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Water Management in Pomegranate

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ABSTRACT

Water management is a critical aspect for the successful cultivation of pomegranate. In arid and semi-arid regions of India, water is a scarce resource and its efficient use has to be prioritized. Regular water supply through a drip irrigation system is essential for sustainable production of pomegranate. Water applied in appropriate irrigation scheduling can influence productivity and fruit quality. In this paper, a critical review of several research studies pertaining to water management in pomegranate has been highlighted.

Keywords: crop evapotranspiration (ET_c), crop coefficient (k_c), irrigation scheduling and methods, reference crop evapotranspiration (ET_r)

CONTENTS

INTRODUCTION

Pomegranate (*Punica granatum* L.) is a favorite dessert fruit of tropical and subtropical climates. In India, its major cultivation is concentrated in the Deccan Plateau. Water scarcity has been observed in the main pomegranate-growing states of India. When water becomes scarce, its demand management becomes key to the overall strategy for managing water (Molden *et al.* 2001). Since horticulture is the major competitive user of diverted water in India (GOG 1999), demand management in horticulture would be a focus point to reduce the aggregate demand of water to match with available future supplies, thereby reducing the extent of water stress that the country is likely to face (Kumar 2003a, 2003b). Improving the productivity of water use in horticulture is an important part of the overall framework for managing water demand, thereby increasing the ability of agencies and other interested parties to transfer water to economically more efficient or other high priority use sectors (Barker *et al.* 2003; Kijne *et al.* 2003).

Water management refers to artificial ways and means to provide a specific quantity of water at an appropriate time to the effective root zone of crops deriving maximum water for higher application efficiency and water use efficiency (WUE). The survival of pomegranate orchards in arid and semi-arid zones depends on the availability of water for irrigation throughout the major growing seasons. The performance of trees i.e. yield, fruit size, fruit quality, storability, and long-term productivity are highly dependent on water. Worldwide, the amount of water available for agriculture/horticulture use is decreasing and, thus water storage is expected. Hence, attempts are required to increase the WUE of different crops, including pomegranate. The level of water in pomegranate cultivation depends on environmental factors that drive evaporative demand and transpiration, salinity, and electrolyte composition in the soil solution, resistance of the soil, root penetration and moisture transport, soil aeration, tree hydraulic architecture and crop load. However, water interacts indirectly with the susceptibility of plants to diseases and pests. Irrigation affects the performance of trees through major mechanisms i.e., stomatal conductance, assimilation rate, turgor and expansive growth. This emphasizes the important role of the tree-water relation (Jones *et al.* 1985; Flore and Lakso 1989). Pomegranate-growing areas often experience drought conditions. Therefore, assured irrigation facility is required for its successful cultivation. Interestingly, this crop is best suited for drought-prone areas as it requires light soil and low rainfall of 180-550 mm (Levin 2006). The area under pomegranate in India is increasing at a faster rate due to its hardy nature, low maintenance cost, low water requirement, high yield potential, good keeping quality and versatile adaptability. However, regular irrigation is essential during the reproductive stage as irregular moisture causes dropping of flowers and small fruits to senesce (Patil *et al.* 2002). A sudden change in soil moisture causes moisture stress, which affects fruit development adversely and leads to fruit cracking (Cheema *et al.* 1954).

IRRIGATION SCHEDULING

Irrigation is a major activity and the most intensively practiced operation throughout the season. Its importance depends on the climate and increases with temperate. The performance of pomegranate trees in terms of crop yield, fruit size, fruit quality, storability and long-term produc-

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Invited Mini-Review

Table 1 Crop coefficient values under various irrigation electrical conductivities with days after bud burst for 'Wonderful' and 'SP-2'*.

