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Effect of drip irrigation and plastic mulch on performance of Nagpur mandarin (*Citrus reticulata*) grown in central India

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ABSTRACT

A field experiment was conducted during 2003–06 to assess the response of various drip irrigation regimes, viz 40, 60, 80 and 100% of alternate day cumulative pan evaporation with black polyethylene mulch of 400 gauge thickness versus basin irrigation method in 1-year-old Nagpur mandarin (*Citrus reticulata* Blanco) trees budded on Rough lemon (*Citrus jambhiri* L.) root stock at Nagpur, Maharashtra. All the drip irrigation regimes with plastic mulch produced a significantly ($P<0.05$) higher annual increase in tree growth parameters over basin irrigation method. However, the highest magnitude of growth parameters was recorded in drip irrigation at 60 % of alternate day cumulative pan evaporation with plastic mulch along with 35.7% water saving over basin irrigation method. Leaf water-use efficiency (leaf photosynthesis rate / transpiration rate) under drip irrigation at 60% of alternate day cumulative pan evaporation with plastic mulch was significantly higher both in winter (1.829 µmol CO_2 / mmol H_2O) and summer (1.880 µmol CO_2/ mmol H_2O) compared to leaf water-use efficiency in winter (1.123 µmol CO_2 / mmol H_2O) and summer (0.961 µmol CO_2 / mmol H_2O) with basin-irrigated trees. Analysis of leaf nutrients (N, P, K, Fe, Mn, Cu, and Zn) indicated that the drip irrigation at 60% cumulative day pan evaporation with plastic mulch produced a significantly higher leaf N (2.47%), K (1.99%), and Fe (113.7 ppm) over leaf N (1.34%), K (1.07%), and Fe (98.4 ppm) under basin irrigation, with other nutrients (P, Mn, Cu, and Zn) non-affected.

Key words: Drip irrigation, Leaf nutrients composition, Leaf water-use efficiency, Nagpur mandarin, Polyethylene mulch

Nagpur mandarin (*Citrus reticulata* Blanco) is a well-known commercial citrus cultivar in the world. It is extensively grown in 4. 85 lakh ha of central India as an irrigated crop (Singh and Srivastava 2004). The acreage under the crop is increasing exponentially each year due to its high production economics, as well as the cultivar suitability in this region. The crop is basically irrigated by bore well or dug well water through conventional basin or furrow irrigation method. For the last few years, the water level in the bore wells and dug wells has declined alarmingly creating water shortage in summer for sustaining the crop. So every year thousand ha under the crop is permanently wilted due to water shortage, which is a great economical loss to the orchard growers of this region. Hence, proper irrigation water management by optimum use of available water resource is quite necessary in this crop condition.

The positive response of drip-irrigation on tree growth and yield along with water economy is well studied in different citrus species in various citrus-growing regions of the world (Cohen 2001, Shirgure *et al.* 2004). Moreover, mulching by plastic polyethylene has proved its effectiveness in conserving the soil moisture and increasing the growth, yield and quality in different citrus cultivars (Shirgure *et al.* 2005, Lal *et al.* 2003). Leaf water-use efficiency which is defined as the ratio of net photosynthesis rate (CO_2 assimilation rate) to transpiration rate (H_2O vapour releasing rate) is a useful integrator of citrus gas exchange, tree growth, yield and water-use efficiency (Jifon and Syvertsen 2003). However, the information regarding water use, tree growth and leaf physiological parameters in response to various drip irrigation regimes with plastic mulch versus conventional basin irrigation method is not reported in case of young Nagpur mandarin grown in central India. Moreover, due to small size and uncertain location of the root zone, it is critical to determine the irrigation requirement of young plantation. Thus, a study was undertaken to evaluate the performance of drip irrigation in conjunction with plastic mulch versus basin irrigation method in young Nagpur mandarin grown in hot sub-humid tropical climate of central India.

