The reason for the high IWUE values obtained in the first year is that less irrigation water was applied to the treatments owing to that year's high rainfall compared to the second year. The WUE values obtained in both years between the treatments showed similarity. The WUE values varied between 0.68 and 0.83 kg m^{-3} in 2018 and between 0.64 and 0.80 kg m^{-3} in 2019. The highest WUE values were obtained from I_3 treatment in the first year of the experiment and from I_1 treatment in the second year. The IWUE and WUE values obtained in this study are similar to the results obtained from previous investigations. Yavuz (2006) reported WUE values for sunflower of 0.53-0.75 kg m^{-3} in Konya, Türkiye, and Karam et al. (2007) obtained WUE values of 0.83 kg m^{-3} in Lebanon. The IWUE values of 1.00-2.36 kg m^{-3} were obtained in Söke, Türkiye, by Süllü and Dağdelen (2015) and 0.70-3.70 kg m^{-3} in Konya, Türkiye, by Yavuz (2006).

The results of plant-based measurements

The plant-based indicators were measured during the flowering period when the sunflower plant is most sensitive to water constraint. The flowering period of the sunflower lasted for a total of 24 days, between 27 June (DOY 178) and 20 July (DOY 201) in the first year of the experiment, and it was completed in 29 days, between 19 June (DOY 170) and 17 July (DOY 198) in 2019. During the flowering period in both research years, the experimental treatments were irrigated four times. The average of the plant-based measurements before irrigation applications from each treatment at the flowering period of sunflowers are given in Table 4. In addition, the relationship between sunflower seed yield and seasonal evapotranspiration with each plant-based measurement is shown in Figures 3 and 4.

The leaf water potential values obtained from treatments varied between -10.6 and -13.3 bar in 2018 and between -12.5 bar and -16.1 bar in 2019 (Table 4). The reason why higher leaf water potential values were obtained in 2019 compared to the first year can be attributed to the high rainfall values measured during the first year. On the other hand, the leaf water potential values obtained depending on the amount of irrigation water applied between the treatments changed, and the leaf water potential values decreased with the increasing water constraint. The lowest leaf water potential values were obtained from I_1 treatment without irrigation water, and the highest leaf water potential values were obtained from I_6 treatment with

