IRRIGATION AND DRAINAGE
Irrig. and Drain. **62**: 67–73 (2013)
Published online in Wiley Online Library (wileyonlinelibrary.com) **DOI**: 10.1002/ird.1719

ECONOMIC ANALYSIS OF DRIP-IRRIGATED KINNOW MANDARIN ORCHARD UNDER DEFICIT IRRIGATION AND PARTIAL ROOT ZONE DRYING†

P. PANIGRAHI[1]*, R. K. SHARMA[1], S. S. PARIHAR[1], M. HASAN[2] AND D. S. RANA[3]

[1]*Water Technology Centre, Indian Agricultural Research Institute, New Delhi, India*
[2]*Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi, India*
[3]*Division of Agronomy, Indian Agricultural Research Institute, New Delhi, India*

ABSTRACT

The profitability of regulated deficit irrigation (RDI), sustained deficit irrigation (SDI), and SDI with partial root zone drying (PRD) strategies was compared to that with full irrigation (FI: 100% crop evapotranspiration) in drip-irrigated Kinnow mandarin in northern India. RDI was scheduled with two irrigation levels: no irrigation and 50% crop evapotranspiration (ETc.) imposed in the early fruit growth period (EFGP) and final fruit growth period (FFGP) singly and in combination, whereas SDI was scheduled at 50% ETc and 75% ETc with and without the PRD technique. The highest fruit yield was recorded with FI, which was statistically on a par ($p > 0.05$) with that with SDI at 50% ETc with PRD (PRD_{50}). Economic-based comparison shows that all the treatments were economically viable since their profitability (net return, INR 137 000–1 300 000 ha^{-1} and benefit–cost ratio, 2.1–14.3) were viable. The net return generated with PRD_{50} was statistically ($p > 0.05$) at par with that generated with FI. However, the benefit–cost ratio and economic water productivity calculated with PRD_{50} were found to be significantly ($p < 0.05$) higher (36 and 87%, respectively) than that with FI. These results lead us to conclude that the PRD_{50} strategy could be used to improve irrigation water productivity substantially in commercial Kinnow mandarin orchards in sandy loam soil.

KEY WORDS: deficit irrigation; partial root zone drying; citrus; economics

Received 21 July 2012; Revised 3 November 2012; Accepted 3 November 2012

RÉSUMÉ

La rentabilité de l'irrigation déficitaire réglementée (RDI), de l'irrigation déficitaire durable (SDI) et SDI avec séchage partiel de la zone racine (PRD) ont été comparées à celle de l'irrigation complète (FI: 100% de l'évapotranspiration des cultures), tous modes en goutte à goutte, sous des mandariniers et dans un site situé dans le Kinnow (Nord de l'Inde). RDI a été prévue avec deux niveaux d'irrigation: aucune irrigation et 50 % de l'évapotranspiration (ETc.) en période de croissance précoce des fruits (EFGP) et dernière période de croissance des fruits (FFGP). SDI a été programmée à ETc. 50% et ETc. 75% avec et sans technique PRD. Le rendement le plus élevé a été enregistré avec des fruits FI, ce qui est statistiquement comparable ($p > 0,05$) à celui de SDI à ETc. 50% et PRD 50. La comparaison économique montre que tous les traitements étaient économiquement viables puisque leur rentabilité est avérée (rendement net, INR 137 000–1 300 000 ha^{-1} et ratio coûts–avantages, de 2,1 à 14,3). Le rendement net généré avec PRD50 était statistiquement ($p > 0,05$) comparable à celui généré par FI. Toutefois, le ratio avantages-coûts et la productivité économique de l'eau calculée avec PRD50 sont significativement ($p < 0,05$) plus élevés (36 et 87%, respectivement) par rapport à FI. Ces résultats permettent de conclure que la stratégie PRD50 pourrait être utilisée pour améliorer la productivité de l'eau d'irrigation dans les vergers commerciaux de mandarine du Kinnow en sol de limon sableux.

MOTS CLÉS: irrigation déficitaire; dessèchement partiel de la zone racinaire; agrumes; économie

* Correspondence to: P. Panigrahi, Directorate of Water Management, Chandrasekharpur, Bhubaneswar, Odisha-751 023, India. E-mail:pravukalyan@rediffmail.com
INR = Indian rupee, 1US$ = INR53, price level 2012.
† Analyse économique de verger de mandariniers du Kinnow sous différents régimes déficitaires d'irrigation au goutte.