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MATERIALS AND METHODS

The field experiment was conducted at experimental farm of National Research Centre for Citrus, Nagpur (21^0 08'45" N, 79^0 02' 15" E and 340 m above mean sea level) during 2003–06 with 1-year-old Nagpur mandarin (*Citrus reticulata* Blanco) plants budded on rough lemon (*Citrus jambhiri* Lush) root stock with spacing of 6m × 6 m. The soil was clay loam (31.65% sand, 23.6% silt and 44.8% clay) with field capacity (–0.33 bar) and permanent wilting point (–15.00 bar) of 29.26% (v/v) and 18.5% (v/v), respectively, with bulk density of 1.18 g/cm^3. The mean daily USWB Class-A pan evaporation rate varied from 1.8 mm in December to 13.5 mm in May at the site. The treatments imposed to irrigate the trees were drip irrigation at 40, 60, 80 and 100 % of alternate day cumulative pan evaporation through 2 no. of 4 litres/hr pressure compensated on-line dripper/tree placed at 0.2 m distance from tree girth and basin (ring of 0.75 m diameter) irrigation at 50% depletion of available soil moisture at 0–0.15 m soil profile. The experiment was in randomized block design with 4 replications and 3 adjacent trees in a row/replication. Irrigation quantity for different drip irrigation treatments was calculated using the formula (Germanà *et al.* 1992):

$$V = S \times Kp \times K_C \times (Ecp - ER) / r$$

where V is the irrigation volume (litre/tree); S the tree canopy area (m^2); Kp, the pan factor (0.7); Kc, the crop factor (0.6); Ecp, the cumulative class-A pan evaporation for 2 consecutive days (mm); ER, the cumulative effective rainfall for corresponding 2 days (mm); and r the water application efficiency of irrigation system (» 90%). Water quantity applied in basin irrigation method was computed using the equation;

$$V = (F\,C - R\,S\,M) \times d \times A$$

where V, irrigation water volume (m^3); F C, field capacity (v/v, %); RSM, required soil moisture level at 50% available soil moisture depletion » 23.9 (v/v, %); d, depth of effective root zone (0.15 m); A, mean canopy area of the plants. The black linear low-density polyethylene sheet of 400 gauge thickness with 1.0 m ´ 1.0 m was used in mulching on each tree basin keeping the tree at the centre. The orchard floor was kept cleaned and all the experimental trees were grown under uniform cultural and management practices.

The soil moisture content at 0.35 m distance from tree trunk was monitored twice in a week before irrigation at 0.15 m and 0.3 m depth by gravimetric method and neutron moisture meter (Troxler model-4300, USA), respectively. The leaf physiological parameters such as net photosynthesis rate (P), transpiration rate (E) and stomatal conductance (C) were recorded fortnightly by CO_2 gas analyzer (CID model - 301PS, USA) during November–June of each season from 7AM to 5PM in 1 hr interval and were poolled as winter (November–January) and summer (February–June) data based on the threshold maximum mean daily air temperature for citrus leaf (31^{0}C). Leaf samples (2nd–4th leaf from tip of branches) surrounding the trees at a height of 1.5 m–1.8 m from the ground surface were collected at the end of irrigation seasons and nutrient (N, P, K, Fe, Mn, Cu, and Zn) analysis was done as per the standard procedure, followed by Srivastava *et al.* (1999). The tree height, stem height, canopy width, and stem (stock and scion) girth were measured for all trees and their pooled annual incremental magnitudes were compared. The canopy volume was calculated based on the formulae

$$0.5233\ H\ W^2$$

where H, tree height – stem height and W, the canopy width (Obreza 1991). All the data generated were subjected to analysis of variance (ANOVA) and the Least Significant Difference (LSD) at 5% probability level was obtained according to Mandal and Nambiar (2002)

RESULTS AND DISCUSSION

Irrigation water

The monthly irrigation water applied was highest in May and lowest in December, irrespective of irrigation method and regime due to highest and lowest atmospheric demand in respective months (Fig 1). The estimated volume of irrigation water under drip irrigation treatments increased non-linearly with pan evaporation rate towards the end of each irrigation season, despite a proportionate (4:6:8:10) pan evaporation scheduling. It was due to the marked difference in incremental tree canopy spread over time, which was involved in estimating irrigation water supply under different drip irrigation treatments with plastic mulch. In the whole, the mean total depth of irrigation water applied was 271.94, 407.84, 543.76

