Rainwater management for improving yield, water productivity and profit in fruit orchards

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Introduction

Rainwater conservation and its management is a key to sustainable cultivation of fruit crops in water scarce regions. Keeping this in view, a study was conducted to compare the performance of three water conservation treatments viz., continuous trench (CT), CT + rainwater harvesting tank (RWHT) + basin irrigation (BI), CT + RWHT + drip irrigation (DRI) with rainfed treatment (RT) in relation to productivity, water productivity and profit in a fruit i.e. citrus orchard. The CT + RWHT + DRI produced 219% higher fruit yield with 298% higher net income (NI) and 130% higher net economic water productivity (NEWP) compared with RT (yield, 7.14 t ha^{-1}; NI, 59704 INR ha^{-1}; NEWP, 15.75 INR m^{-3}). The sustainable yield index (SYI) and energy use efficiency (EUE) were 49% and 87% higher, respectively, in CT + RWHT + DRI than RT.

Key word: citrus, rain water harvesting, micro irrigation, yield, water productivity

1. Introduction

Citrus is the third important fruit crop in India. Water availability becomes a major constraint in citrus production in tropics. The substantial overland flow of rainwater during rainy season and sub-optimum moisture in soil during post-rainy season generally occurs in citrus plantations of tropics (Panigrahi, 2014). The loss of rainwater, soil and nutrients in overland flow not only affects the productivity and longevity of citrus orchards, but also contaminant the surface water bodies in the regions. In this juncture, conserving rainfall runoff using *in situ* and *ex situ* measures and utilization of harvested water through efficient and effective means is indispensable for sustainable citriculture.

The water conservation through inter-row bunds was not found suitable in cracking clayey soil, due to damage of citrus plants by '*phytopthora'* disease caused by standing water behind the bunds. Water conservation by constructing trenches between the tree rows may be an alternative option in citrus cultivation. Furthermore, harvesting the excess rainfall runoff from the orchard with ex *situ* conservation method using water harvesting tank, and recycling the harvested water through DRI may be useful to sustain and improve the orchard efficiency in citrus. However, the studies on the effects of surface runoff conservation through continuous trenches (CT) and rainwater harvesting tank (RWHT), and recycling the harvested water in the tank through DRI in citrus are limited worldwide. Furthermore, the information on overland flow could bring a better planning for land and water management strategies in both micro and macro scales in citrus belts. Keeping these in view, the investigation was carried out to evaluate the impact of integrated approach involving rainwater conservation through CT and RWHT, and recycling the harvested water using DRI in citrus orchards in a tropical climate of central part of India. Forecasting of overland flow from rainfall amount in citrus orchards has also been done.

2. Methodology

The study was laid out at ICAR-Central Citrus Research Institute in Nagpur, India, during 2004–2010 (7 years). The 13 year-old Nagpur mandarin plants spaced at 6 m x 6 m was used for the study. The experimental soil is clayey with 32% sand, 24.5% silt and 44.5% clay. The pH of soil is 8.5 with basic infiltration rate of 3.7 mm/h.

The rainwater conservation measures (RWCM) evaluated against rain-fed treatment (RFT) were (i) CT, (ii) CT + RWHT + basin irrigation (BI) and (iii) CT + RWHT + DRI. The randomized block design (RBD) with 5 replications was used for layout of the treatments. For each treatment, 1.152 ha field plot (240 m x 48 m) having 320 mandarin plants was selected. All the plots were surrounded with a bund of height 0.40 m, to restrict the runoff from adjacent outside areas to the plots and vice versa. The RWHTs were excavated at the outlet (place with least elevation) of the plot with dimension of 35 m × 35 m × 3 m. Water was supplied to the citrus plants using DRI in one treatment and BI in another treatment from RWHT during dry periods in rainy season (July–October) and critical period of the crop (flowering and fruit growth) which falls during December–February in post-rainy season. In DRI, the quantity of water applied was estimated using the formula (Panigrahi *et al,* 2016), volume of water applied (m^3 $plant^{-1}$) = $[\{\pi\ (D^2/4)\ x\ (ET_c - ER)\}/\ (IE\ x\ 1000)]$, where D is the mean plant canopy diameter (m), ET_c is the crop evapotranspiration, ER is the effective rainfall and IE is the irrigation efficiency of DRI (90%). The effective rainfall was determined using water budgeting approach in plot scale of the citrus plantation (Panigrahi et al, 2009). The plants in all treatment plots were uniformly fertilized with 260 kg/ ha N, 185 kg/ ha P and 72 kg/ ha K (Srivastava and Singh, 1997). All the field management practices for the treatments were performed uniformly.

