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Standardization of stage-wise water requirement in sweet orange (*Citrus sinensis* L. Osbeck) cv. Mosambi

PS Pawar, L Mukunda Lakshmi, PS Shirgure and Prakash Patil

Abstract
This field experiment on standardization of stage-wise water requirement in sweet orange (*Citrus sinensis* L. Osbeck) was conducted at Rahuri, Maharashtra (pooled mean 2011-12 to 2015-16) and at Tirupati, Andhra Pradesh (pooled mean 2011-12 to 2016-17) with an objective to study the water requirement at different stages of growth in sweet orange. The experiment was conducted in Randomized Block Design (RBD) with five treatments replicated four times. Plant spacing was 6 x 6 m at both the centres, where developments in terms of growth, yield, fruit quality and water requirement were recorded. The irrigations were scheduled on percent of pan evaporation replenishment (ER) at various stages of growth and fruit development: Stage-I (Jan-Feb), Stage-II (Mar-April), Stage-III (May-June), Stage-IV (July-Aug), Stage-V (Sept-Oct) and Stage-VI (Nov-Dec). At the Rahuri centre, the effect of different levels of irrigation at different stages of growth and yield and fruit quality of sweet orange were found to be significant. The maximum plant height (4.73 m), canopy volume (45.97 m^3), number of fruits/tree (335.85), average fruit weight (194.75 g), fruit yield (65.33 kg/tree and 18.09 t/ha), juice (46.18%), TSS (10.15 ^oB) and B:C ratio (1.55) with minimum acidity (0.49%) were recorded under treatment T_4, i. e. application of irrigation at 80:80:80:80:80:00 ER% from Stage-I (Jan-Feb) to Stage-VI (Nov-Dec). Based on the results, irrigation at 80:80:80:80:80:00 ER% (T_4) through the drip irrigation system in the growing period (January-October) with water stress in November-December is recommended for better growth, yield and quality fruits in *Ambia bahar* of sweet orange in Western Maharashtra. At the Tirupati centre, the maximum canopy volume (20.00 m^3), number of fruits/tree (288.16) and TSS (10.63 ^oB) were recorded under treatment T_4, i. e. application of irrigation at 80:80:80:80:80:80 ER% from Stage-I (Jan-Feb) to Stage-VI (Nov-Dec). However, the maximum fruit yield (46.91 kg/tree and 12.99 t/ha) and B:C ratio of 1.48 were recorded under treatment T_3, i. e. application of irrigation at 60:80:60:80:60:80 ER% from Stage-I (Jan-Feb) to Stage-VI (Nov-Dec). Based on the results, treatment T_3 is recommended for better yield (46.91 kg/tree and 12.99 t/ha) as well as conservation of 15% of water, highest economic returns (1.48) and less incidence of dry root rot in *Ambia bahar* of sweet orange under the Rayalaseem region of Andhra Pradesh.

Keywords: Drip irrigation, plant growth, fruit yield, fruit quality, irrigation scheduling, sweet orange, pan evaporation, water requirements

Introduction
Sweet orange (*Citrus sinensis* L. Osbeck) is an important commercial citrus cultivar, which is mainly grown in Maharashtra and its adjoining States like Andhra Pradesh, Punjab, Haryana and Rajasthan. Well-marked belts of sweet orange cultivation in India include the Marathwada region of Central Maharashtra, the districts of Ahmednagar, Pune and Nasik in Western Maharashtra; Anantapur, Kodur and Chittoor in Andhra Pradesh; Abohar, Fazilka, Faridkot and Hoshiarpur in Punjab; Hisar in Haryana and Ganganagar district in Rajasthan. Sweet orange, which is a tropical fruit crop, is grown on an area of 244 thousand hectares across India, with a total production of 3,468 thousand MT and productivity of 14.21 MT/ha [1]. Successful sweet orange cultivation depends upon selection of proper soil, climate, planting material, irrigation and fertilizer practices, plant protection measures and other improved practices.