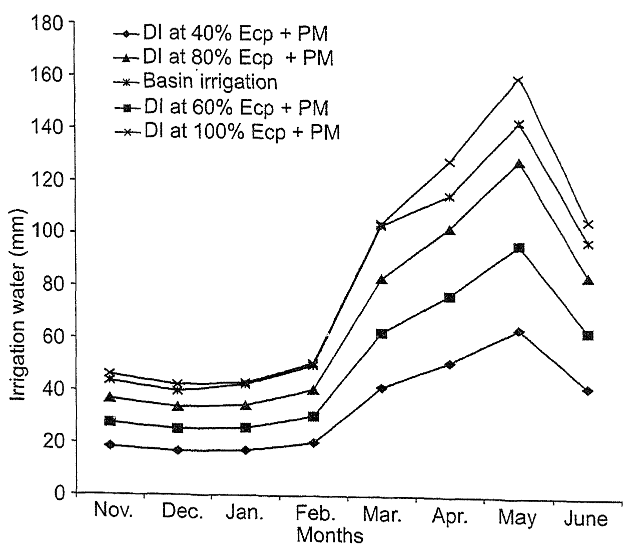

Fig 1 Irrigation water applied in different treatments in various months

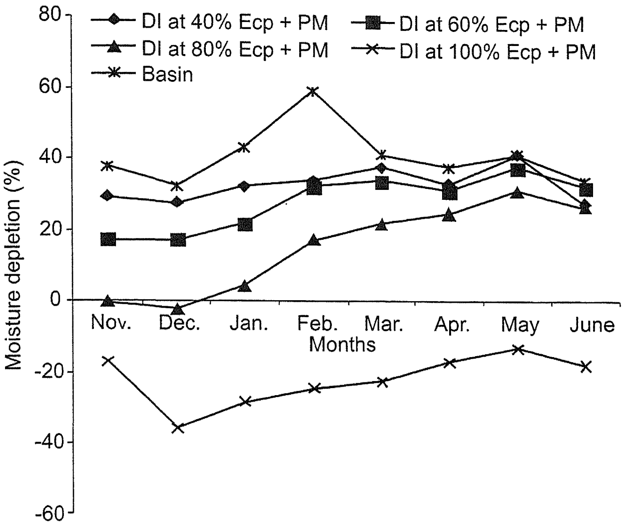

Fig 2 Available soil moisture depletion under various treatments in different months

and 679.77 mm through drip irrigation scheduled at 40, 60, 80 and 100 % of pan evaporation with plastic mulch, respectively, compared to 634.52 mm under basin irrigation method. The reduction of water consumption of 40% in Kinnow (Lal *et al.* 2003) and 45% in acid lime (Shirgure *et al.* 2005) through drip at optimum irrigation level with plastic mulch over the conventional basin method was also studied.

Soil moisture variation

The mean monthly soil moisture variation observed at 0.15 m and 0.30 m depths indicated that drip irrigation at 100 % Ecp with plastic mulch showed the negative soil moisture depletion due to higher moisture content than field capacity of soil (Fig 2). The soil moisture fluctuation between two measurements in a week under basin irrigation was observed to be wider than any of the drip irrigation treatment. It is due to higher rate of evaporation from larger wetted surface area under basin-irrigated soil coupled with higher transpiration rate of the trees caused by higher soil moisture level within the tree rhizosphere just after irrigation under basin method, as reported by Cohen (2001). Among different drip irrigation regimes, the range of soil water depletion at 0.15 m depth was progressively increased with increasing irrigation level, indicating the higher rate of evapotranspiration (ET) of the trees under higher level of irrigation, even with low volume irrigation system. However, the soil moisture depletion under different drip irrigation regimes was almost negligible at 0.3 m depth, whereas some incremental was found under basin method, confirming the percolation of irrigation water from 0 to 0.15 m soil profile under basin irrigation method. This fluctuation was somewhat lower during November-March than April-June, supporting the higher rate percolation under higher rate of irrigation water application in summer (April–June). Above all, the polled soil moisture content under different treatments varied significantly at 0.15 m depth, whereas it was non-significantly affected at 0.3 m depth leading to the fact that the mandarin trees up to 3-year-old have the effective root zone within top 0.15 m soil profile.

