

## Standardization of stage wise water requirement in drip irrigated Kinnow mandarin orchards under sub-tropical conditions

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### ABSTRACT

An experiment on drip irrigation scheduling based on pan evaporation replenishment was conducted in Kinnow orchard at Punjab Agricultural University, Ludhiana during 2010-2018. Year was divided into six stages (stage 1 to stage VI) including two months in each stage. First treatment included irrigation scheduling with 30 and 40% ER, treatment two with 40 and 60% ER, treatment three with 60 and 80% ER, alternatively during stages I to VI. However, fourth and fifth treatments had irrigation with 80% ER and 30% ER, respectively, in all the stages. Maximum daily open pan evaporation (9.15 mm) was recorded in May and minimum (1.19 mm) was recorded in January. The water requirement varied from 2.8 liters day<sup>-1</sup> tree<sup>-1</sup> in stage-I to 58.3 liters day<sup>-1</sup> tree<sup>-1</sup> in stage-III. Linear increase in vegetative and reproductive growth was observed with increase in irrigation water. Polynomial relationship studies indicated the increase in water quantity applied to Kinnow with increase in temperature subject to the prevailing relative humidity. Similarly, volumes of water applied increased with increased mean evaporation. The study concluded that drip irrigation scheduling with 60 to 80% ER alternatively, starting from January to December save significant amount of water, without affecting yield and quality of Kinnow under sub-tropical conditions.

**Key words:** Drip irrigation, evaporation, Kinnow and replenishment

Kinnow mandarin is an important commercially grown citrus crop in Punjab. It occupies an area of 53.0 thousand hectares and the annual production is 1.24 million metric tons (Anonymous, 2019). High quality mandarins are produced in Punjab due to cooler nights during winter at the time of maturity. However, Kinnow being an evergreen perennial fruit tree, irrigation water is a key input for higher yield and quality production. Water management usually involves maintenance of high-water status through proper irrigation scheduling. Higher water use efficiency in citrus is very important due to diminishing water resources with prevailing wheat-paddy rotation in Punjab state.

Water saving techniques and strategies based on periodic estimation of soil water balance and special water exchange distribution processes (Provenzano *et al.*, 2013), may lead to crop sustainability in citrus. In India, mandarin orchards are generally irrigated through drip irrigation system. However, evaporation-based irrigation scheduling is more efficient system of water saving. It has been reported in pomegranate (*Punica granatum* L.) that water requirement by the surface irrigation methods estimated on crop evapotranspiration is even more than water requirement by

drip irrigation (Gorantiwar *et al.*, 2011).

The identification of critical stages of water requirement is an important task to make decisions concerning irrigation planning in citrus (Dazhi *et al.*, 2018). Different irrigation approaches like soil moisture dimensions, evapotranspiration (ET) and plant water stress based can be followed depending on the type of stress evidence (Pardossi and Incrocci, 2011). Different agro-meteorological conditions are reported to affect the physiological processes and hence, lower the productivity of different crops (Adak *et al.*, 2012; Kaur *et al.*, 2020).

It has been documented that water requirement at various stages of trees varied from 651 to 997 mm per year depending upon the prevailing climatic conditions of the region (Ghadekar *et al.*, 1989). Irrigation scheduling at less than 80 per cent of evaporation replenishment (ER) during the all plant growth developmental stages affected the yield and fruit quality in Nagpur mandarin (Shirgure *et al.*, 2014). The saturated area of soil surface should be reduced to 50 to 60 per cent to diminish soil evaporation and to curtail tree transpiration under full grown tree (García-Tejera *et al.*,

2017). Incomplete root zone drying can be economically beneficial in area of extreme drought to sustain tree growth and yield in citrus (Kusakabe *et al.*, 2016). In recent years, several research reports documented the advantages of optimum irrigation water supply at various flowering and fruit developmental phases in different citrus crops (Pérez-Pérez *et al.*, 2008; Gasque *et al.*, 2010; García-Tejero *et al.*, 2010).

Growth responses of young 'Nagpur' mandarin plants showed significantly higher annual increase in vegetative parameters with drip irrigation at 80% of alternate day cumulative pan evaporation (Panigrahi *et al.*, 2012). Panigrahi *et al.* (2014) advocated that irrigation at 50% crop evapotranspiration (ET<sub>c</sub>) during early fruit development stages could save considerable amount of water in 'Kinnow' mandarin without significant reduction in fruit yield. Kinnow plant is highly responsive to water stress at bud sprouting, flowering, fruit set and fruit developmental stages during January-February and March-April under north-India conditions (Hassan and Sirohi, 2006). However, lack of information about the quantity of water required force Kinnow grower to adopt faulty irrigation scheduling which ultimately affects yield and fruit quality.

