



Effect of irrigation frequencies on nutrient uptake, growth and yield of pomegranate (*Punica granatum*) grown on heavy textured soils of semi-arid region

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ABSTRACT

This study evaluates the influence of different irrigation frequencies on the nutrient uptake, growth and yield performance of pomegranate (*Punica granatum* L.) cv. Bhagwa. The experiment was conducted during 2010–13 at National Research Centre on Pomegranate, Solapur, Maharashtra, India. The treatments were consisted of replenishment of irrigation on every day and cumulative irrigation after 1, 2, 3, 4 and 5 days interval. The results revealed that, increase in irrigation interval increased moisture spread in horizontal as well as vertical direction. Horizontal and vertical moisture spread was restricted up to 40 and 60 cm, respectively, in daily irrigation and 40 and 75 cm, respectively at 1 day irrigation interval treatment. Maximum leaf content of N (2.09%) and K (0.93%) was found in irrigation interval at 2 days while P (0.164%) at 3 days irrigation interval treatment. Higher nutrient uptake at 2 and 3 days irrigation interval resulted in attaining significantly higher vegetative growth of the plants. However, scheduling of irrigation frequency did not show effect on growth of the plants during pre-bearing period. Lowest leaf temperature (98.5°F) and highest leaf chlorophyll content (59.61) was recorded in 1 day irrigation interval treatment. Highest fruit yield (4.32 t/ha) was obtained in 2 days irrigation interval treatment. Application of irrigation at 4 and 5 days interval resulted in drastic reduction in fruit yield, which also had very high fruit cracking (11.6 and 15.5%, respectively).

Key words: Chlorophyll content, Fruit yield, Irrigation frequency, Leaf temperature, Nutrient uptake, Pomegranate, Vegetative growth

Pomegranate (*Punica granatum* L.) is one of the most important fruit crops of tropical and subtropical regions of the world. Although native to hot dry regions of Iran, Afghanistan and adjoining areas (De Candolle 1967) pomegranate has been widely cultivated in Mediterranean regions of Asia, Africa and Europe. In India, during last two decades, pomegranate cultivation has registered a high growth and reached to 1.31 lakh ha with an annual production of 13.45 lakh tonnes (Pal *et al.* 2014). Maharashtra contributes more than 70% of the total area under pomegranate cultivation followed by Karnataka, Gujarat and Rajasthan states having arid eco-system. In these areas, pomegranate cultivation is successful as it can withstand the hostile agro-climate and adverse soil conditions prevailing in arid ecosystem. The crop has lot of export potential and good keeping quality (Pal *et al.* 2014). Further, the crop withstands heat, drought and moisture deficit (Jolikop and Kumar 2000).

Water supply is limited worldwide and it is imperative to adopt holistic strategies to harvest more crops per drop of water. Pomegranate can tolerate very dry (1 to 15 atm soil moisture tension) conditions (Badizadegan 1975) but for optimum growth and quality fruit production, proper amount of irrigation at a required frequency is most essential. In pomegranate, information on irrigation scheduling especially irrigation frequency is very meagre. Hence, it is necessary to determine the most appropriate time to proceed with irrigation without causing hydric stress in the plant. Under drip irrigation, proper irrigation frequency reduced percolation and evaporation losses, and improved water use efficiency by maintaining optimum soil moisture in the vicinity of the roots. Predominantly, pomegranate is cultivated by digging 75 cm³ to 1 m³ trapezoidal pits and re-filling it with heavy textured good quality soil occurring in the areas (Marathe *et al.* 2006). These soils have very high water holding capacity (Sehgal 1996) and application of inappropriate amount of irrigation creates problems of waterlogging, poor aeration and weed infestation (Raina *et al.* 2011).

In this perspective, the present investigation was undertaken to evaluate the influence of different irrigation frequencies on growth and yield performance of pomegranate fruit crop.

