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Effective management of irrigation water in citrus orchards under a water scarce hot sub-humid region

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ABSTRACT

Water scarcity is one of the major causes of low productivity and decline of citrus orchards. Deficit irrigation (DI) is a recently proposed water saving technique in irrigated agriculture. The impact DI versus full irrigation (FI: 100% crop water requirement) was evaluated in citrus orchards under a hot sub-humid climate of central India. Two DI strategies applied to citrus trees were DI_1: 20% FI during initial fruit growth period (IFGP) + 40% FI during final fruit growth period (FFGP) + FI during rest of the period, and DI_2: 70% FI during entire irrigation season. Fully irrigated trees had the highest vegetative growth. However, DI_1 produced 18% higher fruit yield with superior quality fruits, resulting 30% improvement in water productivity under this treatment compared to FI. Fruit yield prediction based on vegetative growth and leaf physiological parameters of the trees using principal component regression analysis technique was found reasonable accurate. These results suggest for adoption of DI_1 in citrus orchards of central India and elsewhere having similar agro-climate of this study region.

1. Introduction

Water scarcity is a major constraint in crop production. Efficient water supply through precise irrigation scheduling is one of the pathways to sustain crop production with higher water productivity. Deficit irrigation (DI) has been found as a potential water saving technique in some crops. DI is an irrigation strategy where the amount of water applied is less than the full water requirement of a crop to develop desirable stress that has minimal effects on crop yield (English, 1990). The correct application of DI requires the thorough understanding of the yield response of crops to water supply. In water scarce regions, DI can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land (English, 1990). Citrus, a high water requiring evergreen perennial fruit crop is mainly grown in tropics. Irrigation water is a key input to success of citrus cultivation in tropical and sub-tropical regions of the world (Singh and Srivastava, 2004). The higher vegetative growth in bearing trees reduces the productivity of citrus (González-Altozano and Castel, 1999). Moreover, the water stress during certain crop growth stages enhances the yield and fruit quality of citrus (González-Altozano and Castel, 1999). However, the plants undergo severe stress when soil-water is very low and the water uptake by the roots fails to compensate the optimal evpotranspiration of the tree. Hence, the accurate and precise water application, creating a desirable stress is important for citrus production in water scarce regions.

Nagpur mandarin (C*itrus reticulata* Blanco), a loose skin citrus cultivar is commercially grown in around 0.20 million hectares of central India as an irrigated crop (Singh and Srivastava, 2004). Central India is globally the only commercially important citrus belt where soil water deficit stress is adopted in absence of low temperature stress for induction of flowering in citrus. The crop is mainly grown on smectite rich black clay soil with 35–60% clay content (Srivastava et al., 2001) in this region. The acreage under the crop is increasing exponentially each year due to its high production economics and cultivar suitability in this region. The irrigation water shortage is one of the major *abiotic* constraints for higher and quality production of citrus in central India. Earlier study reported that drip irrigation could save 30% irrigation water with enhancing fruit yield by 50% compared with basin irrigation in citrus of central India (Panigrahi et al., 2012). Further, it becomes a necessary to find a new irrigation strategy under drip irrigation to sustain crop productivity with less water expanse.

In recent years, several contributions have documented the advantages of DI in improving water use efficiency and fruit quality of different citrus cultivars in various regions of the world

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(González-Altozano and Castel, 1999; Pérez-Pérez et al., 2008; García-Tejero et al., 2010). However, pedo-climatic characteristics of the orchard and crop characteristics play a greater role in success of DI scheduling in fruit crops (Ginestar and Castel, 1996; García-Tejero et al., 2010). The most sensitive phenological stages of citrus to water stress are flowering, fruit set and fruit development (fruit enlargement) in which shortage of soil moisture in root-zone reduces yield drastically (Ginestar and Castel, 1996). The reduction of irrigation water quantity to certain level in non-critical growth stages (initial fruit growth period, final fruit growth period) is one of the options to sustain citrus production with higher water productivity in water scarce areas.

Imposition of desirable water stress on trees through DI in clay soils is difficult due to high buffering capacity and intrinsic water holding ability of these soils (Girona et al., 2002; Turner, 2004). Moreover, the information available on citrus production under DI in clay soils is very limited worldwide. Keeping this in view, a study was undertaken to evaluate the performance of various DI strategies in Nagpur mandarin on clay soil (Vertisol) in hot sub-humid tropical climate of central India. Moreover, the yield prediction based on vegetative and physiological parameters of the trees under DI, using principal component regression analysis (PCRA) has been tried. This can be helpful to forecast the yield under different water stress conditions in the crop.

2. Materials and methods

The field experiment was conducted for 3 consecutive years during 2007–2009 at experimental farm of Central Citrus Research Institute, Nagpur (21°08′45″N, 79°02′15″E and 340 m above mean see level) with 12 year-old Nagpur mandarin (*Citrus reticulata* Blanco) plants budded on rough lemon (*Citrus jambhiri* Lush) rootstock with spacing of 6 × 6 m. The experimental soil was clay. The physic-chemical properties of experimental soil are presented in Table S1. The mean daily USWB Class-A pan evaporation rate varied from 2.0 mm in month of December to as high as 12.0 mm in May at the experimental site. The mean monthly weather parameters during the experimental years are presented in Table S2. The irrigation water was free from salinity (EC, 0.12–0.32 dS m^{-1}) and alkalinity (pH, 6.8–7.2). The ground water level in the well near to the experimental field was at 17–19 m depth from land surface.