DAB	EC-0.8		EC-1.4		EC-3.3		EC-4.8		EC-8	
	Wonderful	SP-2	Wonderful	SP-2	Wonderful	SP-2	Wonderful	SP-2	Wonderful	SP-2
30	0.16	0.15	0.15	0.15	0.14	0.14	0.12	0.09	0.09	0.09
60	0.19	0.19	0.19	0.19	0.16	0.15	0.13	0.13	0.09	0.09
90	0.49	0.44	0.45	0.41	0.33	0.31	0.23	0.21	0.13	0.13
120	0.64	0.58	0.52	0.53	0.38	0.35	0.25	0.24	0.12	0.11
150	0.53	0.60	0.42	0.54	0.43	0.37	0.29	0.29	0.17	0.17
180	0.39	0.45	0.32	0.44	0.41	0.32	0.30	0.30	0.21	0.17
210	0.22	0.28	0.19	0.27	0.32	0.23	0.25	0.25	0.16	0.12
240	0.20	0.28	0.17	0.23	0.18	0.33	0.28	0.22	0.15	0.15

* Bhantana and Lazarovitch (2010)

Table 2 Stage-wise water requirement (l/day) of 5-year-old pomegranate tree.*

Stages	Months	SWM	AWR (l/day)	Stage wise AWR(l/day)
Initial	August	31	5.62	8.24
		32	8.24	
		33	10.86	
Crop development		34	14.00	26.16
		35	17.53	
	September	36	19.61	
		37	23.17	
		38	25.04	
		39	26.93	
	October	40	29.83	
		41	31.99	
		42	35.38	
		43	38.33	
Mid-season	November	44	40.00	39.53
		45	42.22	
		46	41.57	
		47	39.12	
		48	38.92	
	December	49	37.89	
		50	37.01	
Late season		51	37.58	41.96
		52	41.70	
	January	1	36.99	
		2	36.46	
		3	37.12	
		4	38.75	
		5	40.55	
	February	6	41.97	
		7	43.05	
		8	46.18	
		9	48.81	
	March	10	48.49	
		11	47.84	
		12	45.20	
		13	47.36	
Rest season	April	14	48.24	48.43
		15	50.23	
		16	53.61	
		17	54.62	
		18	56.76	
	May	19	60.07	
		20	62.14	
		21	59.83	
		22	57.79	
	June	23	50.87	
		24	44.27	
		25	42.78	
		26	39.17	
	July	27	39.58	
		28	37.24	
		29	35.61	
		30	34.78	

Meshram *et al.* (2009)
Note: SMW-Standard meteorological week, AWR-Average water requirement

tivity depends on irrigation. Taking these into account, suitable strategies have to be devised in order to improve the WUE for pomegranate.

Bhantana and Lazarovitch (2010) reported the importance of crop coefficient values for irrigation scheduling of two varieties of pomegranate. They estimated k_c values by using a lysimeter for pomegranate cvs. 'Wonderful' and 'SP-2' on various treatments of irrigation water having an electrical conductivity of 0.8, 1.4, 3.3, 4.8 and 8 dS/m. (**Table 1**). Further, an attempt was made to assess the standard meteorological week-wise water requirement in pomegranate cv. 'Bhagawa' (Meshram *et al.* 2009). From **Table 2**, it can be observed that the water requirement of a 5-year-old pomegranate tree varied from 5.62 to 48.81 l/day at different stages, i.e. initial, crop development, mid and late-season in the western part of Maharashtra, India: specifically 8.24, 26.16, 39.53 and 41.96 l/day, respectively. The seasonal water requirement of pomegranate was 14057.33 l/year/tree. The reference crop evapotranspiration estimated by the Penamn-Monteith method and stage-wise crop coefficient values of 5-year-old pomegranate tree obtained from local information are presented in **Figs. 1** and **2**. From both these figures, it is seen that, the reference crop evapotranspiration (ET_r) values ranged from 24.4 to 56.0 mm/week and crop coefficient (k_c) values at different stages (i.e. initial, crop development, mid- and late-season stages) were 0.15-0.20, 0.20-1.18, 1.18 (constant) and 1.18-0.55, respectively. In fact, the water requirement in the present study was calculated based on a combination of ET_r, wetted area, irrigation efficiency and crop factor parameters. Water use by pomegranate started from the bud break (initial) stage. It increased gradually as the canopy developed and as evaporative demand increased. The canopy was fully developed by mid-August, and peak water use occurred at crop development (September, October) and mid-season (November, December) stages. From **Fig. 2** it can be observed that the lengths of the different growth stages (i.e. phenological stages) of a 5-year-old pomegranate tree were obtained from local observations: initial stage = 31^{st} to 33^{rd} meteorological week (21 days); crop development stage = 34^{th} to 44^{th} meteorological week (77 days), mid-season = 45^{th} to 52^{nd} meteorological week (57 days), late-season: 1^{st} to 15^{th} meteorological week (105 days) and crop rest period: 16^{th} to 30^{th}