Availability of soil moisture and adoption of an ideal irrigation method at different stages of growth and development affect fruit production in sweet orange. Low productivity and quality result mainly due to lack of water, improper method of scheduling the surface basin irrigation method, lack of micro-irrigation systems and inadequate soil moisture during the different stages of plant and fruit development. Due to increasing water scarcity, the use of surface irrigation method in sweet orange orchards is being replaced with the drip irrigation system [12]. However, the drip irrigation system is not scheduled regularly and poses problems in maintaining the correct irrigation intervals at different stages of plant growth and fruit development. The scheduling of irrigation in different months from January to December in sweet orange affect soil moisture and its distribution in the soil, fertilizer application and nutrient uptake, fruit yield

and quality. In sweet orange cultivation, drip irrigation with pan evaporation scheduling is more beneficial due to better water use and fertilizer use efficiency and other advantages like orchard uniformity, immediate response to crop need, better soil-water-plant relationship, rooting environment and better growth, yield and quality. In India, sweet orange is irrigated using the drip system, with watering scheduled on evaporation replenishment for efficient use of water [10]. The water requirement of sweet orange varies with seasons, growth stages and plant age. As water is the prime source for all biological activities and has become precious than gold in the current times, drip irrigation can help to increase the irrigation potential by optimizing the use of available irrigation water. Precise management of irrigation, along with the rate and timing of nutrient application, are of critical importance to obtain desired results in terms of crop quality, productivity and nutrient use efficiency. In citrus production, drip irrigation is gaining popularity owing to better water use efficiency [8] as well as several other advantages like reduced labour force, conservation of water and power, greater orchard uniformity, rooting environment, better yield and quality fruits [18].

Since current day orchards are watered through the flow irrigation or drip irrigation method, without considering the stage-wise water requirement of the plant, and not much research has been conducted on stage-wise application of irrigation water at different levels of cultivation, the present investigation was planned to standardize the stage-wise water requirement in sweet orange in Maharashtra and Andhra Pradesh.

Material and Methods

The present experiment was conducted at AICRP on Fruits, Department of Horticulture, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri (Maharashtra State) and at Citrus Research Station, Tirupati, Dr. YSR Horticulture University, Venkataramannagudem (Andhra Pradesh). To study the water requirement at different stages of growth in sweet orange, field experiments were conducted in a Randomized Block Design (RBD), with five treatments replicated four times at Rahuri and Tirupati. The scientists used 2 plants/treatment at the Rahuri centre and 4 plants/treatment at the Tirupati centre. Mosambi variety of sweet orange was studied at the Rahuri centre, while Sathgudi variety of sweet orange was investgsted at the Tirupati centre. Tree age was 18 years at the Rahuri centre and 10 years at the Tirupati centre. Fertilizer application of 20 kg FYM + 15 kg neem cake + 800:300:600 g NPK/plant/year was given at the Rahuri centre and 40 kg FYM + 8 kg neem cake + 750:350:400 g NPK/plant/year was administered at the Tirupati centre. The irrigation was scheduled on percent of pan evaporation replenishment (ER) in various stages of growth and fruit development. The irrigation quantity was calculated taking into account pan factor (0.70), canopy factor (0.80) and crop factor (0.75). Stage-wise quantity of irrigation was recorded from January to October at the Rahuri centre and from January to November at the Tirupati centre. Observations on plant height, canopy volume, yield, fruit quality and water requirement were recorded at both centres. The canopy volume of sweet orange tree was calculated based on Castle's [4] formula, while fruit yield and quality analysis were conducted in line with Ranganna's [6] procedure. The data were statistically analyzed using the procedure given by Panse and Sukhatme [5]. Monthly precipitation, mean evaporation, temperature and relative humidity recorded at the two centres are depicted in Table 1.