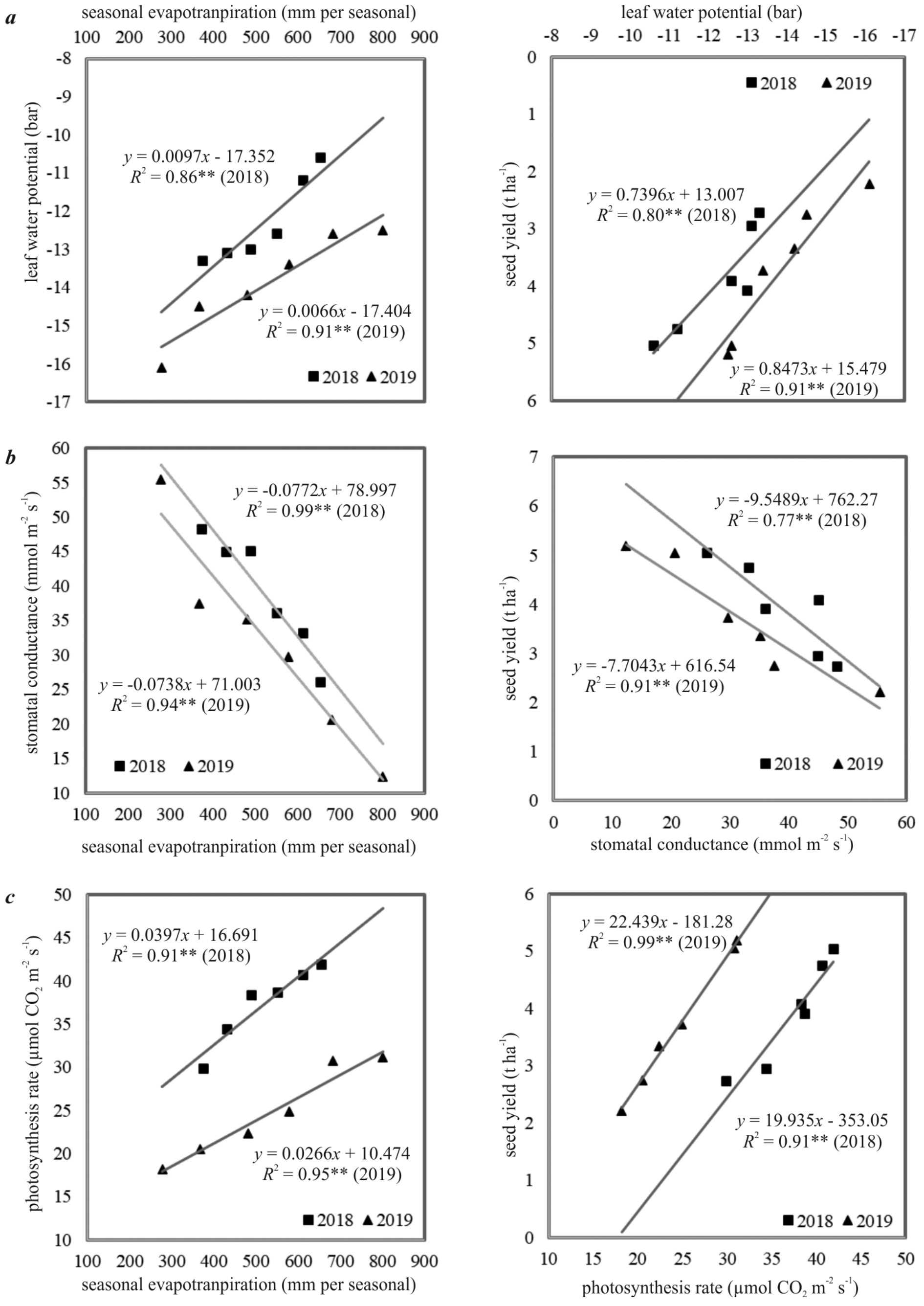

Fig 3. Relationships between seasonal evapotranspiration and seed yield of plant-based measurement techniques: *a* – leaf water potential, *b* – stomatal conductance, *c* – photosynthesis rate

