



Integrated water and nutrient management in Sathgudi sweet orange (*Citrus sinensis*)

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ABSTRACT

The combined effect of drip irrigation with fertigation on plant growth, yield and quality of 10 year-old bearing sweet orange (*Citrus sinensis* cv. Sathgudi) was studied during 2013–17 at Dr YSR Horticultural University, AICRP on Fruits, CRS, Tirupati. The experiment was laid out in factorial randomised block design with nine treatment combinations, comprising three irrigation schedules, viz. 70 % evaporation replenishment (ER), 80 % ER, and 90 % ER, and three fertigation levels, viz. fertigation with 60 % RDF (recommended dose of fertilizers), 70% RDF and 80% RDF based NPK doses replicated six times. The maximum plant canopy volume (16.84 m³), fruit yield (14.18 t/ha) and TSS/acidity ratio (20.7) of sweet orange was observed with the drip irrigation scheduled at 90 % ER combined with 70 % RDF fertigation treatment combination. The fruit yield efficiency per unit of canopy volume was also observed maximum (0.84) with irrigation scheduling at 90 % ER and fertigation with 70 % RDF dose. The sustainable production of sweet orange was obtained with irrigation scheduling at 90 % ER along with fertigation technology at 70 % RDF with 27-30% saving in water and fertilizers.

Key words: Drip irrigation, Fertigation, Irrigation schedule, Partial factor productivity, Sathgudi, Sweet orange

Sweet orange (*Citrus sinensis* Osbeck), cultivar Sathgudi is mainly grown in Rayalaseema region of Andhra Pradesh and adjoining states like Telangana, Karnataka and Tamil Nadu in South India. The productivity of Sathgudi is very low (7-8 t/ha) due to soil application of fertilizers with multiple nutrient deficiencies (Imas 1999, Shirgure 2012, Shirgure P S and Srivastava 2013c). The main prerequisites for sustainable production are correct amount of water and proper schedule of irrigation (Shirgure *et al.* 2001) with required nutrients to be applied at different growth stages to get quality citrus fruits (Bielorai *et al.* 1984, Mageed *et al.* 1988).

Inadequate moisture and nutrients in critical stages of the crop reduces the fruit yield and quality drastically (Davies and Albrigo 1994, Shirgure *et al.* 2014). The partial fertigation of N and K element resulted in low N content in leaves with higher TSS and acidity in juice with fruit yield remaining unaffected in Valencia orange (Koo and Smajstrla 1984, Ferguson *et al.* 1990, Smajstrla 1993). The maximum

fruit yield was observed with fertigation of NPK through Triosol with significant differences in fruit size, acidity, percent juice content and TSS (Fouche and Bester 1987). The maximum growth, yield and fruit quality of Nagpur mandarin were observed with the irrigation scheduled at 20% depletion of AWC (available water content) and 30% depletion of AWC combined with 500 N: 140 P₂O₅: 70 K₂O g/plant as fertigation dose (Shirgure *et al.* 2001, Srivastava *et al.* 2003). Fertigation technology in citrus has shown invariably good response on growth, yield, quality and uniform distribution pattern of applied water as well as nutrients within the active root zone compared to band placement of localized fertilization (Shirgure 2013, Shirgure and Srivastava 2013a). Kumar *et al.* (2013) observed maximum response on fruit yield with irrigation at 80% with 100% RDF produced highest fruit yield coupled with better quality of fruits. The objective of this investigation was to study the integrated effect of different irrigation schedules based on 70–90 % evaporation replenishment and with different 60–80% RDF fertigation doses on growth, yield and fruit quality of Sathgudi sweet orange grown on Alfisols of south India.

MATERIALS AND METHODS

The experiment was conducted on bearing sweet orange cv. Sathgudi plants budded on Rangpur lime root stock (*C. limonia*) with plant spacing of 6 m × 6 m at AICRP on Fruits

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(Citrus), Citrus Research Station, Dr YSR Horticultural University, Tirupati (AP) during 2013–17. Different irrigation schedule treatments were based on evaporation replenishment (ER), viz. I_1 , irrigation scheduling at 70% ER; I_2 , irrigation scheduling at 80% ER and I_3 , irrigation scheduling with 90% ER with three sub-treatments of fertigation levels, viz. F_1 , fertigation with 60% RDF; F_2 , fertigation with 70 % RDF and F_3 , fertigation with 80% RD, where RDF was taken as 750:350:400 g/plant (N : P_2O_5 : K_2O) annually along with 80 kg of FYM and 8 kg neem cake per plant per year as per recommendation of the University. All the treatments were imposed in Randomized Block Design (RBD), with three replications and four adjacent plants in a row per replication. The soil type was sandy loam with 10% clay content. Volumetric soil moisture content at field capacity (FC) and soil moisture characteristics were determined using pressure plate method. The FC and soil moisture at wilting of the experimental soil were 9.1% and 3.2% respectively. While, water holding capacity of the soil was worked out to be 11–12% considering soil bulk density as 1.5–1.6 g/cc, determined using core sampler of 100 cm³ volume.