INTRODUCTION

Water is one of the major limiting factors in crop production. Due to the water demand from rapid industrialization and high population growth, the share of water for agriculture is going to be reduced in the coming decades. The further scarcity of irrigation water for crop production, therefore, should be checked to sustain the food supply through efficient water conservation and management practices even in high-rainfall areas (Panda *et al*., 2004). Moreover, the harvest per every drop of irrigation water should be enhanced while considering the best economic water use efficiency associated with any crop.

The advent of drip irrigation is a significant technological improvement in irrigation systems, which helps to combat water scarcity in agriculture. In recent years, the adoption of drip irrigation has gained momentum owing to its positive impact on water saving, productivity, and produce quality in many crops, including citrus (Fereres *et al*., 2003). Irrigation scheduling is vital for improving the efficiency of drip irrigation systems, as an excessive or suboptimum water supply has detrimental effects on the yield and fruit quality of citrus (Davies and Albrigo, 1994). Moreover, the shortage of water is emerging as the major abiotic constraint limiting the productivity potential of citrus orchards in many arid and semi-arid regions (Abu-Awwad, 2001; Singh and Srivastava, 2004). In these regions, drip irrigation has been observed to be effective in combating such irrigation water shortage.

Deficit irrigation (DI) and partial root zone drying (PRD) are recently proposed water-saving techniques in crop production to reduce irrigation application and improve water productivity. In a broad sense, quoting English (1990), DI consists of the deliberate and systematic under-irrigation of crops. In other words, the amount of water applied is lower than that needed to satisfy the full crop water requirements. The reduction in the water applied usually lowers evapotranspiration (ET) and crop growth rates by limiting their principal component, transpiration, and, as a consequence, carbon assimilation. For this reason, it is of great interest to know the maximal reduction in ET compatible with obtaining benefits similar or even higher than those obtained when crop evapotranspiration (ETc.) is fully satisfied in mature fruit trees.

PRD is a means through which DI can be scheduled in a way that a part of the root system is exposed to watering, while the rest is left in drying soil. The system simultaneously maintains plant water status at an optimum range and controls transpiration, without bringing a significant change in the photosynthesis rate of leaves (Kriedemann and Goodwin, 2001). Moreover, the limited root zone wetting controls water loss through evaporation, resulting in higher water use efficiency with PRD. Past research has revealed that PRD is a way of reducing water use in tree crops and vines with little or no impact on yield and fruit quality (Goldhamer *et al*., 2002; Kang *et al*., 2002; Treeby *et al*., 2007). Overall, in fruit-bearing crops, the correct application of DI and PRD requires a thorough understanding of the trees' responses to water deficits and of the economic impact of reductions in crop value. The potential benefits of DI and PRD, therefore, are expected from: (i) increased water use efficiency (WUE) and (ii) reduced irrigation and production costs, which results in boosting the economics of production.

Nowadays, DI and PRD are common practices adopted in fruit crops in many areas of the world, especially in dry regions (Bravdo *et al*., 2004; Chaves *et al*., 2007; Bindon *et al*., 2008). In these regions it can be more profitable for a farmer to maximize crop water productivity than to maximize the harvest per unit land. The water saved can be used for other purposes or to irrigate extra units of land. When the water supply cannot be guaranteed or its on-site availability depends on external factors such as droughts or political decisions taken at local or national level, as occurs in many arid zones of the planet, the DI is referred to as 'uncontrolled'. But when the water supply is continuous because water is stored in private ponds or collective reservoirs, it is possible to apply one of the following DI strategies: regulated deficit irrigation (RDI) and/or PRD with or without sustained deficit irrigation (SDI). RDI is the deliberately reduced water supply to crops in non-critical growth stages, when SDI is distributing the water deficit uniformly throughout the whole crop cycle to avoid the occurrence of severe water stress at any particular moment.

