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Original Research Paper

Partial root zone drying irrigation in papaya (*Carica papaya* L.) for enhanced water use efficiency under limited water situations

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ABSTRACT

Field experiments were conducted during 2015-17 at ICAR-Indian Institute of Horticultural Research, Hessaraghatta, Bengaluru, to standardize the partial root zone drying irrigation in papaya with 12 treatments in RBD design. The results indicated that better soil moisture in the root zone could be maintained under drip irrigation by shifting laterals on either side at fortnightly intervals as compared to fixed laterals with thesame amount of water. Significantly more primary roots (16.5/plant) were observed when irrigation was scheduled on one side with single emitter meeting 60% of the evaporative demand. PRD irrigation through shifting of laterals recorded significantly higher transpiration rate especially at 50% of ER (8.05 m mol m^{-2} s^{-1}) as compared to the control (3.95m mol m^{-2} s^{-1}). Further, the same treatment recorded significantly lower fruit cavity index (0.26) with relatively higher fruit volume (1388 cm^3). Irrigating papaya only on one side with single emitter resulted in significantly higher T.S.S (13.0%). Higher water productivity (23.7 kg/m^3) could be obtained by scheduling the irrigation at 40% evaporation replenishment through shifting of laterals with saving of substantial water (1285m^3/ha) resulting in higher water use efficiency (237.4 kg/ha.mm).

Key words: Evaporation replenishment, partial root zone drying irrigation, shifting of laterals, water use efficiency

INTRODUCTION

Papaya (*Carica papaya* L.,) is a common fruit crop grown in the Southern region of India. The crop is normally grown under irrigated conditions. Availability of timely and assured irrigation is critical for obtaining optimum growth, yield and quality fruits of papaya. Since the soil moisture content affects the nutrient uptake and other metabolic processes, water deficiency at any of the growth and developmental stages of papaya will adversely affect the overall production and quality. However, in the recent past owing to scarcity of irrigation water, exploring alternate approaches for judicious use of available water and to bring more area under cultivation assumes significance.

In partial rootzone drying (PRD) irrigation method, only part of the rootzone is wetted while the remainder is allowed to dry. Irrigating part of the root system keeps the leaves hydrated while drying on the other part of the root system promote synthesis and transport of so-called chemical signals from roots to the shoot *via* the xylem to induce a physiological response (Dodd *et al*., 2015). Alternating the wet and dry zones (thus re-wetting dry soil) substantially improves crop yields compared to maintaining fixed wet and dry zones or conventional deficit irrigation and modifies phyto-hormonal (especially abscisic acid) signaling. Further, PRD irrigation method limits vegetative vigour and improves water use efficiency (Kriedmann and Goodwin, 2003).

However, wetting and drying each side of roots are dependent on crops, growing stage, evaporative demands, soil texture and soil water balance (Saeed *et al*., 2008). Further, the level of meeting the crop evapo transpiration demand based on the PRD irrigation in a given agro-climatic situation needs to be standardized for the crop.

Keeping this as a backdrop, research trial was initiated at ICAR-Indian Institute of Horticultural Research, to standardize the partial root zone drying irrigation in papaya (*Carica papaya L.*) with the objective of standardising the PRD based irrigation scheduling for papaya.

MATERIAL AND METHODS

Field experiments were conducted from 2015 to 2017 at ICAR- Indian Institute of Horticultural Research, Hessaraghatta, Bengaluru located at latitude13°8'12"N and longitude of 77°29'45"E. The experimental soils was sandy loam in texture with a pH of 6.14 and an EC of 0.067dSm^{-1} . The maximum temperature during the experimental period ranged from 24^{0}C to 36^{0}C and the minimum temperature ranged between 10^{0}C to 22°C. The period between March to May are the warm months with higher temperatures and evaporation while the period between November to January were the cooler months with low temperature and evaporation. The average relative humidity was higher during September and October months. The average rainfall of the region is around 850 mm with two peak periods of rainfall during June-July and September- October months.