The rainfall taken for analysis was measured in the rain gauge installed at the automatic weather station of the research farm. Overland flow (runoff) was quantified using multi-slot divisor in each treatment plot. The runoff quantity from one slot (middle one) out of 5 was collected in a 3 m^3 capacity plastic tank installed at tail end of the plots. After each rainfall, the runoff in the tanks was quantified and pumped in to the respective RWHT. To quantify the runoff from the RWHTs, stage level recorders were installed at their emergency outlets. The yield (kg ha^{-1}) in different treatments was estimated by multiplying the total fruit weight (kg) per plant with number of plants per hectare (278). The water productivity (WP) under different treatments was estimated as the ratios of fruit weight to quantity of water used. Sustainable yield index (SYI) is an indicator of sustaining the productivity of a crop over the years in field condition. The SYI under different treatments was estimated based on the formula (Singh *et al.,* 1990), SYI = (Y_{mean} – SD) / (Y_{max}), where Y_{mean} is the mean yield under a given treatment, SD is the standard deviation of yield for that treatment across the years, and Y_{max} is the maximum yield under that treatment in any year. Energy use efficiency (EUE) becomes one of the important indicators for good agriculture practice in recent years. Energy inputs (EI), energy outputs (EO) and EUE in various treatments in citrus orchard were worked out following the procedure recommended by Singh *et al.* (1997) and Namdari *et al.* (2011). The economic analysis (gross income, GI; net income, NI, benefit-cost ration, BCR) was done following the methodology suggested by Panigrahi *et al.* (2013). The gross economic water productivity (GEWP) and net economic water productivity (NEWP) were estimated as the GI per unit quantity of water used and NI per unit quantity of water used, respectively.

The data collected were statically analyzed for least significant difference (LSD) and Duncan's multiple range test (DMRT) was performed using separation of means (Dean and Voss, 1999). The relation of runoff with rainfall was determined by using Microsoft Office 2010.

3. Results and discussion

The runoff generated and runoff recycled under different treatments is given in Figure 1. The highest runoff (42.9% rainfall) occurred in RT, whereas CT and CT + RWHT produced lower quantity of runoff (29.8–30.4%). The lower runoff was due to maximum conservation (29.2–31.4%) of overland flow in CT and CT + RWHT. The runoff quantity was statistically at par under CT and CT + RWHT. The runoff quantities generated in DI and BI under RWHT were statistically ($P < 0.05$) at par. However, the runoff recycled under DI (1942 m^3) was higher than that under BI (1681 m^3) in the orchard. The higher quantity of runoff recycled was due to lower loss of water through seepage and evaporation in the RWHT under frequent water application under DRI (irrigation frequency: 2–3 days) than BI (irrigation frequency: 7–9 days). Overall, CT + RWHT was observed as the best rainwater conservation measure; whereas DRI was found as the better method for utilization of harvested water in the tank in citrus orchard.

The SWC in different treatments during January–December is presented in Figure 2. During January–February, the SWC under CT + RWHT + DRI (74–111 mm/m soil) was highest, followed by CT + RWHT + BI (72–104 mm/m soil). The lowest SWC during this period was observed in RT (63–87 mm/m soil). The higher SWC was attributed to rainwater conservation and frequent application of harvested rainwater in tank in the citrus orchard under CT + RWHT + DRI. During March–June, the SWC was marginally (8–13%) higher under RWCMs than RT. During July–December, the higher increase in SWC (12–55%) was recorded due to higher conservation and recycling of rainwater in this period. The SWC under different treatments during July–December followed the similar trend of that during January–February. The available SWC in RT reduced during October–December, due to insufficient rainfall to compensate the evapo-transpiration (ET) of mandarin plants in this period. However, the reduction in available SWC during October–December was progressively decreased, reflecting the lower ET of the mandarin plants during December compared with that during October. In earlier studies, Panigrahi *et al.* (2009) and Reddy *et al.* (2013) also reported the lowest ET of Nagpur mandarin plants during December.