This experiment was planned with a hypothesis that early fruit development phases from stage II and III during March-April and May-June respectively, coincides with summer months and later stages during winter months may have different water requirement. Furthermore, efficient irrigation management can save substantial water without effecting the yield and quality of produce. Little information is available on plant responses to water stress conditions during developmental phases in Kinnow mandarin under North-Indian conditions. As one of the most important indicators of yield and water deficit conditions is the tree evidently, a new irrigation scheduling in different growth phases of Kinnow may also benefit farmers.

In view of above discussion, an effort was made to study drip system based on pan evaporation-based irrigation scheduling at various plant growth phases and their effect on fruit yield and quality of Kinnow mandarin under sub-tropical conditions.

## MATERIAL AND METHODS

The research was conducted in New Research Farm, Punjab Agricultural, Ludhiana (Latitude, 30°53'41" N and Longitude, 75°48'26" E) during 2008 to 2018. 'Kinnow' mandarins budded on rough lemon (*Citrus jambhiri* Lush)

rootstock were used in the study. Trees were planted with 6 × 3m spacing in October, 2010. The environment of experimental location is categorized as sub-tropical, with annual rainfall of about 630 mm and out of which 90% was received during rainy season (July to September). The weekly mean temperature and, mean precipitation and mean relative humidity from 2004 to 2013 and 2014 to 2017 period are given in Fig. 1 and 2, respectively. All the recommended practices except irrigation for Kinnow cultivation were given as per PAU recommendations.

The agro-meteorological data recorded from PAU, Ludhiana observatory were used for applying open pan evaporation based irrigation on the basis of pan evaporation replenishment in various periods of tree progression and fruit growth. Year is divided into six different stages i.e. Stage-I (Jan.-Feb.), Stage-II (Mar.-Apr.), Stage-III (May-Jun.), Stage-IV (Jul.-Aug.), Stage-V (Sept.-Oct.) and Stage-VI (Nov.-Dec.). The treatments were irrigation schedule with 30% and 40% ER alternatively from stage-I to stage-IV (T<sub>1</sub>), 40% and 60% ER alternatively from stage-I to stage-VI (T<sub>2</sub>), 60% and 80% ER alternatively from stage-I to stage-IV (T<sub>3</sub>), 80% ER for all stages (T<sub>4</sub>), 30% ER for all stages (T<sub>5</sub>). Each treatment included five trees and treatments were replicated thrice. Water quantity was determined according to average weekly open pan evaporation (Hasan and Sirohi, 2006).

$$E_{tc} = K_p \times K_c \times E_p$$

Where, E<sub>tc</sub> (mm); K<sub>p</sub>-pan coefficient (0.8), K<sub>c</sub>-crop-coefficient (0.80), E<sub>p</sub>-2-days cumulative pan evaporation (mm).

The quantity of water applied was calculated by formula (Germana *et al.*, 1992):

$$V_{id} = (D^2/4) \times (ET_c - R_e)/E_i$$

where, V<sub>id</sub>-irrigation volume applied (litre tree<sup>-1</sup>), D-mean tree canopy spread diameter (m), R<sub>e</sub>-effective rainfall depth (mm), and E<sub>i</sub>- irrigation efficiency of drip system (90%). R<sub>e</sub> was calculated as a sum of soil water content enrichment in root zone (mm) due to rainfall and E<sub>tc</sub> (mm) for the rainfall day (Dastane 1978).

To find out the binomial relationships between different parameters, data of weekly mean temperature and mean evaporation were regressed with quantity of water applied to Kinnow with different treatments. Tree canopy volume was calculated by the equation: volume = 0.524 x height (m) x (average tree spread diameter)<sup>2</sup>. Physical and chemical characteristics were determined by taking 20 fruits

**Table 1:** Average monthly water quantity applied in different irrigation treatments during various stages in years 20015-2018

Treatment	Average monthly total water applied (liters/day/tree)											
	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Stage 6	
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
T <sub>1</sub>	2.8	5.3	11.6	23.2	21.9	20.8	R	R	10.2	8.2	7.1	4.7
T <sub>2</sub>	3.8	7.1	17.4	34.8	29.1	27.7	R	R	13.6	10.9	10.6	7.0
T <sub>3</sub>	5.7	10.6	23.3	46.4	43.7	41.5	R	R	20.5	16.4	14.1	9.3
T <sub>4</sub>	7.6	14.1	23.3	46.4	58.3	55.3	R	R	27.3	21.9	14.1	9.3
T <sub>5</sub>	2.8	5.3	8.7	17.4	21.9	20.8	R	R	10.2	8.2	5.3	3.5

T<sub>1</sub>: irrigation schedule with 30% and 40% ER alternatively from stage 1 to stage 6, T<sub>2</sub>: 40% and 60% ER alternatively from stage 1 to stage 6, T<sub>3</sub>: 60% and 80% ER alternatively from stage 1 to stage 6, T<sub>4</sub>: 80% ER for all stages and T<sub>5</sub>: 30% for all stages, R-Rainfall

in each replication. Total soluble solids (TSS) were calculated with Erma-hand refractometer (0-32°Brix) and fruit acidity (%) in fresh fruits was determined by the method as suggested by AOAC (1995).