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MATERIALS AND METHODS

The field experiment was conducted during 2010-13 at the research farm of National Research Centre on Pomegranate, Solapur, Maharashtra, India located at 17°6' N latitude, 75°90' E longitude, at an altitude of 457 m above mean sea level. The climate of the study area is semi-arid, showing hot summer and moderate winter with a mean annual maximum and minimum temperature of 40.4° and 14.9°C, respectively, and average annual rainfall of 694 mm occurring mostly during the months of July-September. Soil used for pit filling was clayey, 90 cm deep having montmorillonitic mineralogy. The textural and physico-chemical properties of the soil were: coarse fragments (> 2.0 mm) 8.4%, and 26.6%, silt 20.8%, clay 52.6%, pH 7.82, and EC 0.18 dS/m, organic carbon 0.66 %, calcium carbonate 6.31%. The available N, P and K content of surface soil was 337.3, 18.5 and 354.2 kg/ha, respectively. Average monthly maximum and minimum temperature during the experimental period (January to July) varied from 29.9 to 40.2°C and 15.2 to 25.1°C, respectively. The daily pan evaporation ranged between 3.7 to 19.8 mm. The field capacity (33 kPa) and permanent wilting point (1.5 M Pa) of soil was 31.8 and 16.8%, respectively.

The experiment was conducted in randomized block design with six treatments and four replications. The different treatments consisting of application of irrigation water equivalent to 80% of pan evaporation on every day (T_1), cumulative irrigation at 1 day interval (T_2), 2 days interval (T_3), 3 days interval (T_4), 4 days interval (T_5) and 5 days interval (T_6). The crop water requirement of pomegranate crop was computed on daily basis using the following equation (Mane *et al.* 2006).

$$V = E_p \times K_p \times K_c \times S_c \times W_p$$

where, V = volume of water (liters/ day/ plant), E_p = open pan evaporation (mm/day), K_p = pan coefficient, K_c = crop coefficient, S_c = crop spacing (plant to plant \times row to row in meter) and W_p = wetting factor. Irrigation efficiency of drip was considered as 90%. The effective rainfall was calculated by balance sheet method from the actual rainfall received and was used for daily water requirement of crop. Measured quantity of irrigation water was provided to the plants using water meter and separate pipeline for every treatment.

In all the treatments, 150-days-old air-layer saplings of pomegranate cv. Bhagwa were planted during January 2009 and maintained by adopting similar cultivation practices. Under semi arid regions, pomegranate required supplemental irrigation from December to first week of July month (onset of rains). Accordingly, various treatments were imposed on one year old plants from 10 February to 11 June during 2010. Due to severe infestation of bacterial blight disease, as a management practice, plants were cut to ground level during October 2010. All plant debris were literally swept from soil surface of whole farm and disinfected with bleaching powder spraying on soil surface. Again plants were allowed to grow and treatments were imposed from

December 2011 to June 2012 and again during December 2012 to June 2013.

Soil moisture content was determined gravimetrically (Singh 1989) during fruiting period. Samples were collected before subsequent irrigation in different treatments. Soil moisture distribution pattern under different treatment was studied by collecting soil samples on next day of irrigation at a distance of 10, 20, 30, 40 and 50 cm away from the dripper in horizontal direction as well as 0-30, 30-45, 45-60, 60-75 and 75-90 cm below the dripper in vertical direction during May 2012.

Leaf samples were collected from individual plants and processed for nutrient analysis. The samples were digested (Chapman and Pratt 1961) in di-acid mixture ($H_2SO_4:HClO_4$ in 1:2.5). Nitrogen was determined by using micro-kjeldhal steam distillation method, phosphorus by Vanadomolybdo phosphoric acid method, potassium by flame photometer and $Ca^{2+} + Mg^{2+}$ by versenate titration method. All micronutrients (Fe, Zn, Mn and Cu) were determined using atomic absorption spectrophotometer.

Vegetative growth in terms of plant height and plant spread was recorded in each year. Data on flowering intensity and fruit yield were recorded during the year 2013 (Erickson and Brannaman 1960). Cracked fruits were harvested separately and counted in terms of numbers. Chlorophyll content in the leaves as indicated by SPAD values was measured during 2012 using chlorophyll meter. Leaf temperature was measured before application of irrigation during afternoon hours with the help of laser beam thermometer. The data obtained were subjected to statistical analysis such as analysis of variance (ANOVA) using software package of MS Excel and online software WASP-2 developed by ICAR Research Complex, Goa (Anonymous 2016).

RESULTS AND DISCUSSION

Same amount of irrigation water was applied to the plants grown under each treatment. During first year (2010) total amount of irrigation water applied to each plant was 500.9 litres which increased to 1407.8 litres during 2010-11 and 1639.6 litres during 2012-13, respectively, due to increase in plant canopy spread.