The water use, yield, water productivity, SYI and EUE in different treatments are presented in Table 1. The water use under CT + RWHT + DRI was highest (6565 m^3 ha^{-1}), due to water harvesting and recycling of harvested water to the citrus plants in this treatment. The highest fruit yield which occurred in CT + RWHT + DRI was 219% higher than that in RT (7.14 t ha^{-1}). The higher fruit yield attributed to higher number fruits with higher fruit weight under CT + RWHT + DRI compared with RT. The higher flowering, followed by lower flower and fruit drops (104 No.) resulted in higher number of fruits in CT + RWHT + DRI than other treatments. The highest WP (3.47 kg m^{-3}) was in CT + RWHT + DI, followed by CT + RWHT + BI (2.71 kg m^{-3}). The higher yield resulted in higher WP than other treatments. The lowest water productivity was observed in RT (1.88 kg m^{-3}). The SYI was the highest under CT + RWHT + DI (0.88), followed by CT + RWHT + BI (0.79). The lowest value of SYI was observed in RT, indicating the higher efficacy of RWCMs on maintaining the sustainability of citrus production. The EUE also followed similar trend of SYI under different treatments.

The GI, NI, BCR, GEWP and NEWP under different treatments are presented in Table 2. The highest GI (310216 INR ha^{-1}) was in CT + RWHT + DI due to higher fruit yield in this treatment compared with other treatments. The annual NI under CT + RWHT + DI (237916 INR ha^{-1}) was also higher, in spite of higher investment (INR 310000) in RWHT and DI. The higher NI was due to comparatively higher increase in annual GI than increase in investment in CT + RWHT + DRI compared with other treatments. The BCR followed the similar trend of NI under different treatments. The lowest GI resulted in lowest BCR (1.34) under RT. The highest GEWP (47.25 INR m^{-3}) and NEWP (36.24 INR m^{-3}) was in CT + RWHT + DI, followed by CT + RWHT + BI (GEWP, 36.99 INR m^{-3}; NEWP, 27.30 INR m^{-3}). The higher GI and NI due to higher yield resulted in higher GEWP and NEWP in CT + RWHT + DI compared with other treatments.

4. Conclusions

All the conservation measures were found effective in trapping runoff which resulted in significant enhancement in available soil water content in Nagpur mandarin orchard. The higher soil water content helped in boosting both yield and water productivity under conservation measures compared with rain fed treatment in the orchard. Among the measures, continuous trenching coupled with rainwater harvesting tank and drip irrigation was found most suitable in conserving water and producing higher yield, water productivity, net income and net economic water productivity in the citrus orchard. The production of citrus under continuous trenching with rainwater harvesting tank and drip irrigation was also found energy efficient with higher sustainability compared to other treatments. The rainfall-runoff relationship developed may be useful in designing water conservation measures in integrated watershed management program in citrus belts of central India. Overall, it can be concluded that the adoption of continuous trenching along with rainwater harvesting tank based drip irrigation is a potential option for profitable citrus cultivation in rain-fed ecosystem of central India or in the regions with similar pedo-hydrological condition of the study site. It will bring a sizable increase in productivity with substantial water saving in citrus cultivation.

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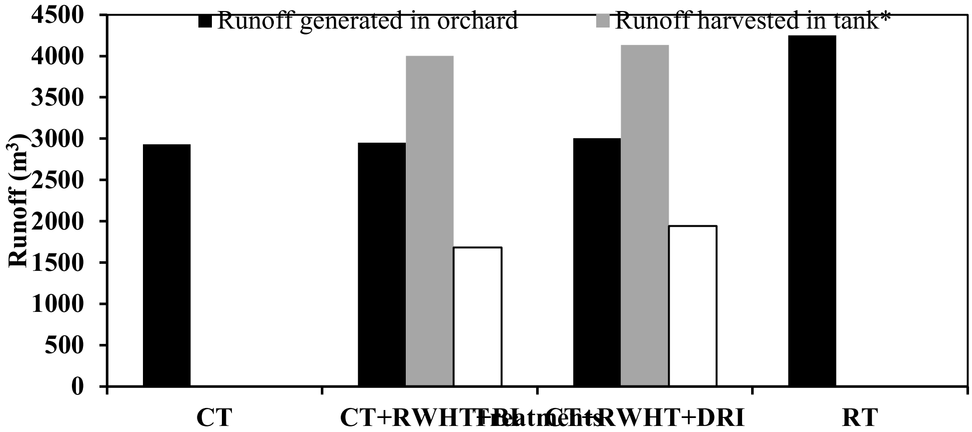

