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ORIGINAL PAPER

Response of young fig (*Ficus carica* cv. Sarılop) trees to different irrigation levels in a semi-arid mediterranean environment

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Abstract

Drought scenarios that will be faced in the near future in the Mediterranean Basin will affect sustainable crop production in the region. Even the drought tolerant crops under rain-fed conditions will need supplemental irrigation. The fig tree originates from this region and is grown under semi-arid conditions as a drought-prone crop. The aim of this research is to develop irrigation strategies under various irrigation levels in young fig trees. Five irrigation levels were investigated, covering the rainfed treatment (S0), as well as the fully irrigated treatment S4 (100%) and the S1 (25%), S2 (50%) and S3 (75%) treatments of the full irrigation level. The vegetative growth parameters including plant height, stem diameter, shoot length and number of leaves were evaluated in a two-year field experiment. Additionally, stem water potential (SWP), leaf area index (LAI) and proline content (PC) were also measured. The average seasonal water use values (ET) of young trees ranged from 25.5 to 472.2 mm. Plant vegetative growth parameters were significantly affected by irrigation levels and higher growth was observed in the S3 (75%) and S4 (100%) treatments. Plant physiological responses to different irrigation levels have a significant impact on SWP, LAI and PC measurements. In conclusion, S3 treatment (75% irrigation level) appears to be a good alternative to fully irrigated treatment for growing young fig trees under water-scarce conditions in western Turkey. SWP could be used as a tool in irrigation scheduling of young fig trees. Mean SWP values between -0.82 and -0.86 MPa can be accepted as threshold value for semi-arid regions.

Keywords: deficit irrigation, fig, vegetative growth, stem water potential, LAI, proline

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INTRODUCTION

Fig (*Ficus carica* L.) is among the earliest cultivated fruit species, and an important crop worldwide for both fresh and dried consumption (Trichopoulou et al. 2006). Seventy percent of the world's fig production is grown in the countries along the Mediterranean coast. Turkey is the leading fig producing and exporting country in the world, with a production area of 53 694 ha (Özen et al. 2007, FAO 2022, TUIK 2022).

Even though the fig sector in Turkey has achieved great superiority in production and trade worldwide, it faces many challenges. Climate change has affected the Mediterranean Basin leading to prolonged dry periods and fluctuations in both minimum and maximum temperatures. Also, the increased frequency of extreme weather conditions, such as heavy rain, hail and drought, poses significant threats to the cultivation of figs (Flaishman et al. 2022). In addition to the climate change, various factors such as cultural practices and variety also affect the quality of figs. Water availability controls the growth, development and yield of crops. However, research is needed to reveal the evapotranspiration of each variety under different conditions. Different fig genotypes exhibit varying responses to deficit water (Oukabli et al. 2008). It has been stated that the annual evapotranspiration of figs in the Aydın region is approximately 560 mm (Anonymous 2017). If the total rainfall amount falls below 550 mm/year, supplemental irrigation is recommended in winter and early spring (İrget and Meriç 2022).

In order to develop an irrigation management strategy, the effects of water stress on plant growth should be quantified (Abdolahipour et al. 2019). Studies conducted on the effect of irrigation on fig trees have been reported by some researchers. The growth and the productivity of figs negatively affected by severe drought conditions (Tapia et al. 2003, Allam et al. 2007, Al-Desouki et al. 2009, El-Dakak et al. 2021) Different levels of irrigation water had significant effect on fruit yield, branch length, fruit diameter and fruit height; improved vegetative growth, total and relative water content and leaf chlorophyll content of 1-year old fig cultivars; more frequent irrigation increased vitamin-C content, total soluble solids and total sugar, carbohydrate percentage, fruit firmness and percentage of fruit cracking, and supplemental irrigation improved vegetative growth, number of fruit, yield and quality (Hernandez et al. 1994, Al-Desouki et al. 2009, Al- Hmeedawi et al. 2013, El-Shazly et al. 2014). Supplemental irrigation resulted in a higher soil water content in the soil profile and sustainable use of water in rainfed fig orchards (Abdolahipour et al. 2018, Abdolahipour et al. 2019).

In recent years, the importance of irrigation has been well understood in the changing climate; however, the research is very limited on determining the crop water requirements and responses of young fig tree to different irrigation regimes. Fig trees in the Aydın region have been mostly grown in the foothills of the Aydın mountains in rainfed conditions for centuries, but especially in the last two-decades, fig orchards have been extensively established in the basin. Therefore, the growers' need for knowledge about the irrigation management of young fig trees has begun to arise. The aim of this research is to observe the morphological and physiological responses of young fig trees to different irrigation levels and to develop an irrigation management strategy for young fig trees in a semi-arid Mediterranean environment.

MATERIALS AND METHODS

Experimental site description

This research was carried out in 2016 and 2017 in the Fig Research Institute located in Aydın, Turkey. The trial area is located between 37°51′50″ northern latitude and 27°39′49″ eastern longitude, at an altitude of 50 m. The Mediterranean climate, characterized by hot and dry summers and warm and rainy winters of the mesothermal type. The average climatic data for the years 2016 and 2017 of the research area were provided by the meteorology station located within the institute (iMETOS 3.3), and presented in Table 1.

The features of the soil profile are listed in Table 2. The soil profile was investigated for its physical and chemical characteristics at a depth of 0-90 cm. The soil has a sandy-loam texture, with average values for $CaCO_3$ content and EC, pH, soil bulk density, field capacity and wilting point ranging from 1.43-2.77%, 0.078 to 0.094, 8.15 to 8.60, 1.53 to 1.59 g cm^{-3}, 12.40 to 14.10% and 5.9 to 6.5% in 0-90 cm in the soil depth.

The irrigation water was extracted from a well located at the Fig Research Institute. From this source, irrigation water is distributed to the area using a pressurized water distribution network. The EC of the irrigation water is 0.958 dS m^{-1} and the pH is 7.74. The characteristics of the irrigation water are provided in Table 3.

Agronomic practices

In the experiment, the Sarilop fig variety, which is widely grown in the Aydın region, was used. The variety adapts optimally to the climate conditions of Aydin and Izmir provinces in the Aegean Region. It has an important advantage in terms of drying technology and quality parameters. The first ripening occurs at the end of July and the beginning of August, and harvesting is completed at the end of September (Özen et al. 2007). The seedlings were reproduced through cuttings in 2014 and grown in peat and perlite substrates. In 2015, they were planted in 6 x 4 m spacing.