The data were analyzed as per standard procedure of Randomized Block Design (RBD). Critical difference at 5% level of probability was calculated to compare different treatments. Analysis of variance was exhibited for various quantitative traits using SAS (Statistical analysis system) 9.3 version software.

## RESULTS AND DISCUSSION

### *Irrigation scheduling and water requirement*

The daily maximum open pan evaporation (9.15 mm) was recorded in May and minimum was recorded in January (1.19 mm). It had been observed that water requirement increased from stage-I to stage-II due to rise in temperature and longer day lengths. Water requirement of bearing Kinnow orchard varied from stage-I to stage-VI. There was a linear increase in water requirement up to stage 3 and thereafter a decrease in water requirement was noticed due to onset of monsoon and winter season from stage-IV to VI, respectively (Table 1). The water requirement among treatments varied from 2.8 liters day<sup>-1</sup> tree<sup>-1</sup> in stage-I to 58.3 litres day<sup>-1</sup> tree<sup>-1</sup> in stage-III. In treatment one, where the irrigation scheduling was applied with 30 to 40 % ER alternatively from stage-I to stage-VI, water requirement varied from 2.8 liters day<sup>-1</sup> tree<sup>-1</sup> in stage-I to 23.2 liters day<sup>-1</sup> tree<sup>-1</sup>. However, water requirement varied from 3.8 liters day<sup>-1</sup> tree<sup>-1</sup> in stage-I to 34.8 liters day<sup>-1</sup> tree<sup>-1</sup> in stage-II where the irrigation was applied with 40 to 60 % ER. For treatment three, water requirement varied from 5.7 (stage-I) to 46.4 liters day<sup>-1</sup> tree<sup>-1</sup>

<sup>1</sup> (stage-II). With 80% ER irrigation scheduling in treatment four, water requirement varied from 7.6 (stage-I) to 58.3 liters day<sup>-1</sup> tree<sup>-1</sup> (stage-III). However, in treatment five, where irrigation was given at 30 % ER, lowest water requirement (2.8 to 21.9 liters day<sup>-1</sup> tree<sup>-1</sup>) was recorded at all the stages (Table 1).

The results indicated that water requirement increased from stage-I to stage-III and thereafter it reduced. The agro-meteorological data recorded during 2004 to 2013 and 2014-2017 (Fig. 1 and 2) indicated that higher temperature and low humidity level during stage III (week 22 to 25) increased open pan evaporation rate and the water requirement of trees increased drastically. However, thereafter onset of rains coupled with low temperature resulted in decreased water requirement of the trees. In another study, significantly higher annual increase in tree height, scion girth, and canopy volume with drip irrigation at 80% of alternate day cumulative pan evaporation had been reported in Nagpur mandarin (Panigrahi *et al.* 2012).

### *Relationship between temperature and volume of water applied*

The polynomial relationship between temperature and volume of water applied was assessed through graphical and equation representation between two variables. Figure 3 illustrates the relationship between weekly mean temperature and volume of water applied to Kinnow mandarin plants at different ER values. The polynomial equation of second order described the relationship between the two variables (Eq. 1-5). It is clear that water requirement increase with increase in temperature (Fig. 3) subject to the prevailing relative humidity (Fig. 2)

