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Original article

Supplemental irrigation and pruning influence on growth characteristics and yield of rainfed fig trees under drought conditions

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Summary

This study was conducted in the south-east of Fars Province, Iran, between 2010 and 2012, to study the effect of pruning and supplemental irrigation (SI) on growth characteristics and yield of rainfed fig trees under drought conditions. The irrigation treatments comprised: no irrigation; one irrigation event in the last month of winter; one irrigation event in mid-spring; one irrigation event in mid-summer; and two irrigations, one in the last month of winter and one in mid-spring. Pruning treatments consisted of moderate thinning out of one-year-old lateral branches; severe thinning out of one-year-old lateral branches; moderate heading back; and green pruning. The results regarding the growth characteristics showed positively response of fig trees to the SI and the maximum yield achieved by using two irrigations in the last month of winter and in mid-spring. However, one irrigation in late winter showed the highest water productivity among irrigation treatments. Among pruning treatments, severe thinning out of one-year-old lateral branches resulted in appropriate vegetative and reproductive characteristics. Conclusively, a combination of severe thinning out of one-year-old lateral branches pruning and one SI event with 750 L per tree (equal to 75 m^3 ha^{-1}) in late winter could be the best choice in drought conditions.

Keywords
supplemental irrigation, thinning out, water productivity, yield

Significance of this study

What is already known on this subject?

- Rainfed fig orchards in Iran, as one of the largest fig producers, have been faced with severe drought events during the last two decades. The supplemental irrigation (SI) and pruning are two suitable methods with high capacity to reduce negative effects of drought in rainfed agriculture. However, there is not enough information about their application in rainfed fig orchards under drought conditions.

What are the new findings?

- Different amounts and times of SI were examined to find the optimum irrigation schedule for rainfed fig trees. SI could improve vegetative traits of fig trees and the two irrigations with 750 L per tree, one in the last month of winter and one in mid-spring resulted in the highest yield. However, one irrigation in late winter with 750 L per tree (75 m^3 ha^{-1}) showed the highest water productivity among irrigation treatments. Also, among different pruning methods, severe thinning out of one-year-old lateral branches can be recommended for rainfed fig trees. The results indicated that during a long period of drought conditions, SI may not be required for every year. This research revealed that compared to leaf temperature, leaf water potential was a more reliable indicator to estimate water stress for rainfed fig orchards.

What is the expected impact on horticulture?

- In recent years, the adverse impacts of drought incidents have been increasing, particularly in countries in arid and semi-arid areas where rainfed agriculture plays such an important economic role. Taking advantage of supplemental irrigation in the optimum amount and time and also appropriate pruning can keep the trees alive and improve water productivity during the droughts.

Introduction

Iran is one of the largest producers and exporters of fig with an average of 75,910 tons of production in the last two decades (1992–2012) (FAO, 2016). Most of the fig trees in Iran are cultivated in Estahban, a semi-arid region in the south-east of Fars Province. The orchard areas in this region consist of 1,875 ha (6.6%) irrigated and 26,700 ha (93.4%) rainfed, of which 74.9% are rainfed fig orchards (Bagheri and Sepaskhah, 2014). In these dryland orchards, rainwater harvesting is a traditional practice for supplying water by using micro-catchments built perpendicular around tree trunks for collecting rain water. Fig trees can be grown in a variety of soils ranging from coarse-texture sand to heavy clay soils (Morton, 1987).

Although the fig tree is an appropriate crop for arid and semi-arid environments due to high tolerance to water stress

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(Dominguez, 1990), its growth and development can be seriously affected by severe drought conditions (Melgarejo, 1996). Virtually, every aspect of plant physiology as well as cellular metabolism are affected by drought. Water stress in fig tree causes reduction in branch growth, leaf area, leaf number, and an increase in trunk sunburn (Al-Desouki *et al.*, 2009; Zare *et al.*, 2009). Consequently, it results in dehydration of the cell and in osmotic imbalance.

Fig production under rainfed conditions is highly dependent on rainfall, and temporal change in rainfall is a major challenge for rainfed fig producers. Extensive drought events in Estahban have seriously affected rainfed fig trees, and in 2010 it resulted in the loss of more than 10% of the trees and the yield was decreased by more than 80% (Jafari *et al.*, 2012).

Previous research have documented that different management techniques such as mulching (Aragüés *et al.*, 2014; Jafari *et al.*, 2012), micro-catchment construction (Fooladmand and Sepaskhah, 2006; Sepaskhah and Moosavi-Fard, 2010; Sepaskhah and Fooladmand, 2004) and potassium nutrition (Honar and Sepaskhah, 2015) can mitigate the adverse effects of drought on fig growth and yield.

One of the most effective strategies to alleviate the adverse effects of soil moisture stress on the yield of rainfed crops during dry years is supplemental irrigation (SI) (Oweis and Hachum, 2012). Tendency to use SI in Estahban fig orchards has increased in recent years (Kamyab, 2015; Sharifzadeh *et al.*, 2012). It must be taken into account that the fig tree is a plant very sensitive to root rot, therefore excessive irrigation water must be avoided (Dominguez, 1990). Besides, unnecessary SI may lead to the decline water resources, the water table depth and the deterioration of water quality in a rainfed fig area (Abdolahipour and Kamgar-Haghighi, 2015).

Another approach to combat drought is pruning at the appropriate time. Most of the fig trees in Estahban orchards are more than 30 years old, and the common pruning practice in the region is moderate thinning out of one-year-old lateral branches in late winter. Some studies on management of fig tree pruning have been conducted in Brazil (Gonçalves *et al.*, 2006; Leonel and Tecchio, 2010; Norberto *et al.*, 2001; Sampaio *et al.*, 1981). Leonel and Tecchio (2008, 2009, 2010) studied the effects of pruning time in four different months with and without irrigation, on the fig trees 'Roxo de Valinhos' in the Botucatu region of the state of São Paulo, Brazil. The weather was hot and air temperature ranged from 17.1 °C (July) to 23.3 °C (February) with mean annual rainfall of 1,314 mm, occurring mainly in summer. August, as a winter month in that area, was found as the best month for pruning and irrigation that could increase the growth and yield of fig trees. Other researchers have also reported the effectiveness of optimum pruning on fig trees production (Chithiraichelvan *et al.*, 2017; Puebla *et al.*, 2003).

In order to improve SI management, it is necessary to quantify the water stress effects on plants. Monitoring of leaf water potential (LWP) and leaf temperature (LT), as two common physiological parameters, can be used in study of plant responses to SI in drought conditions (Idso, 1982; Jackson, 1982; Martin *et al.*, 1990).