Field experiment was conducted in RBD design withfour replications. Papaya (Cv. Red Lady) grown with a spacing of 1.8 m x 1.8 m was planted during June 2015 and the treatments were imposed with the crop establishment after 60 days after planting. There were 12 treatments with one or two emitters per plant with different levels of evapotranspiration replenishment (ER) either fixed or alternating the sides of the irrigation at 15 days interval. Normal irrigation with two emitters per plant with 80% ER served as fully irrigated control.

The crop was managed with recommended package of practices except for irrigation. The irrigations were scheduled as per the treatments and alternate partial irrigation was provided by shifting the laterals at fortnightly intervals. The bio-fertilizer consortium (BFC) applied at planting included *Azotobacter* + PSB + VAM. The observations on all the growth, yield and quality parameters as well as soil moisture and physiological parameters were recorded at periodic intervals. The abscisic acid (ABA) production was analysed following the HPLC procedure as detailed by Kelen *et al*., (2004) with modifications. The relative water content in the leaf samples was anlaysed using standard procedures as per Barr and Weatherly (1962). All the experimental data were statistically analysedas per Panse and Sukhatme (1985) and the differences in means were compared at 5 % level of significance.

RESULTS AND DISCUSSION

Soil moisture at rooting depth and relative water content in papaya

Shifting of the laterals through PRD technique enabled maintenance of significantly higher soil moisture content in general as compared to maintaining fixed laterals **(Table 1)**. Higher soil moisture content (12.4 %) in the dry zone was recorded even with 40% of evaporation replenishment (ER) with the shifting of the laterals as compared to fixed laterals. However, it was at par with other levels of ER under shifting irrigation.

The relative water content of the leaf was in general higher with the shifting of the laterals with higher levels of ERas compared to normal irrigation in fixed sites.The higher relative leaf water content under PRD treatments may be due to nocturnal net flux of water from wetter roots to the roots in dry soil which may assist in the distribution of chemical signals necessary to sustain the PRD effect (Stoll, 2000).

Plant and root growth

Vegetative growth in general was curtailed with the plant undergrowing stress in different PRD treatments **(Table 2)**. The plant height progressively declined with the reduction in levels of ER and significantly lowest height (1.68 m) was recorded with 40% ER even with shifting of laterals with double emitters per plant. Similarly, 50% and 60% of ER with one or two emitters per plant either with or without shifting the laterals also recorded significantly lower plant growth as compared to normal irrigation with 80% of ER (2.18 m). Stoll (2000) attributed this to the reduction in zeatin and zeatinriboside concentrations in roots, shoot tips and buds contributing to the reduction in shoot growth and intensified apical dominance under PRD irrigation. Further, Limas *et al.,*(2015) also observed that the application of 50% water use in PRD in the greenhouse study decreased shoot and root dry weight production, with a more pronounced effect on

Table 1. Soil moisture (in 0-60 cm depth after 24 hours of irrigation) and relative water content (RWC) of leaf as influenced by partial rootzonedrying irrigation treatments inpapaya at sixmonths after planting

Treatments	Soil moisture (%)		RWC (%)
	Moist zone	Dry zone	
Normal irrigation-80% ER: 2 emitters/plant	12.24	10.48	88.9
Normal irrigation-80% ER: 1 emitter/plant	12.93	7.09	91.3
Shifting irrigation-80% ER: 1 emitter/plant	12.60	11.88	94.9
Shifting irrigation-60% ER: 1 emitter/plant	11.89	8.76	95.1
Shifting irrigation-50% ER: 1 emitter/plant	11.88	10.89	91.9
Shifting irrigation-40% ER: 1 emitter/plant	13.01	8.27	87.0
1-Side irrigation-60% ER: 1 emitter/plant	13.53	8.06	89.5
1-Side irrigation-50% ER: 1 emitter/plant	12.77	6.94	87.2
1-Side irrigation-40% ER: 1 emitter/plant	10.23	9.00	94.4
Shifting irrigation-60% ER: 2 emitters/plant	11.34	11.39	92.7
Shifting irrigation-50% ER: 2 emitters/plant	9.85	10.10	92.3
Shifting irrigation-40% ER: 2 emitters/plant	14.42	12.40	88.1
S.Em±	**0.73**	**0.58**	**14.3**
C.D *(P=0.05)*	**2.17**	**1.71**	**NS**

root dry weight compared to full irrigation. This decrease in biomass was associated with a decrease in the net photosynthetic rate in the day of most intense water stress for the plants.