These results showed that volume of water required

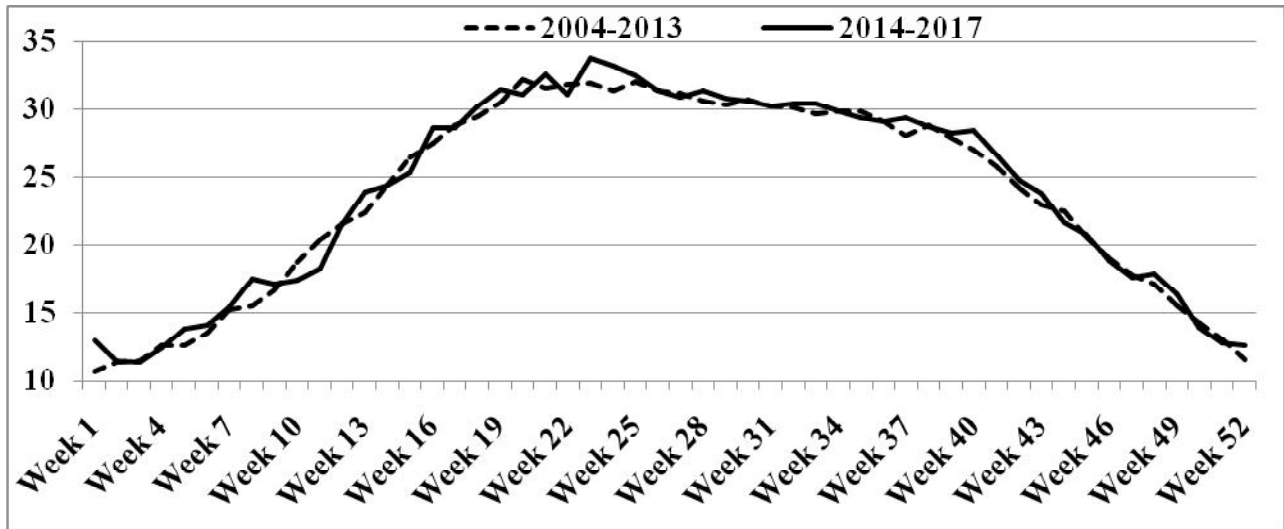


Fig. 1: Weekly mean temperature (°C) of experimental site during 2004-2013 and 2014-2017

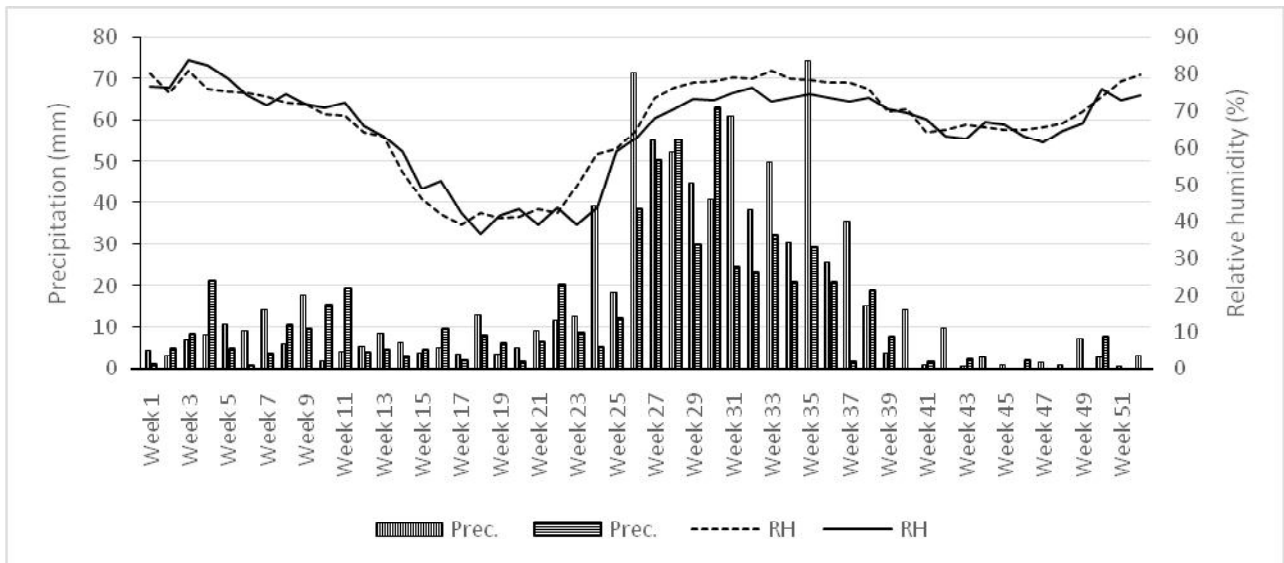


Fig. 2: Weekly precipitation (mm) and weekly relative humidity(%) of experimental site during 2004-2013 and 2014-2017

for drip irrigation to Kinnow mandarin shoots to its maximum for the period between March-April.

$$y = -0.031x^2 + 1.71x - 13.49, R^2 = 0.350 \text{ (T1, 30-40\% ER)} \quad (1)$$

$$y = -0.080x^2 + 3.77x - 32.72, R^2 = 0.386 \text{ (T2, 40-60\% ER)} \quad (2)$$

$$y = -0.138x^2 + 6.37x - 56.1, R^2 = 0.408 \text{ (T3, 60-80\% ER)} \quad (3)$$

$$y = -0.158x^2 + 7.50x - 64.9, R^2 = 0.381 \text{ (T4, 80\% ER)} \quad (4)$$

$$y = -0.084x^2 + 4.53x - 35.62, R^2 = 0.348 \text{ (T5, 30\% ER)} \quad (5)$$

Where, y=volume of irrigation water applied and x=weekly mean temperature.