Table 3 Water requirement (l/day) for pomegranate tree.*

Months	Age of tree (years)				
	1	2	3	4	5
January	2.70	7.59	20.93	29.90	38.87
February	2.83	10.39	28.66	40.95	53.23
March	2.96	11.10	31.08	44.40	57.72
April	3.24	12.15	34.02	48.60	63.18
May	3.40	12.75	35.70	51.00	66.30
June	1.99	7.69	21.95	31.35	40.75
July	1.54	5.94	16.94	24.20	31.46
August	1.33	5.13	14.63	20.90	27.14
September	1.33	5.13	14.63	20.90	27.17
October	1.57	6.07	18.90	27.00	35.10
November	1.80	6.75	18.90	27.00	35.10
December	1.68	6.30	17.64	25.20	32.76

* Bangar and Kadam (2000)

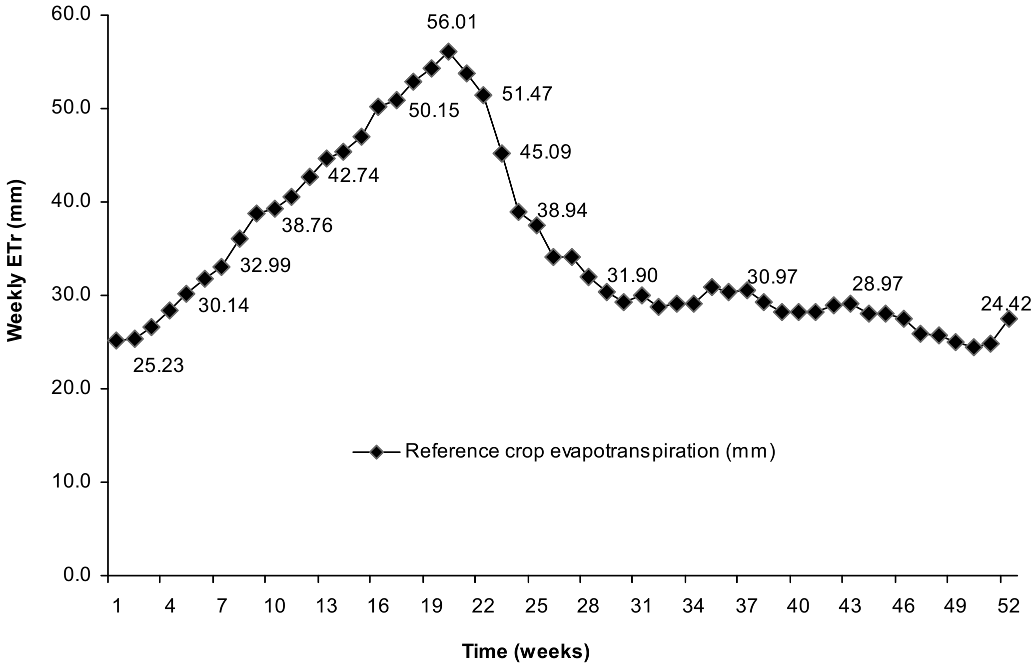

Fig. 1 Average weekly reference crop evapotranspiration (ET_r) estimated by Penman-Monteith method (1984-2007).