It is anticipated that irrigation and suitable pruning can improve the morphological traits and production of fig trees. Despite several studies on the effect of irrigation on yield and growth characteristics of fig trees (Goldhamer and Salinas, 1999; Hernandez *et al.*, 1994; Olitta *et al.*, 1979; Tapia *et al.*, 2003), there is a lack of knowledge on amount and timing of SI in rainfed fig orchards in order to decrease the negative effects of drought stress on fig orchards. Therefore, the present investigation was carried out to find the influence of different amounts and times of SI and various pruning methods on yield, water productivity and vegetative growth of rainfed fig trees.

Materials and methods

Experimental site

The study was performed at a private fig orchard in Estahban, Fars Province, Iran (29°07'N, 54°04'E, altitude 1,749 m a.s.l.) between 2010 and 2012. Extreme temperatures in the region are about -7 and 41 °C in winter and summer, respectively (Jafari, 2004). The mean annual rainfall of the region is 354 mm, with a minimum and a maximum of 92 and 739 mm, respectively (Bagheri and Sepaskhah, 2014). Most of the rainfall occurs during late fall and winter. Meteorological data during the experimental period was collected from a meteorological station in the region (Figure 1). The amounts

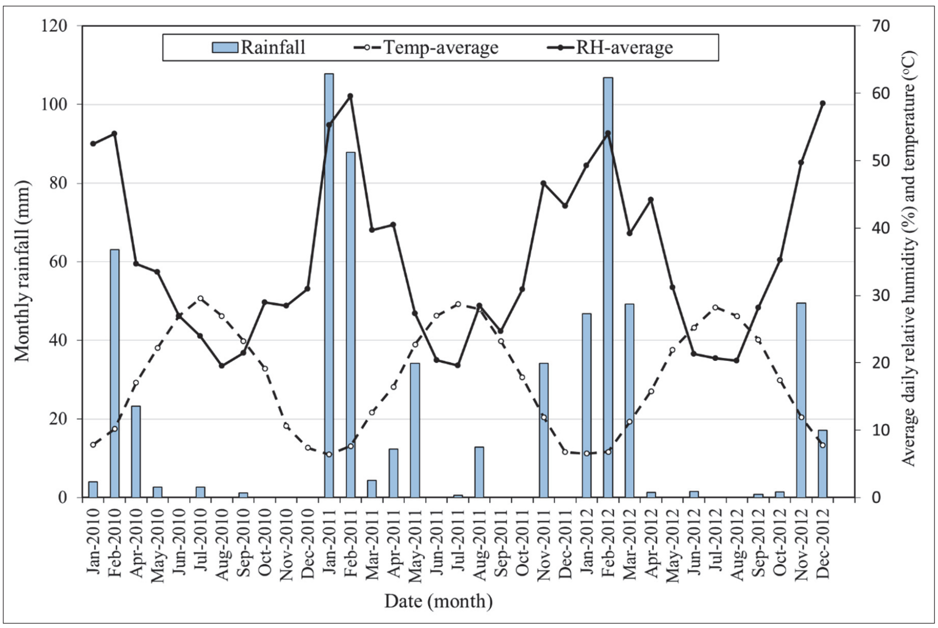

FIGURE 1. Mean daily agro-meteorological data for the study area (2010–2012).

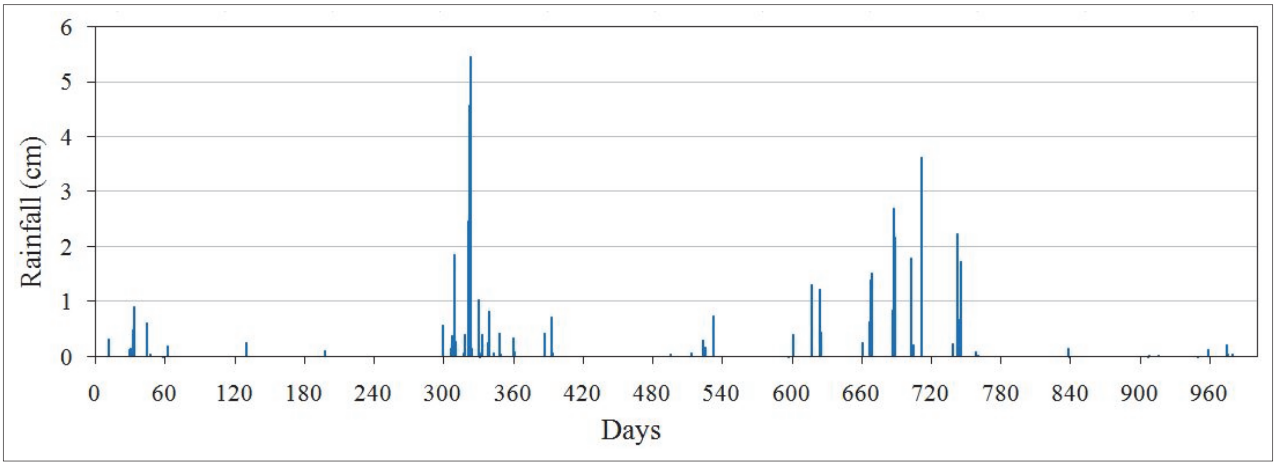

FIGURE 2. Daily rainfall distribution at the experimental site (2010–2012).

of rainfall in 2009, 2010, 2011 and 2012 were 254.7, 103.1, 294.3, and 274.7 mm, respectively (Figure 2), being lower than the long-term average. The soil is gravelly clay loam texture (28, 32, 40, and 30% of sand, silt, clay, and gravel, respectively), with electric conductivity, pH, field capacity, and permanent wilting point of 1.6 dS m^{-1}, 7.4, 31.7% (v/v), and 14.3% (v/v), respectively, for the upper 90 cm soil layer.

Fig orchard details

Different rainfed fig cultivars are planted in the Estahban region, among which the 'Izmir' group is the dominant one (Bagheri and Sepaskhah, 2014). 'Sabz' is the most common commercial fig cultivar in this region (Jafari *et al.*, 2012). Figure 3 describes the different growth stages of a rainfed fig tree in the study area. Sixty uniform mature edible fig 'Sabz' trees, planted 10 m apart, were selected and different treatments of SI and pruning were applied.

Irrigation and pruning treatments

The experiment was carried out in a randomized complete block design (RCBD) with three replications and 20 fig trees in each block (Figure 4). Irrigation treatments included (I0) no irrigation (control); (I1) one irrigation event in the last month of winter; (I2) one irrigation event in mid-spring; (I3) one irrigation event in mid-summer; and (I4) two irrigation events, one in the last month of winter and another one in mid-spring. The volume of irrigation water was 550 L per tree (55 m^3 ha^{-1}) in the first year and it was increased to 750 L per tree (75 m^3 ha^{-1}) in the second and third years of study. The dates of irrigation events were on March 18 (I1 and I4), May 3 (I2 and I4), and August 17 (I3), 2010, March 5 (I1 and I4), May 2 (I2 and I4), and July 25 (I3), 2011, March 3 (I1 and I4), May 4 (I2 and I4), and August 3 (I3), 2012. The volume of water was measured by using a water meter installed at the outlet of the irrigation pipe.

