Irrigation Science (2018) 36:87–96
https://doi.org/10.1007/s00271-017-0565-5

ORIGINAL PAPER

Assessment of different irrigation strategies on yield and quality characteristics of drip irrigated pomegranate under mediterranean conditions

Nazmi Dinc[1] · Koksal Aydinsakir[1] · Mesut Isik[1] · Ruhi Bastug[2] · Nuri Ari[1] · Alpaslan Sahin[1] · Dursun Buyuktas[2]

Received: 9 May 2017 / Accepted: 27 November 2017 / Published online: 17 January 2018

Abstract

This research was carried out to determine the effect of drip irrigation strategies on yield and quality characteristics of pomegranate (*Punica granatum* L. cv. Hicaznar) trees during the growing seasons between 2013 and 2015 years at Batı Akdeniz Agricultural Research Institute in Antalya, Turkey. The amount of irrigation water applied was based on cumulative Class A pan evaporation (K_{cp1} 0.50, K_{cp2} 0.75, K_{cp3} 1.00 and K_{cp4} 1.25) measured in two irrigation intervals (D_1, 3 days; D_2, 6 days). It was determined that irrigation intervals did not affect yield, while irrigation water levels were found to be statistically significant. The average water consumptions determined from a soil water balance were 797 mm for K_{cp4}, 730 mm for K_{cp3}, 658 mm for K_{cp2}, and 591 mm for K_{cp1} irrigation level. According to the averaged values of 3 years, annual yield for K_{cp4}, K_{cp3}, K_{cp2}, and K_{cp1} irrigation levels were 29.2, 28.9, 23.6, and 18.8 t ha^{-1}, respectively. While the effects of irrigation treatment on fruit weight, total soluble solids, total acidity and pH of juice were not significant, its effect on canopy volume and total trunk cross sectional area were found to be significant. It is concluded that pomegranate trees can be irrigated at 6 days interval using the amount of irrigation equal to 75% of cumulative Class A Pan evaporation to obtain the highest water use efficiency.

Introduction

Pomegranate (*Punica granatum* L.) is a perennial plant belonging to the genus Punica from the Lythraceae family, which has been known for 3000 years. The origin of pomegranate is Egypt, Syria, Iraq, Iran, Afghanistan, China, India, and Turkey. The Mediterranean, Aegean and South-East Anatolia regions of Turkey have quite suitable climates for pomegranate growing. The total pomegranate production of Turkey was 465,200 tons in 2016 which corresponds to 13% of world pomegranate production (FAO 2016). Irrigation water is a critical issue limiting pomegranate growth by having impact on anatomical, morphological, physiological and chemical processes. Long-term average annual precipitation in the Mediterranean and Aegean region is about 1000 mm, falling more than 98% of it from October to May. Therefore, irrigation water is needed at pomegranate cultivation to maintain and enhance crop growth and yield in arid and semi-arid conditions.

Pomegranate is categorized to be a drought tolerant plant because pomegranate can tolerate heat and can succeeds well in arid and semi-arid regions, but to reach peak vegetative growth, fruit yield and quality for production, pomegranate trees requires irrigation in arid and semi-arid areas such as Mediterranean (Morton 1987; Holland et al. 2009; Galindo et al. 2014).

Effects of irrigation water on yield and quality of pomegranate were reported by some researchers. El-Kassas (1983), Lawand and Patil (1996), Khattab et al. (2011a) and Noitsakis et al. (2016) found that the highest total soluble solid and total acidity values were recorded in irrigation levels as much as 50% of full irrigation. Blumenfeld et al. (2000) reported that 15 m^3 ha^{-1} day^{-1} in the spring season and 50 m^3 ha^{-1} day^{-1} in the summer season is enough to irrigate pomegranate. Ibrahim and El-Samad (2009) determined the effect of different irrigation regimes (70, 50 and 30% of available soil water) on water use, growth and productivity

Communicated by D. Intrigliolo.

✉ Koksal Aydinsakir
koksal.aydinsakir@tarim.gov.tr

1 Bati Akdeniz Agricultural Research Institute, Antalya, Turkey

2 Department of Farm Structures and Irrigation, Faculty of Agriculture, Akdeniz University, Antalya, Turkey

of pomegranate trees and they stated that pomegranate fruit weight decreased when the water stress increased. Holland et al. (2009) suggested that the irrigation requirement of pomegranate is 500–600 mm in Israel, while Melgarejo et al. (2000) suggested that the irrigation requirement of pomegranate is 527 mm in Murcia, Spain. Khattab et al. (2011b) reported that pomegranate yield increased when applied water increased from 280 to 600 mm. Meshram et al. (2011) found that daily water use of 5-year-old pomegranate tree is 5.3 mm day^{-1}. Mellissho et al. (2012) stated that pomegranate fruits from plants under moderate water stress (32% ETo from the beginning of the season to the end of the first half of linear fruit growth phase, 74% ETo during the second half of linear fruit growth phase and 36% ETo during the end of fruit growth and ripening phase) level showed a decrease in fruit growth, inducing a lower final fruit size and lower total yield, accompanied by changes in colour and fruit chemical characteristics, which reflected earlier ripening. Similarly, Galindo et al. (2014) indicated that pomegranate fruits exhibited a darker and more intense garnet color when not irrigated for 34 days during the second half of rapid fruit growth period resulting decrease in total fruit yield and number of total fruits per tree. Laribi et al. (2013) reported that deficit irrigation, when applied late in the season, during ripening, resulted in an increase in soluble solid content and enhancement of the red colour intensity, allowing then to control the time of ripening and harvest. On the other hand, deficit irrigation, when applied during the summer, during the main linear fruit growth period, increased the concentration of many bioactive compounds as anthocyanins that could be related to healthfulness and taste (Pena et al. 2013). Parvizi and Sepaskhah (2015) investigated that the effect of water saving irrigation under different drip irrigation strategies including partial root drying and deficit irrigation techniques with applying 50 and 75% of water requirement on quality attributes of pomegranate fruit in semi-arid area. They reported that partial root drying strategies increased the juice percentage, and maturity index and decreased the total acidity and the irrigation strategies with higher level of water stress increased the total soluble solid and decreased the vitamin C. Ayars et al. (2017) reported that the water requirement of a 6-year-old multi-trunk tree was 952 mm and the peak daily water use was 10.5 mm using a weighing lysimeter. The maximum crop coefficient (Kc) was reported by the same authors in August and September as much as 1.2. The surface drip irrigation treatments went from 645 to 932 mm and the subsurface drip irrigation treatments increased from 584 to 843 mm from 2013 to 2015. The difference in applied water between the surface drip irrigation (843 mm) and subsurface drip irrigation (932 mm) did not result in any negative effects on crop yield and fruit quality in any year.