The drip irrigation system consisting of 8 LPH (litre/hour) drippers as 4 per plant on the lateral arrangement, were used in the field along with the fertilizer dispenser unit. The irrigations were applied in alternate day interval through a drip and water requirement was estimated by using the equation given by Shirgure *et al.* (2004). Water soluble form of urea phosphate (18:44:0) and white potash (0:0:60) were used for giving the required quantity of P and K respectively. The height of tree was recorded from soil surface to the apex of the longest branch in meters. Stem girth of scion was measured 30 cm above the ground level. Canopy volume of the plant was calculated by using the values of north-south and east-west plant spread (m) by following formula:

$$\text{Canopy volume of plant (m}^3\text{)} = 4/6 \pi r^2 h$$

where π , 22/7; r , plant spread in meter (N-S) + (E-W)/2; h is canopy height of the plant.

Similarly, for the yield, a sample of randomly selected fruits from each tree was weighed and average fruit weight was computed and expressed in g/fruit. Mature fruits were harvested and the weight was recorded by summing up the total weight of fruits at different pickings from each tree and total fruit yield (kg/plant) in t/ha was calculated and recorded accordingly. Five fruits per tree were taken randomly for determination of fruit quality parameters (juice percent, acidity and total soluble solids). Juice and its percent was estimated on weight basis with respect to fruit weight. The total soluble solids (TSS) were determined by digital refractometer (Atago model-PAL 1, Japan) and acidity was measured by volumetric titration with standardized sodium hydroxide using phenolphthalein as an internal indicator (Ranganna 2001). Partial factor productivity (PFP) was estimated by dividing the fruit yield (kg/ha) with total amount of fertilizer nutrient (N+P+ K) applied (kg/ha)

(Devasenapathy *et al.* 2008). The soil and leaf samples were collected as per the treatments and analysed following the standard leaf and soil sampling method (Srivastava *et al.* 1994). The collected leaf samples were digested in di-acid mixture of H_2SO_4 : $HClO_4$ in 2.5:1 ratio (Chapman and Pratt 1961). The leaf N was determined using Auto Nitrogen Analyser, P by vanadomolybdophosphoric acid yellow colour method and K by flame photometrically. Data on growth, fruit yield and quality attributing to the different irrigation schedules and fertigation levels for 5 years were statistically analysed through Analysis of variance following the procedural steps (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Water use through different irrigation schedules: The effect of various irrigation schedules based on pan evaporation replenishment influenced the water use by the sweet orange plant during the study period (2013–17). The total depth of water use is a function of water requirement of plant canopy volume. The total quantity of irrigation used with 70% evaporation replenishment (ER) irrigation schedule was 24684 l/plant, with mean of 4937 l/plant/year (1371 mm/plant/year). While, with 80% evaporation replenishment (ER), irrigation water requirement was optimum for 5 years (28210 l/plant) with mean of 5642 l/plant (1567 mm/plant/year). The water use was 31737 l with 90% ER irrigation schedule with mean water use of 6347 l/plant (1763 mm/plant/year). The irrigation water requirement of sweet orange was less during the year 2016 due to excess and heavy rains for three months (September–November 2015). Similar studies on water use in citrus have been reported in Nagpur mandarin (Shirgure *et al.* 2004), Kinnow mandarin (Mageed *et al.* 1988) and Sathgudi sweet orange (Kumar *et al.* 2013) under Indian conditions.

Response on bio-metric observations and fruit yield: The interactive effect of differential irrigation schedules with fertigation levels showed a significant effect on plant canopy volume, fruit yield and yield efficiency of sweet orange cv. Sathgudi in terms of yield per unit canopy (Table 1). With exception of irrigation schedule at 90% ER, the canopy volume increased from 13.11 to 14.34 m³ and from 14.02 to 15.23 m³ with increased levels of fertigation from 60 % RDF to 80 % RDF, with irrigation schedule at 70% ER and 80% ER respectively. The maximum canopy volume was recorded with irrigation at 90% ER plus fertigation at 70% of RDF (16.84 m³) followed by irrigation at 90% ER plus fertigation at 60% RDF (16.73 m³). Fruit yield was significantly affected by irrigation method and fertigation technology (Srivastava *et al.* 2003, Shirgure *et al.* 2014). Significant effect of treatment combination was observed on number of fruits/ tree. It ranged from 241 to 259, 280 to 305 and 323 to 342 in irrigation schedule at 70% ER, 80% ER and 90% ER respectively (Table 2). Fruit yield of Sathgudi sweet orange at all the three irrigation levels, increased from 10.12 to 11.21 t/ha, 11.45 to 12.67 t/ha and from 13.37 to 14.18 t/ha with increase in fertigation levels from 60% of RDF to 80% of RDF with irrigation schedule at 70% RE,