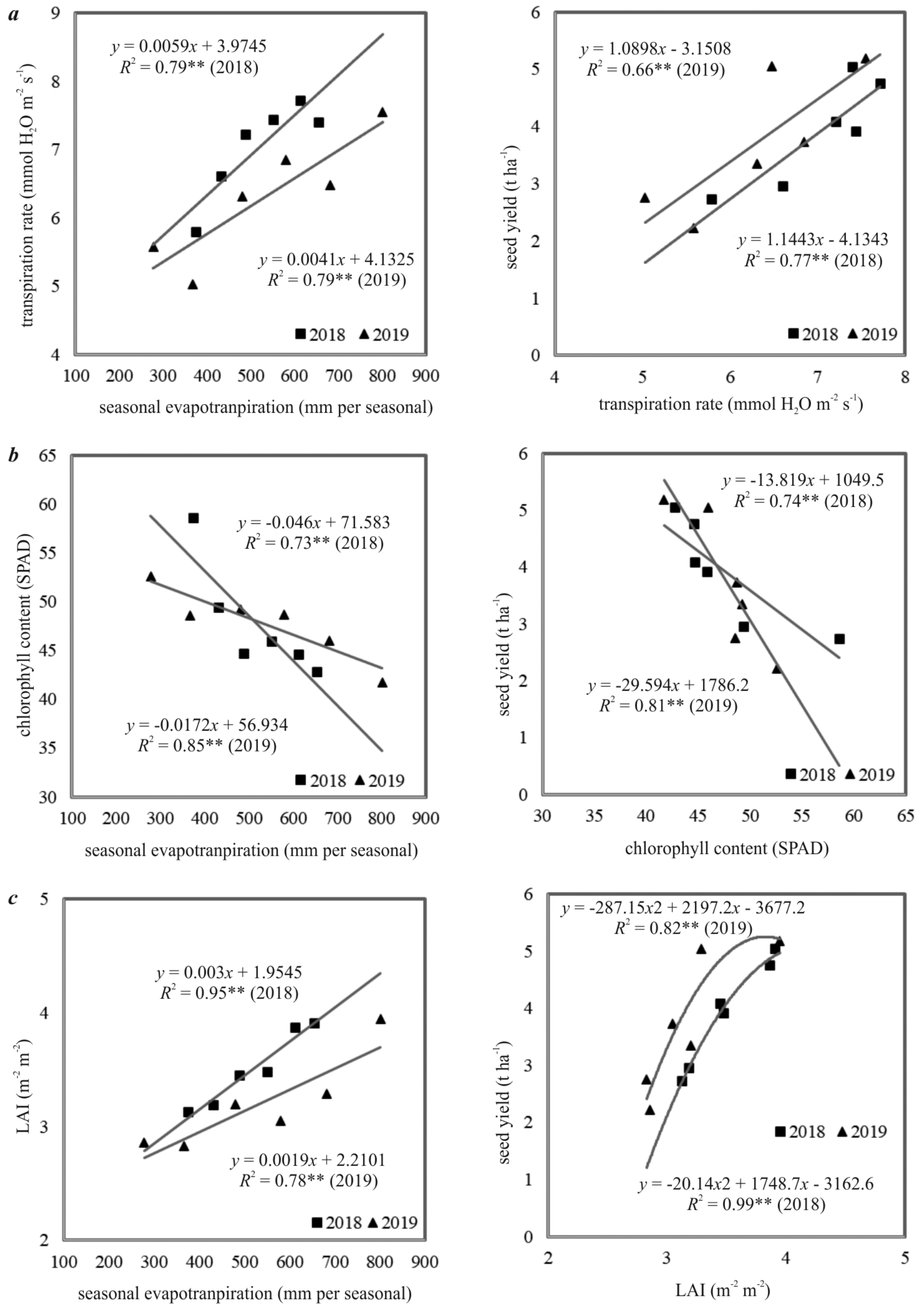

Fig 4. Relationships between seasonal evapotranspiration and seed yield of plant-based measurement techniques: *a* – transpiration rate, *b* – chlorophyll content, *c* – leaf area index

the highest irrigation water amount. As can be seen in Figure 3, linear relationships were obtained between leaf water potential values measured from treatments and sunflower seasonal evapotranspiration, seed yield. In the USA, Sionit and Kramer (1976) irrigated the sunflower when the leaf water potential values reached -16 bar and -23 bar and reported that when the leaf water potential value of the sunflower plant fell below -16 bar, the plant went into water stress.

As can be seen in Table 4, stomatal conductance values corresponding to the flowering period in both years increased due to the irrigation water constraint. The average stomatal conductance values measured during the flowering period varied between 26.02 - 48.23 mmol m^{-2} s^{-1} in 2018 and between 12.33-55.42 mmol m^{-2} s^{-1} in 2019. Linear relationships were obtained between stomatal conductance values measured during flowering and sunflower seasonal evapotranspiration, seed yield (Figure 3). Also, Orta et al. (2002) stated that the stomatal conductance values of sunflower under different irrigation water applications varied between 15 and 110 mmol m^{-2} s^{-1} under same conditions. Carvalho et al. (2020), explained in their study conducted in Brazil that stomatal conductance values of different sunflower varieties varied between 76 and 240 mmol m^{-2} s^{-1} under supplemental irrigation.

The average photosynthesis rate values measured during the flowering period varied between 29.86-41.90 µmol CO_2 m^{-2} s^{-1} in 2018 and between 18.18-31.11 µmol CO_2 m^{-2} s^{-1} in 2019 (Table 4). In both years, the photosyn-

Table 4

Plant-based measurements for treatments

Year	Treatment	LWP (bar)	gs (mmol m^{-2} s^{-1})	P_n (mmol CO_2 m^{-2} s^{-1})	E (mmol H_2O $m^{-2}s^{-1}$)	Chl (SPAD)	LAI (m^2 m^{-2})
2018	I_1	-13.3	48.23	29.86	5.79	58.6	3.13
	I_2	-13.1	44.95	34.42	6.61	49.4	3.19
	I_3	-13.0	45.05	38.31	7.22	44.7	3.45
	I_4	-12.6	36.05	38.68	7.44	45.9	3.48
	I_5	-11.2	33.15	40.69	7.72	44.6	3.87
	I_6	-10.6	26.02	41.90	7.40	42.8	3.91
2019	I_1	-16.1	55.42	18.18	5.58	52.6	2.86
	I_2	-14.5	37.48	20.55	5.03	48.6	2.83
	I_3	-14.2	35.21	22.36	6.31	49.2	3.20
	I_4	-13.4	29.72	24.87	6.85	48.7	3.05
	I_5	-12.6	20.59	30.77	6.48	46.0	3.29
	I_6	-12.5	12.33	31.11	7.55	41.7	3.95

LWP – leaf water potential, gs – stomatal conductance, P_n – photosynthesis rate, E – transpiration rate, Chl – chlorophyll content, LAI – leaf area index thesis rate values obtained from the treatments changed depending on the increase in the amount of irrigation water applied. While the lowest photosynthesis rate values were obtained from I_1 treatment, the highest photosynthesis rate values were obtained from I_6 treatment in both years. The linear relationships at *p*<0.01 level were obtained between the measured photosynthesis rate values and sunflower seasonal evapotranspiration, seed yield (Figure 3). Additionally, Carvalho et al. (2020) measured the photosynthesis rate values of different sunflower varieties under irrigation applications between 27.16 and 31.72 μmol CO_2 m^{-2} s^{-1}.

