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Effect of partial rootzone drying on growth and yield of mango plants

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ABSTRACT

The partial rootzone drying (PRD) is a promising method of irrigation in which wetting of one half of the root zone is done leaving the other half dry, thereby utilizing reduced amount of irrigation water. The wetted and dry sides are inter-changed in the subsequent irrigations. In the current study, PRD irrigation technique was evaluated for its effect on vegetative growth, fruit yield, quality and water use efficiency (WUE) in drip irrigated bearing mango plants in a sub-tropical Indian condition. The experiment was conducted at Research Farm of ICAR-Indian Institute of Water Management, Bhubaneswar in eastern India during the period 2011-2014. The irrigation treatments imposed in mango plants were full irrigation (at 100% ET_c), PRD at 80% ET_c, PRD at 60% ET_c, PRD at 40% ET_c and control (rainfed). The increase in vegetative growth parameters (plant height, 0.35-0.49 m; collar diameter, 15-21.4 mm and canopy volume, 9.81-9.82 m^3) were higher in full irrigation treatments, followed by 80% PRD; whereas, the highest fruit yield (9.6 t ha^{-1}) was observed in 80% PRD treatment followed by full irrigation (9.3 t ha^{-1}). However, the fruit yield in 60% PRD treatment (9.0 t ha^{-1}) was statistically at par with both full irrigation and 80% PRD treatments. The fruit quality was best under 60% PRD treatment (TSS, 21.7 ^{0}Brix; acidity, 0.42%). Highest WUE was observed in 60% PRD treatment which is 85% improvement over full irrigation treatment. Overall, the study suggests for adoption of PRD at 60% ET_c in drip-irrigated mango orchards of eastern India.

1. INTRODUCTION

With changing climatic scenario, there will be increase in frequency of extreme events such as lower rainfall, longer drought periods and higher temperatures in many regions of the world (IPCC, 2001). The increase in population and higher living standards will also increase the water requirement for domestic and industrial uses, which in turn will decrease the allocation of freshwater resources for irrigation in agriculture. The scarcity of water resources for agriculture should be checked to sustain the food supply through efficient use of water in irrigation (Panda *et al.,* 2004). Development of water resources and its multiple use helps in creation of additional water resources, increasing water productivity and in improving livelihood of farmers (Sahoo and Behera, 2017; Mohanty *et al*., 2020). The adoption of drip irrigation has gained momentum worldwide as it is a suitable method for increasing WUE in irrigation (Fereres *et al.*, 2003). Further increase in WUE using drip irrigation can be achieved using deficit irrigation (DI) approach. Some efforts on the use of regulated deficit irrigation (RDI) and PRD has been done on improving WUE of fruit crops (Kang *et al.,* 2002; Wahabi *et al.,* 2005; Leib *et al.,* 2006; Hera *et al.,* 2007; Panigrahi *et al.,* 2014; Conesa *et al*., 2018; Wu *et al.*, 2020).

PRD is an irrigation method in which water application is withheld from a part of the plant's rootzone while the remaining part is irrigated. The theory of this technique is that the roots in drying soil produce abscisic acid and send a hormonal signal, which is transported to the shoots indicating water deficit. In the leaves, the abscisic acid induces partial stomatal closure which decreases water consumption. However, as the other side of the plant is irrigated, the effect on plant water potential is minimal. The irrigation is alternatively applied to each side of the rootzone allowing the wet side to dry and dry side is wetted. The PRD is thus designed to let a part of the rootzone exposed to drying and send drying signals, while the other part of the rootzone is irrigated, so that the leaves are kept hydrated. The drying signal reduces the stomatal opening and thus transpiration, while the leaf photosynthesis is not much affected.

