EFFICIENT WATER MANAGEMENT IN FRUIT CROPS IN WATER SCARCE REGIONS

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ABSTRACT

In spite of well-suited soil and climate, the fruit production is jeopardised in many regions due to water scarcity. In this scenario, efficient and effective water management using deficit irrigation through drip system becomes indispensable. A study was conducted to evaluate the effects of deficit irrigation (DI) under drip system on water use, yield, water productivity and financial return, taking citrus as a test crop. Water was applied at 30% of full irrigation (FI, 100% crop evapotranspiration), 50% of FI, and 70% of FI, and compared with FI in drip-irrigated citrus at Nagpur, India. Fruit yield under 50% FI (11.48 t ha $^{-1}$) was statistically at par with FI (13.14 t ha $^{-1}$). However, 50% reduction in water supply resulted in 75% improvement in water productivity in DI at 50% FI than FI. The highest net profit (INR 94300 ha $^{-1}$) was generated under DI at 50% FI. The study inferred that irrigation at 50% FI could be a water saving and profitable option for citrus production in central India. These results advocate for standardisation of DI in different potential fruit crops grown in water scarce regions of the country.

Key words: Fruit crops, water scarcity, micro irrigation, fruit yield, net income

INTRODUCTION

Limited water availability is one of the major reasons for low yield of the crops in tropics. The whole agricultural sector is going to be shrunk due to less water availability caused by more demand of water for drinking and industrial purposes in near future. In this scenario, development of optimal water supply protocols through efficient irrigation method is one of the options to sustain crop production. Deficit irrigation (DI) is an irrigation strategy to stabilize yield with higher water productivity and better qualities of the crops under water scarcity. Moreover, DI may be more profitable for the farmers compared with traditional irrigation practice.

Central India is one of the major hubs for fruit crop production of the country. However, water scarcity is an obstacle to fruit culture in this region. Citrus is commercially grown in around 2.0 lakh hectares of central India as an irrigated crop in the vertisol using groundwater. Surface irrigation (basin, furrow) is the dominated method of water application in the region. The substantial water loss through preferential pathways/ deep cracks developed at sub-optimum soil water content in the vertisol is a common problem, causing low water use efficiency in agriculture. However, the area under the citrus crop is exponentially increasing due to climate suitability and better financial return compared to other crops in the region. For the last few years, the decline of groundwater due to overexploitation of it becomes a major concern for the farmers. The water shortage affects productivity and quality of citrus produced in this region. The strategies like drip irrigation, continuous trench and mulching have been found as the water saving techniques in citrus (Panigrahi *et al.* 2012). Further, DI with drip system may result in substantial water saving with improving fruit quality and water productivity compared with full irrigation in the crop under water scarce situation of central India. Financial analysis of citrus production under any irrigation system is also important in farmers' perspective. However, the information on optimal DI regime under drip system in relation to water use, fruit yield, fruit qualities and production economics of citrus in central India is limited. Therefore, a field experiment was undertaken to evaluate the effects of DI under drip system in citrus orchard under a hot sub-humid tropical climate of central India.

2. MATERIALS AND METHODS

The field experiment was conducted at experimental farm of National Research Centre for Citrus, Nagpur Maharashtra state, India for 3 consecutive years during 2008–2010. The location map of the experimental site is presented in figure 1. The study was initiated with 19 year-old Nagpur mandarin (*Citrus reticulata* Blanco) plants budded on rough lemon (*Citrus Jambhiri* Lush) root stock. The plant to plant and row to row spacing was 6 m. The experimental soil was clay loam (31.65% sand, 23.6% silt and 44.8% clay) with field capacity and permanent wilting point of 28.7% (v/v) and 17.9% (v/v), respectively, and bulk density of 1.21 g cm^{-3}. The mean daily USWB Class-A pan evaporation rate varied from 2.0 mm during the month of December to as high as 10.0 mm during May/ June at the experimental site. The mean air temperature varies from 13.8 ^{0}C in winter (December) to 36.2 ^{0}C in summer (May). However, the daily maximum temperature seldom rises to 46 ^{0}C at the experimental site. The mean annual rainfall at the site is 810 mm, out of which around 85% takes place during monsoon season (July–October).