Two deficit irrigation (DI) schemes i.e. 20% of full irrigation (FI) during initial fruit growth period + 40% FI during final fruit growth period + FI during rest irrigation season (DI_1), and 70% FI during entire irrigation season (DI_2) were evaluated against FI imposed throughout the irrigation season. The initial fruit growth period (IFGP) and final fruit growth period (FFGP) were taken from mid-February to mid-March and mid-October to November, respectively (Srivastava et al., 1998; Huchche et al., 1999). The orchard having area 2.72 ha with 756 trees was selected for the study. The experimental design was a randomised complete block, with seven replicates per treatment. The selected orchard was divided into 3 equal size plots (252 m × 36 m) and each plot was further divided into 7 sub-plots (36 m × 36 m) with 36 trees per sub-plot in six rows (6 trees per row). Sixteen trees in the four mid-rows of each sub-plot were taken for experimental observations, so called experimental-trees. Each tree was irrigated by four number of pressure compensated on-line drip emitter (8 L h^{-1}) placed at 1.0 m away from tree trunk as suggested by Panigrahi et al. (2008) for the crop. The volume of irrigation water (V) required under FI was computed by using following equation:

$$V = 0.8 \times S \times Kp \times K_C \times (Ep - ER)/r \quad (1)$$

where, V is the irrigation volume (litre day^{-1} $tree^{-1}$), S the tree canopy area (m^2), Kp the pan factor (0.7), Kc the crop factor (0.7) as suggested by Autkar et al. (1989), Ep the daily Class-A pan evaporation (mm), ER the effective rainfall (mm), and r the water application efficiency of irrigation system (≈90%). The amount of effective rainfall during the irrigation seasons (January–June, October–15th December) was equal to total rainfall, as runoff observed in the experimental sub-plots was negligible during these periods (Panigrahi et al., 2009). The irrigation water quantities in different DI treatments were estimated as fractions of FI. Water meters were used to regulate the water supply to various treatments. All the experimental trees were grown under uniform cultural and management practices.

The soil water content was monitored at 0–0.20 m, 0.20–0.40 m, 0.40–0.70 m and 0.70–1.0 m depths daily in morning before initiation of irrigation by neutron moisture meter (Troxler model-4300, USA). As the roots of Nagpur mandarin trees goes up to 1.0 m soil depth, this depth was taken for soil moisture study (Autkar et al., 1989). Four ceramic cup tensiometers per tree (5 trees per treatment) were placed at 0.20 m, 0.40 m, 0.70 m and 1.2 m depths of soil to measure soil water suction. The daily (ith day) water used (WU_i) by the trees was determined by using the water balance equation:

$$WU_i = P_i + I_i + C_i - D_{pi} - R_{fi} - \Delta S_{(i+1,i)} \quad (2)$$

where, P_i is effective rainfall on ith day (≈rainfall) as discussed earlier, I_i is depth of irrigation water applied on ith day, C_i is contribution through capillary rise from ground water table on ith day, D_{pi} is deep percolation loss on ith day, R_{fi} is surface water runoff on ith day and $\Delta S_{(i+1,i)}$ is sum of daily change in moisture storage (difference between moisture content on i + 1th and ith days) in the soil profiles to a depth of 1.0 m. All units are in millimetres. Since no enhancement of water potential was observed at 1.2 m depth during irrigation seasons, deep percolation loss (Dp) was assumed negligible. C was ignored as the water table was below 15 m throughout the growing seasons. As C, Dp, and R_f were negligible, water used was calculated as the difference between rainfall plus irrigation and changes in total moisture content in the soil profiles.

The leaf physiological parameters (net photosynthesis rate, transpiration rate and stomatal conductance) were recorded fortnightly on a clear day by CO_2 gas analyser (model—301PS, CID Bio-Science, USA) during November to June from 9 am to 5pm in one hour interval. Four leaves per plant (one leaf in each direction: North, South, East and West) and two plants per treatment were considered for these measurements. Overall, seventy two observations were taken in each treatment to estimate the leaf physiological parameters fortnightly. Leaf water use efficiency (LWUE) is calculated as the ratio of net photosynthesis rate to transpiration rate of leaves (García-Sánchez et al., 2007).

The vegetative growth parameters (tree height, stem height, canopy spread, stock and scion girth diameter) were measured for all experimental trees and their pooled annual incremental magnitudes were compared. The canopy volume (Vc) was calculated based on the formulae (Obreza, 1991):

$$Vc = 0.5238\, H\, W^2 \quad (3)$$

where Vc is the canopy volume (m^3), H the difference between tree height and stem height (m) and W the mean canopy width measured in North-South and East-West directions (m). The fruits were harvested by mid of December. The number and weight of total fruits from each experimental-tree under various treatments was recorded and the mean yield per tree was estimated. The total yield was computed considering 278 trees per hectare. The water productivity (WP) was calculated as the ratio of annual fruit yield (t ha^{-1}) to total water used (mm) and irrigation water productivity (IWP) was the ratio of annual fruit yield (t ha^{-1}) to total irrigation water used (mm) for Nagpur mandarin. At the harvest, five fruits per experimental tree were taken randomly for determination of