The plant canopy spread was significantly higher (5.23 m^3) with shifting irrigation meeting 60% ER even with one emitter/plant which was similar (5.22 m^3) to that of normal irrigation meeting 80% ER through two emitters/plant depicting the efficacy of shifting of drip laterals.

In general, more roots were produced in papaya when the water was supplied through a single emitter as compared to double emitters/plant. Significantly higher number of primary roots (16.5 / plant) were observed when the irrigation was scheduled on one side with single emitter meeting 60% of evaporative demand **(Table 2)**. The mean root length was significantly lower (76.4 cm and 75.1cm, respectively) when adequate irrigation was given through two emitters meeting 80% of the evaporative demand (T_1 and T_2 treatments). The dry weight of roots was significantly higher (867.5g /plant) when the irrigation was given on one side of the plant meeting 50% of evaporative demand (T_7 treatment). The root volume followed a similar trend with the same treatment recording higher values. Liang *et al*, (1996) attributed this enhanced root biomass increase is due to the plant's ability to explore a greater soil volume potentially increasing soil water and nutrient acquisition. Alternate watering or re-watering, after a long period of soil drying, may improve this situation by inducing new secondary roots. Apparently, such new roots are succulent enough to sense further soil drying and the ability of roots to absorb nutrients also improves which may also enhance the nutrient uptake from the soil zone when the root zone was partially watered (Han and Kang, 2002). Similar results were also found by Skinner *et al.* (1998) wherein as the non-irrigated furrow began to dry, the root biomass increased as much as 126% compared with the irrigated furrow and the greatest increase was at lower depths where moisture was still plentiful.

Physiological parameters

The photosynthetic ratein papaya imposed with PRD irrigation although did not differ significantly, shifting of the laterals with two drippers even at 60%

Table 2. Shoot and root growth characteristics of papaya as influenced by partial rootzone drying irrigation treatments

Treatments	Plant height (m)	Canopy spread (m^2)	No. of primary roots/plant	Mean root length (cm)	Dry root weight (g/plant)	Root volume (cm^3)
Normal irrigation-80% ER: 2 emitters/plant	1.75	3.91	13.0	76.4	467.7	383.5
Normal irrigation-80% ER: 1 emitter/plant	2.18	5.22	15.3	75.1	450.0	1095.0
Shifting irrigation-80% ER: 1 emitter/plant	2.00	4.86	8.0	82.5	275.0	750.0
Shifting irrigation-60% ER: 1 emitter/plant	1.95	5.23	14.3	103.0	766.7	2780.0
Shifting irrigation-50% ER: 1 emitter/plant	1.95	4.02	12.8	87.5	533.3	131.7
Shifting irrigation-40% ER: 1 emitter/plant	2.15	4.63	11.3	95.2	550.0	1817.5
1-Side irrigation-60% ER: 1 emitter/plant	2.15	4.33	16.5	101.4	637.5	1518.8
1-Side irrigation-50% ER: 1 emitter/plant	1.93	3.92	9.8	104.9	867.5	3417.5
1-Side irrigation-40% ER: 1 emitter/plant	2.05	4.35	10.0	99.6	625.0	1550.0
Shifting irrigation-60% ER: 2 emitters/plant	1.90	3.27	12.0	104.8	832.5	2132.5
Shifting irrigation-50% ER: 2 emitters/plant	1.80	3.28	10	105.3	866.8	2232.5
Shifting irrigation-40% ER: 2 emitters/plant	1.68	3.34	10	99.6	616.8	1550.0
S.Em±	**0.08**	**0.40**	**1.55**	**4.71**	**108.1**	**519.8**
C.D *(P=0.05)*	**0.24**	**1.16**	**4.50**	**13.67**	**312.3**	**1508.6**

of evaporation replenishment recorded relatively better photosynthesis (14.03 μ mol m^{-2} s^{-1}). Further, PRD irrigation through shifting of laterals recorded significantly higher transpiration rate especially at 50% of ER (8.05 m mol m^{-2} s^{-1}) as compared to the control (3.95m mol m^{-2} s^{-1}) although it was at par with T_5, T_8, T_9 and T_{12} treatments.

