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Evaluation of drip irrigation emitters arrangement and its effect on soil moisture, leaf nutrients, yield and quality of Nagpur mandarin (*Citrus reticulata*)

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ABSTRACT

A field experiment on different arrangement of emitters in surface micro irrigation system in 14-16 years old Nagpur mandarin (*Citrus reticulata* Blanco) was conducted during 2010-2013 at the research farm of National Research Centre for Citrus, Nagpur. Four different treatments were used, viz. T_1 - 4 lph six emitters/plant in hexagonal arrangement, T_2 - 4 lph three emitters on double lateral arrangement at 1 spacing T_3 - 4 lph eight emitters on single lateral in octagonal arrangement and T_4 - 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from trunk. Each treatment combination had different emitter placement and different irrigation interval with same water quantity. The average quantity of water applied different emitters arrangement of drip irrigation systems varied from 78.2 to 108.2 l/day/plant with 4 lph eight emitters on single lateral in octagonal arrangement during 2010-2013. The higher and uniform soil moisture distribution and plant canopy volume was observed in 4 lph eight emitters on single lateral in octagonal arrangement (84.96 m^3) followed in 4 lph six emitters on single lateral in hexagonal arrangement (81.87 m^3). The results indicated that the moisture distribution and yield was higher (28.78 tonnes/ha) under treatment with 4 lph eight emitters on single lateral in octagonal arrangement followed by treatment with 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from trunk (27.26 tonnes/ha). The TSS to acidity ratio was the highest (13.9) with treatment 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from trunk followed by with 4 lph eight emitters on single lateral in octagonal arrangement (12.4) of drip irrigation system. For higher yield and quality mandarin fruits the 4 lph (8 per plant) on single lateral is suggested.

Key words: Automation, Controller, Drip irrigation, Emitters, Fruit yield, Fruit quality, Inline drippers, Nagpur mandarin, Soil moisture distribution

Citrus, the third largest fruit crop grown in India, covers an area of 1.172 million ha, with a production of 11.8 million tonnes. The average citrus productivity is worked out to be 10.07 tonnes/ha. It is highly imperative to supply adequate soil moisture in water-deficit summer months. It is equally important to provide the right amount of water across different growth stages in order to enhance the growth of fruits and yield of mandarin trees. The common methods of applying water to the orchards are basin, micro-jet irrigation and drip irrigation. Surface basin irrigation using the circular ring generally followed in early establishment phase of trees. Drip irrigation in citrus is commonly practiced in developed citrus growing countries. Drip irrigation have the distinct advantage over surface irrigation methods, due to more constant, uniform and complete wetting of effective rootzone of the plant. Such system of irrigation facilitates better water use efficiency with less expense on energy. Because of uneven water distribution and the difficulty of applying small amounts of water, the importance of surface irrigation in perennial crop like citrus is fast decreasing. Under tree drip irrigation with more number of emitters provides a more uniform distribution of soil moisture and the possibility of applying the exact depth of irrigation water. With the drip irrigation systems, water savings may be obtained because water is applied only to the active rootzone, leaving the remaining part of the inter-plant area. Of these, drip irrigation with four drippers (emitters/plant) irrigation system is widely adopted. This do not cover even 60-70 % soil water regime in the Nagpur mandarin tree basins, which require higher soil moisture constantly throughout its period of plant growth and fruit development (Shirgure *et al.* 2003). With the scarcity of available irrigation water, drip irrigation is becoming more popular with mandarin growers. However, many mandarin growers are still not sure about the efficacy of surface drip irrigation, especially where soil moisture deficit stress is adopted for regulating stress and flowering. Lack of even application on larger surface area and

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uniformity in moisture distribution within the tree's root zone as another possible drawback using four emitters per tree. Any method of surface drip irrigation arrangement capable of replenishing the evapo-transpiration demand of the plant, and simultaneously keeping the soil moisture within the desired limit during the different fruit developmental stages, would ensure a production sustainability of citrus orchards besides enhancing the orchard's productive life (Capra and Nicosia 1987). Drip irrigation systems with different arrangements are most commonly used in citrus orchards throughout the world. Now there is a gradual shift in surface method of irrigation from furrow irrigation to under-tree surface drip irrigation systems (Simpson 1978, Smajstrala 1993, Dasberg 1995). Surface drip irrigation systems for improving the water use efficiency in irrigation management have been reported to be highly effective in commercial citrus cultivars worldwide (Grieve 1988, Germana 1994 and Cevik *et al.* 1987). The various studies in citrus comparing irrigation methods and irrigation schedules showed higher yield and quality with better performance using drip irrigation systems under Indian situation (Kumar and Bhojappa 1994, Shirgure 2012b)