Treatment details: Rahuri centre (For taking *Ambia* bahar, water stress was given in November-December)

Treatments	Stage-I (Jan-Feb)	Stage-II (Mar-Apr)	Stage-III (May-June)	Stage-IV July-Aug)	Stage-V (Sep-Oct)	Stage-VI (Nov-Dec)
T_1	30 ER (%)	40 (ER (%)	30 ER (%)	40 ER (%)	30 ER (%)	*
T_2	40 ER (%)	60 ER (%)	40 ER (%)	60 ER (%)	40 ER (%)	*
T_3	60 ER (%)	80 ER (%)	60 ER (%)	80 ER (%)	60 ER (%)	*
T_4	80 ER (%)	80 ER (%)	80 ER (%)	80 ER (%)	80 ER (%)	*
T_5	30 ER (%)	30 ER (%)	30 ER (%)	30 ER (%)	30 ER (%)	*

(ER = Evaporation Replenishment) (* = Stress period)

Treatment details: Tirupati centre (For taking *Ambia* bahar, water stress was given in December)

Treatments	Stage-I (Jan-Feb)	Stage-II (Mar-Apr)	Stage-III (May-June)	Stage-IV July-Aug)	Stage-V (Sep-Oct)	Stage-VI (Nov-Dec)
T_1	30 ER (%)	40 (ER (%)	30 ER (%)	40 ER (%)	30 ER (%)	40 ER (%)
T_2	40 ER (%)	60 ER (%)	40 ER (%)	60 ER (%)	40 ER (%)	60 ER (%)
T_3	60 ER (%)	80 ER (%)	60 ER (%)	80 ER (%)	60 ER (%)	80 ER (%)
T_4	80 ER (%)	80 ER (%)	80 ER (%)	80 ER (%)	80 ER (%)	80 ER (%)
T_5	30 ER (%)	30 ER (%)	30 ER (%)	30 ER (%)	30 ER (%)	30 ER (%)

(ER = Evaporation Replenishment)

Table 1: Monthly precipitation, mean evaporation, temperature and relative humidity.

Months	Rahuri centre (2012-2016)				Tirupati centre (2012-2017)			
	Precipitation (mm)	Evaporation (mm)	Temperature (° C)	Relative humidity (%)	Precipitation (mm)	Evaporation (mm)	Temperature (° C)	Relative humidity (%)
January	1.2	4.48	29.17	62.75	47.20	3.83	30.04	87.84
February	0	5.58	31.74	61.60	55.50	5.17	32.40	84.30
March	54.33	7.04	34.72	56.84	124.50	6.19	35.88	84.00
April	5.70	8.78	38.04	54.00	208.30	7.01	38.92	74.28
May	17.92	10.39	39.04	58.44	445.00	7.41	39.34	64.47
June	58.56	7.47	34.24	68.35	522.10	7.27	37.00	66.53
July	78.86	5.06	30.97	79.70	783.20	6.22	35.23	71.18

August	83.56	4.95	30.69	78.60	949.80	5.68	34.60	75.60
September	147.10	4.69	31.18	79.55	990.20	4.67	33.27	82.90
October	78.82	5.11	31.97	74.80	1007.50	4.48	32.82	84.23
November	54.46	4.65	30.86	68.92	1243.30	4.68	30.55	86.55
December	0	4.61	29.39	64.65	606.20	3.28	29.53	85.65

Results and Discussion

The water requirement of bearing sweet orange varied according to the different pan evaporation replenishment-based drip irrigation schedule combinations at various growth stages. The daily weather data recorded at the two centres was used for irrigation scheduling based on evaporation.

Results: Rahuri centre (Pooled data 2011-12 to 2015-16): The pooled data (2011-12 to 2015-16) of growth and yield presented in Tables 2 and 3 show that, application of different levels of irrigation at different stages of growth and yield had a significant effect. Treatment T_4, i. e. irrigation at 80:80:80:80:80:00 ER% from Stage-I (Jan-Feb) to Stage-VI (Nov-Dec) recorded significantly maximum figures for plant height (4.73 m), canopy volume (45.97 m^3), number of fruits (335.85 fruits/tree), average fruit weight (194.75 g) and yield (65.33 kg/tree and 18.09 t/ha), followed by treatment T_3, i. e. irrigation at 60:80:60:80:60:00 ER% at different stages of growth. The minimum plant height (3.91 m), canopy volume (38.22 m^3), number of fruits (275.17 fruits/tree), average fruit weight (178.60 g) and yield (49.03 kg/tree and13.57 t/ha) were recorded under treatment T_5 i. e. irrigation at 30:30:30:30:30:00 ER% from Stage-I (January-February) to Stage-VI (November-December). The maximum growth and yield by application of irrigation at 80 ER% at all the growth stages might have been due to its beneficial effects on photosynthesis and dry matter production. Balaganvi and Kumathe 2004 [2] and Shirgure *et al.* 2014 [17] reported similar increase in growth and yield by application of irrigation water at 80 ER% at all growth stages in acid lime and Nagpur mandarin, respectively.