**Relationship between weekly mean evaporation and the volume of water applied**

These results suggest that volume of irrigation water

applied to Kinnow mandarins increased with increased weekly mean evaporation (Fig. 4). The highest volume of irrigation water applied at different ER range was observed for the months with highest mean weekly temperature leading highest evaporation from soil. The polynomial relationships describing the relationship between increased volumes of irrigation water applied with increased mean evaporation are described in Eq. 6-10.

$$y = 0.004x^2 - 0.278x + 9.31, R^2 = 0.989 \text{ (T1, 30-40\% ER)} \dots\dots\dots(6)$$

$$y = 0.075x^2 - 0.581x + 16.8, R^2 = 0.990 \text{ (T2, 40-60\% ER)} \dots\dots\dots(7)$$

$$y = 0.009x^2 - 0.046x + 18.4, R^2 = 0.990 \text{ (T3, 60-80\% ER)} \dots\dots\dots(8)$$

$$y = 0.002x^2 + 0.126x + 6.81, R^2 = 0.988 \text{ (T4, 80\% ER)} \dots\dots\dots(9)$$

$$y = 0.001x^2 + 0.044x + 2.61, R^2 = 0.988 \text{ (T5, 30\% ER)} \dots\dots\dots(10)$$

**Table 2:** Effect of different treatments on tree height, canopy volume and scion girth of Kinnow mandarin under sub-tropical conditions

Treatment	Tree height (m)				Canopy volume (m <sup>3</sup> )				Scion girth (cm)			
	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean
T1	3.51 <sup>cd</sup>	3.75 <sup>e</sup>	3.98 <sup>bc</sup>	3.75 <sup>c</sup>	15.50 <sup>cd</sup>	19.36 <sup>cd</sup>	22.27 <sup>cd</sup>	19.04 <sup>cd</sup>	28.11 <sup>d</sup>	30.21 <sup>abcd</sup>	33.20 <sup>abcd</sup>	30.51 <sup>abcd</sup>
T2	3.68 <sup>bc</sup>	3.68 <sup>cd</sup>	3.82 <sup>cde</sup>	3.73 <sup>cd</sup>	15.59 <sup>e</sup>	19.85 <sup>c</sup>	23.05 <sup>c</sup>	19.50 <sup>c</sup>	29.12 <sup>abc</sup>	31.24 <sup>abc</sup>	33.90 <sup>abc</sup>	31.42 <sup>abc</sup>
T3	3.80 <sup>ab</sup>	3.95 <sup>ab</sup>	4.26 <sup>a</sup>	4.00 <sup>a</sup>	20.36 <sup>ab</sup>	24.62 <sup>ab</sup>	30.21 <sup>a</sup>	25.06 <sup>ab</sup>	29.25 <sup>ab</sup>	31.95 <sup>ab</sup>	35.20 <sup>a</sup>	32.13 <sup>a</sup>
T4	3.84 <sup>a</sup>	3.96 <sup>a</sup>	4.13 <sup>ab</sup>	3.98 <sup>ab</sup>	23.02 <sup>a</sup>	26.86 <sup>a</sup>	29.03 <sup>ab</sup>	26.30 <sup>a</sup>	29.48 <sup>a</sup>	31.98 <sup>a</sup>	34.60 <sup>ab</sup>	32.02 <sup>ab</sup>
T5	3.41 <sup>e</sup>	3.61 <sup>cde</sup>	3.89 <sup>cd</sup>	3.64 <sup>cde</sup>	13.23 <sup>cde</sup>	16.16 <sup>cde</sup>	21.12 <sup>cde</sup>	16.84 <sup>cde</sup>	27.61 <sup>de</sup>	29.21 <sup>cde</sup>	31.60 <sup>e</sup>	29.47 <sup>de</sup>
SE(mean)	0.08	0.07	0.08	0.07	1.79	1.92	1.87	1.84	0.36	0.53	0.62	0.50
CD(P=0.05)	0.18	0.16	0.18	0.16	4.01	4.30	4.17	4.10	0.81	1.20	1.39	1.12

T<sub>1</sub>: irrigation schedule with 30% and 40% ER alternatively from stage 1 to stage 6, T<sub>2</sub>: 40% and 60% ER alternatively from stage 1 to stage 6, T<sub>3</sub>: 60% and 80% ER alternatively from stage 1 to stage 6, T<sub>4</sub>: 80% ER for all stages and T<sub>5</sub>: 30% for all stages

**Table 3:** Effect of different treatments on fruit weight, fruit number per tree and tree yield of Kinnow mandarin under sub-tropical conditions