Table 1

Climatic data of the trial area

Year	Climatic parameter	Months											
		1	2	3	4	5	6	7	8	9	10	11	12
2016	$temperature_{mean}$ (°C)	7.4	12.4	12.5	18.0	20.2	27.6	29.6	28.9	23.9	19.2	13.2	5.6
	$temperature_{min}$ (°C)	-7.8	-3.0	0.7	4.7	8.2	11.6	16.8	16.1	7.9	5.8	-0.8	-6.2
	$temperature_{max}$(°C)	21.6	26.7	26.9	33.1	35.1	38.3	37.0	37.5	36.9	33.0	30.1	19.3
	relative humidity (%)	78.1	78.7	75.4	60.4	61.0	49.3	47.8	54.8	57.1	60.4	69.1	69.9
	wind speed (m s^{-1})	3.8	2.6	2.2	2.2	2.3	2.4	2.5	2.5	2.1	1.9	2.0	1.7
	precipitation (mm)	187.6	50.5	119.6	11.1	46.4	1.9	-	-	6.0	0.1	69.4	5.7
2017	$temperature_{mean}$ (°C)	6.1	9.9	13.0	16.2	21.1	26.2	29.6	28.5	24.1	18.0	12.0	10.9
	$temperature_{min}$ (°C)	-4.8	-3.8	-1.0	2.8	7.8	13.2	15.6	15.0	8.9	6.0	-0.9	-1.9
	$temperature_{max}$(°C)	18.7	22.5	26.8	31.9	34.7	44.1	45.5	40.3	40.5	31.7	25.4	23.6
	relative humidity (%)	77.3	72.4	72.2	62.4	60.2	54.5	46.8	55.0	55.1	63.9	78.9	80.2
	wind speed (m s^{-1})	2.2	1.8	2.2	2.1	2.2	2.3	2.4	2.3	2.2	1.9	1.7	2.2
	precipitation (mm)	192.9	17.4	61.8	38.6	16.1	21.0	-	9.6	-	67.0	85.4	78.5
Long term average	$temperature_{mean}$ (°C)	8.1	9.3	11.7	15.9	20.9	25.8	28.4	27.6	23.5	18.4	13.4	9.5
	$temperature_{min}$ (°C)	4.2	4.9	6.6	10.0	14.1	18.0	20.4	20.2	16.6	12.6	8.7	5.6
	$temperature_{max}$(°C)	12.9	14.6	17.7	22.5	28.1	33.2	36.0	35.6	31.9	26.2	19.7	14.4
	relative humidity (%)	80.1	79.0	73.0	62.5	60.1	53.3	47.9	52.7	57.3	65.9	76.5	78.7
	wind speed (m s^{-1})	3.3	3.1	3.1	3.1	3.2	3.4	3.4	3.2	3.0	2.6	2.5	2.4
	precipitation (mm)	116.5	93.6	70.9	48.8	35.2	13.7	3.7	2.3	12.6	44.1	82.6	122.0

Table 2

Soil properties of the experimental site

Soil depth (cm)	Sand (%)	Clay (%)	Loam (%)	Texture class	$CaCO_3$ (%)	EC (dS m^{-1})	pH	Bulk density (g cm^{-3})	Field capacity (%)	Wilting point (%)
0–30	69.0	9.6	21.4	SL	1.43	0.094	8.15	1.53	12.4	6.2
30–60	72.6	8.1	19.3	SL	1.51	0.094	8.24	1.59	12.7	5.9
60–90	67.9	10.2	22.0	SL	2.77	0.078	8.60	1.56	14.1	6.5

Table 3

Irrigation water properties of the experimental site

Cations (me L^{-1})				Anions (me L^{-1})				pH	EC (dS m^{-1})	SAR (me L^{-1})
Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{-2}	HCO_3^{-}	Cl^{-}	SO_4^{-2}			
0.51	6.72	2.24	0.09	0	8.35	1.2	–	7.74	0.958	1.38

In the experimental site, 300 kg da^{-1} of organic fertilizer was applied in both years of the experiment in order to sustain organic production. Mechanical methods were used in weed management instead of applying herbicides to the trial area. Traps for *Carpophilus sp.* were used in order to prevent possible disease damage.

Experimental design and treatments

The experiment was conducted on-farm when the trees were 2- and 3-year-old (2016 and 2017 years). The trial was set up in the randomized complete block design with three replications. There were a total of fifteen plots in the trial, with each plot containing three fig trees. Thus, a total of 45 young fig trees were used in the trial. In order to prevent the water-interaction between treatments, one tree was excluded from the irrigation treatments in the row, and one row of trees was also excluded between each block, between the rows. The layout of the treatment is given in Figure 1.

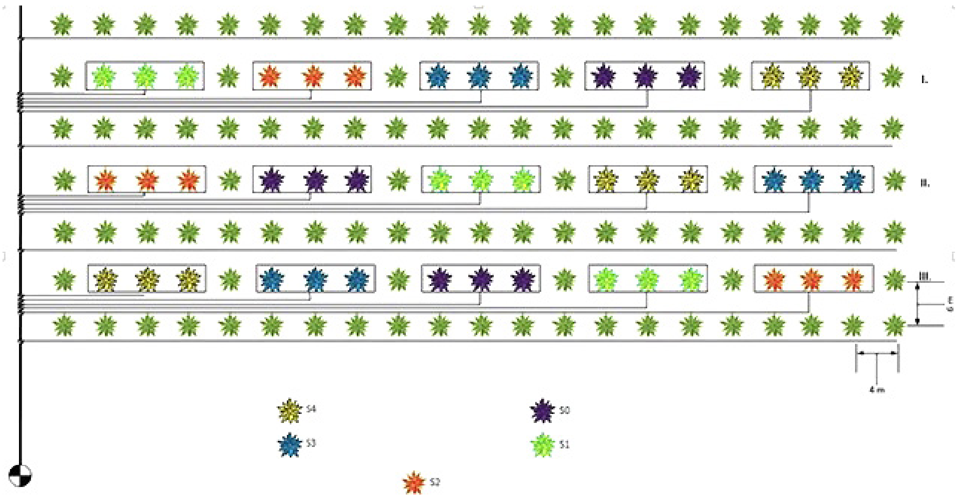

Fig. 1. Layout of the experiment

The trees were irrigated by a drip irrigation system in a circular lateral design, with 6 emitters per tree in 0.75 m emitter distance. Each online emitter has 4 L h^{-1} flow capacity. Irrigation water was extracted from the well with a pump to the trial area, filtered through a control unit and conveyed to the main pipe, manifold and laterals. The amount and duration of irrigation water applied to each plot were controlled by the valves installed at the inlets of each lateral. The experiment was set up according to the randomized block trial design carried out with three replications and with five different irrigation treatments. The irrigation treatments were arranged based on the replenishment of soil water depletion. In this study, five irrigation levels (IL) were investigated. These are the treatments;

S0 which represents the rainfed treatment; S1, S2 and S3 which received 25%, 50% and 75% of the amount applied to S4 and S4, which received 100% of the water needed to bring the 0-90 cm soil profile to field capacity (control treatment).