As seen from the studies cited above, although there are some studies concerning irrigation of young and mature pomegranate trees in the world, there is no research on the effects of deficit and full irrigation on pomegranate trees in Turkey. Therefore, the present study was conducted to reveal the effect of different irrigation practices on water use, yield as well as phenological and chemical characteristics of young pomegranate trees under conditions of West Mediterranean Region in Turkey.

Materials and methods

The experiment was carried out during the growing seasons between 2013 and 2015 years at Bati Akdeniz Agricultural Research Institute in Antalya, Turkey, 36°56′N latitude and 30°53′E longitude, at altitude 28 m above sea level. The climate of the region is typically Mediterranean, i.e. mild and rainy in winter and dry and hot in summer. The long term (1954–2012) average values of temperature, relative humidity, rainfall, evaporation and wind speed between May and October ranged from 20.0 to 14.9 °C, from 56 to 65%, from 2.4 to 135 mm, from 88.2 to 292.3 mm and from 1.7 to 2.7 m s^{-1}, respectively. Meteorological data were obtained from a weather station located at about 150 m from the experimental area and similar values (data not shown) were also measured during the experimental years.

The soil of the experimental area is loam (L) in texture, non-saline (0.45 dS m^{-1}), and rich in calcium carbonate and alkaline. The soil water content (g g^{-1}) at field capacity (FC, soil water kept at 1/3 atm. pressure) was 24.0, 23.5, 21.6, and 21.1 and at permanent wilting point (PWP, soil water kept at 15 atm. pressure) was 12.7, 12.8, 11.3, and 11.9, in 0–30, 30–60, 60–90 and 90–120 cm soil depths, respectively. The corresponding values of field capacity and permanent wilting point values in 1.2 m soil profile were 358 and 193 mm, respectively. The bulk density in 0–30, 30–60, 60–90 and 90–120 cm soil depths was 1.35, 1.30, 1.32 and 1.30 g cm^{-3}. The electrical conductivity (EC) of irrigation water was 0.561 dS m^{-1} which does not pose a risk for pomegranate (Ayers and Westcot 1985).

As an experimental design, 2×3 randomized split plots were applied and each treatment which has fourteen trees was replicated three times (Gomez and Gomez 1984). Irrigation intervals formed by the main plots whereas irrigation levels were designed as sub-plots. The pomegranate (*Punica granatum* L. cv. Hicaznar) trees were planted in 2007 at 4.0 m row spacing and 3.0 m in-row plant spacing. The trees were 6 years old when the experiment started. There were 24 plots at the experimental field. Each plot consisted of 18 pomegranate trees. The 14 trees located on the edge of the experimental plot were excluded for side effect, and the remaining 4 trees in the middle of the plot were used for gathering yield and observation data (Fig. 1).

The experimental plots were irrigated with drip irrigation system and each plant row contained two laterals. The lateral lines were laid 0.25 m away from the tree trunk. The drippers on laterals were located 0.50 m apart and had a discharge of 4 L h^{-1}. The amount of water was controlled by means of a water meter and valves located on the main pipeline and each experimental plot.

Irrigation treatments were based on the evaporation data (E_{pan}, mm) obtained from a Class A Pan located near the experimental area (Doorenbos and Pruitt 1977). The Class A pan was located on a wooden support at a height of 15 cm above soil surface in a grass covered location, away from bushes, trees and other obstacles and readings were recorded manually by means of a hook gage on the irrigation intervals ($D_1=3$ and $D_2=6$ day). Four different irrigation treatments were applied, i.e. $K_{cp1}=0.50\ E_{pan}$, $K_{cp2}=0.75\ E_{pan}$, $K_{cp3}=1.00\ E_{pan}$, and $K_{cp4}=1.25\ E_{pan}$. The amount of irrigation water (L) applied to experimental plots was calculated as follows (Kanber et al. 1996):

$$I = A \times E_{pan} \times K_{cp} \times P \quad (1)$$

where I = irrigation water amount (L); A = plot area (m^2); E_{pan} = cumulative pan evaporation during the irrigation intervals (mm); K_{cp} = crop-pan coefficient ranging from 0.50 to 1.25 for irrigation treatments; and P = percentage of wetted area (%). The percentage of the area wetted (P) was taken as 40% in the application of irrigation water (Keller and Bliesner 1990).

The first irrigation (DOY 159 in 2013, DOY 147 in 2014 and DOY 138 in 2015).was applied when 50% of readily available soil water in the effective root zone (1.2 m) is consumed. At this time, the pomegranate trees were at the flowering phenological stage. Last irrigations were applied when the pomegranate trees leaves turn to yellowish color stage (DOY 272 in 2013, DOY 273 in 2014 and 2015).

