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Rainwater, soil and nutrient conservation for sustainable production of fruit crops in water scarce regions

Dr. Pravukalyan Panigrahi*, Dr. Roomesh Kumar Jena, Er. Ajit Kumar Nayak, Dr. Sanatan Pradhan and Dr. Hemanta Kumar Dash
ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha-751023

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Introduction

Limited water availability and lower soil fertility are the major factors affecting yield and longevity of fruit crop orchards. In India, overall the precipitation is stochastic and seasonal. The substantial overland flow of rainwater during rainy months and sub-optimum moisture availability in soil during post-rainy months generally occurs in orchards of tropics. The disposition of rainwater, soil and nutrients in overland flow not only affects the productivity and longevity of orchards, but also contaminant the surface water in the areas. In this juncture, conserving rainfall runoff along with soil *in situ* is indispensable for sustainable production of fruit crops.

The water conservation by constructing trenches between the tree rows may be an alternative option in fruit crop cultivation. However, the studies on the effects of surface runoff conservation through trenches and grass mulch (GM) in orchards are limited. Furthermore, the information on overland flow and sediment loss along with nutrients and organic carbon (OC) could bring a better planning for land and water management strategies in both micro and macro scales in orchards.

Keeping these in view, the investigation was carried out to evaluate the impact of trenches (continuous, staggered) and GM in a citrus orchard of a tropical climate of central India.

Materials and methods

The study was laid out at ICAR-Central Citrus Research Institute in Nagpur, India, during 2004–2010 (7 years). The 13 year-old citrus plants spaced at 6 m x 6 m was used for the study. The experimental soil was clayey with 32% sand, 24.5% silt and 44.5% clay. The climate of the experimental site is sub-humid tropical. The mean annual rainfall at the site is 860 mm, out of which 84% (722 mm) takes place in rainy season (July–October).

The soil water conservation measures tested against without conservation practice (WCP) were (i) staggered trenching (ST), (ii) continuous trenching (CT) (iii) ST+GM and (iv) CT+GM. The randomized block design (RBD) with 4 replications was used for layout of the treatments. Water was supplied to the citrus plants using micro irrigation at 50% soil moisture depletion in top 0.6 m profile. 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. After each rainfall, the runoff in the tanks was quantified and properly stirred. Two samples (each 1 litre) of the stirred runoff were collected from each replicated plot. Out of the two runoff samples, one was dried at 110 ^{0}C and the dried sediment collected was called sample soil loss. The soil loss after each erosive rainfall event was calculated by multiplying the sample soil loss with total runoff collected in the treatment. The air dried soil samples were analyzed for available macro-nutrients (N, P and K), available micro-nutrients (Fe, Cu, Zn and Mn) and OC. The yield (kg/ ha) in different treatments was estimated by multiplying the total fruit weight (kg) per plant with number of plants per hectare (278). Five citrus fruits were sampled from each treatment for its analysis The rainwater use efficiency (RWUE) and irrigation water use efficiency (IWUE) under different treatments were estimated as the ratios of yield to rainwater quantity and yield to irrigation water quantity, respectively.

Results and discussion

Runoff and soil conservation

The season wise runoff and soil erosion under various treatments are given in Table 1. Both ST and CT without GM produced the runoff and soil erosion during winter season. During monsoon period, the peak runoff (57.8%) with highest soil erosion (7.75 t/ha) occurred in WCP treatment, whereas CT+GM resulted the lowest runoff (31.30%) with minimal soil erosion (3.95 t/ha). The monsoon period was found most vulnerable to runoff generation and soil erosion, followed by post-monsoon period in mandarin orchards of the region. Overall, the conservation practices (CPs) could trap the overland flow and sediment in the orchard significantly during different seasons in a year. The annual mean runoff and soil erosion recorded in the mandarin orchard in without conservation practices (WCP) treatment was 54.9% and 8.10 t/ha, respectively. The GM trapped the soil and runoff up to 20% more than that in non-mulched treatments.

Soil organic carbon and nutrients

The change in OC and available nutrients (N, P, K, Fe, Cu, Zn and Mn) contents in the experimental soil varied significantly in the treatments (Table 2). The OC in soil in non-mulched treatments was reduced by 12–19%, whereas mulching enhanced the OC in soil by 12–16% compared with initial content under CT and ST. The enhancement of OC in soil was attributed to decomposition of mulch and decrease in OC loss in sediment from mulched plots. The maximum increase in micronutrients (Fe, Cu, Zn and Mn) in soil was in CT + GM. The enhancement of nutrients in soil suggests for development of suitable fertilizer application schedule to save fertilizers under conservation practices in citrus.