Soil moisture content of the plots was measured gravimetrically on a weekly basis prior to each irrigation. Measurements were taken at depths of 0-90 cm with 30 cm depth increments using a hand-sampler at sampling points within each plot in the observation block. Based on these values, the amount of irrigation water to be applied to S4 (control) was determined using the equation given below (Doorenbos and Pruitt 1977).

$$I = \frac{[Pw_{FC} - SM_{Ava}]}{100} \times D \times P_{WA} \times \gamma_s$$

Here, I represents the amount of water applied to S4 (mm), Pw_{FC} denotes the field capacity (%), SM_{ava} refers to the available soil moisture (%), D represents the depth of the soil layer (mm), P_{WA} indicates the percentage of the wetted area and γ_S represents the bulk density of the soil (g cm^{-1}). P_{WA} is considered as 0.3 (30%) (Keller and Bliesner 1990).

Evapotranspiration of the fig trees under varying irrigation levels is determined according to the water balance equation (Allen et al. 1998).

$$ET = I + P + \Delta S_w - D_{Per} - R_{off}$$

In the equation, ET represents the evapotranspiration amount in mm, I represents the amount of irrigation water applied in mm, P represents the amount of precipitation in mm, ΔS_w is the amount of the variation in the soil water content at a depth of 0.9 m. D_{Per} and R_{off} are ignored due to the fact that they occur in negligible amounts.

Crop measurements and analyses

In both years of the experiment, the vegetative growth parameters: plant height (m), stem diameter (mm), shoot length (cm) and the number of leaves in the shoot, were determined from three trees in each plot of each replication, at the beginning and end of the experiment. The stem diameter of each plant was measured using a caliper at a height of 5 cm above the ground surface. During the season, the shoot length and the number of leaves in the shoot were measured. One shoot in each of the four directions (north, south, east, west) of the trees was selected and labelled at the beginning of the season, and the average values for the four shoots of each tree were considered in the analysis of vegetative growth.

The stem water potential (SWP) was measured in the leaves selected from the southern part of each tree of each plot using the pressure chamber method (Model 1515D, PMS Instrument Company) (Scholander et al. 1965). The first pair of fully developed leaves from the shoot end point was selected and covered in plastic bags. They were wrapped with aluminum foil approximately 45 minutes before the measurement to allow them to reach an equilibrium with the water potential in the stem (Kong et al. 2013). The latex that leaks from the cutting point of the leaves was immediately dried with a piece of paper towel. SWP was measured throughout the experiment once every two weeks, starting from the beginning of the trial and one day before irrigation between 12:00–14:00 h.

The leaf area index measurements were performed monthly throughout the growing season using an LI-COR LAI-2200 Plant Canopy Analyzer (LI-COR Biosciences, Lincoln, USA). Measurements were taken from each tree in each plot on the days following irrigation when the sky was clear and sun was unobstructed by the clouds. A total of eight readings (four readings from the lower part and four from the upper part of the tree) were taken between 12:00 and 13:30 in four main directions of the tree.

In the experiment, sampling was performed on a monthly basis to determine the proline content of the leaves (Bates 1973). 5.0 ml of 3% sulfosalicylic acid was added to 0.5 g of dried and ground leaf samples and boiled in a water bath for 30 minutes at 100°C. The mixture was centrifuged for 5 min at 25°C. 400 ml of distilled water and 2.0 ml of the reagent mixture were added to 200 ml of the extract and boiled at 100°C for 60 minutes. 6.0 ml of toluene was added after cooling. While reading, toluene used as a blank and the absorbance at 520 nm (A520) was measured from the sample. The proline concentration was determined in μmol g^{-1} DW, using L-proline for the standard curve (Sofo et al. 2004).

Statistical evaluation

The data obtained in the trial were analyzed for variance (ANOVA) using the software SPSS Statistics version 22. In order to compare and rank the treatment averages, the Duncan test with 5% probability of error was used. Relationships between evapotranspiration and physiological measurements were determined through regression analyses.

RESULTS AND DISCUSSION

Irrigation and evapotranspiration

In the first year of the experiment, the climatic conditions in the trial area were consistent with the long-term averages. However, due to heavy rainfall that occurred in a few days in May 2016 (46.4 mm), irrigation application in 2016 was delayed compared to 2017. In 2017, both the mean and maximum air temperatures were higher than the long-term averages during the irrigation period. During both trial years, monthly precipitation fluctuated. The total rainfall for the experimental year 2016 was 8 mm, and it was

55.3 mm in 2017. The irrigation program was launched on the June 2nd and ended on October 25th in 2016, In 2017, it started on May 16th and ended on October19th. The irrigations carried out 26 times in 2016 and 25 times in 2017. Since fig trees are tolerant to water stress (Flaishman et al. 2008), the irrigation program was initiated when 50% of the moisture content in the 0-90 cm of soil profile was depleted. The variation of the soil water content (SWC) in the effective rooting depth (0-90 cm) according to the IL in different trial years is given in Figure 2.

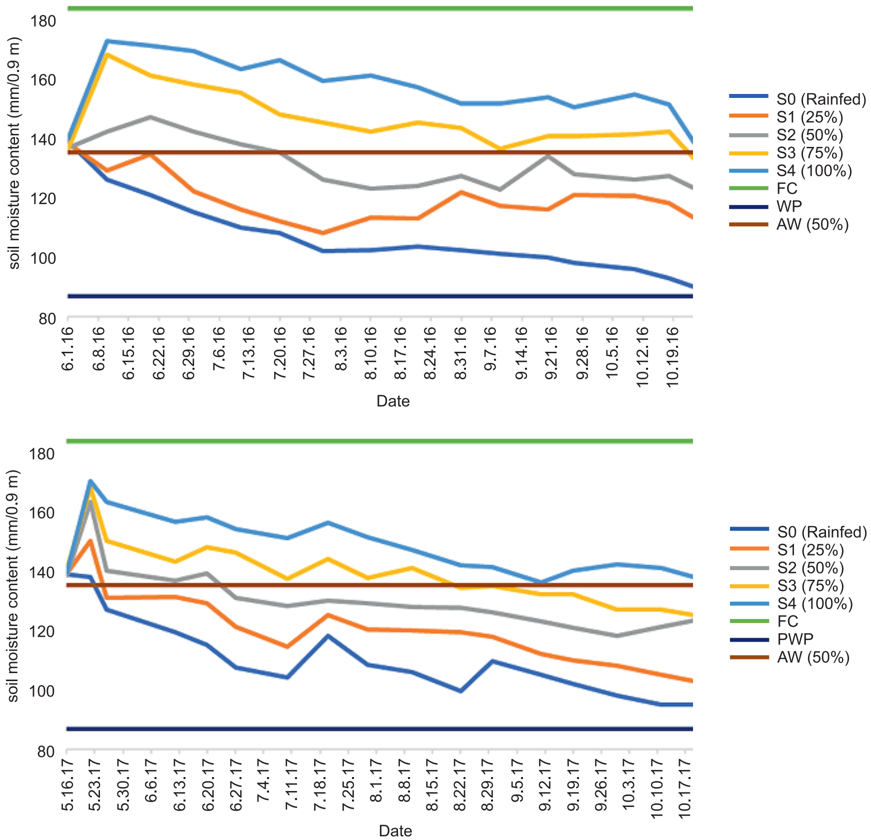

Fig. 2. The variation in the soil water storage according to irrigation levels (2016 - 2017)

The soil moisture fluctuated between the field capacity and wilting point in the plots, depending on the irrigation levels. SWC decreased below the 50% available water level in rainfed, S1 (25%) and S2 (50%) treatments, and continued to decline throughout the irrigation season. The weather conditions in 2017 were more severe and the mean T_{max} being around 10°C higher than the long-term averages. Due to the high sand content in the soil texture and the high temperatures, SWC of the plots fell below the maximum allowable depletion. SWC in S4 (100%) plots remained within 50%

available water level during both irrigation seasons, in contrast to the other treatments.