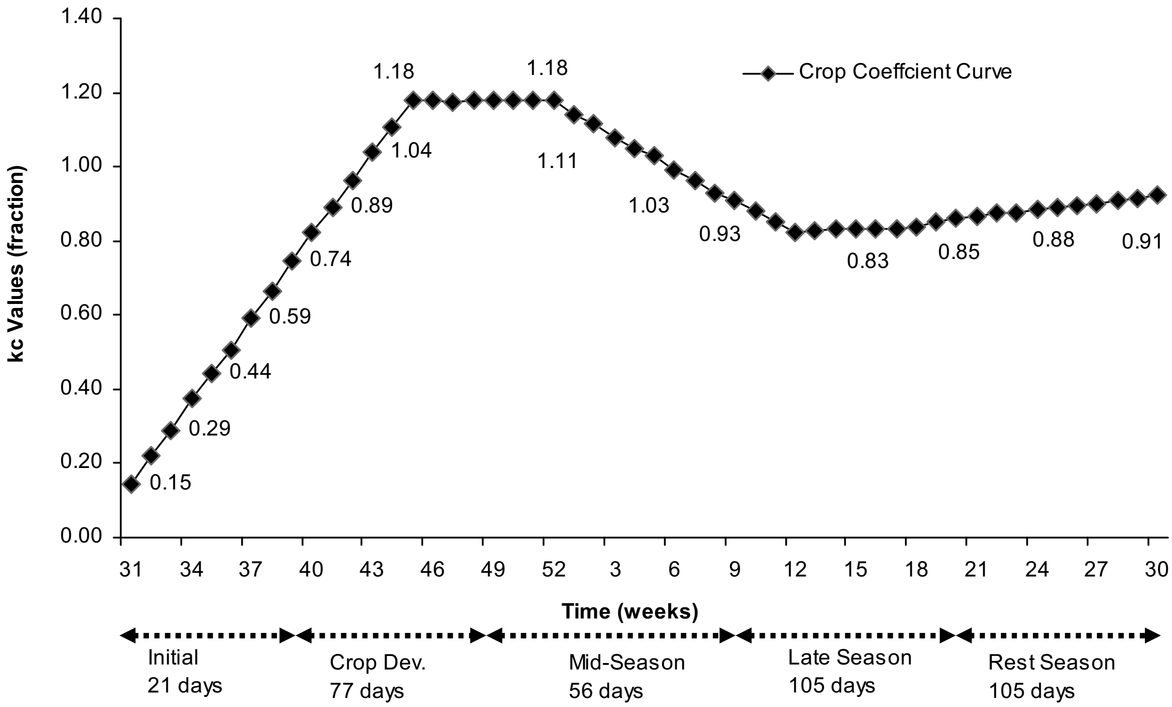

Fig. 2 Crop coefficient curve for a 5-year-old pomegranate tree developed through local information.

meteorological week (105 days) (Meshram *et al.* 2009). Meti *et al.* (2008) reported the water requirement of matured pomegranate cv. 'Jyothi' tree for three seasons (*kharif*, *rabi* and summer seasons) to be 11, 17 and 22 l/day/tree in vertisols of Malaprabha command area, Karnataka. However, earlier Bangar and Kadam (2000) reported the water requirement for pomegranate trees taking into account 100 years of data on cumulative pan evaporation in Maharashtra. The month, season and age-wise water requirement of pomegranate is provided in **Tables 3** and **4**. This data can effectively be used to schedule irrigation, particularly drip irrigation. They estimated the age-wise water requirement (l/day/tree) of pomegranate that ranged from 1.33 to 3.40 in the 1st year, 5.13 to 12.13 in the 2nd year, 14.63 to 35.70 in the 3rd year, 20.90 to 51.00 in the 4th year and 27.14 to 66.30 in the 5th year. The sample size as 10 randomly selected trees from two pomegranate orchards studied in a more scientific way (i.e. using ET_r estimated by the Penman-Monteith method and k_c values estimated by the shaded area approach), while the 2nd method was studied on 100 years pan evaporation data only. Interestingly, in both studies the water requirement for a 5-year-old bearing tree was almost similar, but the precision of stage-wise water requirement in pomegranate was better in the former study.