Soil moisture content

Soil moisture content during fruiting period varied from 16.9% to 22.3%, 19.2% to 24.0% and 20.0% to 25.6% at 0-15, 15-30 and 30-45 cm vertical depth, respectively amongst different treatments (Table 1). At 0-15 and 30-45 cm depth significant variation was observed while in 15-30 cm depth it was non-significant during all the months. During most of the period higher soil moisture content (21.8-25.6%) was recorded in 2 days irrigation interval treatment followed by 3 days and 1 day interval treatment. In these treatments sufficient moisture was maintained at all the depths. Treatment involving daily application of irrigation recorded sufficient moisture in 0-15 and 15-30 cm soil layer which decreased in 30-45 cm depth, indicating that the quantity of

Table 1 Soil moisture content as affected by irrigation interval (sampling before subsequent irrigation)

Period	Soil depth (cm)	Irrigation interval						CD (P=0.05)
		Daily	1 Day	2 Days	3 Days	4 Days	5 Days	
March	0-15	21.9	22.3	22	20.1	18.3	17.8	1.65*
	15-30	22.3	21.3	22.3	23.5	20.2	20.6	NS
	30-45	20.6	24.2	25.2	24	21.3	20	3.22
April	0-15	22.2	21.9	21.8	20.3	17.8	17.5	2.93*
	15-30	21.9	20.9	22.8	24	19.2	21	NS
	30-45	19.9	23.4	25.6	23.4	22.4	19.7	2.83
May	0-15	21.5	22	21.8	20.6	17	16.9	3.25*
	15-30	22.3	21.3	22.3	23.5	20.2	20.6	NS
	30-45	20.6	23.6	24.8	23	20.8	21.2	NS

NS: Non-significant, *significant at P=0.01.

irrigation water was not sufficient to percolate below 45 cm depth to saturate whole soil profile. Application of irrigation at 4 and 5 days interval recorded drastic reduction in soil moisture content in surface layers especially in 0-15 cm depth and even in 15-30 cm depth. It indicated that sufficient moisture was not available in the zone of maximum root activity inducing stress to the plants before subsequent irrigation. In these treatments, application of huge quantity of irrigation water might have lost through percolation and evaporation from the surface.

Soil moisture distribution pattern

Variations in soil moisture distribution during fruit development period was monitored and analysed. Soil available water content at a distance of 10 (7.4 - 9.7%), 20 (5.2 - 7.9%), 30 (3.4 - 8.9%), 40 (0.4 - 8.1%) and 50 (0.0 - 4.7%) cm away from the dripper varied in horizontal direction amongst the treatments (Fig 1). Moisture spread in horizontal direction increased with the increasing irrigation interval. In higher irrigation interval treatments, cumulative amount of irrigation water was applied, which resulted in increased horizontal spread. In daily irrigation treatment, due to less quantity of irrigation water, horizontal moisture spread was only up to 30 cm, while in 1 and 2 days it was restricted up to 40 cm. Available moisture content in 4 and 5 days irrigation interval treatments was 4.4% and 4.7%, respectively at 50 cm horizontal distance.

The available water content below the dripper varied from 4.6-8.6%, 3.2-7.3%, 2.3-7.4%, 0.0-6.6% and 0.0-9.0 % in 0-30, 30-45, 45-60, 60-75 and 75-90 cm depth, respectively under different treatments (Fig 2). In daily irrigation treatment moisture availability was only up to 60 cm depth while in 1 and 2 days interval treatments, it was up to 75 cm depth. In surface layer since high frequency irrigation implied applying small amount of water that resulted in limited superficial water bulbs which probably favoured water evaporation (Sebastian *et al.* 2015). On the contrary, at 4 and 5 days interval treatments, highest available water content was observed at 90 cm depth, which proved