Earlier, few researches on PRD technique reported better irrigation efficiency and fruit quality in horticultural crops. Kang *et al.* (2002) reported that fixed partial root zone irrigation substantially saved water without much reduction in fruit yield (3%) in pear orchard. Wahbi *et al.* (2005) observed a 15-20% yield reduction and 60-70% increase in WUE in Olive trees. Leib *et al.* (2006) conducted experiments to study the effect of DI and PRD on yield and quality of 'Fuji' apples in the semi-arid climate of Washington State. Approximately 45-50% of irrigation water was saved in PRD approach without significant impact on fruit yield and size. Fruit quality in terms of soluble solids and titrable acidity were better in PRD treatments. Hera *et al.* (2007) investigated the effects of PRD on fruit yield, quality and WUE of field grown wine grapes. PRD resulted in 43% higher yield and 40% higher WUE in comparison to conventional drip irrigation. However, the wine quality were not significantly altered by the PRD treatment. Melgar *et al.* (2010) reported that the citrus fruit yield and WUE were not significantly different in PRD treatment. Kusakabe *et al.* (2016) compared drip PRD, micro-sprinklers and normal drip irrigation (control) in an orchard of mature grapefruit trees. In comparison to the control, drip PRD treatment saved 43 to 47% of irrigation water and micro-sprinklers saved 12 to 18% water. PRD irrigated trees maintained or increased yield in comparison to micro-sprinkler irrigated and control trees, and therefore had significantly higher WUE. Mossad *et al.* (2018) compared conventional irrigation (CI), PRD and DI in 'Valencia' orange trees. The PRD and DI treatments almost saved 50% of water in comparison to CI. Differences in fruit growth rates determined 17% yield reduction in DI but not in PRD trees.

In India, mango ranks first in area of cultivation (2.3×10^6 ha) and total production (12.75×10^6 t). However, the productivity of the crop (5.5 t ha^{-1}) is too low compared with the productivity in other advanced countries like China (25-30 t ha^{-1}). One of the reason of low productivity is that majority of the mango orchards in India are rainfed. Moreover, scarcity of irrigation water affects the mango production in the country. In bearing mango tree, water stress during critical period of water requirement leads to reduction in fruit yield and quality. Meanwhile, climate change and expanding land use in horticulture have increased the pressure on water resources. Therefore, there is an urgent need to develop water saving irrigation techniques for mango that can give optimum yield with high water productivity on sustainable basis. Even though a significant amount of research has been conducted on effect of PRD on different fruit crops, the information on PRD in mango is limited. With this background, a field experiment was undertaken to study the effects of PRD on productivity and WUE of mango under drip irrigation.

2. MATERIALS AND METHODS

Experimental Site and Irrigation Treatments

The field experiment was conducted for 3 years (2011-12, 2012-13 and 2013-14) at Research Farm of ICAR-Indian Institute of Water Management, Bhubaneswar, India. The average annual rainfall at the experimental site is 1555 mm, out of which more than 80% rainfall takes place during monsoon season (July-October). The texture of soil is sandy loam (45% sand, 24% silt and 31% clay) with bulk density of 1.44 g cm^{-3}. The field capacity and permanent wilting point of the experimental soil were 0.17-0.31 cm^3 cm^{-3} and 0.05-0.12 cm^3 cm^{-3}, respectively with mean pH of 5.91 (acidic). The hydraulic performance of the drip system was studied on monthly basis and found satisfactory with emitter flow rate variation (Q_v) of 9%, co-efficient of variation (CV) of 8% and distribution uniformity (DU) of 92%. The plants selected for the study was the 5 yrs old (*cv.* Amrapalli), planted at 5 m × 5 m spacing.

The experimental design consisted of five treatments with four replications per each treatment and four plants per unit in a randomized block design. The treatments imposed were (1) conventional drip irrigation at 100% ET_c (FI), (2) drip irrigated PRD at 80% ET_c, (3) drip irrigated PRD at 60% ET_c, (4) drip irrigated PRD at 40% ET_c and (5) control, *i.e.* rainfed. A drip irrigation system was installed in the orchard considering the experimental design and irrigation treatments. The PRD drip irrigation system comprised of two parallel laterals with valve system was designed in such a way that application of water can be done alternatively on both sides of the plant. The irrigation was shifted from wetted side to dry side when the soil water content (SWC) in the drying side reached at 50% of available soil moisture in the crop (around 15 days interval during the winter and around 7 days interval during summer).