Evapotranspiration (ET) was calculated using the soil water balance method for three growing season. The equation can be written as (Doorenbos and Pruitt 1977)

$$ET = I + P - D \pm \Delta W \quad (2)$$

where ET = evapotranspiration (mm); I = irrigation water applied (mm); P = amount of precipitation (mm); D = deep percolation (mm); and ΔW = change in soil water storage

Fig. 1 Layout of experiment plots (D_1 3 days; D_2 6 days)

in the 1.2 m soil profile (mm). For the calculation, I was measured using water meters, and P was observed at the meteorological station located next to the experimental plot. The irrigation water exceeding field capacity of 1.20 m soil profile is considered deep percolations. Soil water measurement taken before irrigation were compared to the amount of evaporation occurred. It is assumed that deep percolation did not occurred, since soil water deficit was less than cumulative evaporation occurred in the corresponding irrigation intervals. ET computed in 10 days intervals were summed to get seasonal ET. The average change of soil–water content (ΔW) in the soil profile was monitored gravimetrically taken in three replications separately 0.10 m away from dripper at 0.30 m increments to a depth of 1.2 m covering the effective root zone throughout the successive growing seasons of 2013, 2014, and 2015.

Water use efficiency and irrigation water use efficiency were defined as yield (Y, t ha^{-1}) divided by the evapotranspiration (ET, mm) and irrigation (I, mm) during the growing season (Howell 2001).

$$\text{WUE} = (Y/\text{ET}) \times 100 \quad (3)$$

$$\text{IWUE} = (Y/I) \times 100 \quad (4)$$

where WUE is the water use efficiency (t ha^{-1} mm^{-1}); IWUE is the irrigation water use efficiency (t ha^{-1} mm^{-1}); ET is the evapotranspiration (mm); I is the irrigation water (mm), and Y is the yield (t ha^{-1}).

The pomegranate fruits of the treatments were harvested for analysis at the commercial harvest seasons on October in trial years.

The pomegranate fruits were harvested according to fruit maturity in October 14, 2013 and 2015 and in October 15, 2015. Total fruit yield (t ha^{-1}) was determined by harvesting all the fruits on the four trees excluding the other trees on the edge of the experimental plot for side effect. Canopy volume (m^3) was calculated by multiplying square of diameter and height in four trees (Verma et al. 2016). Total trunk cross sectional area (cm^2) of the trees consisting of three trunks was computed by measuring perimeter of four trees above 0.10 m of soil surface at the end of each irrigation season. Fruit weight (g) was determined by dividing total fruit weight to the number of fruits. Ten pomegranate fruits from each replication were used in chemical analyses. Chemical analyses were determined by employing the method described by Ayhan and Eştürk (2009). Total soluble solids (%) in the juice were measured using a digital refractometer calibrated using distilled water. Total acidity (%) was measured by titrating an aliquot of juice with 0.1 N NaOH and expressed as grams of citric acid per 100 mL of juice. pH was measured using a pH meter. Analysis of Variance (ANOVA) was used to evaluate the effects of different irrigation treatments on the yield and yield components of pomegranate and the Duncan's multiple range tests was used to compare the averages (Gomez and Gomez 1984).

Results and discussion

The change in soil–water content to the depth of 1.2 m soil profile prior to irrigation in the different treatments is shown in Fig. 2. Pomegranate trees were irrigated starting from 8 June up to 29 September 2013 in the first year, from 27 May to 30 September 2014 in the second year and from 18 May to 30 September 2015 in the third year. The differences in soil water content depending on irrigation treatments occurred after 13 June 2013 in the first year, 3 June 2014 in the second year and 30 May 2015 in the third year when the treatments were irrigated. Soil water content gradually decreased for all treatments after these days, towards the end of the experiment, it dropped below the permanent wilting point only in 2015. It is observed (Fig. 2) that soil–water content in the K_{cp4} and K_{cp3} experimental plots remained higher than in the other treatment plots.

Amount of irrigation water applied, rainfall, soil water depletion, evapotranspiration, water use efficiency and irrigation water use efficiency data were given in Table 1. The plots were irrigated 39, 43 and 45 times for D_1 and 20, 22 and 23 times for D_2 treatments in 2013, 2014 and 2015, respectively. The amount of water applied to K_{cp1}, K_{cp2}, K_{cp3}, and K_{cp4} treatments were 194.2, 272.8, 351.4 and 430.0 mm in 2013, 208.6, 2901.9, 373.2 and 455.5 mm in 2014, and 188.6, 263.9, 339.2 and 414.5 mm in 2015, respectively. Seasonal ET varied from 599.5 to 828.2 mm in 2013, from 569.1 to 783.2 mm in 2014 and from 589.0 to 796.0 mm in 2015. Pomegranate ET were reported to vary from 171.0 to 557.0 mm by Bhantana and Lazarovitch (2010); from 280 to 600 mm by Khattab et al. (2011b); from 645 to 932 mm for surface drip irrigation to 584–843 mm for subsurface drip irrigation by Ayars et al. (2017).