Kinnow is a commercially important citrus cultivar grown in arid and semi-arid conditions in northern India. The major constraint to Kinnow production in this region is the scarcity of irrigation water during its critical period of growth. Drip irrigation has been found to be a potential water-saving technique in Kinnow cultivation (Kumar *et al*., 2003; Singh, 2004). The crop is basically irrigated by groundwater or canal water in this region. However, over the last few years, the groundwater level has declined alarmingly, creating a water shortage in citrus orchards. In addition, the short supply of canal water due to low reservoir levels caused by scanty rainfall is another cause of citrus decline in canal command areas. On the other hand, the area under Kinnow production is increasing exponentially due to the higher economic return from this crop compared with others (Thakur *et al*., 1986; Bhat *et al*., 2011). Farmers are more concerned with sustaining the yield of Kinnow mandarin using less water, which could be achieved through adoption of DI and/or PRD techniques using drip irrigation for this crop. However, suggesting any technique to farmers for adoption requires an impact analysis on crop yield, as well as the economic evaluation of these techniques with the crop in relation to the farmer's perspective. Moreover, the comparative performance of DI and PRD in relation to fruit yield and production economics in citrus grown in semi-arid regions has not yet been studied using drip irrigation. The present experiment was conducted to study the effects of DI and PRD on fruit yield and production economics of drip-irrigated Kinnow mandarin in a sandy loam soil of the semi-arid conditions of northern India.

MATERIALS AND METHODS

The experiment was carried out with 10-year-old Kinnow mandarin plants in the citrus orchard of the Centre for Protected Cultivation Technology (CPCT), Indian Agricultural Research Institute (IARI), New Delhi, India. The climate of the study region is categorized as semi-arid, subtropical with hot dry summers and cold winters with mean annual rainfall of 770 mm, of which approximately 85% is received during the monsoon (June–September) and the rest in winter. The mean daily evaporation rate measured in a USWB (United States Weather Bureau) Class-A pan ranges from 1.6 mm in January to as high as 10.7 mm in June. Soil of the experimental site varies from sandy in the surface layer to sandy-loam in the subsurface. The field capacity and permanent wilting point of the soil varied from 20.8 to 26.1% and 6.7 to 9.7%, respectively, on a volume basis.

The study consisted of regulated deficit irrigation (RDI) and partial root zone drying (PRD) with and without sustained deficit irrigation treatments. The performance of both RDI and PRD was compared with that of full irrigation (FI, 100% ETc.). In the RDI treatments, irrigation was scheduled at different deficit levels (no irrigation and 50% ETc) in the early fruit growth period (EFGP) and final fruit growth period (FFGP) singly and in combination, and compared with full irrigation (100% ETc.) in Kinnow mandarin. The Kinnow fruit has three distinct phases of growth: (i) the early fruit growth period (EFGP, from fruit setting to 60 days after fruit set); (ii) mid fruit growth period (MFGP, from 60 days after fruit set to 180 days after fruit set); and (iii) final fruit growth period (FFGP, from 180 days after fruit set to 255 days after fruit set), as suggested by Dhillon (1986). PRD treatments were applied by irrigating plants with 50% ETc (PRD_{50}) and 75% ETc (PRD_{75}), and compared with DI at 50% ETc (DI_{50}) and 75% ETc (DI_{75}) with irrigation of both sides of the root zone. The treatment details are presented in Table I. The irrigation season was from mid-January to June and from mid-October to December during the experimental years. The treatments were imposed in complete randomised block design, with four replications per treatment and two experimental plants in each replicated plot.

The volume of water applied for the various irrigation treatments was calculated based on the formula for fully-irrigated plants was computed as

$$V_{\mathrm{id}} = \pi\left(D^2/4\right) \times (\mathrm{ETc} - R_e)/E_i \qquad (1)$$

where V_{id} is the irrigation volume applied in each irrigation (l plant^{-1}), D the mean plant canopy spread diameter measured in the north–south and east–west directions (m), ETc. the cumulative crop evapotranspiration for two consecutive days (mm), R_e the effective rainfall depth for the corresponding two days (mm), and E_i the irrigation efficiency of the drip system (90%). ETc. (mm day^{-1}) was estimated as: ETc. = $K_p \times K_c \times E_p$, where K_p is the pan coefficient (0.8) and K_c the crop coefficient (0.85 for mature Kinnow plants) as proposed by Hasan and Sirohi (2006). The effective rainfall was estimated as the summation of change in soil water content (mm) in the root zone of the trees between,