The objective of this investigation is to evaluate the different emitters arrangements in surface drip irrigation systems with drip irrigation scheduling and to study the effect of wetting pattern on plant growth, yield, nutritional status, optimum water use, uniform soil moisture distribution and availability and higher productivity and superiority in quality of Nagpur mandarin (*C. reticulata* Blanco) fruits grown under the sub humid tropical climate of central India.

MATERIALS AND METHODS

To study the different arrangement of emitters in drip irrigation systems and the effect on growth and productivity of 12-14 years old Nagpur mandarin budded on rough lemon rootstock (*C. jambhiri* Lush) a field experiment was conducted in the block of 50 × 50 m with 6 × 6 m spacing at experimental farm of NRCC during the year 2010-2013. The treatments consisted of 4 lph six emitters/plant in hexagonal arrangement (T_1), 4 lph three emitters on double lateral arrangement at 1 m spacing (T_2), 4 lph eight emitters on single lateral in octagonal arrangement (T_3) and 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from trunk (T_4) with six replications in Randomized Block Design. The soil had pH 7.6, $CaCO_3$ 2.5%, sand 33.6%, silt 24.3%, and clay 42.1% in the 0–15 cm depth. The climate was characterized to be sub-humid tropical with 860 mm of rainfall and temperature difference between mean summer and mean winter months of >50^0C. Volumetric soil moisture content at field capacity (FC) and the permanent wilting point (PWP) soil moisture content was determined using pressure plate method. The FC and PWP of the field under study is 30.45% and 22.16% respectively. The available water content of the soil is 8.29%. The bulk density of the soil in field was determined using core sampler having 100 cm^3 volume and oven drying. The bulk density of the field is 1.36 g/cc. The water holding capacity of the soil is 11.27 cm/m depth of soil. The different irrigation systems were installed in January 2010 and irrigation treatments were imposed in April 2010. The flow of water to the irrigation treatment was maintained by control solenoid valves and recorded with water meters. The average daily pan evaporation varied from 3.08 mm in November to as high as 11.67 mm in May. The drip irrigation system consisting of 16 mm dia. lateral having 4 lph drippers in hexagonal as well as octagonal arrangement and 4 lph inline double lateral arrangement are installed in the field along with the other accessories. The average discharge from 4 lph six emitters/plant in hexagonal arrangement, 4 lph three emitters on double lateral arrangement at 1 meter spacing, 4 lph eight emitters on single lateral in octagonal arrangement and 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from trunk was observed to be 24, 24, 32 and 24 lph per tree respectively. The irrigations are followed by setting the time for each treatment based on the water requirement of the plant. The irrigation was accordingly regulated daily by adjusting the operating hours using the Hybrid Station Controller (E-6, Rain Bird, USA) and Solenoid valve (Hunter, USA). The easy Extra Simple Programmable (ESP) hybrid station controller (4 stations) automatically operated the electronic solenoid valve for the specified programmed duration. Aluminium access tubes (50-mm dia.) were installed into the soil to a depth of 0.70 m within the tree basin and 0.90 m from the trunk considering the zone of maximum feeder root distribution. Soil moisture status and distribution under tree basin was monitored regularly using a Neutron moisture probe at 15-cm, 30-cm, 45-cm, and 60-cm depth of soil using the access tubes. The total month wise quantity of irrigation water automated under various treatments was recorded. The plant growth parameters were recorded during October month of 2010-13. The biometric growth parameters, i e plant height, and girth and canopy volume, were recorded in October month of 2010 to 2013. The stock girth was taken 25 cm above the soil surface. The vegetative growth parameters were recorded and expressed as canopy volume using Castle's formula (canopy volume = 0.54 HD^2 where H and D indicate height and diameter, respectively).

