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Deficit irrigation scheduling and yield prediction of 'Kinnow' mandarin (*Citrus reticulate* Blanco) in a semiarid region

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ABSTRACT

Scarcity of irrigation water in critical growth stages of the crop is one of the major causes of low productivity and decline of citrus orchards. Regulated deficit irrigation (RDI) is a recently proposed water saving technique in irrigated agriculture. The present study was planned with a hypothesis that the optimal RDI scheduling at early fruit growth period (EFGP), which coincides with summer months could save substantial amount of water, without significantly affecting the yield of 'Kinnow' mandarin (*Citrus reticulata* Blanco) plants. Two DI strategies: (a) withholding irrigation at EFGP (RDI_0) and (b) irrigation at 50% crop evapotranspiration (ET_c) at EFGP (RDI_{50}) were compared with full irrigation (FI, 100% ET_c) in relation to gas exchange, water relation and nutrient composition of leaves along with growth and yield of the plants. The greater plant growth with maximum fruit yield (61.9–63.2 t ha^{-1}) was recorded with fully-irrigated plants. However, the yield under RDI_{50} was statistically ($p > 0.05$) at par with that under FI. The reduction in water application of around 24% with RDI_{50} resulted in 30% improvement in irrigation water use efficiency with this treatment over that with FI. The maximum rate of net-photosynthesis, stomatal conductance and transpiration of leaves was recorded with fully-irrigated plants. However, the plants under RDI_{50} exhibited the highest leaf water use efficiency. The leaf nutrients (N, P, K, Fe, Mn, Cu and Zn) analysis revealed that RDI_0 produced significantly ($p < 0.05$) lower concentration of all the nutrients except P and Cu than that in other treatments. Relative leaf water content (RLWC), leaf water concentration (LWC) and mid-day stem water potential (Ψ) showed a decreasing trend, whereas water stress integral (S_Ψ) and plant canopy reflectance indices (water band index, WBI; normalised difference water index, NDWI; and moisture stress index, MSI) showed the reverse trend of RLWC with water stress. The prediction model formulated based on midday stem water stress integral, leaf N, leaf K, stomatal conductance and water stress index using Principal component regression technique during EFGP performed well with reasonably accuracy ($R^2 = 0.85$) to forecast annual fruit yield of the citrus plants. Overall, these results reveal that irrigation at 50% ET_c during EFGP could impose desirable water stress on 'Kinnow' mandarin plants, improving their water use efficiency, without significantly affecting the fruit yield under water scarce condition.

1. Introduction

Water availability becomes a major constraint to crop production in almost all regions of the world. In recent years, deficit irrigation (DI) has emerged as one of the potential tools to be used for sustainable crop production in water scarce regions. Reducing water supply to optimal level of crop water requirement in certain growth stages of the crop improves water use efficiency and quality of produces, without affecting the yield significantly (Panda et al., 2004). Therefore, the correct application of DI requires the thorough understanding of the yield response of crops to irrigation (English, 1990).

Citrus, an evergreen and high water requiring perennial fruit crop, is mainly grown in tropical and sub-tropical regions of the world. Irrigation water is a key input to successful cultivation of citrus (Singh and Srivastava, 2004). Drip irrigation is one of the potential water saving irrigation methods in citrus (Abu-Awwadm, 2001; Panigrahi et al., 2012a). In recent years, several research contributions have documented the advantages of DI in citrus in water

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scarce regions. Castel and Buj (1990) reported that 40% reduction in irrigation water supply during flowering and fruit set period did not reduce the fruit yield significantly in 'Salustiana' orange (*Citrus sinensis* Osbeck) trees in Spain. Gonzaalez-Altozano and Castel (1999) compared the 'Clementina de Nules' (*Citrus clementina* Hort. ex Tan.) tree performance under DI at 25% or 50% ETc during flowering and fruit set, initial fruit enlargement phase, and final fruit growth and maturation phases. They reported that water stress during flowering and fruit set period significantly reduced the fruit yield up to 62% over full irrigation. Pérez-Pérez et al. (2008b) observed that withholding irrigation at initial fruit growth period and final fruit growth period of 'Lane late' orange (*Citrus sinensis* Osbeck) reduced the yield significantly. DI scheduled with 40 and 60% reduction in irrigation water quantity at initial fruit enlargement stage of 'Navalina' sweet orange (*Citrus sinensis* Osbeck) in Spain did not affect the yield and fruit quality (Gasque et al., 2010). García-Tejero et al. (2010b) demonstrated that the irrigation applied at 55% crop water requirement during flowering and fruit growth in 'Navelina' sweet orange significantly reduced the fruit yield. However, irrigating the trees at 70% full irrigation at flowering and fruit-growth phases along with 55% FI at fruit maturity phase decreased the yield by 10–12% with 24% enhancement in water productivity. Panigrahi and Srivastava (2011) advocated for irrigation at 70% crop water requirement for 'Nagpur' mandarin (*Citrus reticulata* Blanco) grown in clay soil, which enhanced the water use efficiency substantially without affecting the yield significantly. Overall, the studies indicate that the level and time of water stress along with its duration are the main factors responsible for success of DI in citrus. Moreover, orchard and crop characteristics such as soil, climate, and cultivar also play a role in success of DI (Treeby et al., 2007; Panigrahi and Srivastava, 2011).