The amounts of irrigation water, number of irrigations, and evapotranspiration (ET) for the treatments under different irrigation levels (IL) are presented in Table 4. The ET values were calculated throughout the irrigation program for both experimental years and the ET values of the treatments exhibited differences by years. The range of rainfall varied from 25.5 to 469.0 mm in 2016, and from 74.0 to 472.2 mm in 2017, depending on the irrigation levels.

Table 4

Irrigation water amounts and evapotranspiration of two experimental years

Year	Irrigation levels	Irrigation water amount (mm)	Number of irrigations	Precipitation (mm)	Water use (ET) (mm)
2016	S0 (0%)	-	-	8.0	25.5
	S1 (25%)	111.3	26	8.0	133.9
	S2 (50%)	229.5	26	8.0	243.5
	S3 (75 %)	344.2	26	8.0	356.0
	S4 (100%)	459.1	26	8.0	469.0
2017	S0 (0%)	-	-	55.3	74.0
	S1 (25%)	106.0	25	55.3	176.3
	S2 (50%)	212.1	25	55.3	267.2
	S3 (75 %)	318.3	25	55.3	371.0
	S4 (100%)	424.2	25	55.3	472.2

Differences in ET in the trial years could be attributed to the variation in climatic conditions between 2016 and 2017, which resulted in fluctuations in soil water content throughout the profile. In a two-year study conducted in Iran, the average evapotranspiration values of figs varied depending on the vegetative periods and irrigation treatments. In the first year of the trial, the values ranged between 312.15-417.55 mm, while in the second year, they ranged from 245.43-333.43 mm. Additionally, the application of 2000 L per tree of supplemental irrigation resulted in higher soil water content in the soil profile and reduced evaporation (Abdolahipour et al. 2018). Annual total precipitation nearly meets the water requirements of figs in the Aegean Region of Turkey (İrget and Meriç 2022). However, the uneven distribution of rainfall could pose a challenge, even in rainfed fig production (Bagheri and Sepaskhah 2014). The annual ET of the mature fig tree in the Aydın region calculated using the Penman-Monteith method is approximately 560 mm (Anonymous 2017). The variation in the ET value of the rainfed treatment (S0) between years was due to the high rainfall in the irrigation season in 2017 (55.3 mm). Under deficit irrigation, crops can tolerate a certain level of water stress, resulting in reduced growth and yield. This occurs when the amount of irrigation water supplied is less than the crop ET during the growing season (Costa et al. 2007). Irrigation water applied at 85.19-95.16% ET level under semi-arid conditions yielded the best results for figs in terms of higher water-use efficiency (Al-Desouki et al. 2009). In 3-year-old fig trees, irrigation with 220 mm/year will be adequate for growth and development (Abdolahipour et al. 2022). The irrigation frequency affects the water requirement of the fig tree. More frequent irrigation intervals result in higher kc values in 3-year-old fig trees due to increased evapotranspiration, which is a consequence of higher water content in the soil profile (Hernandez et al. 1994; Andrade et al. 2014). Although the fig is considered a drought-tolerant plant, long-term water deficit can negatively impact its development and yield. Therefore, supplemental irrigation is recommended to achieve higher yields if the precipitation amount is insufficient for fig production (Abdolahipour et al. 2022, Tapia et al. 2003). In this study, ET of the fully irrigated treatment (S4) was 469.0 mm in 2016 and 472.2 mm in 2017, respectively. Considering the age of the trees in this study, The ET values were found to be in parallel with previous studies.

The phenological observation dates of young cv. Sarılop fig trees for the trial years are given in Table 5. Despite the uneven distribution of rainfall in the two experimental years, the main phenological observation dates did not exhibit notable differences.

Table 5

Phenological observation dates of the two experimental years

Phenological observations	2016	2017
Leaf Formation	16th - 19th of March	17th - 20th of March
Onset of fruit	8th - 10th of May	9th - 11th of May
Fall of leaves	End of November-Early December	End of November-Early December

Vegetative growth parameters

Variations in the plant height (m), stem diameter (mm), shoot length (cm) and number of leaves under different irrigation levels for both experimental years are presented in Table 6. Measurements were taken at the beginning and at the end of the experiment, and the differences of measurements were calculated and statistically analyzed in order to exhibit the variations under different irrigation levels.

Differences of the observed values of the plant height among the irrigation levels have shown variations at p<0.01 for 2016. (Table 6). In the first year of the experiment, the differences between the measurements at the beginning and at the end of the experiment were found to be the highest in S3 (0.42 m) and the lowest in S0 (0.13 m). The variations in the periods considered according to the results of the Duncan test showed that the

Table 6

Seasonal variations in the vegetative growth parameters under different irrigation levels

Vegetative growth parameters	Year	Irrigation Levels					
		p	S0 (Rainfed)	S1 (25%)	S2 (50%)	S3 (75%)	S4 (100%)
Plant height (m)	2016	**	0.13*a*[1]	0.33*b*	0.33*b*	0.42*b*	0.34*b*
	2017	ns	0.70	0.80	0.88	0.80	0.76
Stem diameter (mm)	2016	**	6.38*a*	9.95*b*	12.22*bc*	13.57*c*	13.78*c*
	2017	ns	16.56	17.55	17.64	17.84	19.32
Shoot length (cm)	2016	ns	13.59	20.16	25.89	27.74	25.53
	2017	**	8.84*a*	15.85*b*	18.30*c*	20.47*d*	16.61*bc*
Number of leaves	2016	*	5.19*a*	7.78*ab*	8.75*b*	10.83*b*	10.31*b*
	2017	**	7.33*a*	13.5*bc*	13.69*bc*	13.95*c*	12.39*b*

** p<0.01, * p<0.05, ns – not significant

[1] Means with different letters in the same row indicate significant differences between treatments according to the Duncan's multiple range test (n=3 replicates, p<0.05)

S0 (rainfed) treatment differed from the other IL in 2016. In 2017, different IL treatments did not display any remarkable effect on plant height, while the smallest difference in plant height averages was observed in S2 (0.80 m), and the lowest difference was seen in S0 (0.70 m), both at the end of the experiment.