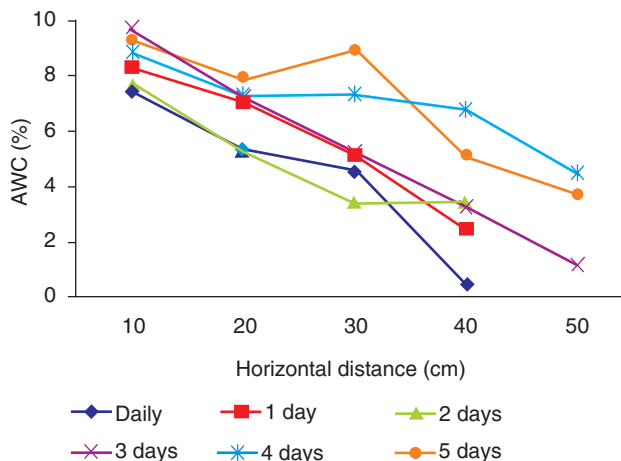


Fig 1 Horizontal moisture spread under different irrigation frequencies

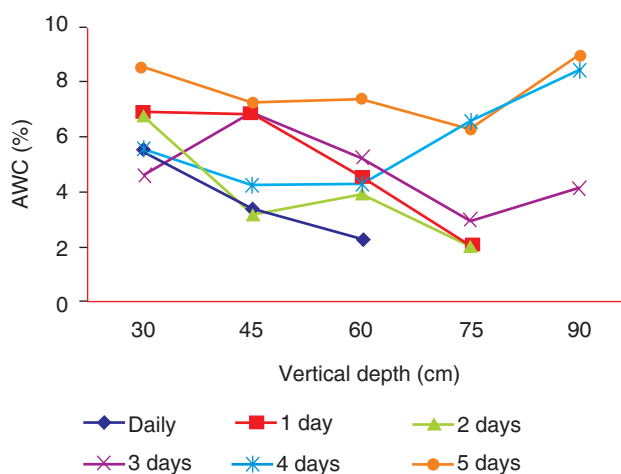


Fig 2 Vertical moisture spread under different irrigation frequencies

detrimental to nutrient uptake.

Leaf nutrient content

The scheduling of irrigation frequency had marked effect on leaf nutrient content of N (1.77-2.09%), P (0.128-0.164%), K (0.64-0.93%) and Fe (106.5-134.6 ppm). Maximum leaf content of N and K was found in 2 days, while P in 3 days irrigation interval treatment. These treatments were more effective owing to application of irrigation water at proper interval. Most of the nutrient absorption processes are aerobic in nature and periodical application of irrigation might have maintained good aeration in soil, resulted in higher uptake of these nutrients by the plants. The greater N, P and K uptake with more frequent irrigation was reported earlier by Pahlavanrad *et al.* (2011). Treatments involving application of irrigation after 4 and 5 days recorded significantly poor nutrient content in the leaves. In these treatments, higher amount of irrigation might have favoured leaching of nutrients from the soil. Similarly, occurrence of drought stress as indicated by low soil moisture content (Table 1) between two subsequent

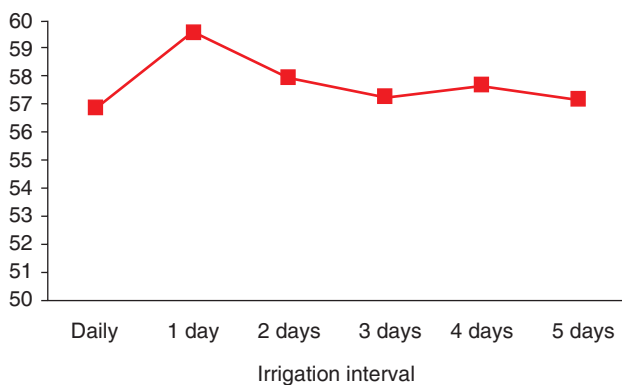


Fig 3 Leaf chlorophyll content (SPAD) under different irrigation frequencies

irrigations resulted in poor nutrient absorption by the plants (Bhagat and Acharya 1987). The findings in present study were in close conformity with the findings of Haneef *et al.* (2014) and Sharma *et al.* (2015).

Leaf content of Fe was significantly highest (134.6 ppm) in daily irrigation treatment. Irrigation at 1 to 3 days interval also recorded higher Fe content (115.9–123.2 ppm) as compared to 4 and 5 days (106.5–109.5 ppm) interval treatments. These observations indicated higher Fe availability under higher soil moisture conditions (Table 1). This might be due to low redox potential and increased solubility of reduced form of iron (Fe^{3+} to Fe^{2+}) in the soil (Drew and Sisworo 1979, Poonamperuma 1984). Marathe *et al.* (2001) observed increased micronutrients concentration in the leaves of Nagpur mandarin under temporary waterlogging condition during rainy seasons.