Irrigation methods

Several methods have been used for applying water in plantation crops and these methods have an important bearing on water management. These methods include flooding water beneath the soil surface or spraying it under pressure as well as by applying in on the surface or subsurface drop by drop. The water losses either through deep percolation beyond the root zone and run off should be minimized or

Table 4 Season wise water management in pomegranate.*

Age of tree	Season	Water requirement per tree (l/day)	Seasonal water requirement per tree (l/day)	Yearly water requirement per tree (Cu.m)	Yearly water requirement per ha (Cu.m)
1	*Karif*	1.54	187.88	0.78	577.2
	Rabi	1.78	218.94		
	Summer	3.11	373.2		
2	*Karif*	5.97	728.34	2.968	2196.32
	Rabi	6.67	813.74		
	Summer	11.66	1426.8		
3	*Karif*	17.03	2077.66	8.373	6196.02
	Rabi	19.09	2348.07		
	Summer	32.36	3947.92		
4	*Karif*	24.34	2969.48	11.871	8784.54
	Rabi	27.27	3354.21		
	Summer	46.23	5547.86		
5	*Karif*	31.63	3858.86	15.433	11420.42
	Rabi	35.46	4361.58		
	Summer	60.11	7213.2		

* Bangar and Kadam (2000)

Table 5 Mean quantity of water applied, water saving, fruit yield and water use efficiency of pomegranate (1995-96 to 2002-2003)*

Sample No.	Treatments		Total water applied (tree/year)	Water applied (l /day/tree)	Water saving over surface (%)	Fruit yield per tree (kg)	Water use efficiency (kg/ha.cm)
	WA (%)	PF (Fraction)					
1	20	0.25	5983	25	54	7.20	120
2	40	0.25	6640	27	49	9.40	142
3	60	0.25	7276	30	44	11.18	154
4	40	0.50	7922	33	39	13.67	173
5	40	0.75	9213	38	29	15.28	166
6	80	0.50	10507	43	19	16.29	155
7	60	0.75	11150	46	16	17.06	153
8	80	0.75	13088	54	--	17.88	137
9	Surface	--	13047	54	--	10.43	80
10	Control	--	5337	22	59	4.02	75
S.Em+				0.78	0.89	0.49	2.18
CD(0.05)				2.30	2.62	1.46	6.44

* Meti *et al.* (2008)
WA-Wetted area PF-Pan evaporation fraction

Table 6 Yield and economics of pomegranate with different levels of irrigation *

Methods/level of Irrigation	Yield (t/ha)	Net income (Rs × 1.000/ha)	Water saving (%)
Drip			
0.3	2.2	25.32	69
0.4	2.8	30.48	60
0.5	2.7	31.69	59
0.6	3.1	37.10	57
0.7	3.5	42.12	49
Surface method	4.2	50.23	-
Rainfed	1.8	20.71	-

* http://www.ncpahindia.com/pfdc

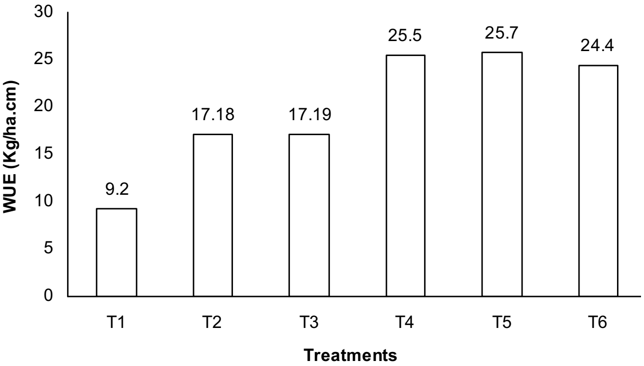

Fig. 3 Water use efficiency as influenced by irrigation and fertigation.