Pruning treatments consisted of (P0) moderate thinning out of one-year-old lateral branches (control); (P1) severe thinning out of one-year-old lateral branches; (P2) moderate heading back; and (P3) green pruning. The pruning treatments were applied on trees on March 4 (P0 and P1), March 16 (P2), and June 19 (P3), 2010, February 25 (P0 and P1), March 8 (P2), and June 10 (P3), 2011, February 25 (P0 and P1), March 11 (P2), and June 9 (P3), 2012.

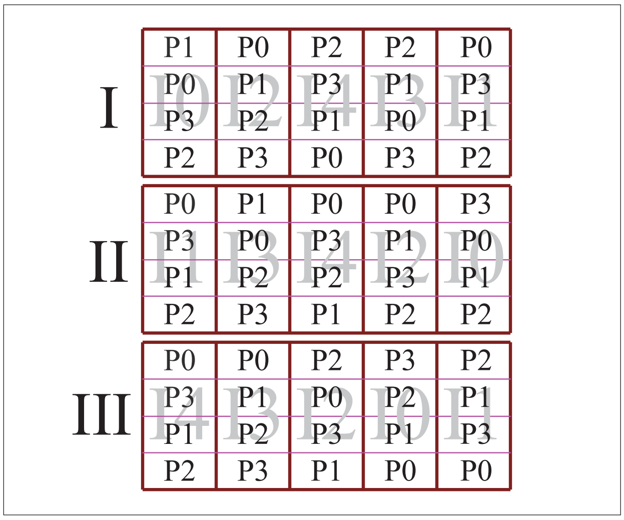

FIGURE 4. A design layout of treatments in a randomized complete block design (RCBD). I, II, III: number of block (replication), (I0: no irrigation (control), I1: one irrigation event in the last month of winter, I2: one irrigation event in mid-spring, I3: one irrigation event in mid-summer, I4: two irrigation events, one in the last month of winter and another one in mid-spring, P0: moderate thinning out of one-year-old lateral branches (control), P1: severe thinning out of one-year-old lateral branches, P2: moderate heading back, P3: green pruning).

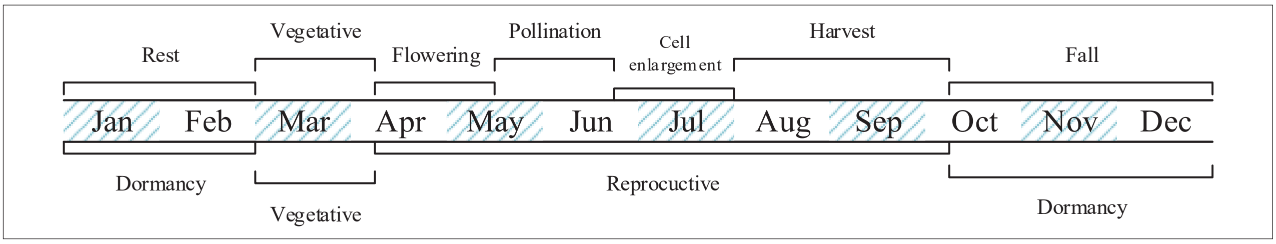

FIGURE 3. Different growth stages of fig tree.

The pruning methods of P0, P1, and P2 were performed in late winter and the P3 was applied in early summer. The P0 method as the traditional pruning method in the region is extensively used by local fig growers. In the P1 pruning technique, all of one-year-old lateral branches were removed and in P2, in addition to the moderate thinning out of one-year-old lateral branches, the top of their fifth nod was shortened. In the P3 technique, the terminal buds of the short current-year lateral branches were pinched, and the long ones were headed back from the upper part of the fifth nod in early summer after the caprification of trees.

Physiological and growth parameters measurements

The LT measurements were made with a portable Kyorisu Model 5500 infrared thermometer with ranges from -40 to 500 °C and an accuracy of ±0.1 °C. The device was calibrated for the emissivity of fig leaves. The monthly measurements were done about one hour after solar noon in four main directions of canopy with the view angle of 45° during the leaf growing period from July to September. The number of measurements for LT parameter were 48 and 60 for each irrigation and pruning treatment, respectively (12 and 15 trees and 4 readings for each tree) in each measurement date. The measurement dates included June 29, August 1, and August 29, 2010, May 30, July 3, July 28, and September 7, 2011, May 28, July 3, July 25, and August 26, 2012.

The LWP measurements were taken at midday time on the same dates as the LT measurements. The water potential of two leaves on each tree was measured by using a pressure chamber (PMS Instrument, Corvallis, OR) and the average value of these measurements was used in the analysis. Therefore, the number of measurements for LWP parameter were 24 and 30 for each irrigation and pruning treatment, respectively (12 and 15 trees and 2 readings for each tree) in each measurement date.

Morphological characteristics were observed on the selected shoots at the first day of July in each experimental year after flowering and pollination stages. One shoot in two sides of each tree in three blocks was tagged and the average value of morphological traits in two shoots was considered in the analysis. Similarly, the leaf width and syconium diameter were determined by choosing two leaves and syconium on the selective shoots in all treatments. Also, the number of leaves for each tree in each treatment was found in the early summer. The growth rate of shoot length, leaf width and diameter of shoot and syconium were measured by using a vernier caliper.

The fruits collection started in about mid-August to end of September with 7-day interval through the harvest period. The fruits for each tree were put in a bag separately and became dry in the sun. The yield of each tree was determined by weighing the fruits per tree using a digital balance with a sensitivity of 0.001 kg.

Water productivity (WP) was determined as criterium to evaluate the performance of SI compared to the rainfed conditions. WP is applied exclusively to denote the quantity or value of product per volume of water depleted or diverted (Kijne *et al.*, 2003). Molden *et al.* (2003) described WP as the relative amount of crop yield over unit of water consumed. In this study, WP is expressed as the ratio between dry yield (kg) and the total water supply (m^3) by SI and rainfall.

The statistical analysis of collected data was carried out using the SPSS statistical software package. Measured data were analyzed by analysis of variance (ANOVA) and Duncan's method was used in order to assess differences among irrigation and pruning treatments at 0.05 probability level.