The results showed that irrigation levels statistically ($P < 0.01$) influenced pomegranate yield in three successive years, but irrigation intervals (3, 6 days) did not affect yield in experimental years. Also the interactions between irrigation interval and irrigation level was not found statistically significant (Table 2). Pomegranate yield varied from 18.5 t ha^{-1} (D_1K_{cp1}) to 32.2 t ha^{-1} (D_1K_{cp3}), 18.6 t ha^{-1} D_2K_{cp1} to 33.2 t ha^{-1} (D_1K_{cp3}), and 16.6 t ha^{-1} (D_1K_{cp1}) to 28.7 t ha^{-1} (D_1K_{cp4}), in 2013, 2014 and 2015, respectively (Table 2). As shown in Table 2, reduction in the quantity of irrigation water resulted in a relatively lower yield. Holland et al. (2009) concluded that pomegranate are considered as a plant that is tolerant to soil water deficit but Rodríguez et al. (2012) stated that it is possible to reach ideal growth, higher yield and quality with regular irrigation. Similarly, Sulochanamma et al. (2005) reported that pomegranate

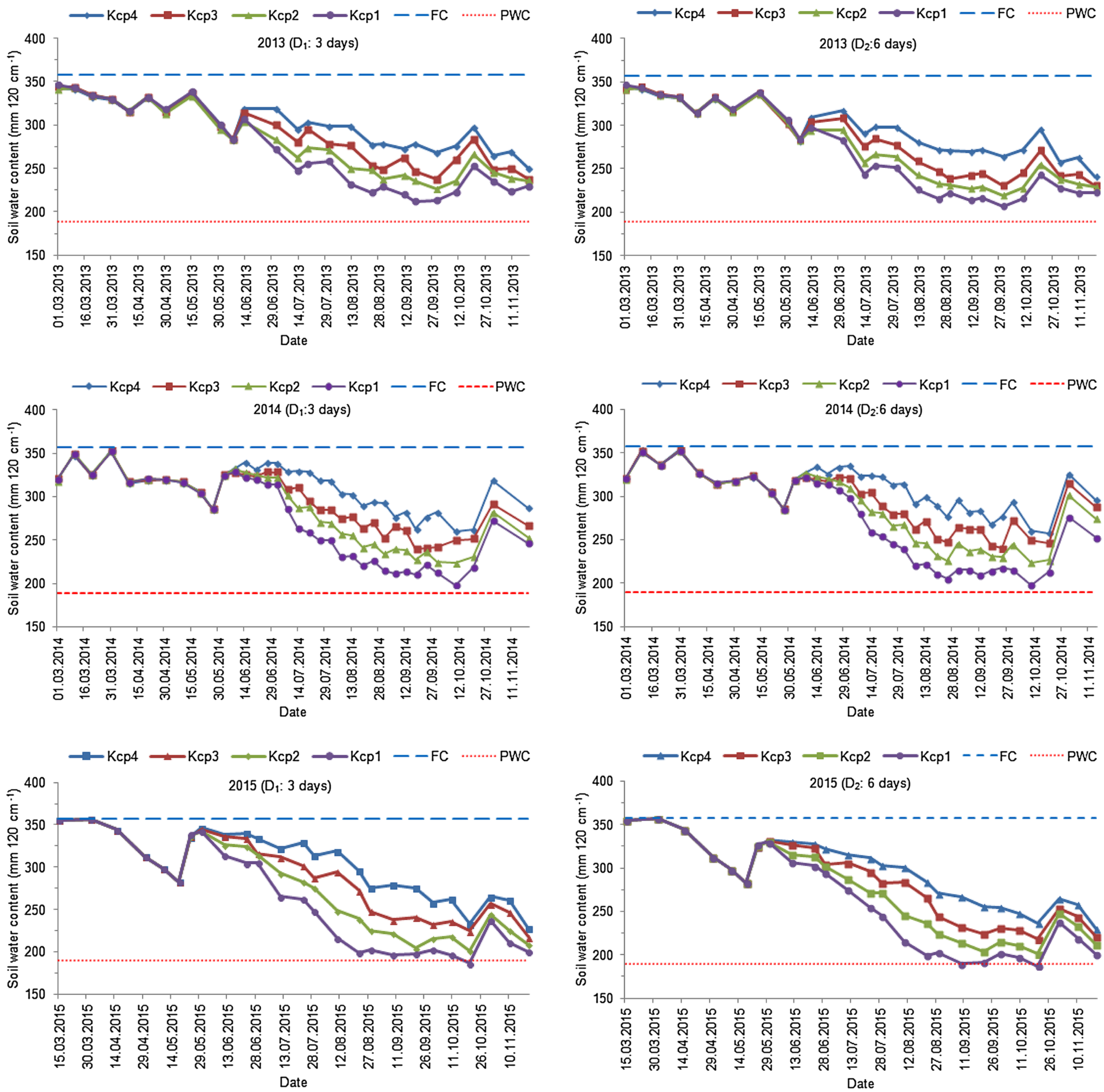

Fig. 2 Change in soil–water content prior to irrigation during the growing seasons (2013–2015)

plants have a tendency to appreciate heat and thrive in arid and semi-arid regions, but desires regular irrigation during the dry period to reach optimum yield. Khattab et al. (2011b) and Meshram et al. (2011) found that yield and quality parameters increased as applied irrigation water increase and water stress decrease. Pomegranate yields were reported to vary from 23.5 t ha^{-1} for deficit irrigation to 27.6 t ha^{-1} for full irrigation by Abdelfatah (2009), from 18.0 t ha^{-1} for deficit irrigation to 42.0 t ha^{-1} for full irrigation by Meshram et al. (2010), from 18.7 t ha^{-1} in stress conditions to 28.9 t ha^{-1} for non-stress conditions by Intrigliolo et al. (2013), from 5.5 t ha^{-1} in drought conditions to 12.8 t ha^{-1} for non-stress conditions by Tavousi et al. (2015). Water stress in deficit irrigation treatments in pomegranate plots resulted in lower yields as compared to the full irrigation treatments in our study. The results obtained in this study are in accord with the results given in the literature.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were found statistically not significant. The WUE varied from 3.1 to 4.3 t ha^{-1} mm^{-1}, from 3.3 to