avoided as much as possible to enhance WUE. Bhardwaj (2001) reported a 50% increase in yield under drip irrigation more than surface irrigation. Meti *et al.* (2008) conducted a 7-year field experiment to assess the WUE of pomegranate cv. 'Jothi' under drip and surface irrigation methods. The combination of wetted area (20, 40, 60 and 80%) and three pan fractions (0.25, 0.50 and 0.75) was compared with surface irrigation. Surface irrigation was provided at 0.6 IW (irrigation water)/CPE (cumulative pan evaporation). The highest mean fruit yield of 17.88 kg/tree was obtained in the 80% wetted area + 0.75 pan fraction treatment. Water applied, WUE and water saving over surface irrigation were in the range of 22-54 l, 75-173 kg/ha-cm and 0-59%, respectively. The highest WUE of 173 kg/ha-cm was observed in 40% wetted area + 0.50 pan fraction with a 39% saving over surface irrigation (**Table 5**). By June, about 30% or less of the root system can be found in the wetted soil volume directly beneath the emitter and less than 15% of the root system can be wetted if the soil has slow infiltration characteristics. Drip irrigation should be applied frequently (every alternate day during weeks of drought) and enough water to satisfy pomegranate water use over that interval. The pomegranate-growing farmers of North Gujarat are advised to adopt drip irrigation system for obtaining higher yield and for saving 49% water. The drip irrigation system operates for 5 hrs 18 min during October to January and 6 hrs 54 min during February to May with two drippers/plant having an 8 l/hr discharge rate and 1.2 kg/cm^2 pressure on alternate days (**Table 6**). (http://www.ncpahindia.com/pfdc). Prabhakar *et al.* (2006) reported that the maximum WUE was with 100% of the recommended dose of fertilizer through fertigation closely followed by 75% of the recommended dose of fertiliser through fertigation. The minimum WUE was found with surface irrigation and recommended dose of fertiliser application. The low WUE was due to less water available to plants resulting in lower yield (**Fig. 3**). The seasonal water requirement for 20% wetted area was

Table 7 Water use efficiency as influenced by irrigation.*

Treatments	Cost of cultivation Rs/Ha	Gross income Rs/Ha	Net income (Rs/Ha)	Benefit cost ratio
T_1- Surface irrigation + RD-Control	52,197	97,063	44,866	1.86
T_2- Drip irrigation + RD	52,654	1,01,913	49,259	1.93
T_3- 50% of RD through fertigation	65,054	1,02,375	37,321	1.57
T_4- 75% of RD through fertigation	75,149	1,52,825	77,676	2.03
T_5- 100% of RD through fertigation	85,246	1,53,825	68,120	1.80
T_6- 125% of RD through fertigation	95,343	1,42,250	46,907	1.49

* Prabhakar *et al.* (2006); Rs = Indian Rupees

Table 8 Water use efficiency (WUE) as affected by irrigation methods.

Methods of irrigation	Good quality water		Saline water	
	Yield (t/ha)	WUE (t/ha/cm)	Yield (t/ha)	WUE (t/ha/cm)
Sub surface drip	26.8	3.0	23.6	2.6
Surface drip	17.5	1.9	15.7	1.8
Surface irrigation at 35 mm CPE	16.4	1.4	9.9	0.9
Surface irrigation at 60 mm CPE	13.9	1.2	6.7	0.6