Figure 1. Runoff generated in orchard, runoff harvested in tank and runoff recycled in orchard under different treatments in citrus orchard; *Runoff harvested in tank: Runoff generated from orchard + Rainfall amount in tank (1053 m^3)

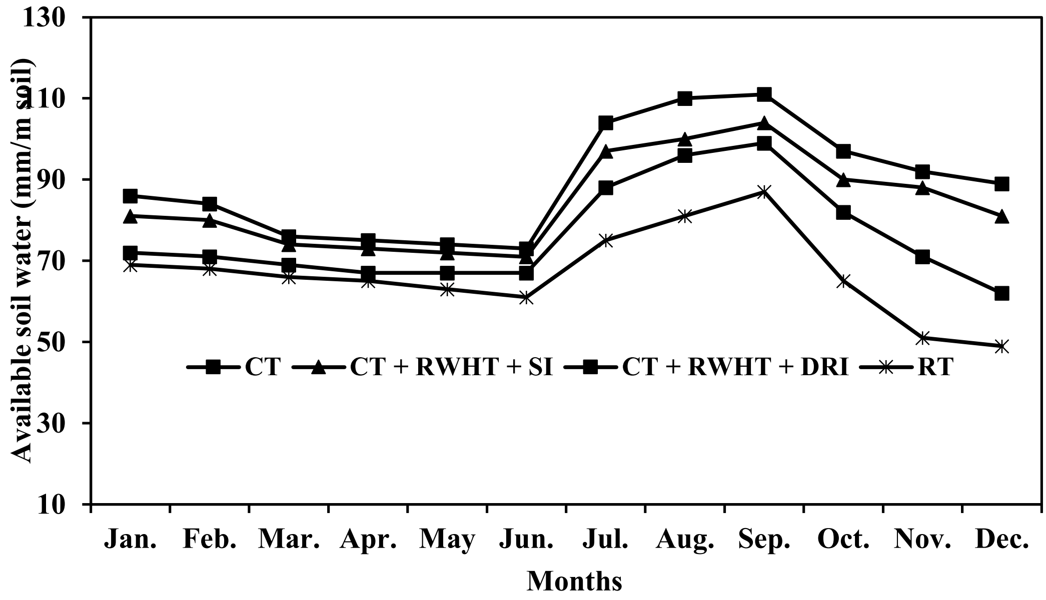

Figure 2. Available soil water content in top 1.0 m soil during January–December under different treatments

Table 1. Water used, yield, water productivity, sustainable yield index (SYI) and energy use efficiency (EUE) and fruit quality under different rainwater conservation measure in citrus

Treatment	Water use (m^3 ha^{-1})	Yield ($t\ ha^{-1}$)	WP ($kg\ m^{-3}$)	SYI	EUE ($MJ\ t^{-1}$)
CT	4675^b	9.74^b	2.08^b	0.66^b	1.13^b
CT+RWHT+BI	6342^c	17.25^c	2.71^c	0.79^c	1.65^c
CT+RWHT+DRI	6565^d	22.81^d	3.47^d	0.88^d	1.91^d
RT	3790^a	7.14^a	1.88^a	0.59^a	1.02^a

Table 2. Economics and economic water productivity in different treatments in citrus

Treatment	Gross Income (INR ha^{-1} $year^{-1}$)	Net income (INR ha^{-1} $year^{-1}$)	Benefit-cost ratio	Gross economic water productivity (INR m^{-3} $year^{-1}$)	Net economic water productivity (INR m^{-3} $year^{-1}$)
CT	132464^{b}	86767^{b}	2.89^{b}	28.33^{b}	18.55^{b}
CT+RWHT+BI	234600^{c}	173175^{c}	3.81^{c}	36.99^{c}	27.30^{c}
CT+RWHT+DRI	310216^{d}	237916^{d}	4.29^{d}	47.25^{d}	36.24^{d}
RT	97104^{a}	59704^{a}	2.59^{a}	25.62^{a}	15.75^{a}