Table 1 The parameters of water balance and water use efficiency in the study

Years	Parameters	D_1				D_2			
		K_{cp1}	K_{cp2}	K_{cp3}	K_{cp4}	K_{cp1}	K_{cp2}	K_{cp3}	K_{cp4}
2013	Irrigation water (I, mm)[a]	194.2	272.8	351.4	430.0	194.2	272.8	351.4	430.0
	Rainfall (P, mm)[b]	292.0	292.0	292.0	292.0	292.0	292.0	292.0	292.0
	Soil water depletion (ΔS, mm)[c]	116.4	105.7	106.3	92.2	123.5	112.5	110.8	103.6
	ET (mm)[d]	602.6	670.5	749.7	814.2	609.7	677.3	754.2	825.6
	ETo (mm)[e]	785.3	785.3	785.3	785.3	785.3	785.3	785.3	785.3
	WUE (t ha^{-1} mm^{-1})	3.1	3.6	4.3	3.9	3.4	3.6	3.5	3.4
	IWUE (t ha^{-1} mm^{-1})	9.5	8.9	9.2	7.3	10.7	9.0	7.6	6.5
2014	Irrigation water (I, mm)[a]	208.6	290.9	373.2	455.5	208.6	290.9	373.2	455.5
	Rainfall (P, mm)[b]	294.0	294.0	294.0	294.0	294.0	294.0	294.0	294.0
	Soil water depletion (ΔS, mm)[c]	73.5	65.5	54.0	32.6	68.5	45.2	33.6	25.7
	ET (mm)[d]	576.1	650.4	721.2	782.1	571.1	630.1	700.8	775.2
	ETo (mm)[e]	716.6	716.6	716.6	716.6	716.6	716.6	716.6	716.6
	WUE (t ha^{-1} mm^{-1})	3.6	3.7	4.6	4.1	3.3	4.4	4.2	3.9
	IWUE (t ha^{-1} mm^{-1})	10.0	8.4	8.9	7.1	8.9	9.6	7.9	6.7
2015	Irrigation water (I, mm)[a]	186.8	261.2	335.6	410.0	186.8	261.2	335.6	410.0
	Rainfall (P, mm)[b]	251.1	251.1	251.1	251.1	251.1	251.1	251.1	251.1
	Soil water depletion (ΔS, mm)[c]	155.3	146.9	137.8	127.4	155.4	143.4	134.8	125.4
	ET (mm)[d]	593.2	659.2	724.5	788.5	593.3	655.7	721.5	786.5
	ETo (mm)[e]	752.6	752.6	752.6	752.6	752.6	752.6	752.6	752.6
	WUE (t ha^{-1} mm^{-1})	2.8	2.9	3.7	3.6	3.0	3.2	3.5	3.1
	IWUE (t ha^{-1} mm^{-1})	8.9	7.4	8.0	7.0	9.5	8.1	7.6	6.0

[a]Irrigation periods are 28 June 2013 to 29 September 2013 (first year) 27 May 2014 to 30 September 2014 (second year) and 18 May 2015 to 30 September 2015 (third year).

[b]As periodically, total rainfall received from 1 March 2013 to 20 November 2013 (first year) 1 March 2014 to 20 November 2014 (second year) and 15 March 2015 to 20 November 2015 (third year); all the rainfall has been accepted to be effective.

[c]Soil water depletion values are from 1 March 2013 to 20 November 2013 (first year) 1 March 2014 to 20 November 2014 (second year) and 15 March 2015 to 20 November 2015 (third year).

[d]Evapotranspiration values are from 1 March 2013 to 20 November 2013 (first year) 1 March 2014 to 20 November 2014 (second year) and 15 March 2015 to 20 November 2015 (third year).

[e]ETo values are computed from 1 March 2013 to 20 November 2013 (first year) 1 March 2014 to 20 November 2014 (second year) and 15 March 2015 to 20 November 2015 (third year) using ETo=Kpan x Epan.

4.6 t ha^{-1} mm^{-1} and from 2.8 to 3.7 t ha^{-1} mm^{-1} in 2013, 2014 and 2015, respectively. The IWUE varied from 6.5 to 10.7 t ha^{-1} mm^{-1}, from 6.7 to 10.0 t ha^{-1} mm^{-1} and from 6.0 to 9.5 t ha^{-1} mm^{-1} in 2013, 2014 and 2015, respectively (Table 1). Goodwin and Boland (2000) reported that deficit or excessive water stress leads to stomatal closure, thereby improving the water use efficiency in water stressed plants. WUE values decreased with either decreasing or increasing irrigation water levels. Meshram et al. (2010) concluded that the low WUE values were due to less water available to plants resulting in lower yield. It is stated that, D_1K_{cp3} treatments gave the maximum profit for using available irrigation water. The results are in agreement with results reported by Intrigliolo et al. (2013), although they are higher than the results reported by Khattab et al. (2011b). These differences can be attributed to the variety of plant and climatic conditions.

The irrigation levels, irrigation intervals and irrigation levels x irrigation intervals interactions did not have a significant effects fruit weight in 2013, 2014 and 2015 years (Table 2). The highest fruit weight was determined 589.0 g for D_1K_{cp2} in 2015. Intrigliolo et al. (2013) noted also that regulated deficit irrigation regime did not affect fruit weight. On the contrary, Khattab et al. (2011a, b) and Mellisho et al. (2012) reported that pomegranate under moderate water stress level showed a decrease in fruit weight. Similar results were found in our study for young pomegranate trees.