The fruit yield and quality data was recorded during the harvesting period. The total fruits harvested from each tree were weighed for computing the yield. A total of 50 fruits per treatment were randomly taken for quality analysis. The total soluble solids were determined using hand refractometer (0-32^o Brix). Titratable acidity was determined by titrating the juice against 0.1N NaOH. Percent juice content was determined by extracting the fresh juice and weighing. Five- to seven-month-old leaf samples from non-fruiting terminals at 1.5–1.8 m from the ground covering a minimum of 2% trees in an orchard were collected. Leaf samples were later thoroughly washed, ground using a

Willey grinding machine to obtain homogenous samples, and subsequently digested in tri-acid mixture of 2 parts $HClO_4$ + 5 parts HNO_3 + 1 part H_2SO_4 (Chapman and Pratt 1961). Analyses made in acid extracts of leaves consisted of N by auto-nitrogen analyser (Model Perkin Elmer-2410), P using vanadomolybdophosphoric acid method, and K by flame photometry. Total numbers of fruits harvested from each tree were weighed to express the yield by weight. Various fruit quality parameters, viz. total soluble solids (TSS) using hand refractometer, acidity, titrimetrically was determined as per procedure (Ranganna 1986). The data collected and generated for all the parameters were statistically subjected to analysis by Least Significant Difference (LSD) according to the standard methods (Raghava Rao 1983).

RESULTS AND DISCUSSION

Drip irrigation scheduling and soil moisture distribution

The drip irrigation was given to all the different systems of arrangements of the emitter by setting the time for each treatment based on the water need of the mandarin plant in every month. The daily weather data recorded from NRCC observatory was used for irrigation scheduling based on evaporation. The daily pan evaporation ranged from 3.4 - 12.7 mm per day in December and May respectively. The water budget was increased from 80 to 120 % of the total with increase in temperature during the October to June months of the years of study period. Water quantity of the plant on daily basis during March 2010 to February 2013 was monitored and measured by water meters installed in the experimental plots. The quantity of water through drip irrigation given to the mandarin plants using 4 lph six emitters/plant in hexagonal arrangement was 71.4 to 110.6 litres/day/plant, with 4 lph three emitters on double lateral arrangement at 1 m spacing was 80.7 to 119.1 litres/day/ plant. The same was 78.2 to 108.2 with 4 lph eight emitters on single lateral in octagonal arrangement and 93.8 to 141.7 litres/day/plant using 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from the trunk during 2010-2013. The quantity of water scheduled using controller based drip irrigation and on daily basis to the Nagpur mandarin plants was minimum (46.4 to 76.3 litres/day/plant) during October month and maximum (100.6 to 141.7 litres/day/plant) during May (Table 1). The total quantity of irrigation water scheduled on daily basis is within 10-15 % variation and according to the treatments and program given to the controller. There was no much variation on monthly quantity of water applied to the mandarin plants. The *in situ* soil moisture was monitored using moisture probe during the summer months from March to June. The observations were taken from 1 March to 22 June during the year 2010 and 2012. The soil moisture distribution pattern under the tree canopy was also studied. The volumetric soil moisture at 15, 30, 45 and 60 cm depth and at 30, 60,90,120,150, 180 and 210 cm from the main trunk was measured. The grids of soil moisture at 4 depths and 6 distances was plotted using the software SURFER.

Table 1 Average quantity of irrigation water applied through drip (litres/day/plant) during 2011-2013 (Pooled data)

Month	Crop stage	Treatment			
		S_1	S_2	S_3	S_4
January	Flowering	71.4	80.7	78.2	93.8
February	Fruit set	69.2	81.0	79.1	104.0
March	Berry size	80.4	92.5	82.6	126.8
April	Pea size	94.3	104.6	103.8	139.3
May	Marble stage	100.6	119.1	108.2	141.7
June	Fruit development	75.0	103.7	86.2	133.4
July	Fruit development	Effective rainfall			
August	Maturity	Effective rainfall			
September	Color break stage	Effective rainfall			
October	Harvesting	46.4	56.1	60.4	76.3
November	Flush	69.6	80.1	62.7	84.3
December	Stress period	Withholding of irrigation for moisture stress			