Leaf chlorophyll content and leaf temperature

Chlorophyll content in the leaves of the plants as expressed by SPAD values significantly varied from 56.89 to 59.61 amongst the treatments (Fig 3). It was highest in 1 day followed by 2 and 3 days irrigation interval treatments, indicating better photosynthetic capacity of the plants. This might be due to better nutrient uptake and ample water availability to the plants. Increased availability and uptake of Fe in these treatments also plays important role in chlorophyll formation (Shaahan *et al.* 1999). Drastic reduction in leaf chlorophyll content was recorded in daily irrigation treatment.

Leaf temperature recorded during fruit development period of March, April and May months significantly varied from 95.5–99.6, 96.6–100.0 and 98.5–103.0° F, respectively amongst the treatments but the results were significant only during the month of May (Fig 4). Leaf temperature, irrespective of frequency of irrigation was lower than air temperature in all the treatments and months. It increased with the increase in ambient temperature and was the highest in May which recorded highest ambient temperature, evapotranspiration (EPan) and lowest relative humidity. Lowest leaf temperature was recorded in 1 day followed by daily irrigation treatment. This might be due to higher soil moisture content in the soil layers providing maximum

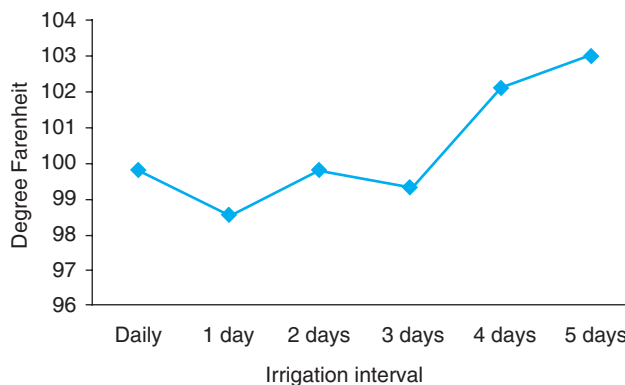


Fig 4 Leaf temperature (°F) under different irrigation frequencies

water for increased rate of transpiration, minimizing temperature of the leaves. Cool canopy was found to be an important physiological principle for tolerance to high temperature stress (Munjal and Rana 2003). It was highest in 5 days followed by 4 irrigation interval treatments indicating maximum stress conditions. In these treatments, as the soil water becomes limited, transpiration got reduced increasing leaf temperature.

Vegetative growth of the plants

The scheduling of irrigation frequency had marked effect on vegetative growth of the plants only during fruit bearing period. During first year of plantation (2010), vigorous growth in terms of plant height (35.6–44.5% over initial) and plant spread (44.0–53.5% over initial) was recorded in all treatments as compared to second (2011–12) and fruit bearing period (2012–13). During first and second year, irrigation frequency does not have much influence on growth parameters and the results were non-significant. Similar type of results were reported in pomegranate (Chopade and Gorantiwar 1998) and fig (Andrade *et al.* 2014) where irrigation methods and frequencies does not have much influence on plant growth during initial years. During the year 2012–13, per cent increase in plant height, plant spread in east-west, north-south and average spread varied significantly from 18.2–24.6%, 23.8–34.1%, 27.1–36.7% and 26.6–35.3%, respectively, amongst the treatments. Highest increase in plant height and plant spread was observed in 2 days interval treatment which was at par with 3 days interval treatment. The increase might be due to periodical supply of ample water to the plant. This maintains the soil moisture at optimum level eliminating water stress to the plants, this facilitated better nutrient availability and uptake by the plants resulted in greater vigor. These findings are in agreement with the results of Ouma (2005).

Plant growth was substantially low in 4 and 5 days irrigation interval treatments. The reduction was more pronounced during bearing period as compared to initial years of plant growth. In these treatments, application of high amount of water might have lost as a percolation and sufficient moisture availability was not maintained (Table 1) till subsequent irrigation, inducing moisture stress to the

Table 2 Leaf nutrient content as influenced by different irrigation frequencies

Leaf nutrient content	Daily	Irrigation interval					CD (P=0.05)
		1 Day	2 Days	3 Days	4 Days	5 Days	
N (%)	1.98	1.98	2.09	1.99	1.97	1.77	0.17
P (%)	0.151	0.134	0.163	0.164	0.153	0.128	0.011*
K (%)	0.88	0.84	0.93	0.87	0.73	0.64	0.16
Ca (%)	1.60	1.69	1.73	1.64	1.64	1.60	NS
Mg (%)	0.50	0.45	0.56	0.49	0.46	0.42	NS
Cu (ppm)	85.2	89.3	87.5	83.9	90.5	82	NS
Zn (ppm)	30.6	29.3	26.7	25.8	29.1	26.4	NS
Fe (ppm)	134.6	115.9	123.2	118	109.5	106.5	16.0
Mn (ppm)	65	64.2	63.4	62.5	69	65.7	NS

NS: Non-significant, *significant at P=0.01.