Results and discussion

Leaf temperature

Results showed that from 2010 to 2012 the LT reduced significantly (with the mean of 15.4%) for both rainfed (12.1%) and irrigated (16.2%) treatments (Figures 5A and 5B). It might be due to higher soil water content in following years because of higher volume of applied irrigation water (36% increase) compared with that in the first year and also cumulative effect of SI. In addition, the meteorological parameters such as air temperature and rainfall could be other effective factors on LT (Figure 1). Rainfed fig trees in Estahban usually have a green canopy from March to Octo-

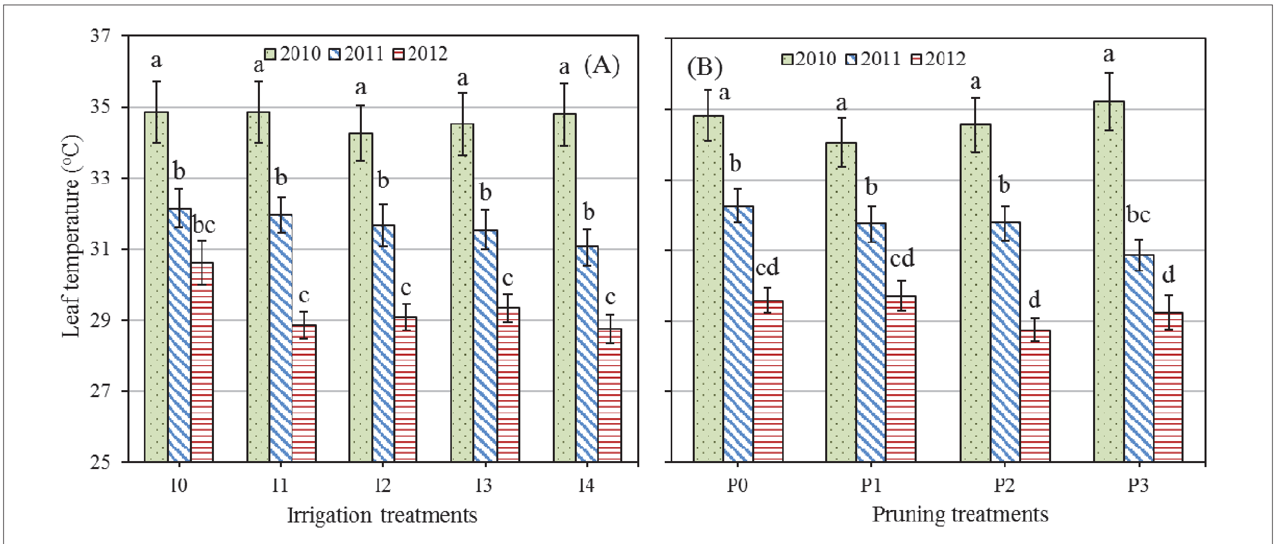

Figure 5. Mean comparison of leaf temperature (°C) under different treatments according to Duncan's multiple range test (I0: no irrigation (control), I1: one irrigation event in the last month of winter, I2: one irrigation event in mid-spring, I3: one irrigation event in mid-summer, I4: two irrigation events, one in the last month of winter and another one in mid-spring, P0: moderate thinning out of one-year-old lateral branches (control), P1: severe thinning out of one-year-old lateral branches, P2: moderate heading back, P3: green pruning, A: irrigation treatments and B: pruning treatments).

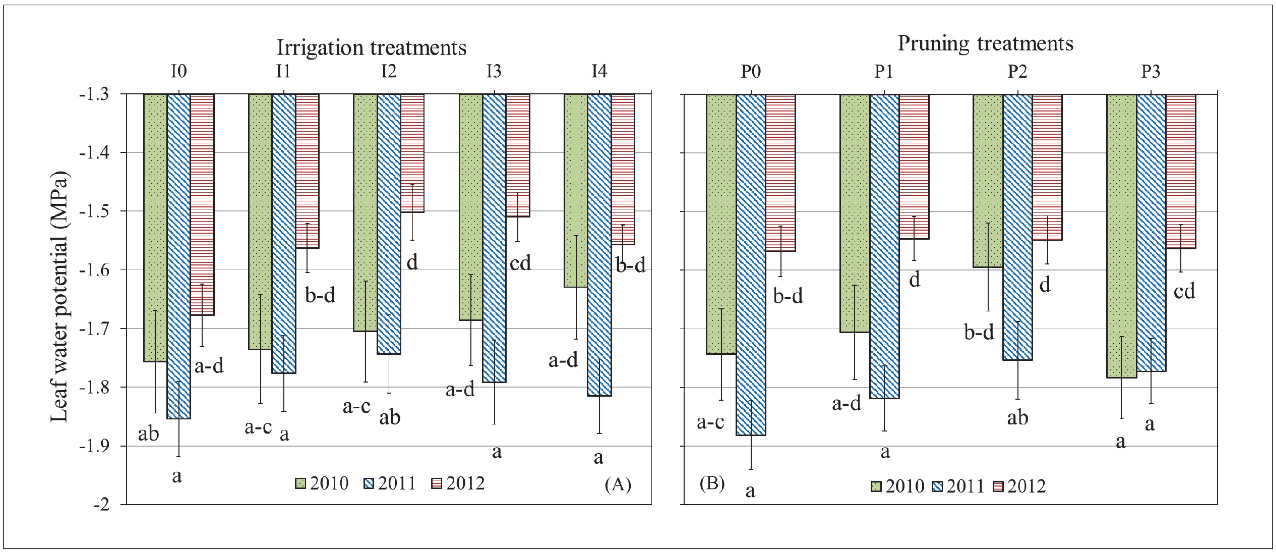

FIGURE 6. Mean comparison of leaf water potential (MPa) under different treatments according to Duncan's multiple range test (I0: no irrigation (control), I1: one irrigation event in the last month of winter, I2: one irrigation event in mid-spring, I3: one irrigation event in mid-summer, I4: two irrigation events, one in the last month of winter and another one in mid-spring, P0: moderate thinning out of one-year-old lateral branches (control), P1: severe thinning out of one-year-old lateral branches, P2: moderate heading back, P3: green pruning, A: irrigation treatments and B: pruning treatments).

ber. Considering this period of time, the mean daily air temperature decreased by 2 and 5% and the average monthly rainfall increased by 8 and 5% in the second and third years, respectively, compared to first year (Figure 1). This variation in air temperature and rainfall might have led the reduction in LT by leaf cooling.

No significant difference in LT within irrigation treatments was observed in different years. However, the LT was higher in the control treatment (Figure 5A) probably due to the effect of water stress on trees without SI. Exposure of plants to water stress causes stomata closure in plants, and this leads to higher LT (Anjum *et al*., 2011; Sdoodee and Kaewkong, 2006; Siddique *et al*., 2000). Among pruning treatments, the highest LT was observed in P3 (the first year, 35.2 °C) and the minimum value was for P2 treatment (the third year, 28.6 °C) (Figure 5B). Reduced foliage and consequently higher transpiration per unit of canopy in P2 could be the reason for lower temperature in this treatment. The LT is a physiological parameter that can reflect the water status in many plants (Jiménez-Bello *et al*., 2011). However, no significant difference in LT between irrigated and non-irrigated trees and also temporal variations in pattern of LT for both irrigation and pruning treatments indicated that the LT might not be an appropriate indicator to show the effect of water stress in rainfed fig orchards.