Table I. Regulated deficit irrigation (RDI) and partial root zone drying (PRD) treatments imposed on Kinnow mandarin

Treatments	EFGP[a]	MFGP[b]	FFGP[c]
$RDI_{0^x-100^y-0^z}$	No irrigation	100%ETc.	No irrigation
$RDI_{0-100-50}$	No irrigation	100% ETc.	50% ETc.
$RDI_{0-100-100}$	No irrigation	100% ETc.	100% ETc.
$RDI_{50-100-0}$	50% ETc.	100%ETc.	No irrigation
$RDI_{50-100-50}$	50% ETc.	100% ETc.	50% ETc.
$RDI_{50-100-100}$	50% ETc.	100% ETc.	100% ETc.
$RDI_{100-100-0}$	100% ETc.	100%ETc.	No irrigation
$RDI_{100-100-50}$	100% ETc.	100% ETc.	50% ETc.
DI_{50}	50% ETc.	50%ETc.	50% ETc.
DI_{75}	75% ETc.	75% ETc.	75% ETc.
PRD_{50}	50% ETc. under PRD	50% ETc. under PRD	50% ETc. under PRD
PRD_{75}	75% ETc. under PRD	75% ETc. under PRD	75% ETc. under PRD
$RDI_{100-100-100}$	100% ETc.	100% ETc.	100% ETc.

[a]EFGP: Early fruit growth period (15 April–15 June).
[b]MFGP: Mid fruit growth period (16 June–15 October).
[c]FFGP: Final fruit growth period (16 October–30 December).
x: level of irrigation at EFGP; *y*: level of irrigation at MFGP and *z*: level of irrigation at FFGP.

before and after rainfall, and potential evapotranspiration for 1 day (day of rainfall, mm) for the crop (Dastane, 1978).

Fruits were harvested from each plant of the experiment and the mean yields were determined by weighing the total fruits for different treatments.

Benefit–cost ratio (BCR) analysis of any project generally indicates its commercial usefulness. In this study, BCR was calculated to analyse the return of the production system of Kinnow fruits with each of the drip irrigation strategies. The following assumptions were made in estimating the components of BCR, which include the capital cost of the drip irrigation system and the gross and net return of each of the different irrigation treatments: (i) the area of field was 1 ha; (ii) the land was flat; and (iii) the water source was located at the corner of the field.

The number of emitters, the length of laterals and the main pipe, filters, and pump were constant in all cases. However, their fixed cost and annual costs were calculated separately. The lateral stopper, which was used to stop irrigation to one side of a tree basin, was considered an extra item for PRD irrigation scheduling. The cost of all the materials required for these systems for a 1-ha field was estimated based on their prevailing prices (Table II). The interest rate considered was 12% per annum. The capital cost and operating cost of the system were calculated for each of the treatments. Subsequently, gross return and net return per hectare were estimated based on the Kinnow yield data.

The annual fixed cost (AFC) includes the annualized capital cost of the irrigation system. AFC was calculated from the capital cost, useful life of the components, depreciation, salvage value, and interest rate. Salvage value was assumed as 10% of the capital cost. Depreciation was calculated by the following formula (Reddy and Ram, 1996):

$$D = \frac{C - S}{L} \qquad (2)$$

where

$D =$ depreciation
$C =$ capital cost
$S =$ salvage value
$L =$ useful life, years

Interest amount (I) for the capital cost (C) and salvage value (S) was calculated at a 12% annual interest rate. It was estimated as follows:

$$I = \frac{C + S}{2} \times i \qquad (3)$$

where i is the interest rate (%).