S_1 - 4 lph six emitters/plant in hexagonal arrangement, S_2 - 4 lph three emitters on double lateral arrangement at 1 m spacing, S_3- 4 lph eight emitters on single lateral in octagonal arrangement and S_4 - 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from the trunk

The treatment wise cross-section of the soil moisture distribution was shown in Fig 1. The soil moisture was categorised into three zones (< 20, 20-30 and >30 % wb). The maximum and optimum soil moisture zone was

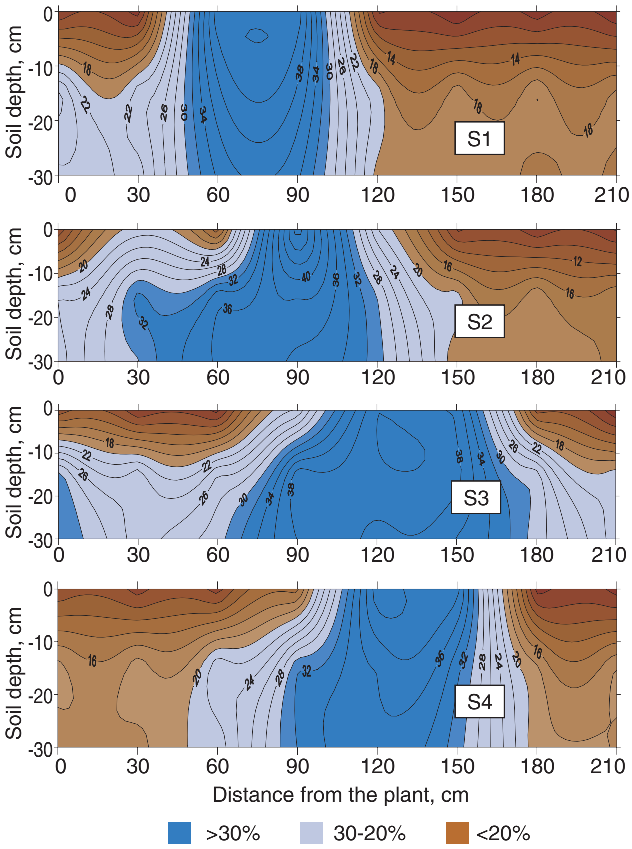

Fig 1 Soil moisture distribution pattern at 10-30 cm depth and 2.1 m radius from trunk

observed in 4 lph eight emitters on single lateral in octagonal arrangement. The soil moisture >30 % was observed from 60cm to 180 cm distance away from main trunk at 30 cm depth. It covered 120 cm distance. The soil moisture zone also observed to be optimum in 4 lph three emitters on double lateral arrangement at 1 meter spacing covering 90 cm distance. The soil moisture distribution pattern in 4 lph six emitters/plant in hexagonal arrangement and 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from the trunk was not suitable for the root zone of the mandarin plant as its coverage in <20 and 20-30 % area is more. This indicates that the arrangements of the emitters in these two systems is not proper for the plants water uptake. This type of effect of number of drippers under drip irrigation was also seen in Clementine citrus trees (Castel 1994), yield and evapotranspiration of young oranges (Kanber *et al.* 1996), irrigation scheduling in Nagpur mandarin (Shirgure *et al.* 2001a, Shirgure 2012a) and acid lime (Shirgure *et al.* 2000) fruit crops.

Plant growth, yield and fruit quality of Nagpur mandarin

The efficacy of the drip irrigation emitters arrangement was studied depending upon the evapo-transpiration of the plant in critical growth stages to maintain a better growth of the mandarin plant. The plant height (5.36 to 5.49 m) and stock girth (7.83 to 75.52 cm) growth was non-significant. The canopy volume of plants was significantly affected by the various arrangements of the emitters under drip irrigation systems during the year 2010-2013 (Table 2). The maximum plant canopy volume (84.96 m^3) was observed in 4 lph eight emitters on single lateral in octagonal arrangement drip irrigation system followed by 4 lph three emitters on double lateral arrangement at 1 m spacing (79.98 m^3). In 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from the trunk the canopy volume recorded is moderate (81.87 m^3). The 4 lph six emitters/plant in hexagonal arrangement drip irrigation emitters arrangement recorded the lowest canopy volume (69.89 m^3) due to variation in emitter placement affecting constant soil moisture availability. Similar observations were earlier reported with Hamlin orange (Marler and Davies 1990), Nagpur mandarin (Shirgure *et al.* 2001b) and acid lime (Shirgure *et al.* 2004).