Table 1 Effect of integrated water and nutrient management on growth, fruit yield, partial factor productivity, water use-efficiency and B:C ratio of sweet orange (2013–17)

Treatment	Canopy volume (m ³)	Fruits/tree	Fruit yield (kg/tree)	Fruit yield (t/ha)	Yield efficiency (t/m ³)	PFP (kg fruit/ kg NPK)	WUE (t/ha-cm)	B:C ratio
I1F1	13.11	241	38.97	10.12	0.772	28.87	0.74	2.91
I1F2	14.34	259	39.95	10.82	0.755	25.28	0.79	2.68
I1F3	13.84	246	38.95	11.21	0.810	21.64	0.82	2.59
I2F1	14.02	289	43.63	11.45	0.817	32.32	0.73	3.29
I2F2	14.61	280	44.32	11.93	0.817	28.05	0.76	2.95
I2F3	15.23	305	47.35	12.67	0.832	26.31	0.81	2.93
I3F1	16.73	323	48.43	13.37	0.799	35.87	0.76	3.84
I3F2	16.84	336	52.95	14.18	0.842	33.51	0.80	3.51
I3F3	16.49	342	51.33	13.79	0.836	28.52	0.78	3.19
CD (P=0.05)	2.02	58.6	6.66	1.60	-	-	-	-
SE(m)±	0.71	20.4	2.32	0.56	-	-	-	-
CV%	11.50	17.2	12.61	11.21	-	-	-	-

I1, Irrigation at 70 % ER; I2, Irrigation at 80 % ER; I3, Irrigation at 90 % ER. F1, Fertigation with 60 % RDF; F2, Fertigation with 70 % RDF and F3, Fertigation with 80 % RDF. PFP, Partial factor productivity (kg fruit/kg NPK use); WUE, Water use efficiency (t/ha-cm).

80% and 90 % respectively. But yield was optimum with irrigation at 90% ER and fertigation at 70% of RDF (14.18 t/ha). These responses of fruit yield confirmed well with the yield efficiency. It was observed maximum with irrigation at 90% ER combined fertigation at 70% of RDF fertigation treatment (0.842 t/m³). Earlier experiments on irrigation schedules at critical stages of water requirements showed higher plant growth and fruit yield with irrigation scheduled at 80% ER in Nagpur mandarin (*Citrus reticulata* Blanco) and acid lime (*Citrus aurantifolia* Swingle) with reduction in fertilizer doses over conventional method (Shirgure *et al.* 2001, Shirgure *et al.* 2014).

Table 2 Effect of irrigation schedules and fertigation levels on fruit quality parameters of sweet orange

Treatment*	Total soluble solids (° Brix)	Juice content (%)	Acidity (%)	TSS/acidity ratio
I1F1	9.81	40.72	0.77	12.74
I1F2	9.82	41.02	0.80	14.94
I1F3	9.98	42.95	0.66	14.52
I2F1	10.48	43.11	0.81	18.30
I2F2	10.08	43.49	0.69	15.67
I2F3	10.06	41.80	0.84	17.09
I3F1	10.45	42.70	0.79	18.90
I3F2	10.90	43.17	0.78	20.70
I3F3	11.23	43.66	0.78	20.39
CD (P=0.05)	0.70	NS	NS	3.44
SE(m)±	0.25	0.74	0.08	1.20
CV%	5.83	4.29	24.87	17.23

* The treatments are as given in Table 1.

Partial factor productivity and water-use-efficiency: The effect of integrated use of water and fertilizers, irrigation schedule with fertigation enhanced not only the partial factor productivity but also the input use-efficiencies. Partial factor productivity is an indicator of the fertilizer use efficiency. The partial factor productivity (PFP) of macro-nutrients (NPK) for *ambia bahar* (kg fruits/kg NPK) was calculated with pooled analysis of the observations recorded (Table 1). Maximum PFP, i.e. 35.87 and 33.51 kg fruit/ kg NPK use were noticed in the irrigation schedule at 90% ER along with fertigation level F₁ (60 % RDF fertigation) and F₂ (70 % RDF fertigation) respectively, which were significantly superior over rest of the interaction effects. The fertigation of citrus for improved nutrient uptake efficiency and to minimize leaching of nutrients below the root zone also advocated fertigation because of soil fertility improvement coupled with water use efficiency (WUE) which is the ratio of fruit yield per unit water use (Alva *et al.* 2008, Shirgure and Srivastava 2013b). The maximum WUE of 0.82 t/ha-cm was observed in irrigation schedule at 70% ER along with fertigation level 80% RDF (I₁F₃), which was at par with irrigation schedule at 80% ER with fertigation level 80 % RDF (0.81 t/ha-cm) and with irrigation schedule at 90% ER and fertigation level 70% RDF (0.80 t/ha-cm). Quality fruits give market price with lower cost of drip irrigation and fertigation. From Table 1, it is revealed that the maximum cost benefit (B:C) ratio of 3.84 was observed in irrigation schedule at 90% ER combined with fertigation level at 60 % of RDF followed by irrigation at 90% ER and fertigation at 70% of RDF (3.510).