The annual operating cost of the drip irrigation system includes the cost of cultivation and energy costs for running the irrigation system. Energy costs include the electrical cost, which was INR 5 kWh^{-1}, at the time of the experiment. The

Table II. Cost of drip irrigation system under regulated deficit irrigation (RDI) and deficit irrigation (DI) with and without partial root zone drying (PRD) in Kinnow mandarin

Sl No.	Item	RDI				DI and PRD				
		Technical specification	Quantity	Unit cost (INR[a])	Total cost (INR)	Technical specification	Quantity	Unit cost (INR)	Total cost (INR)	Useful life (years)
1	Emitter	8 lph PC	3 000 No.	3.00	9 000	8 lph PC	3 000 No.	3.00	9 000	7
2	Laterals	16 mm LDPE	2 000 m	6.00	12 000	12 mm LDPE	2 000 m	4.50	9 000	7
3	Micro-tube	4 mm	500 m	2.70	1 350	4 mm	500 m	2.70	1 350	5
4	Lateral end cap	–	160 No.	2.00	320	–	160 No.	2.00	320	7
5	Lateral valve (for PRD only)	–	–	–	–	12 mm	160 No.	20.00	3 200	7
6	Main/sub-main pipe	75 mm PVC	275 m	65.00	17 875	63 mm PVC	275 mm	45.00	12 375	7
7	Control valves	75 mm PVC	2 No.	750	1 500	63 mm PVC	2 No.	750	1 500	7
8	Filter, Pressure gauge and water meter	Disc filter	1 No.	6 000	6 000	Disc filter	1 No.	6 000	6 000	5
9	Venturi	PVC	1 No.	1 000	1 000	PVC	1 No.	1 000	1 000	7
10	Fittings and accessories	–	–	5 000	5 000	–	–	5 000	5 000	5
11	Monoblock pump	5 hp	1 No.	10 000	10 000	3 hp	1 No.	8 000	8 000	7
Grand total (INR)					64 000/	Grand total (INR) for DI			53 500/	
						Grand total (INR) for PRD			56 700/	

[a]Indian rupee.

energy consumed was calculated based on the operating hours of the irrigation system. The cost of cultivation of Kinnow includes inter-cultivation, weeding, application of manure, fertilizer and plant protection and harvesting, etc. The operating cost is adjusted according to irrigation system running hours. The total annual cost of the system includes both the AFC and annual operating cost.

The gross income from the production system includes the market return from the Kinnow crop. The wholesale price of Kinnow fruit for the Delhi region was taken as INR 23.10 kg^{-1} and INR 14.58 kg^{-1} in January 2011 and January 2012, respectively (National Horticulture Board (NHB), 2012).

The BCR was calculated following the formula (Reddy and Ram, 1996) as

$$\text{BCR} = \frac{\text{Gross income}}{\text{Total cost}} \tag{4}$$

The payback period was calculated to analyse the time required to get back the invested cost:

$$\text{Payback Period} = \frac{\text{Total cost}}{\text{Gross Income}} \times \text{Useful Life} \tag{5}$$

The data generated were subjected to analysis of variance (ANOVA), and separation of means was obtained using Duncan's multiple range test (DMRT), according to the methods described by Gomez and Gomez (1984). The *t*-test was performed to find the significance in difference of the data for the two experimental years.

RESULTS AND DISCUSSION

Tables III and IV show that the yield and gross income generated with the irrigation treatments were affected significantly ($p < 0.05$). The highest yield was harvested under FI, generating maximum gross income (INR 921 000–1 430 000) among the treatments, followed by $RDI_{100\text{-}100\text{–}50}$ (INR 917 000–1 390 000). However, the yield and gross income with PRD_{50} were statistically ($p > 0.05$) on a par with that with FI. The minimum yield and gross income were observed with $RDI_{0\text{-}100\text{–}0}$ (INR 265 000–508 000). The gross income in 2010 was significantly ($p < 0.05$) higher than that in 2011, in spite of higher yield under different treatments in 2011. This difference between the years was ascribed to the higher selling price of Kinnow in 2010, caused by lower Kinnow production in the country in 2010.

The AFC of Kinnow production, which mainly consisted of a drip irrigation system, was estimated to be INR 12 600 ha^{-1} for RDI and FI treatments. However, the AFC was estimated to be lower for PRD_{50} and PRD_{75} (INR 11 000 ha^{-1}), due to the reduced cost of pipelines (sub-main and laterals) and control valves caused by reduction of the pipe diameter required in PRD. Further, the AFC with DI_{50} and DI_{75} (INR 10 400) was estimated to be lower than that with PRD. The higher AFC with PRD compared to DI was attributed to the cost of lateral valves used to regulate the irrigation with PRD.