Leaf nutrients composition

The imposed irrigation treatments showed a differential response on leaf nutrient status of mandarin trees (Table 1). The higher leaf N (2.47%) was registered under drip irrigation at 60% Ecp with plastic mulch compared with leaf N (1.34%) under basin irrigation method. The leaf K uptake was highest (1.99%) under drip irrigation at 60% of alternate day cumulative pan evaporation, which was at par with other drip irrigation regimes, probably due to high available K in soil (244 mg/kg). But, it was significantly lower (1.07%) under basin irrigation method. The lower level of leaf N and K with basin-irrigated trees might be caused by leaching of the NO_3-N and K^+ in soil within the effective root zone of trees due to flooding in this treatment. Though the highest leaf P (0.134 %) content was registered under drip irrigation

Table 1 Leaf nutrients composition of Nagpur mandarin under various irrigation treatments with plastic mulch (mean data during 2003–06)

Treatment	Macronutrient (%)			Micronutrient (ppm)			
	N	P	K	Fe	Mn	Cu	Zn
*Drip irrigation at 40% Ecp + plastic mulch	1.89	0.074	1.58	98.6	47.7	8.5	8.9
Drip irrigation at 60% Ecp + plastic mulch	2.47	0.083	1.99	113.7	50.4	9.6	19.9
Drip irrigation at 80% Ecp + plastic mulch	1.99	0.134	1.76	121.9	55.7	13.5	12.8
Drip irrigation at 100% Ecp + plastic mulch	1.98	0.127	1.65	131.8	58.3	12.4	10.4
Basin irrigation	1.34	0.096	1.07	98.4	48.7	8.9	12.9
#LSD (*P*=0.05)	0.5	ns	0.32	5.5	ns	ns	ns

*DI, Drip Irrigation; Ecp, alternate day cumulative pan evaporation
#LSD (P= 0.05), Least significant difference at 5% probability level

Table 2 Photosynthesis rate (P), transpiration rate (E), stomatal conductance (C) and leaf water-use efficiency of Nagpur mandarin under different irrigation treatments and plastic mulch during winter* and summer# (mean data during 2003–06)

Treatment	P(μmol /m²/s)		E(mmol/m²/s)		C (mmol/m2/s)		LWUE (μmol CO_2 / mmol H_2O)	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
+Drip irrigation at 40% Ecp + plastic mulch	3.931	3.794	2.342	2.434	69.6	46.1	1.609	1.630
Drip irrigation at 60% Ecp + plastic mulch	4.935	4.312	2.746	2.467	57.8	51.6	1.829	1.880
Drip irrigation at 80% Ecp + plastic mulch	3.923	3.938	2.753	2.723	77.4	71.9	1.484	1.418
Drip irrigation at 100% Ecp + plastic mulch	2.021	2.163	2.004	2.736	38.1	74.8	0.896	0.980
Basin irrigation	3.152	1.712	2.324	1.891	76.1	31.5	1.123	0.961
LSD (P=0.05)	0.39	0.62	0.28	ns	3.03	ns	0.18	0.09

* Winter : November, December and January

\# Summer : February, March, April, May and June

+DI, Drip irrigation; Ecp, alternate day cumulative pan evaporation; PM: plastic mulch

LSD (P=0.05) Least significant difference at 5% probability level

at 80 % Ecp with plastic mulch, but overall it was not affected significantly within the treatments. The treatments imposed had no significant effect on the fluctuation in leaf micronutrient contents, except Fe statistically ($P < 0.05$). Highest leaf Fe (131.8ppm) was registered under drip irrigation at 100 % Ecp with plastic mulch, followed by drip irrigation at 80 % Ecp with plastic mulch as compared with lowest (98.4 ppm) in basin irrigated trees. Highest uptake of Fe with drip irrigation at 100 % Ecp with plastic mulch is attributed to increased solubility of reduced form of iron (Fe^{2+}) due to lack of oxygen in the rhizosphere under increased waterlogged condition in this treatment (Schaffer 1992). The leaf-Fe content under drip irrigation 60% Ecp with mulch (113.7 ppm) was at optimum level as per the standard foliar diagnosis chart for Nagpur mandarin developed by Srivastava *et al.* (2001).