Table 3 Vegetative growth of the plant grown under different irrigation frequencies

Growth parameter	Daily	Irrigation interval					CD (P=0.05)
		1 Day	2 Days	3 Days	4 Days	5 Days	
<i>Per cent increase during February to October 2010</i>							
Plant height	44.5	38.4	43.3	35.6	37.0	39.0	NS
East-West spread	48.0	47.4	47.7	46.6	42.9	43.8	NS
North-South spread	44.0	44.7	49.6	46.5	53.5	43.3	NS
Average spread	46.1	45.9	48.6	46.4	48.0	43.5	NS
<i>Per cent increase during December 2011 to July 2012</i>							
Plant height	15.4	16.2	19	15.5	15.9	13.3	2.50*
East-West spread	15.4	17.6	18.1	15.9	16.5	15.6	NS
North-South spread	17.0	17.4	16.8	18.2	16.8	16.3	NS
Average spread	16.2	17.5	17.3	17.0	16.6	15.9	NS
<i>Per cent increase during December 2012 to July 2013</i>							
Plant height	18.3	23	24.6	22	18.2	15.9	2.62*
East-West spread	27.7	31.2	34.1	30.1	26	23.8	4.49*
North-South spread	30.1	34.2	36.7	32.9	27.1	28.2	4.90*
Average spread	28.8	32.5	35.3	31.5	26.6	26.0	3.37*

NS: Non-significant, *significant at P=0.01.

plants. This resulted in low nutrient uptake (Table 2), leaf chlorophyll content (Fig 3) adversely affecting growth of the plants. The treatment involving irrigation on every day also had adverse effect on plant growth. This practice tends to keep the soil in wet condition in effective root zone, thereby, hampering aeration, nutrient uptake and plant growth. The results revealed that irrigation interval should be neither too low nor too high to attained maximum growth of pomegranate plants.

Flowering and fruit yield

A critical stage in fruit production is the transition and completion of flowering. Flowering intensity in terms of

Table 4 Flowering and fruit yield under different irrigation frequencies

Yield parameter (per plant)	Daily	Irrigation interval					CD (P=0.05)
		1 Day	2 Days	3 Days	4 Days	5 Days	
Male flowers	175.8	168.6	186.2	222.5	206.6	233.5	32.23*
Hermaphrodite flowers	101.0	115.3	126.3	112.9	120.0	107.1	NS
Total number of flowers	276.8	283.9	312.4	335.4	326.5	340.6	NS
Number of fruits	27.1	34.0	38.0	35.0	24.2	22.3	4.00*
Percent cracked fruits	3.1	0.0	0.0	3.8	11.6	15.5	6.26*
Weight of fruits (kg)	5.839	6.859	7.790	7.453	4.507	3.858	0.492*
Weight of each fruit (g)	216.3	202.7	206.0	214.0	189.6	176.2	19.2

NS: Non-significant, *significant at P=0.01.

number of male, hermaphrodite and total flowers varied from 168.6-233.5, 101.0-126.3 and 276.8-340.6 flowers/plant, respectively amongst the treatments. Significantly highest number of male flowers were produced in 5 days irrigation interval treatment having less moisture content in the soil (Table 3). In general, flowering intensity increased with increasing irrigation interval. Becerra *et al.* (2008) reported positive correlation between flowering number and severity of drought (-2.1 to 3.0 MPa) in sweet orange.