Effects of different irrigation levels on some physical parameters of the pomegranate in the three successive years are presented in Table 3. The canopy volume was affected

Table 2 Effect of different irrigation intervals and levels on yield and fruit weight of pomegranate cv. Hicaznar in 2013, 2014 and 2015 seasons

Years	Irrigation intervals	Irrigation levels				Average D
		K_{cp1}	K_{cp2}	K_{cp3}	K_{cp4}	
Yield (t ha^{-1})						
2013	D_1	18.5	24.2	32.2	31.6	26.6
	D_2	20.7	24.4	26.5	28.1	24.9
	Average K_{cp}	19.6c	24.3b	29.4a	29.8a	
	D ns, K_{cp}**, $D \times K_{cp}$ ns					
2014	D_1	20.9	24.3	33.2	32.2	27.6
	D_2	18.6	28.0	29.7	30.4	26.7
	Average K_{cp}	19.8b	26.2a	31.4a	31.3a	
	D ns, K_{cp}**, $D \times K_{cp}$ ns					
2015	D_1	16.6	19.4	26.8	28.7	22.9
	D_2	17.7	21.2	25.4	24.4	22.2
	Average K_{cp}	17.2b	20.3ab	26.1a	26.6a	
	D ns, K_{cp}**, $D \times K_{cp}$ ns					
Fruit weight (g)						
2013	D_1	470.2	458.9	465.2	481.4	468.9
	D_2	480.0	465.3	483.2	478.9	476.9
	Average K	475.1	462.1	474.2	480.2	
	D ns, K ns, $D \times K$ ns					
2014	D_1	534.5	493.7	448.4	550.1	506.7
	D_2	476.6	475.5	503.3	472.8	482.1
	Average K	505.6	484.6	475.9	511.5	
	D ns, K ns, $D \times K$ ns					
2015	D_1	557.6	589.0	570.8	552.4	567.5
	D_2	527.6	539.9	551.4	548.0	541.7
	Average K	542.6	564.5	561.1	550.2	
	D ns, K ns, $D \times K$ ns					

Means designated with the same letter in the same line are not significantly different at 0.05 level of probability

ns non-significant

**Significant at $P < 0.01$

Table 3 Effect of different irrigation intervals and levels on some growing characteristics of pomegranate cv. Hicaznar in 2013, 2014 and 2015 seasons

Years	Irrigation intervals	Irrigation levels				Average D
		K_{cp1}	K_{cp2}	K_{cp3}	K_{cp4}	
Canopy volume (m^3)						
2013	D_1	8.3	8.6	9.2	9.0	8.8 a
	D_2	7.1	7.0	7.6	8.0	7.4 b
	Average K_{cp}	7.7b	7.8a	8.4a	8.5a	
	D*, K_{cp}*, $D \times K_{cp}$ ns					
2014	D_1	8.4	8.6	9.3	9.5	8.9 a
	D_2	8.0	8.1	9.08	9.2	8.6 b
	Average K	8.2b	8.3b	9.2a	9.3a	
	D*, K_{cp}**, $D \times K_{cp}$ ns					
2015	D_1	8.0	8.4	9.3	9.4	8.9 a
	D_2	8.0	8.4	9.2	9.3	8.5 b
	Average K	8.0c	8.4b	9.3a	9.4a	
	D ns, K_{cp}**, $D \times K_{cp}$ ns					
Total trunk cross sectional area (cm^2)						
2013	D_1	119.7	116.4	125.8	123.9	121.5
	D_2	115.9	111.7	119.4	117.2	116.0
	Average K_{cp}	117.8	114.1	122.6	120.6	
	D ns, K_{cp} ns, $D \times K_{cp}$ ns					
2014	D_1	138.8	142.5	143.5	154.9	144.9
	D_2	139.8	138.0	156.4	145.1	144.8
	Average K_{cp}	139.3b	140.3ab	149.9a	150.0a	
	D ns, K_{cp}*, $D \times K_{cp}$ ns					
2015	D_1	162.3	170.8	178.4	174.4	171.5
	D_2	160.0	165.6	171.3	181.4	169.6
	Average K_{cp}	161.2b	168.2ab	174.4a	177.9a	
	D ns, K_{cp}**, $D \times K_{cp}$ ns					

Means designated with the same letter in the same line are not significantly different at 0.05 level of probability

ns non-significant

*Significant at $P < 0.05$

**Significant at $P < 0.01$

statistically by different irrigation levels and intervals in 2013 and 2014, but it was affected only by irrigation levels in 2015. The average canopy volume of K_{cp2} (7.8 m^3), K_{cp3} (8.4 m^3), and K_{cp4} (8.5 m^3) irrigation treatments were in the same statistical groups in 2013 while K_{cp3} (9.2 and 9.3 m^3), and K_{cp4} (9.3 and 9.4 m^3) irrigation treatments were in the same statistical groups in 2014 and 2015. Mellisho et al. (2012) concluded that deficient irrigation water application in pomegranate cultivation could completely inhibit water absorption, transpiration, photosynthesis, development of new shoot, brunch and canopy growth. Additionally, Intrigliolo et al. (2011) stated that water stress caused a reduction in rate of transpiration and photosynthesis, and stomatal conductance. It is clear that low irrigation water level affected canopy volume in our study.

Effects of different irrigation intervals and irrigation levels on total cross sectional area of trunk were not statistically significant in 2013, but irrigation levels were statistically significant in 2014 and 2015 (Table 3). Total cross sectional area of trunk decreased linearly with decreasing level of irrigation in 2014 and 2015 except for 2013. The average total cross sectional area of trunk values were changed between 114.1 and 122.6 cm^2 in 2013, 139.3 and 150.0 cm^2 in 2014, and 161.2 and 177.9 cm^2 in 2015. In our experiment, irrigation interval did not affect total cross sectional area of trunk while irrigation levels affected total cross sectional area of trunk in 2014 and 2015. Even though the differences are not statistically significant, the highest average trunk cross-sectional area (121.5, 144.9, 171.5 cm^2) was obtained from D_1 irrigation level in three experimental years. Correa-Tedesco et al. (2010), Makus et al. (2014) and de la Rosa et al. (2016) reported that trunk cross-sectional area was decreased linearly with decreasing irrigation water levels in olive, pomegranate and nectarine, respectively.