* Agrawal and Khanna (1983)

less in drip irrigation (29.59 cm) than in surface irrigation (51.54 cm). The total water applied by drip irrigation was considerably less than that of surface irrigation, thereby saving 27.5% irrigation water. They found that fertigation at 75% of the recommended dose gave yield at par with full fertigation giving highest yield and most economical and profitable fetching the highest net profit and highest benefit/ cost ratio (**Table 7**). Further, Sulochanamma *et al.* (2005) reported the response of pomegranate cv. 'Ganesh' to different evaporation replenishment rates under drip and basin irrigation systems. They found that drip irrigation had positive effects on pomegranate growth parameters such as tree height, stem diameter, and plant spread than the basin irrigation system. However, irrigation levels did not influence plant growth while the number of fruits was higher in the drip irrigation system than in the basin irrigation system. Earlier, Prasad *et al.* (2003) reported the response of 6-year-old pomegranate cv. 'Bhagawa' with four levels of drip irrigation: 4, 8 and 12 l/hrs applied for 3 hrs daily at flowering and fruiting stages and a control with a basin irrigation system based on pan evaporation at 60 l/m^2 of basin. They found that plants treated with drip irrigation were more vigorous (assessed by plant canopy development) than those treated with the basin irrigation system. Drip irrigation at 8 l/hr/day for 3 hrs increased yield from 17.7 kg/plant in the control to 28.2 kg/plant with considerable reduction in fruit cracking. Fruit quality in terms of weight, size and juice content was better in drip-irrigated plants than that in the control plant. However, the total soluble solids TSS of juice was slightly reduced in drip-irrigated plants compared with control plants. Shailendra and Narendra (2005) also noted that drip irrigation had a positive effect on fruit yield. In fact, drip irrigation is most commonly used in commercial orchards, although some growers prefer sprinklers. However, some of the large commercial orchards in Israel, India and United State use drip irrigation methods (Holland and Bar-Ya'akov 2008). Interestingly, the experiments conducted in India and Iran indicated that drip irrigation can save up to 66% water compared to surface and bubbler irrigation systems (Chopde *et al*. 1998; Behnia 1999; Chopde *et al.* 2001). However, the TSS of the fruit juice was slightly reduced in drip-irrigated plants.

Factors affecting transpiration and irrigation level

Irrigation level is affected by the amount of intercepted radiation by the canopy and the presence of a crop, which directly affects tree transpiration rate. The demand for assimilates increases by increasing the expected crop yield and it may affect irrigation level as well. Potential fruit size may affect the optimal tree water status needed to achieve the target fruit size and therefore it will affect irrigation level. These aspects and the attention that needs to be paid to application efficiency of irrigation water are discussed next.

1. Crop yield

Regular irrigation is needed in pomegranate to produce an economic crop yield of about 6 t/ha. The skin of pomegranate fruit will crack if the tree is stressed for water and then suddenly irrigated. A mature pomegranate tree requires a 0.45 kg of nitrogen annually to restore what was removed by the crop, pruning and leaching by rains and irrigations (Janick and Paull 2007). Pomegranate has a tendency to enjoy heat and thrive in arid and semi-arid areas, but needs regular irrigation throughout the dry season to reach optimum yield and fruit quality (Sulochanamma *et al.* 2005; Levin 2006). In Israel, irrigation usually starts in late April and lasts throughout the summer, producing yields of 25 to 45 t/ha. Control of irrigation timing and seasonal application are important not only for better growth and yield of pomegranate trees but are also used to control ripening time. For example in India, timing of irrigation is used to control and optimise the harvesting season of evergreen pomegranate (Sonawane and Desai 1989).