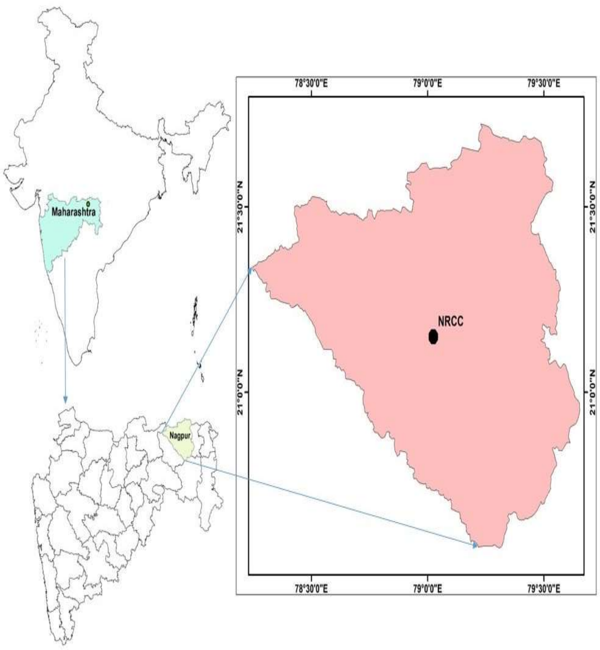

Figure 1. Location map of the study site

The treatments imposed to irrigate the plants were drip irrigation at 30%, 50% and 70% of full irrigation (FI), and compared with 100% FI (control). Water was applied through four numbers of 8 L h^{-1} pressure compensated on-line dripper per plant, placed at 1.0 m away from the trunk. The quantity of water applied was estimated based on daily irrigation supply considering

FI at 100% ET_c (crop evapotranspiration), which was estimated based on the suggestion given by Panigrahi *et al.* (2012). The experiment was laid out in randomized block design (RBD) with five replications. A plot having an area 0.65 ha (90 m x 72 m) with 180 mandarin plants was selected for the study. The whole plot was divided into 20 equal subplots with each sub-plot area of 324 m^2 (18 m x 18 m). Nine plants in three adjacent rows (3 plants per row) within a sub-plot were taken as a replicated treatment plot under the study. Irrigation requirement for different drip irrigation treatments was calculated using the formula adopted by Panigrahi *et al.* (2009);

$V = S \times K_p \times K_c \times WF \times (E_p - ER) / IE$ (1)

where, V is the irrigation volume (litre day^{-1} $plant^{-1}$), S the tree canopy area (m^2), K_p the pan factor (0.7), K_c the crop coefficient (0.7) as suggested by Autkar *et al.* (1989), WF the wetting factor (0.4), E_p the daily class-A pan evaporation (mm), ER the cumulative effective rainfall for corresponding two days (mm), and IE the irrigation efficiency under drip system (90%). The water supply was monitored using digital water meters and control valves placed on each sub-main pipe line installed for different irrigation treatments.

The vegetative growth parameters such as plant height, stem height, stock girth diameter and scion girth diameter were measured for all experimental plants. The canopy (hemispheroid shape) volume was calculated based on the formula 0. 5233 H W^2, where H is difference between tree height and stem height, and W is the canopy width (Obreza 1991). The number of fruits, fruit weight and weight of total fruits from each experimental plant under various treatments were recorded. The total fruit yield was estimated by multiplying the mean fruit yield of the experimental plants with total number of plants per hectare (278) in different treatments. The water productivity (yield per unit quantity of water used) was calculated as the ratio of total fruit yield (kg ha^{-1}) to total water used per hectare (m^3 ha^{-1}) in different treatments. Five fruits per plant were taken randomly for determination of fruit quality parameters (juice, acidity and total soluble solids).

The economics under various irrigation treatments was determined based on the seasonal cost of production (cost of fertilizers, pesticides, energy for pumping of irrigation water), labour cost for basin cleaning, irrigation, fertilizer application, spraying and fruit harvesting and cost of drip irrigation system. The data were subjected to analysis of variance (ANOVA) and separation of means was obtained using Duncan multiple range test (DMRT) which was performed by using the Least Significant Difference (LSD) values at 5% probability level.