The stomatal conductance could not differ significantly among the treatments in the present investigation **(Table 3)** although Stoll (2000) observed in grapes that stomatal conductance of vines under PRD irrigation was significantly reduced when compared with vines receiving water to the entire root system. PRD results in increased xylem sap ABA concentration and increased xylem sap, pH, both of which are likely to result in a reduction in stomatal conductance. It was concluded that a major effect of PRD is the production of chemical signals in drying roots that are transported to the leaves where they bring about a reduction in stomatal conductance.

The perusal of the data on ABA production in different PRD treatments indicated higher ABA production with one emitter per plant either with fixed or shifting of laterals (278 and 266.8ng/g tissue, respectively) as compared to two emitters at the same level of ER (210.6ng/g tissue) indicating that the plant underwent moisture stress with water supply through a single point source leading to higher ABA production. Stoll *et al.,* (2000) inferred that PRD reduces plant water consumption by enhancing ABA production in the dry half of the roots, a hormonal signal that reduces stomatal aperture and thus, transpiration of the leaves (Davies *et al.,* 2001). Further, this small narrowing of the stomatal opening may reduce water loss substantially with little effect on photosynthesis (Jones, 1992). A similar study by Stoll *et al.,* (2000) showed ten fold increase in ABA concentration in the drying roots, but ABA concentration in leaves of grapevines under PRD increased only by 60% compared with a fully irrigated control. Further, it was inferred that there was a nocturnal net flux of water from wetter roots to the roots in dry soil and this may assist in the distribution of chemical signals necessary to sustain the PRD effect.

Quality, fruit yield and water use efficiency

Assessment of impact of the PRD treatments on the quality attributes of papaya indicated that fruit cavity index and T.S.S of papaya fruits were significantly influenced **(Table 4)**. Shifting irrigation even at 50% of ER recorded significantly lower cavity index (0.26) with relatively higher fruit volume (1388 cm^3). Further, fixed irrigation using single emitter at 40% of ER resulted in significantly higher T.S.S (13.0%). The increased T.S.S under fixed emitters at lower level of ER indicates that the plant under stressed situations accumulated more sugars in the fruits. Stoll *et al*., (2000), also observed increased sugar content in grapes with PRD and this was attributed to better control of vegetative growth. Further in wine grape, the quality parameters of fructose and tannins were improved significantly with PRD (Fang *et al.*, 2013).

Although irrigation in papaya meeting 80% replenishment of evaporation even with one emitter per plant resulted in significantly higher number of fruits (54/plant), higher water productivity (23.7 kg/m^3) could be obtained by scheduling the irrigation at 40% ER through shifting of laterals at fortnightly intervals. This also led to a saving of substantial water (1285m^3/ha) resulting in 144.2 % higher water productivity. It is worth to mention that the papaya plants withstood the water stress and functioned normally even when irrigation was scheduled at 40% of ER. Water use efficiency followed a similar trend with scheduling the irrigation at 40% evaporation replenishment through shifting of laterals at fortnightly interval leading to 159.5 % higher water use efficiency (237.4 kg/ha.mm). Dry *et al.,* (2000) stated that this increased WUE with PRD

Table 3. Physiological parameters in papaya as influenced by PRD irrigation treatments