Leaf water potential

The irrigated trees showed higher LWP (5.7%) compared to control treatment, indicating that SI can increase the water status in rainfed fig trees (Figure 6A). Irrigation increased accessible water to cells, which leads to increasing the cell water content and LWP. Certain metabolic processes cause an increase in the concentration of net cell solute, and movement of water into the leaf leads to a rise in leaf turgor (Mahajan and Tuteja, 2005). In this study, there was not a significant difference among irrigation amounts and times (Figure 6A). It might be due to the fact that fig trees adapted to rainfed conditions can show the suitable physiological response to water stress and keep water in the plant tissues through decreasing the transpiration (Abdolahipour *et al*., 2018).

While, there was no significant difference in LWP among pruning treatments, P2 showed the maximum LWP among treatments (Figure 6B). In this pruning method, the end bud is removed, and the effect of apical dominance decreases on the lower leaves and branches, which produces wider leaves, more axillary (lateral) buds, and thereby higher LWP. The young parenchyma tissues resulting from the pruning provide higher power in accumulation of water in the following years. By using heading back, the auxin production is decreased and consequently the apical dominance effect is declined and resulted in higher activity of axillary bud (Rivals, 1978).

In P3 treatment, the leaves and fruits located in the last third to half of the current-year lateral branches were removed in early summer. It imposed a severe stress on the trees because a large amount of soil water content had been consumed up to this time and the trees may not compensate the lost biomass during this physiological phase. Hence, reduction of green canopy in P2 and P3 treatments caused lower rate of transpiration and consequently increased the LWP in 2011 and 2012. The conventional pruning technique in the region (P0) showed the lowest LWP.

The lowest and highest mean LWP for different treatments were obtained in 2011 and 2012, respectively. The similarity of the temporal pattern of LWP for the irrigation and pruning treatments during three years indicated the experimental precision. However, variation in LWP from year to year might have been mainly following the amount of applied irrigation water and also stored soil water left from the previous year's rainfall. The severity, duration of the drought event, and plant species are other effective elements on LWP (Yang and Miao, 2010).

There was a highly significant correlation between LT and LWP as $r^{***} = 0.49$ ($p < 0.001$) for three years (Figure 7). The LT and LWP in this study ranged from 25.6 to 42.3 °C and -2.67 to -1.0 MPa, respectively. The results revealed that higher LT resulted in lower LWP during growing seasons.

Plant characteristics

The combined statistical analysis was applied for different plant characteristics of three experimental years. Considering the significant interaction effects of pruning × year and irrigation × year (Table 1), the data analysis was done in separate years for shoot length, leaf width, and number of leaves (Table 2). Also, the descriptive analysis of these parameters were performed as mean comparison of three years (Table 3). The three-year analysis of data for other plant characteristics are presented in Table 4.

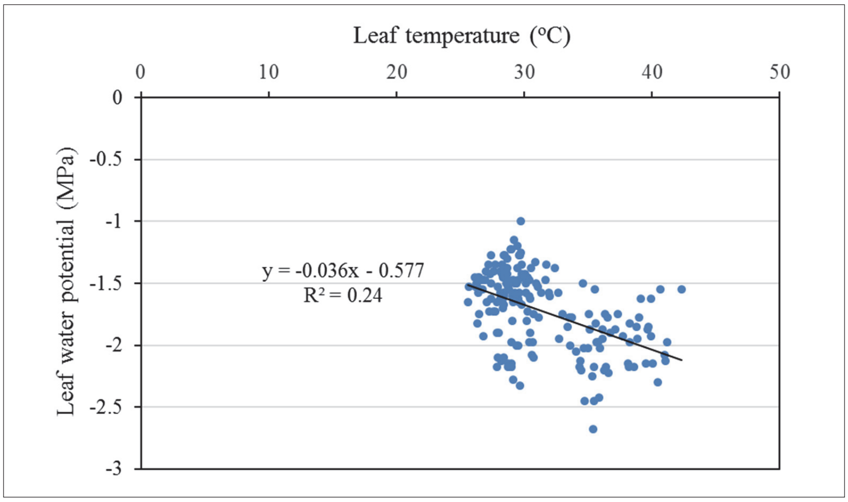

Figure 7. Relationship between leaf temperature (°C) and leaf water potential (MPa) for all treatments during 2010, 2011, and 2012 growing seasons ($n = 180$).

Table 1. Combined variance analysis on plant characteristics of fig trees (2010–2012).

S.O.V.	d.f.	M.S.						
		Growth rate of shoot length (cm)	Shoot diameter (mm)	Leaf width (cm)	Number of leaves	Syconium diameter (mm)	Yield (kg tree^{-1})	Water productivity (kg m^{-3})
Replication (R)	2	4.22**	1.23*	9.21**	1.47^{ns}	23.78**	12.40*	0.02**
Year (Y)	2	299.14**	8.94**	11.36**	100.22**	92.38**	24.10**	0.05**
Error a	4	1.96	0.58	4.60	0.64	8.03	3.21	0.01
Pruning (P)	3	16.81**	1.35*	0.52^{ns}	9.15**	12.79**	13.71**	0.01**
Irrigation (I)	4	5.98**	0.82^{ns}	4.18**	3.13**	8.98**	58.91**	0.03**
P × I	12	0.66^{ns}	0.17^{ns}	1.09^{ns}	1.18^{ns}	2.68^{ns}	4.77^{ns}	0.01^{ns}
P × Y	6	3.99**	0.71^{ns}	10.89**	1.79*	1.32^{ns}	5.81^{ns}	0.01^{ns}
I × Y	8	2.61**	0.72^{ns}	3.67**	2.34**	2.41^{ns}	5.53^{ns}	0.01^{ns}
P × I × Y	24	0.62^{ns}	0.31^{ns}	0.88^{ns}	0.59^{ns}	3.44^{ns}	2.28^{ns}	0.01^{ns}
Error b	114	0.54	0.37	0.70	0.65	2.33	2.84	0.01

NS, * and **: Non-significant, significant at $P < 0.05$ and $P < 0.01$, respectively.

Table 2. Effects of irrigation and pruning on plant characteristics of fig trees (2010–2012).