The annual operating cost (AOC) was observed to be highest with FI (INR 122 000–131 000), due to higher power costs and labour charges involved in irrigation under

Table III. Economics of Kinnow production using drip irrigation with RDI and PRD treatments in 2010 –2011

Treatments	Yield (t ha^{-1+})	Gross income (INR* ha^{-1})	Fixed cost (INR ha^{-1})	Operating cost (INR ha^{-1})	Total cost (INR ha^{-1})	Net income (INR ha^{-1})	B/ C	Economic water productivity [INR (mm irrigation water used)$^{-1}$]
$RDI_{0\text{-}100\text{–}0}$	22.0$^{ab\#}$	508 000^{ab}	12 600^{a}	109 000^{b}	121 000^{b}	387 000^{d}	4.2^{ab}	962^{ab}
$RDI_{0\text{-}100\text{–}50}$	27.9^{d}	644 000^{d}	12 600^{a}	112 000^{b}	125 000^{b}	520 000^{c}	5.2^{ab}	1 100^{ab}
$RDI_{0\text{-}100\text{–}100}$	30.6^{c}	707 000^{c}	12 600^{a}	120 000^{a}	132 000^{a}	575 000^{c}	5.3^{ab}	1 100^{ab}
$RDI_{50\text{-}100\text{–}0}$	49.9^{b}	1 153 000^{b}	12 600^{a}	80 000^{bc}	92 000^{d}	1 061 000^{b}	12.5^{c}	1 730^{c}
$RDI_{50\text{-}100\text{–}50}$	58.0^{a}	1 340 000^{a}	12 600^{a}	83 000^{ab}	96 000^{d}	1 244 000^{a}	14.0^{b}	1 840^{c}
$RDI_{50\text{-}100\text{–}100}$	59.6^{a}	1 380 000^{a}	12 600^{a}	93 000^{d}	106 000^{c}	1 270 000^{a}	13.0^{b}	1 720^{c}
$RDI_{100\text{-}100\text{–}0}$	53.0^{b}	1 220 000^{b}	12 600^{a}	109 000^{c}	121 000^{b}	1 103 000^{b}	10.0^{d}	1 350^{d}
$RDI_{100\text{-}100\text{–}50}$	60.2^{a}	1 390 000^{a}	12 600^{a}	113 000^{b}	125 000^{b}	1 265 000^{a}	11.1^{b}	1 430^{d}
DI_{50}	51.2^{b}	1 180 000^{b}	10 400^{c}	80 000^{bc}	92 000^{d}	1 091 000^{b}	12.8^{c}	2 300^{b}
DI_{75}	58.0^{a}	1 340 000^{a}	10 400^{c}	91 000^{d}	102 000^{c}	1 240 000^{a}	13.2^{b}	1 740^{c}
PRD_{50}	56.5^{a}	1 300 000^{a}	11 000^{b}	80 000^{bc}	91 000^{d}	1 210 000^{a}	14.3^{a}	2 560^{a}
PRD_{75}	58.7^{a}	1 360 000^{a}	11 000^{b}	95 000^{d}	106 000^{c}	1 250 000^{a}	12.9^{c}	1 760^{c}
FI	61.9^{a}	1 430 000^{a}	12 600^{a}	122 000^{a}	132 000^{a}	1300 000^{a}	10.8^{d}	1 370^{d}

Wholesale price of Kinnow = INR 2310 per quintal.
*Land charge is not considered assuming the land belongs to the grower. Electric power cost is assumed as INR 5 kWh^{-1}.
$^{+}$tonnes per hectare.
*Indian rupee.
$^{\#}$Data within a column followed by same letters do not differ significantly at $P < 0.05$.