The fruit quality parameters presented in Table 4 were also affected under various treatments, with the maximum figures for juice (46.18%) and TSS (10.15 ^oB) and minimum figure for acidity (0.49%) recorded under treatment T_4. The application of irrigation water at 80 ER% at all the growth stages enhanced the photosynthetic rate and auxin production, which in turn improved the fruit quality of sweet orange. This is in conformity with the findings of Shirgure *et al.* 2001 [9] and Shirgure and Srivastava 2013 [16] in Nagpur mandarin.

The reduction in the irrigation level from 80 ER% to 30 ER% during different stages of fruit growth reduced yield from 18.09 t/ha to 13.57 t/ha. The treatment T_5, i. e. irrigation at 30:30:30:30:30:00 ER% from Stage-I (Jan-Feb) to Stage-VI (Nov-Dec) recorded the highest WUE (1.35 t/ha cm) (Table 4) and obtained normal yield by application of less total quantity of irrigation water (3603.60 litre/plant/year) than all other treatments (Table 5), which presents data on the stage-wise water requirement in sweet orange. The total quantity of water applied from T_1 to T_5 was in the range of 3603.60 litre/plant/year to 9399.60 litre/plant/year under the drip irrigation method from Stage-I (Jan-Feb) to Stage-VI (Nov-Dec).

Economics

The economics of stage-wise application of irrigation water on benefit-cost ratio is shown in Table 7. Treatment T_4 was found superior to other treatments in terms of growth, yield and quality fruits and recorded higher benefit-cost ratio (1.55). Barua and Hazarika 2014 [3] reported similar results in their study on Assam lemon. Treatment T_3 was found to be the second best treatment and recorded a benefit-cost ratio of 1.45.

Recommendation

Irrigation at 80:80:80:80:80:00 ER% (T_4) through the drip method during January-October and water stress in November-December is recommended for better growth, yield and quality fruits, with efficient utilization of irrigation water in *Ambia bahar* of sweet orange in Western Maharashtra.

Likely beneficiaries of the technology: Growers of sweet orange in Maharashtra and adjoining States.

Results: Tirupati centre (Pooled analysis 2011-12 to 2016-17): Table 2 shows that application of irrigation water at different phonological stages did not significantly influenced plant height in ten-year old orchards of Sathgudi sweet orange. Irrigation at 60:80:60:80:60:80 ER% (T_3) at different growth stages namely, Stage-I (Jan-Feb-flowering) and Stage-V (Sept-Oct-harvesting), followed by 80 ER% at Stage-VI (Stress period) recorded maximum fruit yield (46.91 kg/tree and 12.99 t/ha) (Table 3). Similar fruit yield results were observed in experiments on verna lemon by Sanehez *et al.* 1989 [7]., Nagpur mandarin by Shirgure *et al.* 2001 b [11]; 2003 b [13] and acid lime by Shirgure *et al.* 2004 b [15]. Data presented in Tables 2, 3 and 4 show that treatment T_4, significantly maximum figures for canopy volume (20.00 m^3), number of fruits/tree (288.16) and TSS (10.63 ^{0}Brix). Similar data were recorded in earlier studies on irrigation scheduling in Nagpur mandarin by Shirgure *et al.* 2001 a [10] and acid lime Shirgure *et al.* 2004 a [14] under the central Indian climatic conditions. Treatment T_4 appeared to be the second best treatment for yield (46.29 kg/tree and 12.82 t/ha).

The total irrigation water requirement under T_3 (4,950 litre/plant/year) was less, compared to that under T_4 (5,707 litre/plant/year) (Table 6). The reduction in irrigation from 80 ER% to 30 ER% during any stage resulted in reduction in yield from 12.82 t/ha to 10.19 t/ha (Table 3).