The fruit yield and quality of Nagpur mandarin were highly influenced by the various arrangements of the emitters in drip irrigation systems (Table 2). However, the arrangement of 4 lph eight emitters on single lateral in octagonal arrangement was more profound than the other three type of emitter arrangements of drip irrigation treatments. The average number of fruits/plant was 580 to 724 in all the emitters arrangement drip irrigation system treatments. The highest number of fruits/plant (724 fruits/plant) was in the drip irrigation 4 lph eight emitters on single lateral in octagonal arrangement irrigation pattern followed by irrigation arrangement of 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from the trunk (676 fruits/plant) and irrigation 4 lph three emitters on double lateral arrangement at 1 m spacing (583 fruits/plant). The lowest number of fruits per plant was observed with irrigation 4 lph six emitters/plant in hexagonal arrangement (580 fruits/plant). This may be due to outside application point and inadequate soil moisture distribution within the surface rooting pattern during the critical growth and fruit development stages. The higher fruit yield under 4 lph eight emitters on single lateral in octagonal arrangement irrigation pattern was attributed to consistent and regulated supply of soil moisture having eight point application in the root zone. The highest mandarin fruit yield was recorded with 4 lph eight emitters on single lateral in octagonal arrangement (28.78 tonnes/ha) (Table 2). The moderate yield was observed with 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement (27.26 tonnes/ha) followed by 4 lph six emitters/plant in hexagonal arrangement (24.02 tonnes/ha). The lowest mandarin fruit yield (23.14 tonnes/ha) was recorded in 4 lph three emitters on double lateral arrangement at 1 m spacing system of emitters.

The study clearly indicated that the different arrangements of the emitters in drip irrigation systems maintained different and continuous soil moisture zones influenced by the water and nutrient uptake transforming into quality fruits besides enhancing yield. The highest average fruit weight and TSS (147.3 g and 10.43^0 Brix) with lower acidity (0.75) was observed with 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement. The juice percent (41.4 %) was more in the 4

Table 2 Plant growth, yield and fruit quality of Nagpur mandarin under different treatments during 2010-13 (Pooled data)

Treatment	Plant growth			Fruit yield			Fruit quality			
	Plant height (m)	Stock girth (cm)	Canopy volume (m^3)	No. of fruits	Average fruit weight (g)	Yield (tonnes/ha)	Juice (%)	TSS (^{0}Brix)	Acidity (%)	TSS/acidity ratio
S_1	5.36	70.83	69.89	580	139.5	24.02	41.95	9.84	0.85	11.7
S_2	5.42	74.14	79.98	583	143.4	23.14	40.91	9.87	0.85	11.6
S_3	5.48	75.52	84.96	724	142.7	28.78	38.90	10.16	0.82	12.4
S_4	5.49	73.75	81.87	676	147.3	27.26	38.10	10.43	0.75	13.9
LSD (P = 0.05)	NS	NS	1.68	32	NS	1.32	NS	NS	NS	

lph six emitters per plant in hexagonal arrangement. The ratio of total soluble solids (TSS) to acidity was analysed for all the treatments. The highest TSS/acidity was found 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement (13.9) followed by 4 lph eight emitters on single lateral in octagonal arrangement (12.4). The lowest TSS/acidity was observed with 4 lph three emitters on double lateral arrangement at 1 m spacing (11.6) and 4 lph six emitters per plant in hexagonal arrangement (11.7). The studies comparing different emitters arrangements in drip systems demonstrated comparatively higher fruit weight, rind thickness, and juice content in Sweet orange (Kumar and Bhojappa 1993). The improvement in fruit yield and quality due to drip irrigation systems was also reported in Satsuma mandarin (Peng Young Hong and Rabe 1999), Valencia orange (Koo and Smajstrala 1984, Madrid *et al.* 1989) and Nagpur mandarin (Shirgure *et al.* 2014).