The difference in the stem diameter under different IL in the first year of the experiment was found significant at p<0.01. When comparing the variation between the pre- and post-experiment periods, the largest change in stem diameter in 2016 was observed in S4, with a difference of 13.78 mm. On the other hand, the smallest difference was observed in S0, with a change of 6.38 mm. Although there was no statistically significant difference in the variations obtained from the measurements taken between the end and the beginning in 2017, the highest value was observed in S4 (19.32 mm), and the lowest value was obtained from S0 treatment (16.56 mm), in which they resembled the results obtained in 2016.

The data in Table 6 revealed that deficit irrigation had a negative effect on the shoot length development of young fig trees during the trial. Experimental results of 2017 related to shoot length indicated a significant effect of reduced irrigation levels at p<0.01, but results of 2016 showed no significance. The largest disparity between the end and the beginning of the 2016 experiment was observed in the S3 treatment, with a difference of 27.74 cm. In contrast, the rainfed (S0) treatment had an average difference of 13.59 cm. In the second year of the study, the highest shoot length growth occurred in the S3 treatment (20.47 cm), as determined by pre- and post-experimental measurements. The averages of each treatment were found to be significantly different from each other based on statistical comparisons.

A significant change was observed in the number of leaves per shoot at the $p<0.05$ level for the year 2016 and at $p<0.01$ level for the year 2017, as presented in Table 6. In the first year of the trial, the highest foliation value was observed in the S3 treatment throughout the entire period (10.83), while a decrease was observed in the treatments with reduced irrigation water application. The rainfed treatment exhibited a lower number of leaf formations in the shoot compared to the other irrigation levels. Similar results were reached in 2017; the highest rate of leaf formation occurred in S3 (13.95) and the lowest one – in the S0 treatment.

Significant differences were observed in the vegetative growth parameters depending on the irrigation level throughout the trial years. As regards all the traits examined, the highest change was observed in the trees where the 75% (S3) irrigation level was applied, except for the stem diameter. The stem diameter yielded the best results under the full irrigation treatment (S4). As shown in Table 6, a notable finding is that various ILs applied in 2016 had a significant impact on plant height and stem diameter at $p<0.01$ level. However, shoot length did not show a significant effect, while the number of leaves in the shoot was affected at $p<0.05$ level. On the contrary, in 2017, plant height and stem diameter were not significantly affected. However, shoot length and the number of leaves per shoot were significantly affected by the treatments at $p<0.01$ level. This may indicate that the 2-year-old fig trees showed better development in terms of plant height and stem diameter, while the 3-year-old ones exhibited growth and development in shoot and leaf formation. In light of this information, careful consideration should be given to irrigation strategies during the establishment and management of young fig orchards. Previous studies have presented results emphasizing the importance of irrigation in improving either the vegetative growth or the yield of fig trees under water stress conditions. The findings of the study align with other similar studies. Six different irrigation levels applied to figs have improved branch length (Hernandez et al.1994). Increasing amounts of irrigation improved the vegetative development of figs grown in Egypt (Al-Desouki et al. 2009). Three different irrigation levels (100% ETc, 75% ETc and 50% ETc) had a positive impact on the vegetative growth of 1-year-old fig trees (El-Shazly *et al*. 2014). In a two-year study, the timing and amount of irrigation at different distances from the tree trunk did not affect the growth parameters of figs (Abdolahipour et al. 2019). A high correlation was found between irrigation amount and shoot length of 3-year-old six fig varieties (Tapia et al. 2003). Therefore, it can be concluded that excessive irrigation or water restriction will adversely affect plant growth. The variation in vegetative growth parameters between pre- and post-experiment measurements can be considered useful indicators for understanding the extent of plant development.

Stem water potential

Data showing the impact of different ILs on stem water potential (SWP) measured once every two weeks during the experiment and one day before irrigation are given in Table 7 and Table 8.

Table 7

Effects of different irrigation levels on the stem water potential (2016) (MPa)

Day of year	*p*	Irrigation levels				
		S0 (Rainfed)	S1 (25%)	S2 (50%)	S3 (75%)	S4 (100%)
153.	**	-0.81*a*[1]	-0.76*ab*	-0.73*b*	-0.72*bc*	-0.70*c*
167.	**	-0.85*a*	-0.81*b*	-0.80*bc*	-0.78*c*	-0.74*d*
179.	**	-0.90*a*	-0.88*ab*	-0.83*b*	-0.77*c*	-0.68*d*
193.	**	-1.04*a*	-1.00*b*	-0.96*c*	-0.88*d*	-0.81*e*
202.	**	-1.02*a*	-0.99*a*	-0.94*b*	-0.89*c*	-0.80*d*
218.	**	-0.99*a*	-0.91*b*	-0.89*b*	-0.84*c*	-0.81*d*
228.	**	-1.11*a*	-1.02*b*	-0.98*c*	-0.96*c*	-0.90*d*
239.	**	-1.17*a*	-1.08*b*	-1.01*c*	-0.94*d*	-0.90*d*
249.	**	-1.08*a*	-1.04*b*	-1.00*c*	-0.97*cd*	-0.95*d*
264.	**	-1.07*a*	-1.02*b*	-0.98*b*	-0.93*c*	-0.88*d*
277.	**	-0.97*a*	-0.97*a*	-0.90*b*	-0.87*b*	-0.82*c*
284.	**	-0.96*a*	-0.95*a*	-0.91*ab*	-0.87*b*	-0.80*c*
291.	**	-0.93*a*	-0.92*a*	-0.79*b*	-0.75*bc*	-0.72*c*
Average	**	-0.99*a*	-0.95*b*	-0.90*c*	-0.85*d*	-0.81*e*

** $p<0.01$

[1] Means with different letters in the same row indicate significant differences between treatments according to the Duncan's multiple range test (n=3 replicates, $p<0.05$)

In 2016 (Table 7), various ILs influenced the SWP throughout the experiment at a significance level of $p<0.01$. In the S4 treatment, where the plant's water requirement was fully met, SWP values ranged from -0.68 to -0.95 MPa in 2016. On the other hand, SWP values of the rainfed (S0) treatment which received no irrigation fluctuated between -0.81 and -1.17 MPa in the first year of experiment. The lowest SWP values were obtained from the rainfed treatment and were included in the first group (a), while the highest values were observed from S4. Stem water potential of the fig tree was determined to be around -1 MPa (Garrido et al. 2022). Considering the dates, a decreasing trend was observed between the DOY-193 and DOY-264 values after the first three SWP measurements in 2016, which indicates higher stress. That can be attributed to the decrease in soil water content caused by high temperatures that occurred around mid-July and mid-Sep-