The irrigation levels, irrigation intervals and irrigation level × irrigation interval interactions did not have a significant effect on fruit weight in 2013, 2014 and 2015 years (results not shown). Although the differences are not statistically significant, the highest fruit weight was determined 589.0 g for D_1K_{cp2} in 2015. In terms of irrigation levels, the highest fruit weight was found in K_{cp4} (480.2 and 511.5 g) irrigation level in 2013 and 2014, while it was obtained in K_{cp3} (561.1 g) for 2015. Intrigliolo et al. (2013) noted that regulated deficit irrigation regime did not affect fruit weight. On the contrary, Khattab et al. (2011b) and Mellisho et al. (2012) reported that pomegranate under moderate water stress level showed a decrease in fruit growth and fruit size. Similar results were found in our study for young pomegranate trees.

Effects of different irrigation strategies on the total soluble solids, total acidity and pH were not affected statistically by different irrigation levels and intervals in the study (results not shown). However, an increase in total soluble solid and total acidity in juice was observed as the amount of irrigation decreased. On the contrary, pH values decreased as irrigation applications were restricted. There is a dilemma about the change in some chemical parameters in pomegranate juice as some of the studies reporting that chemical parameter such as total soluble solid, total acidity and pH are not changed with water stress whereas some of them showing that these parameters are affected by water stress. Laribi et al. (2013), Mena et al. (2013), and Noitsakis et al. (2016) reported that water stress did not affect chemical parameters of the pomegranate, while El-Kassas (1983), Lawand and Patil (1996), Khattab et al. (2011a) and Mellisho et al. (2012), showed that water stress did affect chemical characteristics of the pomegranate juice.

Conclusions

The effects of different irrigation levels and irrigation intervals in young pomegranate grown in Mediterranean region on yield and quality parameters were examined in the study. The effects of different irrigation levels on yield, canopy volume and total trunk cross sectional area were statistically significant; nevertheless fruit weight and total soluble solids, total acidity and pH of juice were statistically insignificant under the experimental conditions. The irrigation intervals did not affect pomegranate yield and parameters statistically. The highest yield was obtained from the K_{cp4} treatment, followed by K_{cp3} treatment. Canopy volume and trunk total cross sectional area values decreased as the amount of water deficit increased. On the contrary, total soluble solids and total acidity values increased as the amount of water deficit decreased. With regards to the combined effect of yield reduction and water use efficiency, the K_{cp3} treatment (which was irrigated as much as 100% of the Class A pan evaporation) could be suggested in semiarid conditions where the irrigation water resources are limited, as this treatment could save as much as 18.2% of water with only a 1.2% relative yield decrease in three successive years. Based on all results obtained from the experiment, it can be expressed that pomegranate trees can be irrigated either 3 or 6 days interval as much as the cumulative evaporation measured in Class A pan between irrigation intervals to obtain high yield and good quality. However, it is concluded that pomegranate trees can be irrigated at 6-day interval with the amount of irrigation equal to 75% of the Class A Pan evaporation to obtain the maximum water use efficiency under Mediterranean region of Turkey.

Acknowledgements We gratefully acknowledge for the financial support of the General Directorate of Agricultural Research and Policies under Project no: TAGEM/TSKAD/11/A13/P02/02.

References

Abdelfatah MAM (2009) Response of pomegranate trees (*Punica granatum* L., cv. Mollar de Elche) to deficit irrigation at different phenological stages. Master Thesis, Universitat Politecnica De Valencia

Ayars JE, Phene CJ, Phene RC, Gao S, Wan D, Day KR, Makus DJ (2017) Determining pomegranate water and nitrogen requirements with drip irrigation. Agric Water Manag 187:11–23

Ayers RS, Westcot DW (1985) Water Quality for agriculture. Irrigation and drainage paper no. 29. FAO, Rome

Ayhan Z, Eştürk O (2009) Overall quality and shelf life of minimally processed and modified atmosphere packaged "ready-to-eat" pomegranate arils. J Food Sci 74(5):399–405

Bhantana P, Lazarovitch N (2010) Evapotranspiration, crop coefficient and growth of two young pomegranate (*Punica granatum* L.) varieties under salt stress. Agric Water Manag 97:715–722

Blumenfeld A, Shaya F, Hillel R (2000) Cultivation of pomegranate. Options Méditerranéennes Ser A 42:143–147

Correa-Tedesco G, Rousseaux MC, Searles PS (2010) Plant growth and yield responses in olive (*Olea europaea*) to different irrigation levels in an arid region of Argentina. Agric Water Manag 97:1829–1837

De la Rosa JM, Conesa MR, Domingo R, Aguayo E, Falagán N, Pérez-Pastor A (2016) Combined effects of deficit irrigation and crop level on early nectarine trees. Agric Water Manag 170:120–132

Doorenbos J, Pruitt WO (1977) Guidelines for predicting crop water requirements FAO irrigation and drainage paper no. 24. FAO, Rome, p 144

El-Kassas SE (1983) Effect of irrigation at certain soil moisture levels and nitrogen application on the yield and quality of Manfalouty pomegranate cultivar. ASSIUT J Agric Sci 14:167–179

FAO (2016) FAOSTAT, Statistics database, agriculture. Food and Agriculture Organization, Rome

Galindo A, Calín-Sánchez Á, Collado-González J, Ondoño S, Hernández F, Torrecillas A, Carbonell-Barrachina ÁA (2014) Phytochemical and quality attributes of pomegranate fruits for juice consumption as affected by ripening stage and deficit irrigation. J Sci Food Agr 94(11):2259–2265

Gomez KA, Gomez AA (1984) Statistical procedures for agricultural research. John Wiley, New York, p 680 **(An Int. Rice Res. Inst. Book)**