Treatments	Photosynthetic rate (µ mol m^{-2} s^{-1})	Transpiration rate (m mol m^{-2} s^{-1})	Stomatal conductance (mol m^{-2} s^{-1})	ABA (ng/g tissue)
Normal irrigation-80% ER: 2 emitters/plant	10.71	2.81	0.21	210.6
Normal irrigation-80% ER: 1 emitter/plant	9.51	3.95	0.18	278.0
Shifting irrigation-80% ER: 1 emitter/plant	11.62	5.52	0.25	266.8
Shifting irrigation-60% ER: 1 emitter/plant	11.05	5.08	0.20	150.6
Shifting irrigation-50% ER: 1 emitter/plant	13.35	6.54	0.27	149.1
Shifting irrigation-40% ER: 1 emitter/plant	9.18	4.00	0.13	151.2
1-Side irrigation-60% ER: 1 emitter/plant	10.34	5.59	0.19	123.4
1-Side irrigation-50% ER: 1 emitter/plant	11.44	6.65	0.22	134.8
1-Side irrigation-40% ER: 1 emitter/plant	10.18	7.14	0.28	164.7
Shifting irrigation-60% ER: 2 emitters/plant	14.03	5.87	0.20	106.0
Shifting irrigation-50% ER: 2 emitters/plant	9.89	8.05	0.29	99.3
Shifting irrigation-40% ER: 2 emitters/plant	9.38	6.92	0.20	136.8
S.Em±	**1.09**	**0.59**	**0.04**	**12.16**
C.D *(P=0.05)*	**NS**	**1.73**	**NS**	**35.88**

is because the well-watered half of the root ensures the maintenance of fruit growth, while vegetative growth is reduced. The ability of roots to absorb nutrients was also improved when the root zone was partially watered and the partial watering was shifted alternately in a horizontal direction or along the vertical soil profile (Han and Kang, 2002).

Table 4. Quality attributes, yield and water use efficiency of papaya as influenced by different PRD irrigation treatments

Treatments	Fruit cavity index	T.S.S. (%)	Fruits / plant	Fruit volume (cm^3)	Fruit yield/ plant (kg)	Fruit yield (t/ha)	Water use efficiency (kg/ha.mm)	Water productivity ($kg\ m^{-3}$)
Normal irrigation-80% ER: 2 emitters/plant	0.47	10.8	46	1185	37.88	117.43	91.5	9.15
Normal irrigation-80% ER: 1 emitter/plant	0.69	9.9	54	645	40.21	124.66	97.2	9.72
Shifting irrigation-80% ER: 1 emitter/plant	0.60	8.2	39	603	29.44	91.27	71.1	7.11
Shifting irrigation-60% ER: 1 emitter/plant	0.31	8.9	43	1450	33.43	103.64	134.6	13.46
Shifting irrigation-50% ER: 1 emitter/plant	0.31	10.5	51	1053	37.49	116.21	181.2	18.12
Shifting irrigation-40% ER: 1 emitter/plant	0.51	9.6	49	995	39.30	121.83	237.4	23.74
1-Side irrigation-60% ER: 1 emitter/plant	0.27	8.3	46	940	40.56	125.73	163.3	16.33
1-Side irrigation-50% ER: 1 emitter/plant	0.64	10.4	50	410	41.50	128.66	200.6	20.06
1-Side irrigation-40% ER: 1 emitter/plant	0.67	13.0	50	715	37.65	116.70	227.4	22.74
Shifting irrigation-60% ER: 2 emitters/plant	0.54	8.1	35	623	27.21	84.35	109.6	10.96
Shifting irrigation-50% ER: 2 emitters/plant	0.26	8.9	25	1388	19.74	61.19	95.4	9.54
Shifting irrigation-40% ER: 2 emitters/plant	0.44	6.9	33	677	25.63	79.46	154.8	15.48
S.Em±	**0.10**	**1.02**	**5.60**	**308.8**	**4.68**	**14.50**	**20.36**	**2.03**
C.D *(P=0.05)*	**0.29**	**2.94**	**16.20**	**NS**	**13.54**	**42.00**	**58.85**	**5.88**

Similar results of higher WUE were recorded by De la Hera *et al*., (2007) in grapes under PRD treatments. Further, Du *et al*., (2008) concluded that improved WUE, earlier fruit maturity and better quality of table grape without detrimental effects on the fruit yield in arid areas are the advantages of PRD irrigation.