Table 8

Effects of different irrigation levels on the stem water potential (2017) (MPa)

Day of year	p	Irrigation Levels				
		S0 (Rainfed)	S1 (25%)	S2 (50%)	S3 (75%)	S4 (100%)
132.	ns	-0.73	-0.69	-0.78	-0.76	-0.77
149.	**	-0.80*a*[1]	-0.76*ab*	-0.73*b*	-0.71*bc*	-0.66*c*
163.	*	-0.83*a*	-0.80*ab*	-0.78*b*	-0.76*b*	-0.77*b*
194.	**	-1.04*a*	-0.93*b*	-0.87*b*	-0.81*c*	-0.77*c*
200.	**	-0.88*a*	-0.85*ab*	-0.84*bc*	-0.81*cd*	-0.78*d*
205.	**	-0.95*a*	-0.95*a*	-0.93*ab*	-0.89*b*	-0.83*c*
212.	**	-1.01*a*	-0.99*ab*	-0.96*bc*	-0.92*c*	-0.86*d*
219.	**	-1.04*a*	-0.90*b*	-0.85*bc*	-0.82*cd*	-0.78*d*
223.	**	-1.17*a*	-1.10*b*	-1.09*b*	-1.06*c*	-1.04*c*
234.	**	-1.15*a*	-1.07*bc*	-1.08*b*	-1.02*cd*	-1.00*d*
248.	**	-1.07*a*	-1.02*b*	-1.00*b*	-0.98*bc*	-0.95*c*
261.	**	-1.05*a*	-1.01*b*	-0.98*b*	-0.92*c*	-0.88*d*
277.	*	-0.95*a*	-0.95*a*	-0.90*ab*	-0.89*ab*	-0.86*b*
291.	**	-0.93*a*	-0.98*a*	-0.93*a*	-0.87*b*	-0.87*b*
Average	**	-0.97*a*	-0.93*b*	-0.91*c*	-0.87*d*	-0.84*e*

** $p<0.01$, * $p<0.05$, ns – not significant

[1] Means with different letters in the same row indicate significant differences between treatments according to the Duncan's multiple range test ($n=3$ replicates, $p<0.05$)

tember, specifically between DOY-193 and DOY-264. The SWP averages of S3 and S4 fall into the same group in DOY-239 and DOY-249. Additionally, the S2 and S3 treatments are included in the same group for DOY-228 and DOY-249 measurements. The last three measurements of 2016 were taken in October, and relatively lower stress was observed in all treatments. This can be attributed to the lower mean temperature and the moisture stored in the soil profile. The seasonal averages of the treatments were each included in different group and varied between -0.81 MPa (S4) and -0.99 MPa.

In 2017, a total of 14 SWP measurements were taken (Table 8). Because of the favorable weather conditions in May, the irrigation program was initiated in mid-May. As a result, the effect of IL was not found to be significant during the first SWP measurement (DOY-132). The IL influenced the other measurements at a significance level of $p<0.01$, except for DOY-163 and DOY-277. The average SWP of the treatment ranged between -0.84 and -0.97 MPa in the second year of the trial. The measurements between DOY-212 and DOY-261 (a period covering the end of July to midst of September) exhibited lower SWP values due to the prevailing high temperatures (approx.

10°C above the long-term averages), and heatwaves occurred more frequently in 2017, resulting in lower soil water content. In DOY-223 and DOY-234 measurements, the S3 and S4 treatments were included in the same group, as they appeared to exhibit similar responses. Some fig genotypes survived at low leaf water potential levels, as low as -4.0 MPa, in a fig orchard in Mexico (Oukabli et al. 2008) In the last two measurements taken in October (DOY-277 and DOY-291), the SWP values tended to increase. The results revealed that SWP could be used to monitor the water status of young fig trees. Mean SWP values between -0.82 and -0.86 MPa can be considered as threshold values for irrigation scheduling of young fig trees in semi-arid regions.

SWP measurements exhibited differences depending on the IL, and increased as the water stress decreased. An increase was observed in all irrigation levels for both years in the period from mid-July until the end of September. The soil water potential depends on the amount of irrigation water applied, which determines how much available soil water the plant can extract (Espadafor et al. 2018). Under seven different ILs, the SWP measurements varied between -0.40 and -1.00 MPa. The results showed that the SWP measurements of fig cultivars were more sensitive to irrigation compared to predawn xylem water potential measurements (Goldhamer and Salinas 1999). Rainfed fig trees close their stomata around −2 MPa, and this level can be accepted as a threshold value in classifying figs as drought--tolerant (Abdolahipour *et al*. 2022). Increasing the amount of applied irrigation water significantly increased leaf water potential in figs (Abdolahipour et al. 2019). The weekly SWP values of fully-irrigated figs varied between -0.40 and -0.93 MPa under deficit irrigation conditions. In August, the SWP was measured at -0.70 MPa, while in October it was measured at -1.20 MPa (Kong et al. 2013).

The results of this study are consistent with the previous research, supporting the hypothesis that fully meeting the water demand of the fig tree helps maintain higher SWP in young fig trees.

Leaf area index

The leaf, as an important organ of plants, is directly involved in the processes of transpiration and photosynthesis, and therefore associated with plant growth. Leaf area measurements play a crucial role in understanding physiological processes in plant growth. The leaf area index (LAI) readings were performed monthly in both experimental years. In the determination of LAI, the calculation involves the total leaf area of the canopy and the total projection area of the tree. LAI affected by different ILs is presented in Table 9.

In the first year of the study, there was a significant influence of different ILs at $p<0.01$. The means of LAI values varied between 1.50 and 2.45 during the experiment. The highest mean LAI was recorded in September

Table 9

Effects of different irrigation levels on leaf area index values (m^{-2} m^{-2})

Months	Year	Irrigation Levels					
		p	S0 (Rainfed)	S1 (25%)	S2 (50%)	S3 (75%)	S4 (100%)
May	2016	**	1.50*a*[1]	2.14*b*	2.16*b*	2.13*b*	2.12*b*
	2017	ns	1.49	2.13	2.16	2.11	2.09
June	2016	**	1.53*a*	2.22*b*	2.25*b*	2.19*b*	2.17*b*
	2017	ns	1.51	2.15	2.15	2.15	2.15
July	2016	**	1.62*a*	2.28*b*	2.30*b*	2.30*b*	2.24*b*
	2017	ns	1.53	2.20	2.23	2.21	2.17
August	2016	**	1.72*a*	2.34*b*	2.37*b*	2.37*b*	2.33*b*
	2017	ns	1.52	2.24	2.26	2.17	2.18
September	2016	**	1.75*a*	2.41*b*	2.45*b*	2.43*b*	2.37*b*
	2017	ns	1.63	2.32	2.31	2.30	2.23
October	2016	**	1.75*b*	2.43*b*	2.45*b*	2.44*b*	2.37*b*
	2017	ns	1.61	2.24	2.30	2.30	2.24
Average	2016	**	1.64*a*	2.30*b*	2.33*b*	2.31*b*	2.27*b*
	2017	**	1.54*a*	2.21*b*	2.24*b*	2.21*b*	2.17*b*

** $p<0.01$, ns – not significant

[1] Means with different letters in the same row indicate significant differences between treatments according to the Duncan's multiple range test (n=3 replicates, $p<0.05$)

and October for the S2 treatment (2.45), while the lowest was obtained from the S0 in May (1.50). In the second year of the experiment, the application of different amounts of irrigation water did not have a significant effect on monthly LAI, but the seasonal averages were significantly affected. The values varied between 1.49-2.32 and very close LAI averages were observed in September for S1(2.32), S2 (2.31) and S3 (2.30), while the lowest index value was recorded for S0 in May (1.49).