2. Recycled water and saline water

One of the most important issues concerning pomegranate irrigation is the ability to use alternative water resources, particularly recycled water and saline water. Earlier, an attempt was made to exploit saline water for irrigation in pomegranate in which the relative performance of saline and fresh canal water was tested by Agrawal and Khanna (1983) using drip and surface irrigation methods. They found significant differences in yield and WUE using both water sources (**Table 8**). Use of recycled water is strongly connected to salinity since qualities of soil often increases salinity in recycled water (Raviv *et al.* 1998). Pomegranates are amenable to irrigation with saline water and considered to be moderately tolerant to salinity (Mass 1993; Allen *et al.* 1998). In Israel, several desert orchards in the Niger Highlands and in the Southern Arava are irrigated with saline water. The level of salinity in the water of these orchards ranges between 2.5 and 4.0 dS/m. Under these conditions in Israel, Israeli and Turkmen cultivars grew to produce normal yield and fruit qualities without apparent damages on the trees. Production using saline water requires constant irrigation to leach the salt and prevent the detrimental effects of such practices in higher vegetative growth, which should be controlled in trees that grow too fast. Pomegranate trees were irrigated with 4000 to 6000 ppm saline water. Under these conditions, the saline water negatively affected various growth parameters, while the application of Paclobutrazol with concentration of 250 ppm was reported to reduce salinity damage (Saeed 2005). Salinity tolerance among 10 commercials Iranian cultivars in pots was reported (Tabatabaei and Sarkhosh 2006). In this experiment, the authors indicate pronounced differences to irrigation with saline water among the cultivars. A positive response to irrigation with recycled water was also reported in pomegranate in Turkmenistan (Levin 2006). As high quality water becomes less available and more expensive, it is expected that recycled water will become a common irrigation practice in arid and semi-arid areas. The mechanisms responsible for pomegranate tolerance to saline water are not yet fully understood. However, it is well documented that pomegranate tissues accumulate sodium, chlorine and potassium in response to irrigation with saline water and that the concentration of these ions increase with increased concentrations of salt in the irrigation water (Doring and Ludar 1987; Naeini *et al.* 2006). These authors indicated tolerance to saline water up to concentrations of 40 mM NaCl in the water. Above this concentration, growth parameters such as length of the main stem, length and number of internodes, and area of leaf surface were severely affected. The results show that 'Malas Shirin' grew better under saline conditions than 'Malas Torsh' and 'Alak Torsh' (Naeini *et al.* 2006). Moreover, in a similar experiment with the same three pomegranate varieties, over the course of an 80-day experimental period, irrigation with 0, 40, 80 and 120 mM NaCl resulted in increased Na, Cl and K concentrations and decreased Ca, Mg and N concentrations in the plant tissues. The amount of soluble sugars in the plant tissues decreased with increasing NaCl concentrations (Naeini *et al.* 2004). Bhantana and Lazarovitch (2010) conducted experiment using saline water with various treatments to see the response of ET_c, k_c and growth parameters. Two varieties of pomegranate cv. 'Wonderful' and 'SP-2' were included in the experiment. They have applied irrigation water with electrical conductivity (EC_{iw}) of 0.8, 1.4, 3.3, 4.8 and 8 dS/m. The significant seasonal ET variation was observed for the EC_{iw}-8 dS/m treatment. Salinity treatment had a significant effect on both daily ET_c and Total ET_c. Furthermore, the electrical conductivity of the drainage water (EC_{dw}) in the EC_{iw}-8 dS/m treatment was five times higher than that of the EC_{iw}-0.8 treatment in the peak season. The data suggests that the tolerance of pomegranate to salinity is due to resistance of its tissues to higher levels of salts rather than the ability to prevent penetration of ions into its tissues.

CONCLUDING REMARKS

Research done in the past has clearly shown that pomegranate growers benefit with irrigation technologies. The main benefit would be in saving water, improving productivity and fruit quality. Thus, water management technologies ensure increased crop yield, high WUE, reduced water and energy consumption. Although application of drip irrigation in salty environments has been quite encouraging in experimental fields, its popularity and adoption under these conditions is not satisfactory. In view of global warming and increasing water shortages experienced in many arid and semi-arid regions that are most suitable regions for pomegranate growth, water availability and irrigation are major considerations. Therefore, many more efforts will be required to develop optimum and effective irrigation methods that are suitable for pomegranate culture. One direction towards this goal is the development of an appropriate computer programme for calculating water requirements in pomegranate and appropriate watering models for different agro-climatic conditions, none of which currently exist for pomegranate.

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