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REFERENCES

Barr, H.D. and Weatherley, P.E. 1962. A re-examination of the relative turgidity technique for estimating water deficit in leaves, *Australian Journalof Biological Sciences,* **15**:413-428.

Davies, W.J., Wilkinson, S. and Loveys, B.R. 2001. Stomatal control by chemical signaling and the exploitation of this mechanism to increase water use efficiency in agriculture. *New Phytologist,* **153**: 449-460.

De la Hera, M.L., Romero, P., Gomez-Plaza, E., Martinez, A. 2007. Is partial root-zone drying an effective irrigation technique to improve water use efficiency and fruit quality in field-grown wine grapes under semiarid conditions? *Agricultural Water Management*, **87**: 261-274.

Dodd Ian C., Jaime Puértolas, Katrin Huber, Juan Gabriel Pérez-Pérez,Hannah R. Wright and Martin S. A. Black. 2015. The importance of soil drying and re-wetting in crop phyto-hormonal and nutritional responses to deficit irrigation, *Journal of Experimental Botany,* **66** (8) : 2239–2252.

Dry, P. R., Loveys, B. R., Stoll, M., Stewart, D. and McCarthy, M. G. 2000. Partial root-zone drying- an update.*Australia Grape grower and Winemaker*, **438**: 35–39.

Du, T., Kang, S., Zhang, J., Li, F. 2008. Water use and yield responses of cotton to alternate partial root-zone drip irrigation in the arid area of north-west China. *Irrigation Science*, **26**: 147-159.

Fang, Y.L, Sun, W., Wan, L., Xi, Z.M., Liu X. and Zhang, Z.W. 2013. Effects of regulated deficit irrigation (RDI) on wine grape growth and fruit quality. *Scientia AgriculturaSinica*, **46**: 2730–2738.

Han, Y.L. and Kang, S.Z. 2002. Effects of the controlled partial rootzone irrigation on root nutrition uptake of maize (*Zea mays*), *Transactions of Chinese Society of Agricultural Engineers*,**18**(1): 57–59.

Jones, H.G. 1992. Plants and microclimate: a quantitative approach to environmental plant physiology, 2nd edition. Cambridge: Cambridge University Press.

Kelen, M., Demiralay, E.C., Sen, S. and Ozkan,G., 2004. Separation of abscisic acid, indole acetic acid and gibberellic acid in 99R and rose oil by reverse phase liquid chromatography, *Turkish Journal of Chemistry*, **28**: 603-610.

Kriedmann, P.E. and I. Goodwin, 2003. Regulated deficit irrigation and partial rootzone drying. *Irrigation insights* No.4, Land and Water Australia, Canberra, 102p.

LimasRoberta Samara Nunes de, Fábio Afonso Mazzei Moura de Assis Figueiredo, Amanda Oliveira Martins, Bruna Corrêa da Silva de Deus, Tiago Massi Ferraz, Mara de Menezes de Assis Gomes, Elias Fernandes de Sousa, David Michael Glenn, Eliemar Campostrini. 2015.Partial rootzone drying (PRD) and regulated deficit irrigation (RDI)effects on stomatal conductance, growth, photosynthetic capacity and water-use efficiency of papaya, *Scientia Horticulturae,* **183** : 13–22.

Panse, V.G. and Sukhatme, P.V. 1985. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research Publication, 87-89.

Saeed, H., Grove, I.G., Kettlewell, P.S. and Hall. N.W. 2008. Potential of partial root zone drying as an alternative irrigation technique for potatoes (*Solanum tuberosum*). *Annals of Applied Botany*, **152:** 71-80.

Skinner, R.H, Hanson, J.D. and Benjamin, J.G. 1998. Root distribution following spatial separation of water and nitrogen supply in furrow irrigated corn. *Plant and Soil*, **199**: 187–194.

StollManfred, Brian Loveys and Peter Dry. 2000. Hormonal changes induced by partial rootzone drying of irrigated grapevine. *Journal of Experimental Botany*,**51** (350): 1627-1634.

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