Treatment	Fruit weight (g)				Fruit number per tree				Fruit yield (kg/tree)			
	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean
T1	143.3 <sup>cd</sup>	148.2 <sup>d</sup>	156.5 <sup>cde</sup>	149.3 <sup>cd</sup>	341.3 <sup>cd</sup>	370.0 <sup>cd</sup>	482.0 <sup>bcd</sup>	397.8 <sup>cd</sup>	48.9 <sup>bcd</sup>	54.8 <sup>cd</sup>	75.4 <sup>cde</sup>	59.7 <sup>cd</sup>
T2	150.9 <sup>c</sup>	157.0 <sup>abc</sup>	160.5 <sup>c</sup>	156.1 <sup>c</sup>	350.8 <sup>c</sup>	394.0 <sup>abc</sup>	488.0 <sup>bc</sup>	410.9 <sup>ca</sup>	52.9 <sup>bc</sup>	59.9 <sup>bc</sup>	78.3 <sup>cd</sup>	63.7 <sup>c</sup>
T3	164.4 <sup>ab</sup>	169.0 <sup>a</sup>	174.8 <sup>a</sup>	169.4 <sup>a</sup>	410.1 <sup>a</sup>	415.0 <sup>ab</sup>	519.0 <sup>a</sup>	448.0 <sup>ab</sup>	67.4 <sup>ab</sup>	70.1 <sup>a</sup>	90.7 <sup>a</sup>	76.1 <sup>a</sup>
T4	168.7 <sup>a</sup>	158.0 <sup>ab</sup>	172.9 <sup>ab</sup>	166.5 <sup>ab</sup>	404.8 <sup>ab</sup>	429.0 <sup>a</sup>	512.0 <sup>ab</sup>	448.6 <sup>a</sup>	68.3 <sup>a</sup>	67.8 <sup>ab</sup>	88.5 <sup>ab</sup>	74.9 <sup>ab</sup>
T5	138.4 <sup>cde</sup>	141.5 <sup>de</sup>	159.6 <sup>cd</sup>	146.5 <sup>cde</sup>	284.9 <sup>e</sup>	325.0 <sup>e</sup>	497.0 <sup>bc</sup>	369.0 <sup>de</sup>	39.4 <sup>de</sup>	46.0 <sup>c</sup>	79.3 <sup>c</sup>	54.9 <sup>cde</sup>
SE(mean)	5.86	4.68	3.74	4.54	23.0	18.3	7.0	15.3	5.54	4.39	3.01	4.17
CD(P=0.05)	13.11	10.45	8.37	10.16	51.4	41.0	15.7	34.1	12.39	9.82	6.73	9.33

**Table 4:** Effect of different treatments on TSS, acidity and TSS/acidity of Kinnow mandarin under sub-tropical conditions

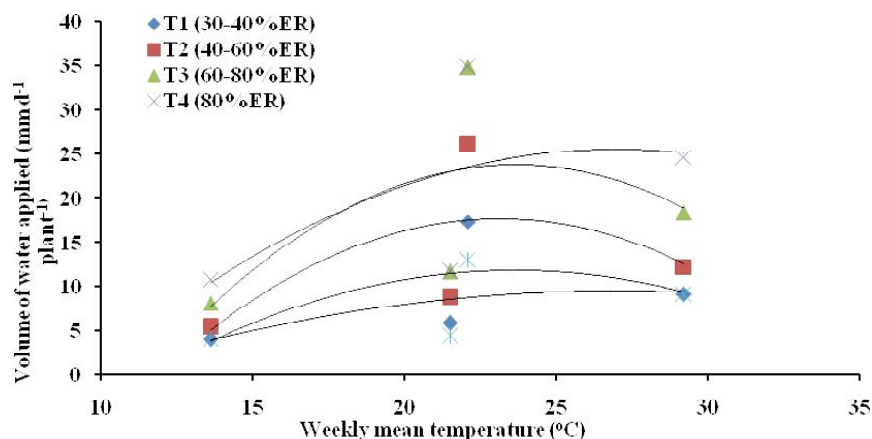
Treatment	TSS (Brix °)				Acidity (%)				TSS/Acidity			
	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean
T1	9.41 <sup>cd</sup>	9.80 <sup>bc</sup>	9.60 <sup>bc</sup>	9.60 <sup>bcd</sup>	0.82 <sup>ab</sup>	0.81 <sup>a</sup>	0.81 <sup>ab</sup>	0.81 <sup>a</sup>	11.48 <sup>cde</sup>	12.10 <sup>bcd</sup>	11.85 <sup>bc</sup>	11.81 <sup>bcd</sup>
T2	9.58 <sup>c</sup>	9.40 <sup>d</sup>	9.20 <sup>d</sup>	9.39 <sup>bcdde</sup>	0.83 <sup>a</sup>	0.78 <sup>ab</sup>	0.78 <sup>bc</sup>	0.80 <sup>ab</sup>	11.54 <sup>cd</sup>	12.05 <sup>bcdde</sup>	11.79 <sup>bcd</sup>	11.80 <sup>bcdde</sup>
T3	9.88 <sup>ab</sup>	10.2 <sup>a</sup>	10.0 <sup>a</sup>	10.03 <sup>a</sup>	0.76 <sup>cd</sup>	0.69 <sup>d</sup>	0.73 <sup>de</sup>	0.73 <sup>cd</sup>	13.00 <sup>ab</sup>	14.78 <sup>a</sup>	13.70 <sup>a</sup>	13.83 <sup>a</sup>
T4	9.91 <sup>a</sup>	9.40 <sup>d</sup>	9.80 <sup>ab</sup>	9.70 <sup>b</sup>	0.71 <sup>e</sup>	0.74 <sup>bc</sup>	0.76 <sup>cd</sup>	0.74 <sup>c</sup>	13.96 <sup>a</sup>	12.70 <sup>b</sup>	12.89 <sup>b</sup>	13.19 <sup>ab</sup>
T5	9.32 <sup>cde</sup>	10.10 <sup>ab</sup>	9.60 <sup>bc</sup>	9.67 <sup>bc</sup>	0.78 <sup>bc</sup>	0.81 <sup>a</sup>	0.84 <sup>a</sup>	0.81 <sup>a</sup>	11.95 <sup>c</sup>	12.47 <sup>bc</sup>	11.43 <sup>bcdde</sup>	11.95 <sup>bc</sup>
SE(mean)	0.12	0.17	0.13	0.10	0.02	0.02	0.02	0.02	0.48	0.50	0.42	0.42
CD(P=0.05)	0.27	0.38	0.30	0.23	0.05	0.05	NS	0.04	1.07	1.13	0.94	0.94