3. RESULTS AND DISCUSSION

3.1. Irrigation quantity

The monthly irrigation water applied under different irrigation regimes under drip system was lowest in December and highest in June (Table 1). The increase in water application was due to increasing rate of daily pan evaporation rate from December (2.5–3.0 mm) to June (8.0–10.0 mm) during the study years. Earlier studies by Autkar *et al.* (1989) and Panigrahi *et al.* (2012) recorded the similar trend of water use by citrus plants from December to June under Central India condition. Overall, the quantity of water applied under 30% FI, 50% FI, 70% FI and 100% FI regimes were 806 m^3 ha^{-1} yr^{-1}, 1343.4 m^3 ha^{-1} yr^{-1}, 1880.7 m^3 ha^{-1} yr^{-1} and 2686.8 m^3 ha^{-1} yr^{-1}, respectively.

Table 1. Mean daily irrigation water applied (L day^{-1} $plant^{-1}$) in citrus under different irrigation treatments in various months

Treatment	Months								TWA (m^3 ha^{-1} yr^{-1})
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
DI at 30 % FI	8.6	5.8	9.1	11.5	12.8	14.3	16.9	18.8	806.0
DI at 50 % FI	14.3	9.7	15.1	19.2	21.4	23.8	28.2	31.3	1343.4
DI at 70 % FI	20.0	13.6	21.2	26.9	29.9	33.3	39.5	43.8	1880.7
FI	28.6	19.5	30.3	38.4	42.8	47.6	56.5	62.6	2686.8

DI: Deficit irrigation; FI: Full irrigation; TWA: Total water applied; the data for different variables did not vary significantly among the years.

3.2. Vegetative growth

The annual incremental growth (plant height, PH; stock girth, SG; scion girth, SCG and canopy volume, CV) of the plants showed that only plant height and canopy volume were significantly influenced by irrigation treatments (Table 2). The highest increase in plant height and canopy volume was observed in FI followed by DI at 70% FI. This may be due to better photosynthesis and partitioning of higher amount of photosynthates towards vegetative growth under FI compared with other treatments. The minimum vegetative growth was observed under DI at 30% FI. The lower vegetative growth under lower level of irrigation corroborates the findings of García-Tejero *et al.* (2010) in 'Salustiano' orange under DI in Spain.

Table 2. Annual incremental plant growth parameters of citrus under different irrigation treatments

Treatment	Plant height (m)	Stock girth (mm)	Scion girth (mm)	Canopy volume (m^3)
DI at 30% FI	0.18^c	22^a	21^a	7.10^c
DI at 50%FI	0.30^b	24^a	23^a	8.73^b
DI at 70%FI	0.35^a	30^a	27^a	9.41^a
FI (Control)	0.38^a	31^a	29^a	9.48^a

DI: Deficit irrigation; FI: Full irrigation; Data within a column followed by same letters do not differ significantly at P<0.05, the data for different variables did not vary significantly among the years.

3.3. Fruit yield, water productivity and fruit quality

The fruit yield was higher under higher level of irrigation (Table 3). However, the yield under FI was statistically at par with that under DI at 70% FI and DI at 50% FI. The fruit yield at 30% FI was significantly lower compared with other treatments. The lower photosynthesis rate and partitioning of lower portion of photosynthates towards yield parameters might be the reason for low yield under irrigation at 30% FI compared with other irrigation treatments. More number of fruits with lower fruit weight was observed in FI as compared with DI at 70% FI and DI at 50% FI. The higher number of fruits probably caused lower fruit weight under FI and 70% FI compared with 50% FI treatment. The fruit yield was significantly lower in DI at 30% FI, due to lower number of fruits and lower fruit weight than other treatments. The similar results of lower fruit yield due to reduced fruit number and fruit weight under DI were also reported by Pérez-Pérez *et al.* (2008) in 'lane late' orange and García-Tejero *et al.* (2010) in 'Salustiano' orange. The higher water productivity was observed under DI at 50% FI compared to FI and DI at 70% FI. The higher water productivity under DI at 50% FI and 70% FI was attributed to higher increase in fruit yield with comparatively less water supply under these treatments compared with FI.