Response on fruit quality attributes: The fruit quality parameters have shown a significant response to irrigation as well as fertigation due to precise and optimum use of water and nutrients. Amongst the fruit quality parameters,

juice content and acidity were found non-significant due to the internal fruit quality parameter (Table 2). Best fruit quality parameters were recorded with irrigation at 90% ER (TSS 11.23°Brix, juice content 43.66% and acidity 0.78%) coupled with fertigation at 80% RDF significantly better than either irrigation at 70% ER along with fertigation at 80% RDF (TSS 9.98°Brix, juice content 42.95 % and acidity 0.66 %) or an irrigation at 80% ER with fertigation at 80% RDF schedule (TSS 10.06°Brix, juice content 41.8% and acidity 0.84%). However, the irrigation schedule with 70% ER and fertigation at 60% RDF gave the poorest effect on different fruit quality parameters (TSS 9.81° Brix, juice content 40.72% and acidity 0.77 %). The higher Brix acidity ratio is the indicator of sweetness of the fruit of *ambia* flush. The highest TSS to acidity ratio (18.9–20.7) was found in the irrigation schedule with 90% ER irrigation scheduling in combination with 60–80 % RDF fertigation followed by the irrigation schedule with 80% ER with 60–80 % RDF fertigation (15.67–18.9). Studies in the past showed improvement in the fruit quality in response to irregular schedule based on evaporation replenishment and fertigation in Nagpur mandarin (Shirgure *et al.* 2014, Shirgure *et al.* 2016b) as well as acid lime (Shirgure *et al.* 2003).

Response on leaf nutrient composition: The integrated effect of irrigation schedules in combination of the fertigation levels have shown a profound response on leaf nutrients (leaf N, P and K) uptake in Sathgudi cultivar of sweet orange. The leaf nitrogen (N) content was observed to be 2.57%, 2.75% and 3.03% with irrigation schedule at 70% ER, 80% ER and 90% ER respectively. Leaf N content increased from 2.52 to 3.05% and from 2.77 to 3.08% with increase in fertigation levels from 70% to 80% RDF, with significant effect of irrigation at 80% and 90% ER. Similarly, leaf phosphorus (P) concentration was maximum (0.42%) with irrigation at 90% ER, which was significantly higher than either irrigation at 70% ER (0.34%) or at 80% ER (0.39%). Leaf P content increased from 0.39–0.42% and 0.42% with increase in fertigation levels from 70% to 80% RDF, with significant effect of irrigation at 80% and 90% ER. The lower leaf P uptake (0.32%) was observed in irrigation schedule of 70% with 60% RDF fertigation due to lower mobility and fixing of the P with soil in inadequate moisture regime. These optimum leaf K can be achieved with irrigation schedule at 80% ER. The K uptake influences the fruit quality and the interactive effect of water and nutrients results in quality fruits. The leaf K increased from 1.43–1.49%, 1.53–1.86% and from 1.65–1.70% with increasing fertigation level from 60% RDF to 80% RDF in combination with irrigation at 80% ER, 90% ER and 70% ER, respectively (Table 3). The increase in leaf K was higher with increasing fertigation levels from 60% RDF to 80% RDF, proportionately much higher with irrigation at 80% ER than at either 70% ER or 90 % ER. Similar results were also reported in Nagpur mandarin (Panigrahi *et al.* 2012, Shirgure *et al.* 2016b).

This investigation clearly showed a significant interactive effect of irrigation schedule based on evaporation

Table 3 Leaf nutrient composition of sweet orange in various treatments

Treatment*	Leaf nutrient concentration (%)		
	N	P	K
I1F1	2.43	0.32	1.43
I1F2	2.52	0.34	1.47
I1F3	2.77	0.38	1.49
I2F1	2.58	0.37	1.53
I2F2	2.78	0.39	1.69
I2F3	2.90	0.42	1.86
I3F1	2.96	0.41	1.65
I3F2	3.05	0.42	1.66
I3F3	3.08	0.42	1.70
CD (P=0.05)	0.22	0.04	0.10
SE(m)±	0.07	0.01	0.03
CV%	4.44	5.49	3.58

* The treatments are as given in Table 1.

replenishment along with RDF fertigation levels on growth, leaf nutrient build up, higher yield and fruit quality of sweet orange cv. Sathgudi.

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