	Growth rate of shoot length (cm)			Number of leaves			Leaf width (cm)			Yield (kg tree^{-1})		
Irrigation	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
I0	3.31 a*	5.49 b	6.77 c	3.17 a	4.96 b	4.44 c	8.19 a	8.47 b	8.81 b	2.96 a	5.12 a	6.32 a
I1	3.60 a	6.10 ab	8.49 a	3.14 a	6.08 a	5.02 ab	8.39 a	9.09 b	8.18 c	4.44 a	8.14 a	8.97 a
I2	3.00 a	5.63 b	7.52 b	3.18 a	5.33 b	4.74 bc	8.21 a	8.54 b	9.43 ab	3.94 a	4.73 a	6.37 a
I3	3.35 a	6.02 ab	7.05 bc	3.02 a	4.92 b	4.38 c	8.06 a	8.55 b	8.11 c	4.25 a	7.95 a	9.09 a
I4	3.10 a	6.43 a	8.70 a	2.58 a	6.46 a	5.12 a	7.80 a	9.74 a	9.92 a	4.81 a	8.37 a	9.04 a
Pruning												
P0	3.30 b	6.02 b	6.98 b	3.02 a	5.94 a	4.54 b	8.60 a	9.10 ab	7.89 c	3.89 a	6.03 a	7.11 a
P1	3.41 b	6.60 a	8.72 a	3.57 a	5.52 ab	5.14 a	8.21 ab	9.29 a	8.27 c	3.94 a	7.09 a	9.31 a
P2	4.11 a	5.66 b	8.23 a	3.53 a	5.62 ab	5.03 a	7.45 b	8.64 bc	10.25 a	4.37 a	7.95 a	7.92 a
P3	2.27 c	5.45 b	6.90 b	1.96 b	5.13 b	4.26 b	8.26 ab	8.48 c	9.15 b	4.12 a	6.38 a	7.49 a

* Means in each column followed by the same letter(s) are not significantly different at $P < 0.05$ according to Duncan's multiple range test. (I0: no irrigation (control), I1: one irrigation in the last month of winter, I2: one irrigation in mid-spring, I3: one irrigation in mid-summer, I4: two irrigation events one in the last month of winter and another one in mid-spring, P0: moderate thinning out of one-year-old lateral branches (control), P1: severe thinning out of one-year-old lateral branches, P2: moderate heading back, and P3: green pruning).

Table 3. Three-year mean comparison of effects of irrigation and pruning on plant characteristics of fig trees (2010–2012).

Irrigation	Growth rate of shoot length (cm)	Leaf width (cm)	Number of leaves
I0*	5.19	8.49	4.19
I1	6.06	8.55	4.75
I2	5.38	8.73	4.42
I3	5.47	8.24	4.11
I4	6.08	9.16	4.72
Pruning			
P0	5.43	8.53	4.50
P1	6.25	8.59	4.74
P2	6.00	8.78	4.73
P3	4.88	8.63	3.78

* I0: no irrigation (control), I1: one irrigation in the last month of winter, I2: one irrigation in mid-spring, I3: one irrigation in mid-summer, I4: two irrigation events one in the last month of winter and another one in mid-spring, P0: moderate thinning out of one-year-old lateral branches (control), P1: severe thinning out of one-year-old lateral branches, P2: moderate heading back, and P3: green pruning.

Growth rate of shoot length and shoot diameter

While the average length of new shoots increased under different irrigation treatments, I4 showed significantly higher growth in years 2011 and 2012 (Table 2). The average shoot growth of all treatments increased significantly from 3.27 cm in the first year to 5.93 and 7.71 cm in the second and third years, respectively (Table 5). The best results among pruning treatments belonged to P1 (6.25 cm) and the least shoot growth was obtained in P3 treatment (4.88 cm) (Table 3). Elimination of the shoot apex resulted in the release of dormant axillary buds below it to form branches (Gaaliche *et al*., 2016). Whereas, apical dominance resulted in focusing of plant resources into the major axis of growth, stimulation of dormant buds caused recovery after injury of the main shoot (Müller and Leyser, 2011). However, considering the application of green pruning treatment (P3) in early summer (after vegetative stage), the plants might not be able to recover the growth of shoot length. Caetano *et al*. (2005) showed early pruning can increase the length of new Breba-producing shoots in fig trees.

Among different measured morphological characteristics, shoot growth showed the maximum range of variation (28%) for different pruning methods. This is in agreement with those reported by Puebla *et al*. (2003) that the difference in shoot length is clearly significant within four selected green pruning dates (between June to August) in 'Tiberio' fig trees in Badajoz, Spain. Other researchers reported that morphological traits of fig trees such as shoot length depend on the cultural conditions, pruning system, rainfall, and cultivar type (Chatti *et al*., 2004; Gaaliche *et al*., 2016; Mars *et al*., 2009).

The shoot diameter significantly increased by 81.3 and 135.8% in 2011 and 2012, respectively, compared with that obtained in the first year (Table 5). The shoot diameter in all irrigation treatments was higher (2–6%) than control (I0), though this difference was not significant (Table 4). Among different pruning treatments, P2 and P3 treatments showed significantly lower shoot diameter (4.7 and 6.5%, respectively) compared with that obtained in control (P0). Leonel and Tecchio (2010) reported that irrigation provided higher diameter and length of branch, regardless of the timing of pruning.

Table 4. Three-year analysis of effects of irrigation and pruning on plant characteristics of fig trees (2010–2012).

Irrigation	Shoot diameter (mm)	Syconium diameter (mm)	Yield (kg tree^{-1})	Water productivity (kg m^{-3})
I0	5.90 a*	17.84 b	4.80 b	0.21 b
I1	6.28 a	18.95 a	7.18 a	0.25 a
I2	6.02 a	18.50 ab	5.01 b	0.18 c
I3	6.04 a	18.16 b	7.10 a	0.25 a
I4	6.20 a	18.99 a	7.41 a	0.22 b
Pruning				
P0	6.32 a	18.82 a	5.68 b	0.20 b
P1	6.10 ab	19.07 a	6.78 a	0.24 a
P2	6.02 b	18.03 b	6.75 a	0.23 a
P3	5.91 b	18.04 b	6.00 b	0.21 ab

* Means in each column followed by the same letter(s) are not significantly different at $P < 0.05$ according to Duncan's multiple range test. (I0: no irrigation (control), I1: one irrigation in the last month of winter, I2: one irrigation in mid-spring, I3: one irrigation in mid-summer, I4: two irrigation events one in the last month of winter and another one in mid-spring, P0: moderate thinning out of one-year-old lateral branches (control), P1: severe thinning out of one-year-old lateral branches, P2: moderate heading back, and P3: green pruning).

Table 5. Mean comparison of plant characteristics of fig trees (2010–2012).

Plant characteristics	Year		
	2010	2011	2012
Growth rate of shoot length (cm)	3.27 c*	5.93 b	7.71 a
Shoot diameter (mm)	5.66 b	6.21 a	6.40 a
Number of leaves	3.02 c	5.55 a	4.74 b
Leaf width (cm)	8.13 b	8.88 a	8.89 a
Syconium diameter (mm)	17.06 b	19.13 a	19.28 a
Yield (kg tree^{-1})	4.08 c	6.86 b	7.96 a
Water productivity (kg m^{-3})	0.18 c	0.21 b	0.27 a

* Means in each row followed by the same letter(s) are not significantly different at $P < 0.05$ according to Duncan's multiple range test.