Leaf physiology parameters

The mean leaf physiological parameters such as photosynthesis rate, transpiration rate and stomatal conductance observed under different treatments during winter and summer indicated that photosynthesis rate was significantly higher in winter (4.935 μmol m²/ s) and summer (4.312 μmol/m²/s) under drip irrigation at 60% Ecp with plastic mulch compared to winter (3.152 μmol/m²/s) and summer photosynthesis rate (1.712 μmol/m²/s) under basin irrigation method (Table 2). But, both winter transpiration rate (2.753 mmol/m²/s) and stomatal conductance (77.4 mmol/m²/s) values were significantly higher under drip irrigation at 80 % Ecp with plastic mulch over winter transpiration rate (2.324 mmol/m²/s) and stomatal conductance (76.1 mmol/m²/s) with basin irrigated trees. This is due to consistently higher available soil moisture content at the effective root zone of the trees under drip irrigation at 60% Ecp with plastic mulch over basin irrigation treatment during winter months. The summer transpiration rate and stomatal conductance were not affected significantly under various irrigation treatments, due to high vapour pressure deficit (VPD) between leaf and air, caused by high atmospheric temperature during this period. Overall, the leaf water use efficiency during winter (1.829 μmol CO_2/mmol H_2O) and summer (1.880 μmol CO_2/mmol H_2O) under drip irrigation at 60% Ecp with plastic mulch was significantly higher compared to LWUE during winter (1.123 μmol CO_2/ mmol H_2O) and summer (0.961 μmol CO_2/mmol H_2O) under basin irrigation method. These results are in concurrence with the findings of Hu *et al.* (2007) in Satsuma mandarin. The correlation and regression analysis indicated a stronger relationship between available soil moisture depletion and transpiration rate than the available soil moisture depletion and photosynthesis rate both in drip and basin irrigation methods (Table 3).

Table 3 Relative effect of available soil moisture depletion on leaf photosynthesis rate and transpiration rate of Nagpur mandarin under various irrigation methods

Regression equation	R^2
Drip irrigation with plastic mulch	
$Y = 8.360–0.252 X + 0.003 X^2$	0.384
$Y_1 = 2.319 + 0.053 X–0.001 X^2$	0.938
Basin irrigation	
$Y = 5.053–0.093 X + 0.001 X^2$	0.241
$Y_1 = 8.050–0.235 X + 0.002 X^2$	0.975

Y, Net photosynthesis rate (μmol CO_2/m²/s); X, available soil moisture depletion (%); Y_1, leaf transpiration rate (mmol H_2O/m²/s)

Table 4 Annual incremental vegetative growth parameters of Nagpur mandarin under various irrigation treatments with plastic mulch (mean data during 2003–06)

Treatment	Tree height (m)	Stock girth (mm)	Scion girth (mm)	Canopy volume(m^3)
*Drip irrigation at 40% Ecp + plastic mulch	0.48	42	40	0.582
Drip irrigation at 60% Ecp + plastic mulch	0.62	52	49	0.988
Drip irrigation at 80% Ecp + plastic mulch	0.53	48	45	0.661
Drip irrigation at 100% Ecp + plastic mulch	0.45	40	38	0.503
Basin irrigation	0.43	36	36	0.451
#LSD (P=0.05)	0.06	ns	6.3	0.07

#LSD (P=0.05), Least significant difference at 5% probability level

Vegetative growth

The annual increase in tree height (0.45 – 0.62 m) responded significantly to different drip irrigation levels with the maximum value at 60% Ecp with plastic mulch over tree height (0.43 m) under basin irrigation method (Table 4). The treatments had no significant influence on stock girth, whereas, a significant increase in the scion girth (38 – 49 mm) and canopy volume (0.503 – 0.988 m^3) was observed in response to drip irrigation treatments with plastic mulch in comparison to basin irrigation (32 mm, scion girth; 0.451 m^3, canopy volume). The maximum scion girth diameter and tree canopy volume were recorded under drip irrigation at 60% Ecp with plastic mulch, followed by drip irrigation at 80 % Ecp with plastic mulch. The better tree growth even with 35.7 % less water supply under drip irrigation at 60 % Ecp with plastic mulch over basin irrigation is due to higher leaf photosynthesis rate and better availability and uptake of nutrients at consistently supply of optimum soil moisture (18–39.5% depletion of available soil moisture) under the former treatment compared to larger variation and sub-optimal soil moisture (32–59% depletion of available soil moisture) under the later treatment. The beneficial effect of drip irrigation with plastic mulch on annual vegetative growth over basin irrigated young trees was also reported with acid lime (Shirgure *et al.* 2005).

The higher leaf nutrients uptake, improved leaf physiological parameters and better tree growth with around 36% less irrigation water use under drip at optimum irrigation regime (60% Ecp) with black polythene mulch over basin irrigation method warrants the adoption of drip irrigation with black polyethylene mulch in young mandarin orchards of central India. It could enhance the longevity and productivity of the citrus orchards in sustainable basis and support the further expansion of area under the crop. The data presented in this paper also provides a useful basis for further investigation to improve the water management scenarios for reducing irrigation water use by citrus trees.

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