Irrigation Application and Moisture Content

The crop ET_c was calculated based on the daily pan evaporation data and the crop coefficient of the mango plant. In the current study, a pan coefficient of 0.7 and a crop coefficient of 0.8 were considered for irrigation scheduling. After the end of monsoon season, in all the three years, irrigation was started in December and continued till June (onset of monsoon). The irrigation was withheld from mid-January to mid-February to impose water stress on the trees, which is a pre-requisite for better flowering. Irrigation was also stopped during the period of intermittent rains. The average depth of irrigation applied in different months is shown in Table 1. The soil moisture content was monitored on weekly basis at 30 cm interval within top 90 cm of soil by gravimetric method.

Table: 1
Average month-wise depth of irrigation water applied

Treatment	Month (mm)						
	December	January	February	March	April	May	June
100% ET_c	30	23	25	70	80	82	46
80% PRD	24	18	20	56	64	65	37
60% PRD	18	14	15	42	48	49	27
40% PRD	12	9	10	28	32	33	18
Control	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Monitoring of Vegetative Growth and Yield Parameters

Plant vegetative growth parameters (plant height, collar diameter and canopy volume) were measured at six monthly intervals, *i.e.* in the first week of January and July, respectively, every year. Yield parameters like number of fruits / plant, fruit weight and fruit yield were measured during the harvest in the month of May/June. Fruit quality parameters like pulp percentage, total soluble solid (TSS) and juice content in different treatments were measured. Sugar refractometer was used for measurement of fruit TSS. WUE was calculated as the ratio of fruit yield to water used under different treatments in the crop. As the data for different variables did not vary significantly within the years, mean data for the years is presented. Treatment wise comparison of plant vegetative growth parameters, fruit yield and quality was done based on statistical analysis.