Table IV. Economics of Kinnow production using drip irrigation with RDI and PRD treatments in 2011–2012

Treatments	Yield (t ha^{-1+})	Gross income (INR* ha^{-1})	Fixed cost (INR ha^{-1})	Operating cost (INR ha^{-1})	Total cost (INR ha^{-1})	Net income (INR ha^{-1})	B/ C	Economic water productivity {INR (mm irrigation water used)$^{-1}$}
$RDI_{0-100-0}$	18.2[ab#]	265 000[ab]	12 600[a]	116 000[b]	128 000[b]	137 000[d]	2.1[ab]	498[ab]
$RDI_{0-100-50}$	35.4[d]	516 000[d]	12 600[a]	121 000[b]	134 000[b]	345 000[c]	3.6[ab]	492[ab]
$RDI_{0-100-100}$	37.7[c]	550 000[c]	12 600[a]	129 000[a]	141 000[a]	439 000[c]	4.1[ab]	1 044[ab]
$RDI_{50-100-0}$	51.3[b]	750 000[b]	12 600[a]	76 000[bc]	89 000[d]	659 000[b]	6.4[c]	1 586[c]
$RDI_{50-100-50}$	61.4[a]	895 000[a]	12 600[a]	81 000[ab]	94 000[d]	783 000[a]	9.3[b]	1 605[c]
$RDI_{50-100-100}$	62.3[a]	908 000[a]	12 600[a]	89 000[d]	101 000[c]	807 000[a]	9.0[b]	1 440[c]
$RDI_{100-100-0}$	54.4[b]	793 000[b]	12 600[a]	104 000[c]	116 000[b]	677 000[b]	6.8[d]	1 217[d]
$RDI_{100-100-50}$	62.9[a]	917 000[a]	12 600[a]	108 000[b]	120 000[b]	797 000[a]	7.6[b]	1 268[d]
DI_{50}	52.8[b]	769 000[b]	10 400[c]	75 132[bc]	86 000[d]	684 000[b]	9.0[c]	1 451[b]
DI_{75}	60.3[a]	879 000[a]	10 400[c]	88 000[d]	98 000[c]	773 000[a]	9.0[b]	1 472[c]
PRD_{50}	57.2[a]	834 000[a]	11 000[b]	76 000[bc]	87 000[d]	747 000[a]	9.6[a]	2 130[a]
PRD_{75}	62.0[a]	904 000[a]	11 000[b]	89 000[d]	100 000[c]	800 000[a]	9.0[c]	1 524[c]
FI	63.2[a]	921 000[a]	13 000[a]	131 000[a]	127 000[a]	794 000[a]	7.3[d]	1 134[d]

Wholesale price of Kinnow = INR 1458 per quintal.
[+]tonnes per hectare.
*Indian rupee.
[#]Data within a column followed by same letters do not differ significantly at $P < 0.05$.

this treatment. As the cultural operation and fertilizer application were performed uniformly, these operating costs did not change within the treatments. Among RDI treatments, the highest AOC was calculated for the treatment $RDI_{0-100-100}$ (INR 120 000–128 600), followed by $RDI_{100-100-50}$ (INR 108 000–113 000). Moreover, within DI with and without PRD treatments, the maximum AOC was observed with PRD_{75}, whereas the minimum AOC was observed with DI_{50}. However, the AOC for PRD was higher than that with DI, in the corresponding irrigation regime. That finding was due to the higher labour cost involved in controlling lateral operations (closing and opening) in partial root zone drying under drip irrigation.

The Net income (NI) was observed to be highest with FI (INR 794 000–1 300 000), followed by $RDI_{50-100-100}$ (INR 807 000–1 270 000). The NI with DI_{75}, PRD_{50} and PRD_{75} were INR 773 000–1 240, 000, INR 747 000–1 210 000, and INR 800 000–1 250 000, respectively. However, BCR was highest with PRD_{50} (9.6–14.3). Also, PRD_{50} produced the highest economic water productivity (INR 2130–2560 mm^{-1} water used) among the treatments.

Based on this analysis, it can be concluded that partial root zone dying with deficit irrigation at 50% ETc. is a productive and potential water-saving technique for Kinnow cultivation in northern India. In spite of a marginally lower net return due to lower fruit yield, higher BCR and economic water productivity were generated under this treatment due to savings of labour and electric power tariffs. Thus, the adoption of PRD_{50} is an economically viable option compared to RDI and full irrigation for Kinnow mandarin cultivation using drip irrigation in sandy loam soils.

REFERENCES

Abu-Awwad AM. 2001. Influence of different water quantities and qualities on lemon trees and soil salt distribution at the Jordan Valley. *Agricultural Water Management* **52**: 53–71.

Bhat A, Kachroo J, Kachroo D. 2011. Economic appraisal of Kinnow production and its marketing under north-western Himalayan region of Jammu. *Agricultural Economic Research Review* **24**: 283–290.