The average transpiration rate values obtained from the treatments varied between 5.79-7.72 mmol H_2O m^{-2} s^{-1} in 2018, and between 5.03-7.55 mmol H_2O $m^{-2}s^{-1}$ in 2019 (Table 4). The transpiration rate measured for the treatments changed depending on the increase in the amount of irrigation water applied in both years. The lowest transpiration rate values were obtained from I_1 treatment in 2018 and the I_2 treatment in 2019, while the highest transpiration rate values were obtained from I_5 treatment in 2018 and I_6 treatment in 2019. The linear relationships at *p*<0.05 level was obtained between measured transpiration rate values and sunflower seasonal evapotranspiration and seed yield for treatment in both years.

Average chlorophyll content values obtained from treatments varied between 42.8 and 58.6 in 2018 and between 41.7 and 52.6 in 2019 (Table 4). In both years, SPAD values obtained from treatments changed depending on the increase in the amount of irrigation water applied. The lowest SPAD values were obtained from I_6 treatment in both years. Linear relationships were obtained between SPAD values measured during flowering and sunflower seasonal evapotranspiration, seed yield (Figure 4). Furtado et al. (2016) stated in the study conducted in Brazil, where five different amounts of irrigation water were applied that the SPAD values increased with the decrease in the amount of water applied. The SPAD values obtained for the sunflower plant are in parallel with the values obtained from previous studies (Furtado et al. 2016, Uçak 2018).

The average leaf area index values measured before each irrigation application during the flowering period of the sunflower ranged from 3.13 to 3.91 m^2 m^{-2} in 2018, from 2.86 to 3.95 m^2 m^{-2} in 2019 (Table 4). In both years, LAI values increased due to the increase in the amount of irrigation water applied. Linear relationships were obtained between LAI values measured during flowering period and seasonal evapotranspiration of sunflower (Figure 4). Also, Orta et al. (2002) explained that sunflower LAI values were at the highest in the flowering period and these values varied between 3.31-4.05 m^2 m^{-2} under different irrigation water applications.

CONCLUSIONS

In this research, linear relationships were calculated between applied irrigation water, measured seasonal evapotranspiration and seed yields of sunflower. As the amount of irrigation water applied and the measured evapotranspiration increased, the yield of sunflower seed yield increased. The highest seasonal evapotranspiration and seed yield values were achieved in both years in the treatment where 125% of the open water surface evaporation amount measured from A class pan was applied. When all the data obtained on sunflower seed yield harvested after different irrigation regimes were examined together, it was concluded that the plant is relatively resistant to water shortage. This result supports the claim that obtaining higher yields than the country's average from the sunflower plants grown only under rain-fed conditions in the region's conditions is possible. On the other hand, it is also possible to increase the sunflower yield owing to irrigation. The IWUE and WUE values were found to be high in the experimental treatments with less irrigation water. As a result of evaluating these data together, it can be recommended to apply 100% and 125% of the open water surface evaporation amount measured from the A class pan in a 7-day irrigation interval where the water resources are sufficient and a drip irrigation method is applied. On the other hand, taking into account the high IWUE and WUE values in conditions where the water supply is limited, it can be recommended to apply 25 and 50% of the open water surface evaporation amount measured from the A class pan in a 7-day irrigation interval.

Leaf water potential values obtained from the treatments varied between -10.6 and -13.3 bar in the first year and between -12.5 bar and -16.1 bar in the second year. According to these results, it can be suggested to use -13 and -14 bar leaf water potential values for irrigation of sunflower plants, especially under limited water resource conditions. Stomatal conductance values measured before irrigation increased as the amount of irrigation water applied increased. It can be suggested to take the stomatal conductance value of 35-70 mmol m^{-2} s^{-1} as indicating the need to start irrigation of sunflowers grown under limited water supply conditions. In both years, the photosynthesis rate and transpiration values obtained from the experimental treatments changed depending on the increase in the amount of irrigation water applied. In water deficit conditions, it can be suggested to consider the photosynthesis rate in the range of 25-35 μmol CO_2 $m^{-2}s^{-1}$ and transpiration rate in the range of 5-8 mmol H_2O m^{-2} s^{-1} for planning the irrigation of sunflower plants. No major differences were found in the measured leaf area index (LAI) values from the treatments and the values varied between 2.83 and 3.95 m^2 m^{-2}. LAI values increased as the amount of irrigation water applied increased. The SPAD values obtained from the experimental treatments changed depending on the increase in the amount of irrigation water applied. It can be suggested to consider the chlorophyll content (SPAD) value in the range of 45-50 for planning the irrigation of sunflower plants under water deficit conditions.

As a result, it is important to determine the data required for the irrigation of sunflower, related to the protection of soil and water resources where irrigation practices are not very intensive and drip irrigation installations have only been started recently. For this reason, it is thought that the data obtained in this research will be useful for producers and researchers.

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