Goodwin I, Boland AM (2000) Scheduling deficit irrigation of fruit trees for optimizing water use efficiency. In: Deficit irrigation practices, water reports, vol 22, FAO, Rome, pp 67–78

Holland D, Hatib K, Bar-Yàakov I (2009) Pomegranate: botany, horticulture, breeding. In: Jules J (ed) Horticultural reviews, vol 35, John Wiley & Sons, Inc., pp 127–191

Howell T (2001) Enhancing water use efficiency in irrigated agriculture. Agron J 93(2):281–289

Ibrahim AM, El-Samad ABDGAA (2009) Effect of different irrigation regimes and partial substitution of N-mineral by organic manures on water use, growth and productivity of pomegranate trees. Eur J Sci Res 38(2):199–218

Intrigliolo DS, Nicolas E, Bonet L, Ferrer P, Alarcon JJ, Bartual J (2011) Water relations of field grown pomegranate trees (*Punica granatum*) under different drip irrigation regimes. Agric Water Manag 98:1462–1468

Intrigliolo DS, Bonet L, Nortes PA, Puerto H, Nicolas E, Bartual J (2013) Pomegranate trees performance under sustained and regulated deficit irrigation. Irrig Sci 31(5):959–970

Kanber R, Koksal H, Onder S, Eylen M (1996) Effects of different irrigation methods on yield, evapotranspiration and root development of young orange trees. Turk J Agric For 20:163–172

Keller J, Bliesner RD (1990) Sprinkle and trickle irrigation. Von Nostrand Reinhold, New York

Khattab MM, Shaban AE, El-Shrief AH, El-Deen Mohamed AS (2011a) Growth and productivity of pomegranate trees under different irrigation levels. II: fruit quality. IJHSOP 3(3):259–264

Khattab MM, Shaban AE, El-Shrief AH, El-Deen Mohamed AS (2011b) Growth and productivity of pomegranate trees under different irrigation levels I: vegetative growth and fruiting. IJHSOP 3(2):194–198

Laribi AL, Palou L, Intrigliolo DS, Nortes PA, Rojas-Argudo C, Taberner V, Bartual J, Pérez-Gago MB (2013) Effect of sustained and regulated deficit irrigation on fruit quality of pomegranate cv. 'Mollar de Elche' at harvest and during cold storage. Agric Water Manag 125:61–70

Lawand BT, Patil VK (1996) Effect of different water regimes on fruit quality of pomegranate (*Punica granatum* L.). Int J Trop Agric 14:153–158

Makus DJ, Ayars JE, Wang D (2014) Influence of white plastic and water replacement rates on pomegranate orchard phenology, fruit yield and quality. ASHS Conference. https://ashs.confex.com/ashs/2014/webprogramarchives/Paper17739.html. Accessed 17 Jan 2018

Melgarejo P, Salazar DM, Artés F (2000) Organics acids and sugar composition of harvested pomegranate fruits. Eur Food Res Technol 211:185–190

Mellisho CD, Egea I, Galindo A, Rodríguez P, Rodríguez J, Conejero W, Romojar F, Torrecillas A (2012) Pomegranate (*Punica granatum* L.) fruit responses to different deficit irrigation conditions. Agric Water Manag 114:30–36

Mena P, Galindo A, Collado-González J, Ondono S, García-Viguera C, Ferreres F, Torrecillas A, Gil-Izquierdo A, Gil-Izquierdo A (2013) Sustained deficit irrigation affects the colour and phytochemical characteristics of pomegranate juice. J Sci Food Agric 93(8):1922–1927

Meshram DT, Gorontiwar SD, Teixeira JA, Jadhav VT, Chandra R (2010) Water management in pomegranate. Fruit Veg Cereal Sci Biotech 4:106–112

Meshram DT, Mittal HK, Purohit RC, Gorantiwar SD (2011) Water requirement of pomegranate (*Punica granatum* L.) for Solapur district of Maharashtra State. International Society for Horticultural Science (ISHS), Leuven, pp. 311–322

Morton J (1987) Pomegranate. In: Morton JF (ed) Fruits of warm climates. Creative Resource Systems, Inc., Miami, pp 352–355

Noitsakis B, Chouzouri A, Papa L, Patakas A (2016) Pomegranate physiological responses to partial root drying under field conditions. EJFA 28(6):410–414

Parvizi H, Sepaskhah AR (2015) Effect of drip irrigation and fertilizer regimes on fruit quality of a pomegranate (*Punica granatum* (L.) cv. Rabab) orchard. Agric Water Manag 156:70–78

Pena ME, Artés-Hernández F, Aguayoa E, Martínez-Hernández GB, Galindoc A, Artés F, Gómez PA (2013) Effect of sustained deficit irrigation on physicochemical properties, bioactive compounds and postharvest life of pomegranate fruit (cv. 'Mollar de Elche'). Postharvest Biol Technol 86:171–180

Rodríguez P, Mellisho CD, Conejero W, Cruz ZN, Ortuno MF, Galindo A, Torrecillas A (2012) Plant water relations of leaves of pomegranate trees under different irrigation conditions. Environ Exp Bot 77:19–24

Sulochanamma BN, Reddy TY, Reddy GS (2005) Effect of basin and drip irrigation on growth, yield and water use efficiency in pomegranate cv. Gennesh Acta Hort 696:277–279

Tavousi M, Kaveh F, Alizadeh A, Babazadeh H, Tehranifar A (2015) Effects of drought and salinity on yield and water use efficiency in pomegranate tree. J Mater Environ Sci 6(7):1975–1980

Verma NK, Lamb DW, Reid N, Wilson B (2016) Comparison of canopy volume measurements of scattered eucalypt farm trees derived from high spatial resolution imagery and LİDAR. Remote Sens 8(5):1–16