Where,  $y$ =volume of irrigation water applied and  $x$ =weekly mean evaporation.

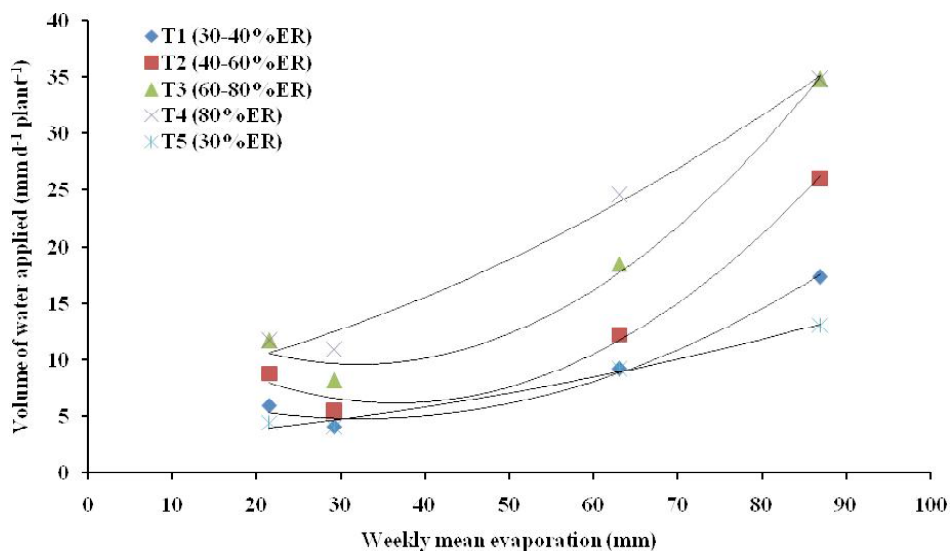
#### Tree growth parameters

The data with respect to tree growth parameters were recorded from fully grown trees during 2016 to 2018 is

presented in Table 2. The maximum average tree height (4.0 m) and average scion girth (32.13 mm) were recorded in treatment three, where irrigation scheduling was done based on 60 and 89 % ER alternatively from stage-I to stage-VI. These values of tree height and scion girth were at par with treatment four and significantly higher than all other



**Fig. 3:** Relationship between weekly mean temperature ( $^{\circ}\text{C}$ ) and the volume of irrigation water applied ( $\text{litre day}^{-1} \text{ tree}^{-1}$ ) at different ER value ranges for scheduling drip irrigation to Kinnow mandarin.



**Fig. 4:** Relationship between weekly mean evaporation (mm) and the volume of irrigation water applied ( $\text{litre tree}^{-1}$ ) at different ER range for scheduling drip irrigation to Kinnow mandarin.

treatments. The significant growth in terms of canopy volume of Kinnow mandarin was observed from 13.23 to 23.02  $\text{m}^3$ , 16.16 to 26.86  $\text{m}^3$  and 21.12 to 30.21  $\text{m}^3$  during the year 2015-16, 2016-17 and 2017-18, respectively (Table 2). The highest average canopy volume (26.30  $\text{m}^3$ ) was recorded in treatment four where higher amount of water was applied with 80% ER scheduling. It was statistically at par with canopy volume of 25.06  $\text{m}^3$  in treatment three where 60 and 80% ER was applied.

The results indicated linear relationship in amount of water applied and tree development parameters. This may be due to better uptake of nutrients by the tree with higher soil moisture which ultimately favours vegetative growth of the tree. Furthermore, high photosynthetic and metabolic

accomplishments of fully irrigated trees under favorable soil conditions lead to higher vegetative growth. The results were also supported by Shirgure *et al.*, 2014 who reported higher vegetative growth with higher irrigation in Nagpur mandarin and acid lime trees under central tropical conditions, respectively.