The highest variation was observed at the 75% irrigation level (S3) from the beginning to the end of the experiment in both years (0.31 and 0.29). Changes in LAI values can be attributed to high temperatures and/or heatwaves, as well as a decrease in soil water storage, resulting in water deficit conditions. Another reason for the variation in LAI values among the experimental years can be the difference in vegetative growth exhibited by 2-year-old and 3-year-old fig trees. Thus, the vegetative growth status, which depends on the age of a tree, is a determining factor for LAI, particularly in young trees that experience growth and development year after year. LAI is an indicator of a plant's growth potential because the leaf area determines the photosynthetic carbon assimilation. Additionally, the distribution of sunlight within the plant's canopy directly affects vegetative growth (Scurlock et al. 2001, Trad et al. 2013).

Olive trees under deficit irrigation showed a significant decrease in leaf area (Hernandez-Santana et al. 2017). In bell peppers under deficit irrigation, LAI decreased towards the end of season due to leaf senescence in all treatments (Bozkurt Çolak 2021). The leaf area index values were observed to be highest during the flowering period in a deficit irrigation trial conducted on pomegranate in Iran (Parvizi et al. 2016). Due to the fluctuation of soil water storage and the differential growth and development of trees related to their age, there are some contradictions between the results of this study and the literature cited above.

Proline content

Proline is the first amino acid to accumulate in arid conditions and is used to determine whether the plants are experiencing water stress (Verbruggen and Hermans 2008). The results of the monthly proline analysis on the dried leaf samples taken during the irrigation season are presented in the Table 10. In both trial years, the proline content was significantly influenced by different ILs (p<0.01). A direct relationship between drought stress and proline content is indicated (Naser et al. 2010).

The mean proline contents of the treatments varied between 1.47 and 2.96 μmol g^{-1} in the first experimental year, while it ranged from 1.24

Table 10

Effects of different irrigation levels on proline content (μmol g^{-1})

Months	Year	Irrigation Levels					
		p	S0 (Rainfed)	S1 (%25)	S2 (%50)	S3 (%75)	S4 (%100)
May	2016	-	-	-	-	-	-
	2017	**	2.82*a*[1]	2.61*b*	1.97*c*	1.78*d*	1.81*cd*
June	2016	**	2.63*a*	2.42*b*	1.98*c*	1.84*cd*	1.78*d*
	2017	**	2.75*a*	2.52*b*	1.96*c*	1.64*d*	1.58*d*
July	2016	**	2.71*a*	2.36*b*	2.19*c*	1.83*d*	1.65*e*
	2017	**	2.86*a*	2.49*b*	1.98*c*	1.62*d*	1.57*d*
August	2016	**	2.82*a*	2.39*b*	2.22*c*	1.90*d*	1.52*e*
	2017	**	2.84*a*	2.48*b*	1.81*c*	1.59*d*	1.52*d*
September	2016	**	2.87*a*	2.24*b*	2.17*b*	1.77*c*	1.50*d*
	2017	**	2.91*a*	2.39*b*	1.75*c*	1.49*d*	1.41*d*
October	2016	**	2.96*a*	2.26*b*	2.11*c*	1.75*d*	1.47*e*
	2017	**	2.93*a*	2.32*b*	1.72*c*	1.33*d*	1.24*d*
Average	2016	**	2.79*a*	2.33*b*	2.13*c*	1.82*d*	1.58*e*
	2017	**	2.85*a*	2.47*b*	1.95*c*	1.57*d*	1.52*d*

** p<0.01

[1] Means with different letters in the same row indicate significant differences between treatments according to the Duncan's multiple range test (n=3 replicates, p<0.05)

to 2.93 μmol g^{-1} in 2017. According to the results of 2016, the amount of proline in the S0 treatment was 2.63 μmol g^{-1} in June, increasing to 2.96 μmol g^{-1} in October. In response to stress conditions, plants tend to increase their proline concentrations in order to maintain turgor and protect proteins (Öztürk 2015). In S4, there was a decrease in proline from1.78 to 1.47 μmol g^{-1} (June – October). In other irrigation treatments (S1, S2, S3), peak values were reached in August, followed by a relative decreasing trend in September and October. The means of the treatments were grouped separately, and there is a noticeable decreasing trend in relation to the increase in irrigation levels (Table 10).

In the second year of the experiment, it was determined that the proline content of the rainfed treatment (S0) was 2.82 μmol g^{-1} in May, increasing to 2.93 μmol g^{-1} in October. A correlation was determined between the proline content and drought stress in the leaves of fig trees. It was found that the fig trees under water stress had higher proline concentrations than fully irrigated ones (El-Dakak and El-Darier 2021). A decreasing trend from May to October was observed in the full irrigation treatment (S4) in 2016. Similar results were observed in the proline content of the other treatments in 2017. According to the study results, there is a clear effect of increasing IL on the proline content. As more irrigation water is applied or as the soil water content increases, there is a decrease in proline accumulation in the leaves, indicating reduced water stress.

Proline is thought to be exported from the xylem to the shoots, and it is synthesized in the reproductive organs of plants. As a result, its quantity varies in different plant organs and is dependent on the age of a plant, as well as the position and part of the sampled leaf (Verbruggen and Hermans 2008). The proline content and electrolyte leakage increased in four fig cultivars under deficit irrigation and full irrigation conditions, while the relative water content of the leaf and chlorophyll content decreased due to water stress (Abdolahipour et al. 2022). Different soil management techniques significantly influenced the proline content of 20-year-old fig trees. The amount of proline changed throughout the season, depending on the sampling date of leaves. At the beginning of the season, the proline content was high (3.23 μmol g^{-1}), but continued to decrease until September (2.80 μmol g^{-1}). However, it started to increase again in mid-September (Tan et al. 2013). Proline levels in olive leaves ranged between 1.09-1.59 μmol g^{-1} under moderate and severe drought conditions. In this study, different irrigation treatments influenced the accumulation of proline, and these findings are consistent with the previous study cited. As a result, its concentration could be considered a biochemical indicator of drought stress in young fig trees.