Bindon K, Dry P, Loveys B. 2008. Influence of partial root zone drying on the composition and accumulation of anthocyanins in grape berries (*Vitis vinifera* cv. Cabernet Sauvignon). *Australian Journal of Grape Wine Research* **14**: 91–103.

Bravdo B, Naor A, Sabih T, Gal Y. 2004. The effect of water stress applied alternately to part of the wetting zone along the season (PRD) on wine quality, yield and water relations of red wine grapes. *Acta Horticulturae* **664**: 101–109.

Chaves MM, Santos TP, Souza CR, Ortuño MF, Rodrigues ML, Lopes CM, Maroco JP, Pereira JS. 2007. Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. *Annals of Applied Biology* **150**: 237–252.

Dastane NG. 1978. Effective rainfall in irrigated agriculture. FAO Irrigation and Drainage Paper 25. FAO: Rome, Italy.

Davies FS, Albrigo LG. 1994. Citrus. CAB International: Wallingford, UK.

Dhillon BS. 1986. Bio-regulation of developmental process and subsequent handling of Kinnow mandarin. *Acta Horticulturae* **179**: 251–256.

English M. 1990. Deficit irrigation. I: Analytical framework. *Journal of Irrigation and Drainage Engineering (ASCE)* **116**(1): 399–412.

Fereres E, Goldhamer DA, Parsons LR. 2003. Irrigation water management of horticultural crops. *HortScience* **38**(5): 1036–1042.

Goldhamer DA, Salinas M, Crisosto C, Day KR, Soler M, Moriana A. 2002. Effects of regulated irrigation and partial root zone drying on late harvest peach tree performance. *Acta Horticulturae* **592**: 343–350.

Gomez KA, Gomez AA. 1984. Statistical Procedures for Agricultural Research. John Wiley & Sons: New York.

Hasan M, Sirohi NPS. 2006. Irrigation and fertigation scheduling for peach and citrus crops. *Journal of Agricultural Engineering* **43**(4): 43–46.

Kang S, Hu X, Goodwin I, Jerie P. 2002. Soil water distribution, water use, and yield response to partial root zone drying under a shallow groundwater table condition in a pear orchard. *Scientia Horticulturae* **92**: 277–291.

Kriedemann PE, Goodwin I. 2001. Regulated Deficit Irrigation and Partial Root Zone Drying—an Overview of Principles and Applications. Irrigation Insights No. 3. Land and Water Australia: Australia; 102 pp.

Kumar S, Narayan M, Kumar A. 2003. Studies on effect of trickle irrigation system in orchard. *New Agriculturist* **14**(1/2): 117–120.

National Horticulture Board (NHB). 2012. Price and annual arrival of fruits, vegetables and flowers. www.nhb.gov.in/onlineclient/mothwiseannual-priceandarrivalreport.aspx (last accessed on 6 June 2012).

Panda RK, Behera SK, Kashyap PS. 2004. Effective management of irrigation water for maize under stressed conditions. *Agricultural Water Management* **66**: 181–203.

Reddy SS, Ram PR. 1996. Agricultural Finance and Management, 2nd edn. Oxford and IBH Publishing Co. Pvt. Ltd: New Delhi.

Singh CJ. 2004. Efficient use of water in canal command of Punjab. In Chopra K, Hanumantorao CH, Sengupta R (eds). Water Resources, Sustainability Livelihood and Eco-system Services, Concept Publishing Company: New Delhi; 23–34.

Singh S, Srivastava AK. 2004. Citrus industry of India and overseas. In Singh S, Shivankar VJ, Srivastava AK, Singh IP (eds). Advances in Citriculture, Jagmander Book Agency: New Delhi; 8–67.

Thakur DS, Saibabu MVS, Sharma KD. 1986. Economics of Kinnow cultivation in Himachal Pradesh. *Himachal Journal of Agricultural Research* **12**(91): 47–51.

Treeby MT, Henriod RE, Bevington KB, Milne DJ, Storey R. 2007. Irrigation management and rootstock effects on navel orange (*Citrus sinensis Osbeck*) fruit quality. *Agricultural Water Management* **91**: 24–32.