'Kinnow' mandarin, a hybrid of 'King' mandarin (*Citrus nobilis* Loureiro) and 'Willow leaf' mandarin (*Citrus deliciosa* Ten), is a leading citrus cultivar in India. The cultivation of the crop is mainly confined to semiarid and arid environments of northern India, where more than 90% of annual rainfall (600 mm) is concentrated in 3–4 months (June–October) of a year. Irrigation is practised during January–June to improve the productivity of citrus orchards in this region. Water from ground water wells is the common source of irrigation for the crop. For last few years, the shortage of irrigation water caused by over exploitation of ground water has become a major threat to citrus production. On the other hand, the area under the crop has been exponentially increasing due to the cultivar suitability and its high production economics in this region (Bhat et al., 2011). Farmers are more concerned with the sustained production of 'Kinnow' mandarin using less water. Optimal DI scheduling under drip irrigation is one of the option for sustaining 'Kinnow' mandarin production in this region.

The earlier study by Hasan and Sirohi (2006) on 'Kinnow' mandarin indicated that the crop is most sensitive to water stress at flowering and fruit set stage which takes place during month of March in northern India. The water scarcity caused by low water level in the wells in summer months (March–June) has forced the orchard growers to opt for DI during this period. In absence of the information on the crop response to DI in early fruit growth period (EFGP, April–June), the orchard growers have adopted faulty irrigation strategy which has affected the yield drastically with inferior quality fruits. Moreover, the information on the responses of mandarin cultivars of citrus to water stress in summer months, which coincides with EFGP, is very limited worldwide. Further, the yield prediction under differential water stress condition is also limited in fruit crops. Since it has been recognised that the tree itself is the best indicator of water stress and yield (Braun et al., 1989; Goldhamer et al., 2003), a new methodology for forecasting yield using plant-based measurements in any growth stage of citrus could also benefit growers.

The present study was, therefore, carried out with following objectives: (i) to optimize the DI scheduling in EFGP in relation to yield, fruit quality, and water use efficiency of 'Kinnow' mandarin and (ii) to develop the plant parameter-based yield forecasting model for the crop under differential water stress conditions in EFGP using principal component regression (PCR) technique, in a semiarid subtropical climate of North India.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at the Research orchard of the Centre for Protective Cultivation Technology, Indian Agricultural Research Institute, New Delhi (latitude 28° 38′23″ N, longitudes 77° 09′27″ E and at an average elevation of 228.61 m above the mean sea level), India. The citrus plant used in the study was 'Kinnow' mandarin budded on rough lemon (*Citrus jambhiri* Lush) rootstock. The experiment was conducted for two consecutive years (2010 and 2011) with 10 year-old plants, which were drip-irrigated from initial year of planting. The plant to plant spacing in a row and within the row was 4 m and 5 m, respectively.

The texture of experimental soil was sandy loam with bulk density 1.54 g cm^{-3}. Taxonomically the soil belongs to Typic Haplustept. The field capacity (−0.033 MPa) and permanent wilting point (−1.50 MPa) of the soil were 24.0% and 8.5% on volume basis, respectively. The soil had almost neutral pH (7.2) with mild EC (0.15 dS m^{-1}). The mean available N, P, K, Fe, Mn, Cu, and Zn concentration in the soil was 63.6, 11.7, 85.7, 7.4, 10.0, 6.6 and 1.4 mg kg^{-1} soil, respectively. The irrigation water was free from salinity (EC, 1.15 dS m^{-1}), alkalinity (pH, 7.3) and sodicity (SAR, 4.4). The water level in the groundwater wells, situated at 20 m distance from the experimental plot, was around 17.0 m deep.

The climate of the experimental site is characterized as semiarid sub-tropical, with hot and dry summers. The mean annual rainfall is 600 mm, out of which around 90% is received during monsoon (June–October). The mean daily class-A pan evaporation rate varied from 1.6 mm in January to as high as 10.7 mm in June. The meteorological parameters during different growth stages of the crop are presented in Table 1. The rainfall amount in EFGP during 2010 (8.8 mm) was lower than that during 2011 (82.2 mm). However, the daily mean maximum temperature (40.7 °C), mean minimum temperature (25.4 °C) and pan evaporation (10.0 mm day^{-1}) in EFGP during 2010 were higher than the mean maximum temperature (38.9 °C), mean minimum temperature (23.3 °C) and pan evaporation (7.0 mm day^{-1}) in EFGP during 2011.

2.2. Treatments and layout

Two DI regimes: no irrigation (RDI_0) and 50% crop evapotranspiration (RDI_{50}) were applied at EFGP and their impact on crop performance was compared with that under full irrigation (FI: 100% crop evapotranspiration). The duration of EFGP was taken from mid-April to mid-June, as suggested by Dhillon (1986) and Singh et al. (1998) for 'Kinnow' mandarin in the study region. Irrigation was applied through drip system from mid-January to June and from October to December. Water supply was stopped during monsoon season (July–September) due to adequate rainfall fulfilling the crop water need during this period. The irrigation treatments were laid out in randomized complete block design with 7 replications. Each replicated plot having size 240 m^2 (15 m × 16 m) had 12 trees in 3 adjacent rows and two central trees of the rows were considered as experimental trees. All the measurements were taken from the experimental trees.