#### **Fruit yield and other attributes**

Drip irrigation scheduling based on open pan evaporation replenishment significantly affected fruit yield and quality in Kinnow mandarin during all the years under report (Table 3, 4). The fruit weight recorded variation from 138.4 to 168.7g, 141.5 to 169 g and 156.5 to 174.8 g during the year 2015-16, 2016-17 and 2017-18, respectively. However, higher fruit weight (169.4 g) was recorded in

treatment three (60% and 80% ER) which was at par with treatment four (166.5 g) and significantly higher than all other treatments. Significantly higher fruits number per tree (448.6) was recorded in treatment four where the irrigation was scheduled with 80% ER and it was at par with treatment three (448 fruits tree<sup>-1</sup>) (Table 3). The fruit yield varied from 39.4 to 68.3 kg tree<sup>-1</sup>, 46.0 to 70.1 kg tree<sup>-1</sup> and 75.4 to 90.7 kg tree<sup>-1</sup> during the year 2015-16, 2016-17 and 2017-18, respectively. Maximum average yield (76.1 kg tree<sup>-1</sup>) was recorded in treatment four which were at par with treatment three (74.9 kg tree<sup>-1</sup>) (Table 3). Significantly higher TSS and acid ratio (13.83) was recorded in treatment three and it was at par with treatment four (13.19) and significantly higher than all other treatments. The reason behind high fruit TSS and acidity in third treatment is the increased alteration of acids into soluble sugars in dried up juice sacs that is necessary to keep up the osmotic potential of fruit cells under deficit water conditions (Huag *et al.*, 2000).

The results showed that there was a linear increase in vegetative as well as reproductive growth with increase in irrigation water which ultimately resulted in higher tree volume with higher fruit yield and quality. However, no significant difference was noticed in terms of fruit weight and yield if there was increase of water in treatment three (60 to 80 ER% alternatively) to T<sub>4</sub> (80 % ER). The investigation showed that maximum water use efficiency in term of fruit quality and yield could be obtained by irrigating Kinnow orchard at 60 to 80 % ER alternatively from stage-I to stage-VI under sub-tropical conditions.

Our results are reinforced by Shirgure *et al.* (2014) who reported that irrigation scheduling based on evaporation replenishment less than 80% in all the stages of plant growth affected the yield and fruit quality in Nagpur Mandarin. Furthermore, our results were fully supported by the findings which indicated that deficit irrigation during fruit growth period resulted in 20% water saving without significant reduction in yield and fruit quality in mandarins (Ballester *et al.*, 2011). Our results were further supported by findings that irrigation at 50% crop ETc during initial fruit growth period could save significant amount of water in 'Kinnow' mandarin without significant reduction in fruit yield (Panigrahi *et al.*, 2014). Root zone water stress conditions suppressed vegetative growth of plant without affecting much the photosynthetic rate. Hence, more photynthates partitioned from leaves to reproductive growth under deficit irrigation conditions. Similar studies on Kinnow mandarin orchards demonstrated that partial root drying up to 50 per

cent improved irrigation water productivity in sandy loam soils (Panigrahi *et al.*, 2013). Similarly, in Navalina' sweet orange (*C. sinensis* Osbeck), deficit irrigation with 40 to 60% reduction in irrigation water at initial fruit expansion stage did not affect fruit yield and quality (Gasque *et al.*, 2010). The reduction of fruit yield and quality in Kinnow mandarin with 30% ER in our study was supported by findings that water stress during flowering and fruit set profoundly decreased fruit yield in sweet oranges (Pérez-Pérez *et al.*, 2008). High evaporation from soil surface during the dry summer season coupled with high temperature and low relative humidity resulted in poor yield and quality in mango cv. Dashehari. (Adak *et al.*, 2017). Our results indicated that adequate water amount (60-80% ER) of water are especially important during all flowering, fruit set and spring development stages for getting higher yield and quality fruits in Kinnow under Punjab conditions.

## CONCLUSION

The highest volume of irrigation water applied at different ER range was observed for the months with highest mean weekly temperature and evaporation from the soil. Wide variation in vegetative and yield attributes was inferred at different phonological stages during 2015 to 2018 fruiting seasons. However, highest productivity (76.1 kg tree<sup>-1</sup>) was recorded in treatment four which were at par with treatment three (74.9 kg tree<sup>-1</sup>) with less water applied. Significantly higher fruit TSS and acid ratio (13.83) was recorded in treatment three. So, the study concluded that drip irrigation scheduling with 60 to 80 ER% alternatively during six growth stages could save substantial water without negotiating with fruit yield and quality in Kinnow orchard under sub-tropical conditions.

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