Number of leaves and leaf width

Irrigated trees of I4 and I1 treatments showed significantly higher number of leaves (with the mean increase of 18.2%) in years 2011 and 2012 compared with those obtained in other irrigation treatments (Table 5). Although I3 had the least leaf number in three experimental years, its difference with rainfed treatment results was not significant (Table 2). Water deficit could hinder the growth of fig trees which results in severe leaf drop (Ezzat *et al.*, 1975). Trees under summer pruning treatment (P3) showed the least number of leaves in different years and the difference was significant in year 2010. Results showed that in 2011, the number of leaves significantly increased by 83.8% compared with that obtained in 2010 and significantly reduced by 14.6% in the following year (2012). As this variation follows the similar trend for both irrigated and rainfed treatments (Table 2), it is considered that in comparison with SI, rainfall parameter could be more effective on yearly change of number of leaves. This result is in agreement with higher rainfall in resting period (January and February) of fig trees in 2011 (195.7 mm) compared with that obtained in 2010 (67.1 mm) and 2012 (153.7 mm).

During 2011 and 2012, significantly higher leaf width was achieved in I4 irrigation treatment (9.74 cm and 9.92 cm) in comparison with control (Table 2). Among all treatments, the least width of leaves was recorded for trees under I3 (8.24 cm) (Table 3). While trees respond to water stress with reduction in leaf area, many studies have reported shedding of leaves under severe drought conditions (Jones and Higgs, 1979; Lakso, 1983; Steffens and Wang, 1984).

Reduced expansion of leaf depends on sensitivity of stomata to abscisic acid (ABA) (Wilkinson and Davies, 2002). As an important phytohormone, ABA plays an essential role in such reactions related to different stress signals. Regulation of plant water balance and osmotic stress tolerance is the critical function of ABA (Mahajan and Tuteja, 2005). When drought becomes too severe or prolonged, wilting of plants and shrinkage of the cells may occur and it could lead to mechanical constraint on cellular membranes (Mahajan and Tuteja, 2005).

Among different pruning treatments, the least and highest width of leaves, occurred in P0 (8.53 cm), and P2 (8.78 cm), respectively (Table 3). In the P0 and P1 treatments, axillary leaves and buds showed no extensive growth due to existence of terminal bud and apical dominance. Compared with the first year, the leaf width increased by the mean values of 9.2% in the following years.

Syconium diameter

The mean syconium diameter was 17.0 mm in the first year and had a significant increase by 12 and 13% in the second and third years, respectively (Table 5). It might be due to a higher applied water amount of SI (36%) and also higher rainfall in resting and vegetative stages (January, February, and March) of 2011 (200.1 mm) and 2012 (202.9 mm) compared with that obtained in 2010 (73.5 mm) which resulted in higher accessible SWC for the trees.

The mean comparison effect of SI on syconium diameter showed that irrigation could increase the syconium diameter. The I4 (19.0 mm) and I1 (18.9 mm) showed significantly higher diameter values in comparison with control (17.8 mm) over three years (Table 4).

Trees under P2 and P3 pruning methods had significantly lower values for syconium diameter in comparison with control. However, severe thinning out of one-year-old lateral branches showed the highest value for syconium diameter compared to other pruning treatments. This finding might be attributed to reduction of apical dominance effect on lower part of shoots in this type of pruning. Larger syconium results in a larger fruit which is more favorable for fig growers and marketable fig. Dried fruit size is the major factor in marketing of fig production especially for direct consumption (İrget *et al.*, 2008).

Yield and water productivity

The results showed that P1 and P2 pruning methods significantly improved the yield and WP in comparison to the control (Table 4). Higher yield might be the result of higher growth rate of shoots in P1 and P2 treatments (Table 2). Gaaliche *et al.* (2011) showed that the number of figs increases

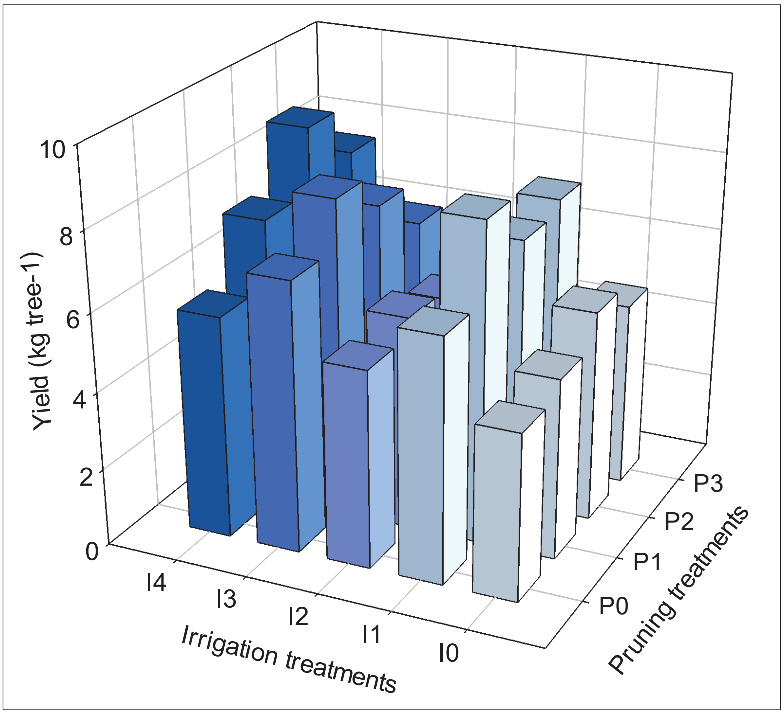

FIGURE 8. The interaction effect of irrigation and pruning treatments on 3-year mean value of yield (I0: no irrigation (control), I1: one irrigation event in the last month of winter, I2: one irrigation event in mid-spring, I3: one irrigation event in mid-summer, I4: two irrigation events, one in the last month of winter and another one in mid-spring, P0: moderate thinning out of one-year-old lateral branches (control), P1: severe thinning out of one-year-old lateral branches, P2: moderate heading back, P3: green pruning).