3. RESULTS AND DISCUSSION

Soil Water Variation

Fig. 1(a-c) show the mean SWC in different treatments

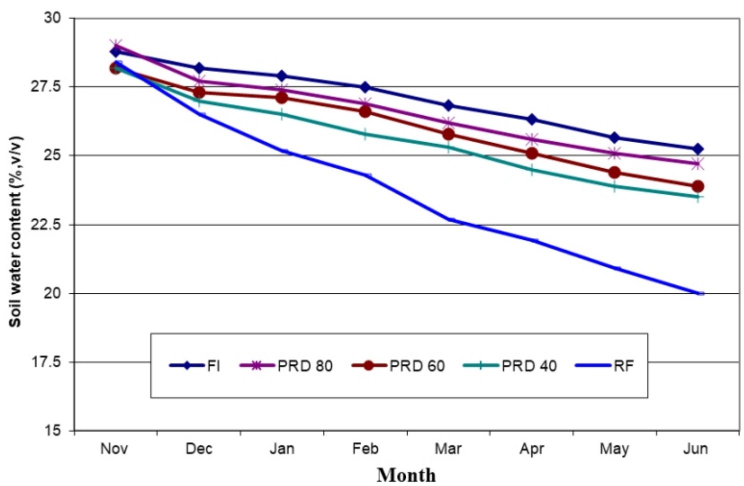

Fig. 1(a). Soil water variation at 0-30 cm depth

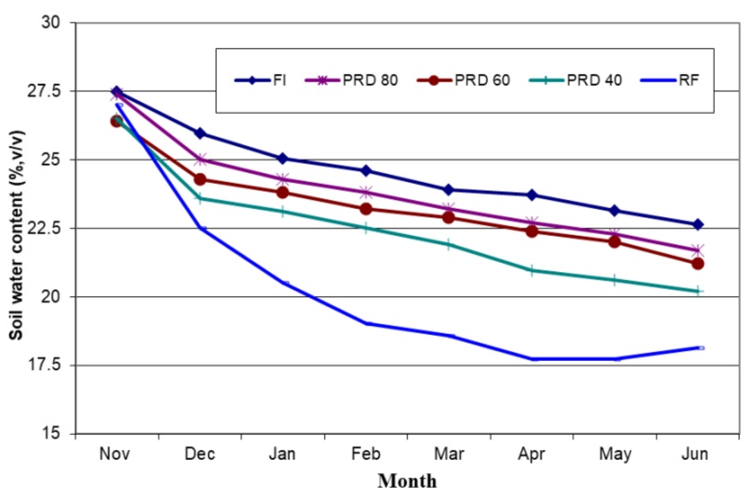

Fig. 1(b). Soil water variation at 30-60 cm depth

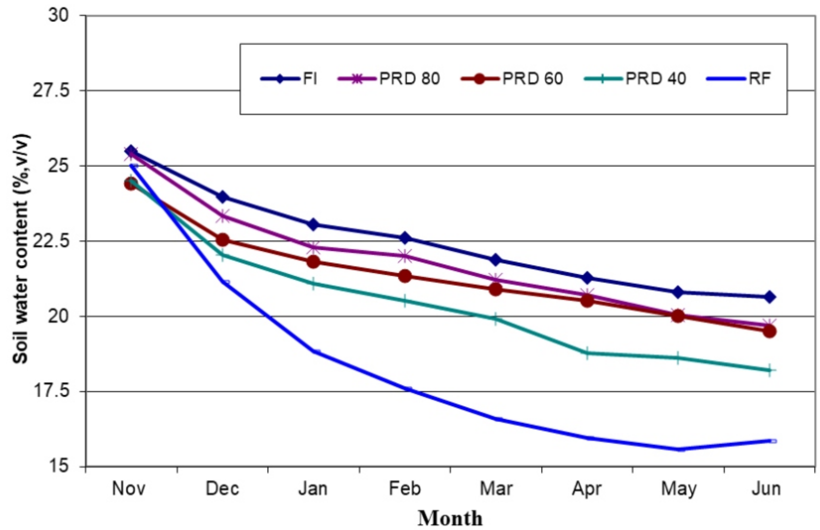

Fig. 1(c). Soil water variation at 60-90 cm depth

at different months for the 0-30 cm, 30-60 cm and 60-90 cm depth, respectively. Full irrigation (FI, 100% ET_c) resulted in significantly higher SWC compared to other treatments. The SWC in top 30 cm soil was significantly higher than that in 30-60 cm and 60-90 cm soil depths. The higher water content in 0-30 cm soil was due to wetting of top soil layers under drip irrigation in the crop. However, the soil water depletion at 60-90 cm soil depth was lower than that in 0-30 cm and 30-60 cm soil depths. The higher soil water depletion indicates the existence of effective root zone of the mango plants in top 60 cm soil under drip irrigation. The SWC consistently reduced from the month of November to June in all the treatments. The magnitude of SWC was significantly reduced under rainfed treatments over other treatments. The SWC increased during November, due to residual soil moisture of the rainfall that took place during July to October. The mean soil water fluctuation between two consecutive measurements during irrigation season under full irrigation treatment was observed to be higher than that under other treatments, reflecting the highest evapotranspiration rate of the plants under full irrigation. This result corroborates with the findings of earlier research done by Leib *et al.* (2006) and Panigrahi *et al.* (2014).

Vegetative Growth

The three years average increase in vegetative growth parameters (plant height, collar diameter and canopy volume) in the periods of January to June and July to December is presented in Table 2. The increases in all the parameters were highest with fully-irrigated trees. The growth parameters showed a decreasing trend with decreasing irrigation regimes under different PRD treatments. It can be attributed to reduction in soil moisture content under decreasing irrigation regimes. The sub-optimum soil moisture might have caused reduced photosynthesis rate resulting lower vegetative growth of the plants under lower irrigation regimes (Panigrahi *et al.,* 2009). The magnitudes of the increment of the parameters were higher during July-December than that during January-June, due to adequate soil moisture caused by rainfall in the former period. However, the growth parameters were not affected significantly during July-December. This can be attributed to uniform rainfall amount received by all the treatments.