Leaf nutrient status of Nagpur mandarin

The effect of different arrangement of emitters under the tree canopy on leaf status and nutrient uptake was monitored with periodical analysis of leaf. The initial and final leaf samples were collected from different drip irrigation systems treatments were analysed for N, P and K contents as well as Fe, Mn, Zn and Cu elements in 2010-2013. After the leaf nutrient analysis the 4 lph eight emitters on single lateral in octagonal arrangement recorded the highest concentration of macronutrients (N, P and K) compared to rest of the other drip emitters arrangements treatments (Table 3). The 4 lph eight emitters on single lateral in octagonal arrangement recorded the highest concentration of macronutrients (2.19 % N, 0.09 % P and 1.11 % K) compared to rest of the other treatments. Leaf P (0.08 %) and K (1.02 %) contents were observed significantly higher with 4 lph six emitters/plant in hexagonal arrangement than P (0.07 %) and K (0.53 %) content with 3 lph inline emitters at 0.75 m spacing on the lateral and double lateral arrangement 3 feet apart from the trunk. The lowest leaf nutrient composition N (1.99 %), P (0.07 %) and K (1.04 %) was observed with 4 lph three emitters on double lateral arrangement at 1 m spacing during 2010-2013.

Similarly the elemental leaf analysis of micro-nutrients (Fe, Mn, Cu and Zn) is done during March 2013. The micro-nutrients were non-significant due to the different arrangements of emitters in surface drip irrigation. The leaf analysis revealed that the 4 lph three emitters on double lateral arrangement at 1 m spacing recorded the highest concentration of micronutrients Fe (118.8 ppm) and Mn (53.95 ppm) compared to rest of the other emitters arrangements treatments. Leaf Cu (10.75 ppm) was observed to be higher in 4 lph eight emitters on single lateral in octagonal arrangement and leaf Zn (18.05 ppm) was observed as high in 4 lph six emitters/plant in hexagonal arrangement. The lowest leaf micronutrients nutrient composition leaf Fe (100.4 ppm) was recorded in 3 lph inline emitters at 0.75 meter spacing on the lateral and double lateral arrangement. Similarly the lower Mn 40.0 ppm) was recorded in 4 lph six emitters per plant in hexagonal arrangement and the lower Cu (8.75 ppm) and Zn (13.25 ppm) was seen in the 4 lph three emitters on double lateral arrangement at 1 meter spacing during 2010-13 (Table 3). Similar studies on leaf nutrient uptake due to drip irrigation schedules and systems on fruit productivity of Nagpur mandarin was studied by Shirgure and Srivastava (2012).

Table 3 Leaf nutrient concentration under different treatments during 2010-13 (Pooled data)

Treat-ment	Macronutrients (%)			Micronutrients (ppm)			
	N	P	K	Fe	Mn	Cu	Zn
S_1	2.01	0.08	1.02	111.85	40.00	9.00	18.05
S_2	1.99	0.07	1.04	118.80	53.95	8.75	13.25
S_3	2.19	0.09	1.11	115.65	53.80	10.75	16.50
S_4	2.10	0.07	0.53	100.40	52.70	9.15	16.00
CD (P=0.05)	0.16	NS	0.25	NS	NS	NS	NS

The sustainable Nagpur mandarin fruit production is possible with different arrangements of emitters in drip irrigation systems using controller accessed irrigation scheduling. The higher number of drippers/emitters and drip irrigation scheduling using controller maintained to the higher soil water uniformity to the mandarin plants. The Nagpur mandarin yield was highest with 4 lph eight emitters on single lateral in octagonal arrangement drip irrigation system. The 4 lph eight emitters on single lateral in octagonal arrangement irrigation system could be better drip irrigation arrangement for enhancing the water-use, yield, fruit quality, and water use efficiency. The fast depleting water resource in Central India and other citrus growing areas needs more precise arrangement and management emitters of drip irrigation systems in lieu of growing conditions where flowering is regulated by soil-water deficit stress. The eight emitters (4 lph) on single lateral in octagonal arrangement irrigation system can be used in field for commercial production of Nagpur mandarin. The yield and fruit quality of Nagpur mandarin could be substantially improved by adopting more numbers of emitters per plant and uniform distribution of the soil moisture in drip irrigation systems and used for better and uniform soil moisture pattern mainly required during fruit growth and development period.

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