Fruit quality (juice percentage, acidity and TSS) under various irrigation treatments showed that the FI produced the fruits with higher juice contents compared with other treatments (Table 3). However, the higher TSS and lower acidity of fruits were observed in DI at 50% FI than that in DI at 70% FI. The fruits with lowest TSS and acidity were harvested in DI at 30% FI. The reduction in juice percentage is one of the reasons for enhancement of soluble solids concentrations in fruits under DI except at 30% FI. Secondly, the higher TSS and lower acidity of fruits under optimum water-stress (DI at 50% FI, 70% FI) was probably due to the enhanced transformation of acids to sugars in dehydrated juice sacs which is required to maintain the osmotic pressure of fruit cells. Earlier studies also demonstrated comparatively better fruit quality (higher TSS and lower acidity) of citrus fruits under optimal DI over FI (Panigrahi *et al*., 2014).

Table 3. Fruit yield, water productivity and fruit quality of citrus under different irrigation treatments

Treatment	**Yield parameters**			**Water productivity (kg m^{-3})**	**Quality parameters**		
	No. of fruits plant^{-1}	Fruit weight (g)	Total yield (t ha^{-1})		Juice (%)	Acidity (%)	TSS (^{0}Brix)
DI at 30% FI	323^{d}	78.3^{d}	7.03^{b}	8.72^{a}	36.2^{d}	0.87^{a}	9.6^{d}
DI at 50% FI	389^{c}	106.2^{c}	11.48^{a}	8.54^{a}	39.8^{c}	0.83^{d}	10.3^{a}
DI at 70% FI	435^{b}	102.6^{b}	12.41^{a}	6.60^{b}	40.1^{b}	0.84^{c}	10.1^{b}
FI (Control)	480^{a}	98.5^{a}	13.14^{a}	4.89^{c}	40.3^{a}	0.85^{b}	9.8^{c}

DI: Deficit irrigation; FI: Full irrigation; Data within a column followed by same letters do not differ significantly at P<0.05, the data for different variables did not vary significantly among the years.

3.4. Economics of production

Economic analysis shows that FI produced the maximum gross income, followed by DI at 70% FI and DI at 50% FI, due to higher fruit yield under higher level of irrigation (Table-4). However, the net income generated under DI at 50% FI was highest, followed by DI at 75% FI. This was due to higher cost of production caused by higher investment in drip irrigation (INR 82000 ha^{-1}), labour charges for irrigation and electrical energy used in pumping water under FI. These results corroborate the findings of Panigrahi *et al.* (2013) under DI in Kinnow mandarin grown in a semi-arid environment of north India. The DI at 50% FI produced the highest net economic water productivity and benefit: cost ratio among the treatments. On the other hand, the highly water stressed plants which were under DI at 30% FI resulted in lowest economic net return among the treatments.

Table 4. Economic analysis for different irrigation treatments in citrus

Treatments	Total seasonal cost of production (INR ha^{-1})	Gross seasonal income (INR ha^{-1})	Net seasonal income (INR ha^{-1})	Net economic water productivity (INR m^{-3})	Benefit-cost ratio
DI at 30% FI	19900^{d}	70300^{d}	50400^{d}	62.53^{b}	2.53^{c}
DI at 50% FI	20500^{c}	114800^{c}	94300^{a}	70.19^{a}	4.60^{a}
DI at 70% FI	31100^{b}	124100^{b}	93000^{b}	49.45^{c}	2.99^{b}
FI	39500^{a}	131400^{a}	91900^{c}	32.20^{d}	2.32^{d}

DI: Deficit irrigation; FI: Full irrigation; INR: Indian Rupee; Data within a column followed by same letters do not differ significantly at P<0.05

4. CONCLUSIONS

The deficit irrigation was found as a potential water saving strategy in citrus production. Irrigation with 50% reduction in water supply could increase the water productivity by 75%, without affecting the fruit yield significantly compared with full irrigation in Nagpur mandarin in vertisol. Moreover, it was demonstrated that a matured mandarin plant could be grown with the application of 10–31 litre day^{-1} water under drip system in a hot-dry climate of central India. Overall, substantial water saving and increased water productivity with better quality fruits under 50% deficit water supply suggests for its adoption in matured Nagpur mandarin orchards in the study region, and elsewhere having similar agro-climate of the study region. This study also encourages for development of optimal deficit irrigation strategy for other fruit crops in water scarce environments.

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