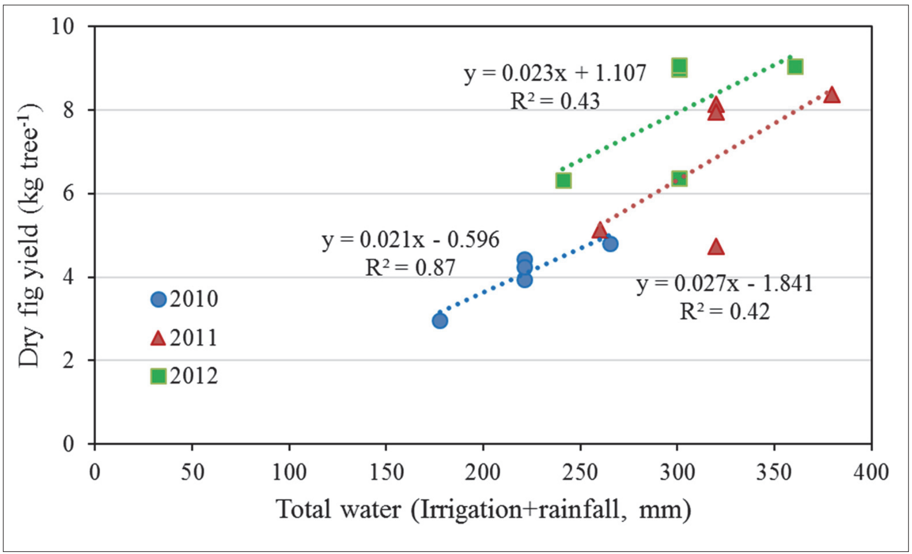

FIGURE 9. Relationship between total supplied water (supplemental irrigation and rainfall) and fig yield for the experimental years (2010, 2011 and 2012).

regularly with the length of shoots for different fig cultivars ('Khedhri' and 'Chetoui'). Also, results are in agreement with that reported by Zare *et al.* (2002) that severe thinning out of one-year-old lateral branches can significantly increase the fig production compared with the moderate thinning out of one-year-old lateral branches pruning method. Chithiraichelvan *et al.* (2017) reported that annual pruning of previous season's shoots to the basal six nodes during September is promising for considerable increase in fruit productivity of two fig cultivars 'Poona' and 'Deanna' in Bengaluru, India, under the mild tropical, semi-arid conditions. Also, Gonçalves *et al.* (2006) showed the effectiveness of pruning date on yield of 'Roxo de Valinhos' fig trees. Among different pruning dates of June, September, December, and March, they found higher yield for pruning dates of March and June in Salinas, Brazil.

In addition, SI increased fig yield compared to control. This increase is significant for all irrigation treatments except irrigation in mid-spring. Significant effects of SI on fig yield is in agreement with the results obtained by Leonel and Tecchio (2008, 2009, 2010), and Stover *et al.* (2007) in fig orchards. Positive effect of using SI in late winter on soil water content in fig orchards is reported by Abdolahipour *et al.* (2018). Bagheri and Sepaskhah (2014) found that rainfall in winter is the vital parameter for fig production in rainfed conditions.

The maximum increase in average yield of fig fruits belonged to I4 which showed 1.54 times higher yield compared with the control. The reasons might be due to higher volume of applied water (two times more than other irrigation treatments) and appropriate irrigation timing (in resting and vegetative stages). Irrigation in late winter increased fig yield by 49.6% compared with that obtained in control indicating the suitability of irrigation in this time. For the first experimental year, fig yield was 4.08 kg per tree and increased to 6.86 and 7.96 kg (68 and 95% increase) in the second and third years, respectively (Tables 2 and 5). Adaptation of fig trees to pruning and SI and also higher rainfall and applied irrigation water might be the reasons for higher yield achieving in the second and third years. The obtained result was in agreement with the interaction effect of irrigation and pruning treatments on 3-year mean value of yield (Figure 8). Result showed the maximum yield of 8.93 kg per tree for combined use of P2 and I4 treatments. It might be due to highest plant water status provided by using these two treatments. The relationship between fig yield and total consumed water including rainfall and SI water obtained for three experimental years (Figure 9). The linear equations are presented for 2010, 2011, and 2012 in Eq. (1), (2), and (3), respectively, as follows:

$$Y = 0.021X - 0.596,\ R^2 = 0.87 \quad (1)$$

$$Y = 0.027X - 1.841,\ R^2 = 0.42 \quad (2)$$

$$Y = 0.023X + 1.107,\ R^2 = 0.43 \quad (3)$$

where Y is the fig production (in kg per tree) and X is the annual summation of rainfall and supplementary irrigation (in mm).

According to Eq. (1) and Eq. (2), supplied water lower than 28.3 and 67.7 mm would result in no yield during 2010 and 2011, respectively. However, during the third year, there would be about 1 kg per tree production for rainfed fig trees in no supplied water condition Eq. (3). It might be due to stored soil water from the SI in earlier years and cumulative effect of SI. The results indicated that during a long period of drought conditions, SI may not be required for every year. However, high positive coefficient of determination (R^2) for the first year (with up to 265 mm supplied water) compared with the following years (with supplied water up to 380 and 360 mm) showed the vital role of SI in severe drought conditions. Considering the water scarcity in the area, in order to find the optimum amount of applied irrigation water for fig trees, the WP values were obtained for different treatments.

The mean WP for trees under rainfed treatment during the three-year period was 0.21 kg m^{-3}. I1 showed the significantly highest WP among irrigation treatments, followed by I3 (Table 4). I2 significantly reduced WP compared to control treatment (14%). Higher WP in I1 and I3 in comparison with I4 showed that despite lower production, application of lower volume of water in suitable time can be adequately efficient to satisfy both lower water resource and fig grower's economics. Compared with the first year, WP in the second and third years increased by 16 and 44%, respectively. These rates were 18 and 57% for trees under rainfed treatment. Whereas higher rainfall was reported for the 12-month periods which led to harvest stage (October to September) in 2011 and 2012 (260.1 and 240.9 mm, respectively) compared with this period in 2010 (177.4 mm), higher WP in the latest years is mainly due to higher annual yield. Among pruning treatments, a significantly higher WP in P1 pruning technique supported the results of yield and growth traits in appropriateness of this pruning method during the drought conditions. Reduction in total transpiration amount through severe thinning out in winter resulted in lower consumed water and consequently increased the LWP that ended up with higher yield and WP.

Conclusion

The obtained results raised doubts about the reliability of leaf temperature to be an appropriate indicator for supplementary irrigation scheduling in rainfed fig orchards. However, a highly significant correlation was observed between leaf temperature and leaf water potential. Irrigated trees and moderate heading back pruned trees showed higher LWP in comparison with other treatments.

Using SI improved production and some morphological traits of rainfed fig trees during three experimental years. However, the effects of mid-summer irrigation on yield and mid-spring irrigation on growth parameters were not significant. For different SI tested, the highest yield and best growth traits were obtained by using the two irrigation events, one in the last month of winter and another one in mid-spring. However, considering consumed water, irrigation in late winter with 750 L per tree (equal to 75 m^3 ha^{-1}) showed the highest water productivity among irrigation treatments. The relationship between total supplied water (SI and rainfall) and fig yield also revealed that application of SI in a dry year can decrease the necessity of irrigation in the following years of drought.

Significant effects of SI on plant morphological traits and also fig production in the second and third years might be attributed to higher applied irrigation water, higher rainfall amount in current year and also stored soil water left from the previous year's rainfall.

Green pruning method in the summer by pinching the end bud could not improve plant growth parameters compared with the winter pruning methods. Results showed that under drought conditions, severe thinning out of one-year-old lateral branches could be the best pruning technique in rainfed fig orchards.

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