Relationships between evapotranspiration and physiological parameters

The relationship between ET-SWP, ET-Proline, and ET-LAI values was investigated and presented in Figure 3 (*a*, *b*, *c*) respectively. SWP was deter-

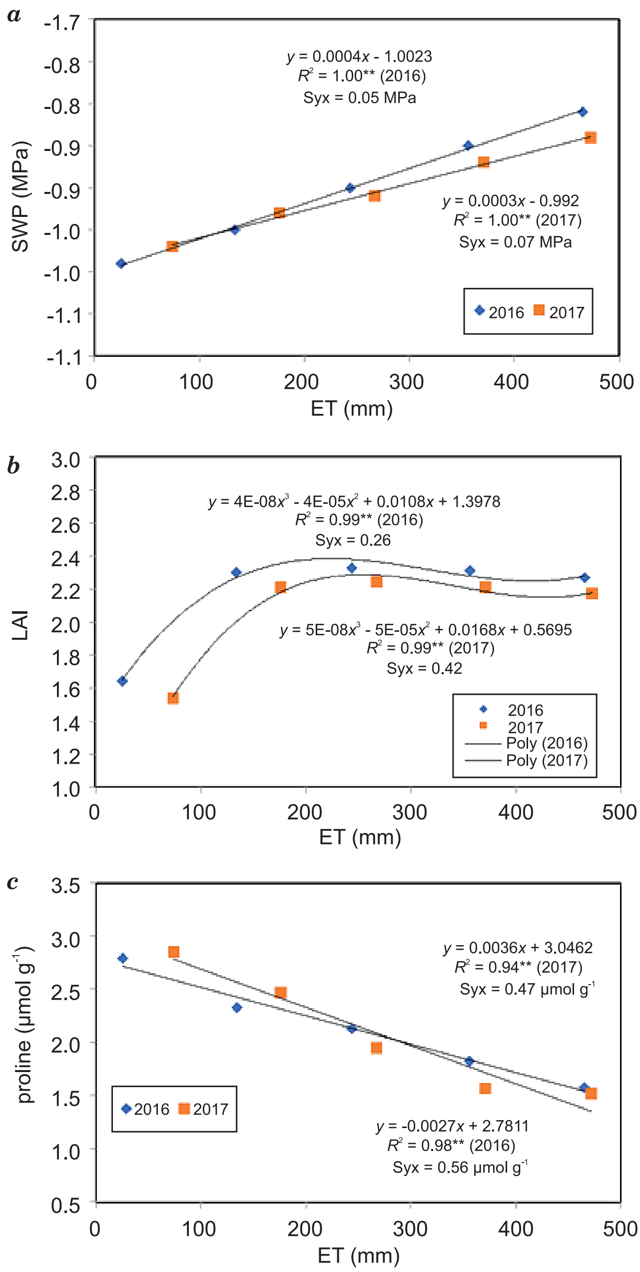

Fig. 3 (*a*,*b*,*c*). Relationships between ET (mm) vs. SWP – LAI and proline content mined to be closely associated with the amounts of ET (p<0.01) (Figure 3a, b, c). A positive linear relationship with high determination coefficients was determined for both years, indicating that the SWP increases as the water use increases. The determination coefficient (R^2) was found to be 1.00. The relationship between ET and LAI is best described as significant (p<0.01) by third-order polynomial equations with high determination coefficients R^2 (0.99 for both years). This shows that as the ET increases to a certain level, LAI also increases, but then decreases slightly. Inverse linear relationships were observed at a significance level of p<0.01 between ET and proline content, as shown in Figure 3. This indicates that as water consumption increased, the accumulation of proline in the leaves decreased. For both experimental years, the relationship between ET and the proline content had high determination coefficients, with R^2 =0.98 and 0.94 respectively.

LWP values were linearly correlated with soil moisture in grapevines (Williams and Araujo 2002). A significant and positive correlation was found between LWP and yield, DM yield, LAI and soil moisture in bell peppers irrigated differentially (Bozkurt Çolak, 2021). Linear relationships were observed between evapotranspiration and LWP and LAI obtained from sunflower plants subjected to various irrigation treatments (Salbaş and Erdem 2023). A positive linear relationship was observed between ET and fruit quality in a deficit-irrigated apple orchard (Küçükyumuk et al. 2013). In deficit-irrigated grapes, LWP decreases as the ET rates decrease, resulting in a decreased LWP (Bozkurt Çolak and Yazar 2012).

CONCLUSIONS

The assessment of the relationships between water use, vegetative growth of aerial organs, plant water status, and the plant's biochemical response, such as proline accumulation, to different irrigation levels, allowed us to conclude that irrigation is important for young fig trees to mitigate the effects of water stress.

The results revealed that the highest seasonal evapotranspiration of young fig trees under different irrigation levels were achieved in both trial years in the full irrigated treatment (S4). The greatest variation between the start and end of the experiment was observed in plant height, shoot length, and the number of leaves at the S3 (75%) irrigation level. As an exception, stem diameter yielded the highest results under the full irrigation treatment (S4). When the results were interpreted, it was observed that the 2-year-old fig trees had higher height and stem development, while the 3-year-old ones showed better growth and development in shoot and foliation. Therefore, in the establishment and management of orchards, careful consideration should be given to irrigation management strategies in order to promote healthy vegetative development of young fig trees.

The increase in the amount of applied irrigation water significantly increased the stem water potential in young fig trees. In order to maintain the health of the tree under less stressful conditions, it is suggested to apply full irrigation water doses (S4). However, in water scarce conditions, it is recommended to apply 75% of the irrigation water (S3). SWP could be used as a tool in irrigation scheduling for young fig trees, and values between -0.82 and -0.86 MPa can be accepted as the threshold value for semi-arid regions.

LAI values were significantly influenced by different ILs in both years. Since the S3 treatment had the highest LAI values, it is recommended to use the irrigation scheduling treatment of 75% (S3) in order to achieve higher LAI values. The positive effect of SI on the proline content is evident. Higher soil water content leads to lower proline accumulation in the leaves, indicating non-water stress conditions. Therefore, providing full irrigation treatment might help the plant to mitigate the adverse effects of water stress, particularly in terms of proline accumulation.

In order to mitigate the adverse impacts of water stress, young fig trees should be irrigated to meet their water requirements. In conclusion, meeting the water demand of trees at a 75% level appears to be a good alternative to a fully irrigated (100%) treatment for growing young fig trees under water scarce conditions in western Turkey.

Author contributions

S.A. – conceptualization, methodology, investigation, formal analysis, writing – review & editing; P.D. - investigation, data curation.

All authors have read and agreed to the published version of the manuscript.

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Conflicts of interest

The authors ensure that they have neither professional nor financial connections related to the manuscript sent to the Editorial Board.

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