Varying irrigation interval had significant effect on fruit yield and yield contributing parameters (Table 4). Total yield in terms of number and weight significantly varied from 22.3-38.0 and 3.858-7.790 kg/plant, respectively, amongst the treatments. Highest fruit yield was obtained in 2 days irrigation interval treatment which was at par with 3 days treatment. The increase in yield could be attributed to maintenance of soil in optimum moisture condition resulted in balanced nutrient uptake, better plant growth, bigger fruit size and least fruit cracking under these treatments. Drastic reduction in fruit yield was recorded in the plants receiving irrigation after 5 days followed by 4 days interval. Yield in terms of fruit weight is closely associated with lack of soil water in the root zone; when the soil water deficit in the root zone increases, there is loss of turgidity and reduction in growth and fruit weight (Jain and Tiwari 2012). Further reduction in fruit yield was due to significantly higher (15.5 and 11.6%) fruit cracking in these treatments. Results on fruit cracking showed highly significant variation (0.0 - 15.5%) and was highest in 5 days followed by 4 days interval treatments. In these higher irrigation interval treatments, low soil moisture content coupled with higher leaf temperature might (Fig 4) have created frequent water stress to the plants between two irrigations especially at the time of fruit maturity, resulted in cracking of the fruits. Water stress has significant effect on fruit cracking. Fruit cracking to the

extent of 33.5 to 72.0% under different cultivars (Charan 1984) and 9.5 to 63.0 % in different season (Pant 1976) was reported due to high air temperature under extremely arid climate of western Rajasthan. Reduced fruit cracking (11.5 %) with increased irrigation frequency was reported in litchi fruit crop (Lal and Kumar 1997). The fruit cracking was associated with hardening of peel under prolonged drought condition (Chundawat 1990). It was also observed that under frequent irrigation (daily) treatment fruit yield was 24.5% less as compared to 2 days irrigation interval treatment. This might be due to the reason that, this practice tends to keep the soil always in wet condition in effective root zone, thereby, hampering aeration, nutrient uptake and yield.

It can be concluded that under drip system of irrigation cumulative irrigation (i.e. 80% EPan) should be provided at 2 days interval to pomegranate orchards grown on clay textured soils of semi-arid regions. With this irrigation frequency, balanced uptake of major and micronutrients was achieved, which resulted in to better plant growth and the highest fruit yield. Irrigation at 3 days interval might not make much harm to pomegranate plants due to high water retention capacity of clayey soils. But during fruiting period, irrigation interval exceeding 3 days causes fruit cracking thereby, adversely affecting the fruit yield. Practice of daily irrigation tends to keep the soil always in wet conditions which adversely affect crop productivity. Pomegranate has been proved a boon to the farmers of semi-arid regions. Thus, the optimum irrigation (i.e. irrigation at 2 days interval) would ensure the maximum productivity and help in enhancing and stabilizing the socio-economic growth of pomegranate growers.