Fruit Yield and WUE

The yield parameters (fruit number, fruit weight and fruit yield) and water productivity in different treatments

Table: 2
Three years average incremental vegetative growth parameters of mango trees under different treatments

Treatment	January-June			July-December		
	Plant height (m)	Collar diameter (mm)	Canopy volume (m^3)	Plant height (m)	Collar diameter (mm)	Canopy volume (m^3)
100% ET_c	0.35	15.0	9.82	0.49	21.4	9.81
80% PRD	0.26	10.6	7.39	0.42	16.7	8.57
60% PRD	0.25	9.6	6.77	0.37	14.9	7.7
40% PRD	0.20	8.1	4.51	0.35	11.6	6.58
Control	0.18	7.7	2.90	0.38	10.6	6.21
$CD_{0.05}$	0.01	NS	0.62	NS	NS	NS

Table: 3
Average fruit yield parameters and water productivity in different treatments

Treatment	Yield parameters			Water applied (m^3 $tree^{-1}$)	Water productivity ($kg\ m^{-3}$)
	Fruit number	Fruit weight (g)	Fruit yield ($t\ ha^{-1}$)		
100% ET_c	112	208.63	9.3	6.65	3.50
80% PRD	98	246.10	9.6	4.77	5.03
60% PRD	82	274.44	9.0	3.48	6.47
40% PRD	67	194.43	5.2	2.05	6.34
Control	62	169.35	4.2	--	--
$CD_{0.05}$	2.5	9.89	0.65	--	--

indicated that higher number of fruits per tree were harvested under full irrigation treatments followed by PRD treatment at 80% ET_c (Table 3). However, the fruit weight was lower in full irrigation treatment compared to that in 80% PRD and 60% PRD treatments. The higher number of fruits probably caused lower fruit weight under full irrigation. In PRD treatments, even though fruit numbers were lower, overall yield was better due to more fruit weight. The plant spacing being 5 m × 5 m, the fruit yield was calculated considering 400 plants ha^{-1}. Yield was highest in 80% PRD followed by full irrigation treatment. The higher yield might be due to lower vegetative growth of the plants under 80% PRD than full irrigation. However, yield in the 60% PRD was statistically at par with full irrigation and 80% PRD treatment. There was 40% water saving and 85% improvement in WUE in 60% PRD treatment in comparison to full irrigation treatment.

Fruit Quality

The fruit quality parameters (pulp content, TSS and acidity) in different treatments show that fruit quality was better in PRD treatments in comparison to full irrigation treatment (Table 4). The TSS values were highest and acidity values were lowest in 60% PRD treatment. The better transformation of acid to sugar resulted in higher TSS and lower acidity in the fruits under 60% PRD treatment compared with other treatments (Wu *et al.,* 2020). However, in 40% PRD treatment, fruit quality is significantly inferior due to excess water stress.

4. CONCLUSIONS

The field experiments on drip irrigated bearing mango showed that partial rotzone drying technique controls vegetative vigour by reducing the amount of water used. But this did not decrease the fruit yield, and thereby resulted in higher WUE. In PRD treatments, even though fruit numbers were lower, overall yield was better due to more fruit weight. Highest fruit yield was observed under 80% PRD treatment followed by full irrigation treatment. However, the yield under 60% PRD treatment was statistically at par with 80% PRD and full irrigation treatment. The water productivity was highest and fruit quality was best under 60% PRD treatment. There was 40% water saving and 85% improvement in water productivity under 60% PRD treatment in comparison to full irrigation treatment.

Table: 4
Average fruit quality parameters in different treatments

Treatment	Quality parameters		
	Pulp (%)	TSS (^{0}Brix)	Acidity (%)
100% ET_c	67.13	16.2	0.51
80% PRD	70.06	20.1	0.46
60% PRD	70.43	21.7	0.42
40% PRD	67.76	16.3	0.58
Control	62.51	12.4	0.62
$CD_{0.05}$	8.23	1.77	0.01

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