Economics

Table 8 shows the economics of stage-wise application of irrigation water on benefit-cost ratio. Treatment T_3 was found superior to other treatments in terms of yield and recorded higher benefit-cost ratio (1.48). Treatment T_4 emerged as the second best treatment and also recorded a benefit-cost ratio of 1.48.

Recommendation

Irrigation at 60:80:60:80:60:80 ER% (T_3) from Stage-I (January-February) to Stage-VI (November-December) and water stress in December is recommended for better yield (46.91 kg/tree and 12.99 t/ha), efficient utilization of irrigation, water conservation 15%, highest economic returns (1.48) and less incidence of dry root rot in *Ambia bahar* of sweet orange in the Rayalaseem region of Andhra Pradesh.

Likely beneficiaries of the technology: Growers of sweet orange in Andhra Pradesh and its adjoining States.

Table 2: Effect of stage-wise application of water on growth in sweet orange (Pooled mean: 2011-12 to 2015-16 at the Rahuri center and 2011-12 to 2016-17 at the Tirupati center)

Treatment	Plant Height (m)		Canopy Volume (m^3)	
	Rahuri	Tirupati	Rahuri	Tirupati
T_1	4.08	2.57	40.72	17.01
T_2	4.21	2.79	42.46	19.04
T_3	4.57	2.56	44.66	18.71
T_4	4.73	2.67	45.97	20.00
T_5	3.91	2.51	38.22	15.60
S. E.(m) ±	0.04	0.07	0.34	1.03
C. D. at 5%	0.13	NS	1.01	3.07
C. V. (%)	2.08	6.88	2.50	13.99

Table 3: Effect of stage-wise application of water on yield in sweet orange (Pooled mean: 2011-12 to 2015-16 at the Rahuri center and 2011-12 to 2016-17 at the Tirupati center)

Treatment	Number of Fruits/Tree		Average Fruit Weight (g)		Fruit Yield (kg/tree)		Fruit Yield (t/ha)	
	Rahuri	Tirupati	Rahuri	Tirupati	Rahuri	Tirupati	Rahuri	Tirupati
T_1	281.61	242.01	180.99	164.77	50.90	38.64	14.08	10.71
T_2	300.35	265.75	186.51	166.81	56.11	42.08	15.53	11.66
T_3	317.36	283.13	188.57	173.54	59.90	46.91	16.57	12.99
T_4	335.85	288.16	194.75	170.30	65.33	46.29	18.09	12.82
T_5	275.17	227.45	178.60	164.88	49.03	36.79	13.57	10.19
S. E.(m) ±	2.17	15.25	1.10	3.35	0.56	2.17	0.15	0.60
C. D. at 5%	6.50	45.31	3.29	NS	1.68	6.46	0.46	1.79
C. V. (%)	1.99	14.30	1.25	4.88	2.40	12.63	2.37	12.63

Table 4: Effect of stage-wise application of water on fruit quality and water use efficiency in sweet orange (Pooled mean: 2011-12 to 2015-16 at the Rahuri center and 2011-12 to 2016-17 at the Tirupati center)

Treatment	Juice (%)		TSS (ºBrix)		Acidity (%)		WUE (t/ha cm)	
	Rahuri	Tirupati	Rahuri	Tirupati	Rahuri	Tirupati	Rahuri	Tirupati
T_1	44.43	40.93	9.63	9.88	0.55	0.74	1.25	1.56
T_2	45.27	41.15	9.43	9.89	0.53	0.75	0.98	1.19
T_3	45.41	40.18	9.32	10.19	0.52	0.71	0.74	0.94
T_4	46.18	43.39	10.15	10.63	0.49	0.69	0.69	0.81
T_5	43.74	39.89	9.23	9.73	0.54	0.77	1.35	1.71
S. E.(m) ±	0.25	1.15	0.12	0.19	0.01	0.03	--	--
C. D. at 5%	0.76	NS	0.36	0.56	0.03	NS	--	--
C. V. (%)	2.17	6.83	2.17	4.56	3.05	8.83	--	--