REFERENCES

- Andrade I P S, Carvalho D F, Almeida W S, Silva J B G and Silva L D B. 2014. Water requirement and yield of fig trees under different drip management. *Journal of the Brazilian Association of Agricultural Engineering* **34**(1): 17–27.
- Anonymous. 2016. Web Agri. Stat. Package 2.0, Developed by Jangam A K and Pranjali Thali. ICAR Research Complex for Goa, India.
- Badizadegan M. 1975. Growth of pomegranate (*Punica granatum* L.) as affected by soil moisture tension. *Journal of Horticultural Science* **50**: 227–32.
- Becerra B J, Narváez-Vásquez J, Orozco-Cárdenas M and Lovatt C J. 2008. Regulation of flowering in Citrus: Preliminary results on the role of water-deficit stress and abscisic acid. (in) *Proceedings of the International Citrus Congress*, Wuhan, China, pp 320.
- Bhagat R M and Acharya C L. 1987. Effect of soil management on hydrothermal regime and root growth. *Soil Tillage Research* **9**: 65–77.
- Chapman H D and Pratt P F. 1961. *Methods of Analysis for Soil, Plants and Water*, pp 182–6. Division of Agricultural Sciences, University of California, USA.
- Charan R. 1984. 'Studies on fruit cracking in pomegranate'. PhD thesis, University of Jodhpur, India.
- Chopade S O and Gorantiwar S D. 1998. Effect of various methods of irrigation on growth and yield of pomegranate. *Annals of Plant Physiology* **12**: 98–102.
- Chundawat B S. 1990. *Arid Fruit Culture*, pp 56. Oxford and IBH Publication Co., New Delhi.
- De Candolle A. 1967. *Origin of Cultivated Plants*, p 468. Hafner Publishers Co., New York.
- Drew M C and Sisworo E J. 1979. The development of waterlogging damage in young barley plant in relation to plant nutrient status and change in soil properties. *New Phytopathology* **82**: 301–14.
- Erickson L C and Brannaman B L. 1960. Abscission of reproductive structures and leaves of orange trees. (in) *Proceedings of American Society of Horticultural Sciences* **75**: 222–9.
- Haneef Mohd, Kaushik R A, Sarolia D K, Mordia A and Dhakar Mahesh. 2014. Irrigation scheduling and fertigation in pomegranate cv. Bhagawa under high density planting system. *Indian Journal of Horticulture* **71**: 45–8.
- Jain P K and Tiwari Akhilesh. 2012. Effect of irrigation systems and frequencies on growth and yield of papaya. *Indian Journal of Horticulture* **69**(2): 277–80.
- Jolikop S H and Kumar P S. 2000. New fruit crop varieties for arid regions: Ruby (pomegranate) and Arka Sahan (custard apple). *Indian Horticulture* **45**: 19–20.
- Lal R L and Kumar G. 1997. Effect of irrigation frequencies on yield and quality of litchi fruits cv. Rose Scented. *Indian Journal of Horticulture* **54**(1): 10–5.
- Mane M S, Ayare B L and Magar S S. 2006. *Principles of Drip Irrigation System*, pp 24–87. Jain Brothers, New Delhi.
- Marathe R A, Chandra R and Kumar P. 2006. Soil types and micronutrient status of pomegranate (*Punica granatum* L.) orchards of Nasik regions of Maharashtra. *Abstract National Symposium on Improving Input Use Efficiency in Horticulture*, IIHR, Bangalore, India pp 174.
- Marathe R A, Mohanty S and Shyam Singh. 2001. Waterlogging – as a soil related constraint to performance of Nagpur mandarin orchards. *Agropedology* **11**: 134–8.
- Munjal R and Rana R K. 2003. Evaluation of physiological traits in wheat (*Triticum aestivum* L.) for terminal high temperature tolerance. (in) *Proceedings of the Tenth International Wheat Genetics Symposium*. Poestum, Italy, pp 804–5.
- Ouma George. 2005. Root confinement and irrigation frequency affect growth of Rough lemon (*Citrus limon*) seedlings. *Fruits* **60**(3): 195–202.
- Pahlavanrad M R, Movahedi Naeini S A R and Pessarakli M. 2011. Nutrient uptake, soil and plant nutrient content and yield components of wheat plants under different planting systems and various irrigation frequencies. *Journal of Plant Nutrition* **34**(8): 1 133–43.
- Pal R K, Dhinesh Babu K, Singh N V, Maity A and Gaikwad N. 2014. Pomegranate research in India – status and future challenges. *Progressive Horticulture* **46**: 184–201.
- Pant T. 1976. Fruit cracking in pomegranate (*Punica granatum* L.) in variety Jodhpuri. *Udyanika* **2**: 29–35.
- Poonamperuma F N. 1984. Effect of flooding in soil. *Flooding and Plant Growth*, pp 9–45. Kozlowski T T (Ed.). Academic Press, London.
- Raina J N, Sharma T and Suman S. 2011. Effect of drip fertigation with different fertilizers on nutrient distribution in soil, leaf nutrient content and yield of apricot (*Prunus armeniaca* L.). *Journal of the Indian Society of Soil Science* **59**: 268–77.
- Sebastian B P, Santesteban, L G, De Miguel P S, La Fuente M D and Lissarrague J R. 2015. Response of Grapevine cv. Syrah to irrigation frequency and water distribution pattern in clay soil.

- Agricultural Water Management* **148**(31): 269–79.
- Sehgal J. 1996. *A Text Book of Pedology – Concepts and Application*, pp 274–6. Kalyani Publishers, Daryaganj, New Delhi.
- Shaahan M M, Ei-Sayeed A A and El-Nour A. 1999. Predicting nitrogen, magnesium and iron nutritional status in some perennial crops using portable chlorophyll meter. *Scientia Horticulturae* **82**: 339–48.
- Sharma Rajni, Pandey S K and Sharma T A. 2015. Influence of soil moisture on growth and nutrient content in healthy and malformed panicles of mango varieties. *Indian Journal of Horticulture* **72**: 133–8.
- Singh R A. 1989. *Soil Physical Analysis*. Kalyani Publishers, New Delhi.