Table 5: Stage-wise water requirement of sweet orange through drip irrigation system (liters/plant/stage) at the Rahuri centre (2011-12 to 2015-16)

Treatment	Stage-I (Jan - Feb)	Stage-II (Mar - April)	Stage-III (May - June)	Stage-IV (July -Aug)	Stage-V (Sept -Oct)	Stage-VI (Nov -Dec)	Total (Liters/Plant/ Year)
T_1	532.80	1342.80	1076.40	626.40	471.60	*	4050.00
T_2	709.20	2016.00	1436.40	946.80	540.00	*	5648.40
T_3	1065.60	2685.60	2156.40	1263.60	813.60	*	7984.80
T_4	1490.40	2685.60	2872.80	1263.60	1087.20	*	9399.60
T_5	532.80	1004.40	1076.40	518.40	471.60	*	3603.60

(* = Water stress period)

Table 6: Stage-wise water requirement of sweet orange through drip irrigation system (liters/plant/stage) at the Tirupati centre (2011-12 to 2016-17)

Treatment	Stage-I (Jan -Feb)	Stage-II (Mar -April)	Stage-III (May -June)	Stage-IV (July -Aug)	Stage-V (Sept -Oct)	Stage-VI (Nov -Dec)	Total (Liters/Plant/ Year)
T_1	372.00	822.00	646.00	369.00	118.00	148.00	2475.00
T_2	495.00	1233.00	861.00	554.00	157.00	222.00	3522.00
T_3	743.00	1645.00	1292.00	739.00	236.00	295.00	4950.00
T_4	991.00	1645.00	1722.00	739.00	315.00	295.00	5707.00
T_5	372.00	617.00	646.00	277.00	118.00	111.00	2141.00

(Water stress period - December)

Table 7: Economics of effect of stage-wise application of water in sweet orange at the Rahuri centre

Treatment	Total Expenditure (Rs/ha)	Yield (t/ha) Pooled mean	Gross Monetary Return (Rs/ha)	Net Profit (Rs/ha)	B - C Ratio
T_1	2,40,788=57	14.08	3,09,760=00	68,971=43	1.28
T_2	2,46,149=52	15.53	3,41,660=00	95,510=48	1.38
T_3	2,50,027=56	16.57	3,64,540=00	1,14,512=44	1.45
T_4	2,55,640=09	18.09	3,97,980=00	1,42,339=91	1.55
T_5	2,38,906=20	13.57	2,98,540=00	59,633=80	1.24

Produce sold @ Rs. 22,000/tone

Table 8: Economics of effect of stage-wise application of water in sweet orange at the Tirupati centre

Treatment	Total Expenditure (Rs/ha)	Yield (t/ha) Pooled mean	Gross Monetary Return (Rs/ha)	Net Profit (Rs/ha)	B – C Ratio
T_1	2,61,550=00	10.71	3,21,300=00	59,750=00	1.23
T_2	2,62,018=00	11.66	3,49,800=00	87,782=00	1.34
T_3	2,63,588=00	12.99	3,89,700=00	1,26,112=00	1.48
T_4	2,60,420=00	12.82	3,84,600=00	1,24,180=00	1.48
T_5	2,58,388=00	10.19	3,05,700=00	47,312=00	1.18

Produce sold @ Rs. 30,000/tonne

Conclusion

Rahuri centre: Considering five-year study of stage-wise application of irrigation water, it was recommended that, irrigation at 80:80:80:80:80:00 ER% (T_4) through the drip method during January-October and water stress in November-December is recommended for better growth, yield and quality fruits with efficient utilization of irrigation water in *Ambia bahar* of sweet orange in Western Maharashtra.

Tirupati centre: Considering six-year study of stage-wise application of irrigation water, it was recommended that, **i**rrigation at 60:80:60:80:60:80 ER% (T_3) from Stage-I (January-February) to Stage-VI (November-December) and water stress in December is recommended for better yield (46.91 kg/tree and 12.99 t/ha), efficient utilization of irrigation, water conservation 15%, highest economic returns (1.48) and less incidence of dry root rot in *Ambia bahar* of sweet orange in the Rayalaseem region of Andhra Pradesh.

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