All the micronutrients contents except Cu decreased in soil. The reduction in available micronutrients was lowest in CT + GM. The conservation of runoff and soil along with the nutrients available from decomposed GM resulted in higher availability of micronutrients in soil under CT + GM and ST + GM than other treatments. The improvement of Cu in soil in all the treatments might be due to the use of fungicide containing Cu in controlling '*phytophto*ra' disease in citrus. However, the application of micronutrients based fertilizers in appropriate quantity in soil is suggested for citrus cultivation in the region.

Yield and water use efficiency

The yield parameters (number and weight of fruit, total yield), water use efficiency and internal quality of fruits (juice, total soluble solid, acidity and ascorbic acid) in different CPs and WCP are given in Table 3. The number of fruits per plant under conservation treatments was increased up to 37% compared with that in WCP. The lower number of fruits dropped (104–272) under CPs than WCP (305) resulted in higher number of fruits in the former treatments. In earlier studies, higher fruit drop under sub-optimum SWC was also observed in citrus orchard (Panigrahi and Srivastava, 2011). The fruit weight was higher in CPs than WCP. The total fruit production of mandarin plants was highest in CT + GM. The enhancement of fruit yield was 3–17% in non-mulched treatments compared with WCP. Further, mulching produced 26–36% higher fruit yield than without mulched treatments. Earlier, Lalruatsangi and Hazarika (2018) and Lal et al. (2003) also reported 15–25 % higher yield under GM compared with without mulch in citrus. The yield in CT + GM was 53% higher than that in WCP. The production of higher yield using less water (31%) resulted in higher RWUE (53%) and IWUE (123%) in CT + GM than WCP. The CT + GM produced the highest RWUE and IWUE which were 9–53% and 20–123% higher than that in other treatments, respectively.

The fruit qualities (juice, total soluble solids, ascorbic acid) were better in CPs than WCP. The TSS of fruits was lower in CT + GM than ST + GM. The fruits produced under CPs were having lower acidity than that in WCP. The ST + GM produced the fruits with lowest acidity among the treatments. The ascorbic acid content was higher in the fruits harvested from the plants under CPs compared with WCP. Moreover, the ascorbic acid was higher in the fruits under mulched treatments (CT + GM, ST + GM) than other treatments. Past study by Liu et al. (2012) also recoded higher ascorbic acid content in the citrus fruits under mulching.

Conclusions

All the conservation measures were found effective in trapping runoff and sediment which resulted in significant enhancement in available water and fertility in citrus orchards. The higher available nutrients helped in boosting the productivity of the citrus plants. Among the measures, continuous trenching coupled with grass mulch was found most suitable to conserve rainfall runoff and soil compared with without conservation practice in the citrus orchard. Overall, it can be concluded that continuous trenching and grass mulch is a potential conservation option for citrus orchards of water scarce central India. It's adoption will bring a sizable increase in productivity with substantial water saving in citrus and in other fruit crop cultivation.

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Table 1 Rainfall runoff and soil erosion under different treatments in Nagpur mandarin orchard$^{\#}$

Treatments	Rainfall runoff (mm)				
	*W $^{\#\#}$(24.7)	**PRM (12.0)	$^{+}$M (726.0)	^{x}POM (36.8)	Yearly (799.5)
ST	3.6^{c}	0	339.0^{c}	4.4^{c}	347.0^{c}
CT	1.4^{b}	0	282.0^{b}	1.9^{b}	285.3^{b}
ST + GM	0^{a}	0	286.3^{b}	0^{a}	286.3^{b}
CT + GM	0^{a}	0	227.0^{a}	0^{a}	227.0^{a}
WCP	5.9^{d}	0	426.0^{d}	7.6^{d}	439.5^{d}
	Soil erosion (t/ha)				
	*W	**PRM	$^{+}$M	^{x}POM	Annual
ST	0.04^{c}	0	5.77^{c}	0.08^{c}	5.89^{c}
CT	0.03^{b}	0	4.79^{b}	0.02^{b}	4.84^{b}
ST + GM	0^{a}	0	4.71^{b}	0^{a}	4.71^{b}
CT + GM	0^{a}	0	3.95^{a}	0^{a}	3.95^{a}
WCP	0.2^{d}	0	7.75^{d}	0.14^{d}	8.10^{d}

ST: Staggered trench; CT: Continuous trench; GM: Grass mulch; WCP: Without conservation practice; *W: Winter, **PRM: Pre-monsoon, $^{+}$M: Monsoon, ^{x}POM: Post-monsoon; $^{\#\#}$ Average rainfall (mm) in respective duration; Data within a column followed by different letters differ significantly at P<0.05; Values within the years were statically at par.

Table 2 Organic carbon and available nutrients changes in soil under different treatments in Nagpur mandarin#

Treatments	OC (%)	Macronutrients (mg kg^{-1})			Micronutrients (mg kg^{-1})			
		N	P	K	Fe	Cu	Zn	Mn
ST	-0.06^{b}	+1.10^{b}	+0.07^{b}	+1.02^{b}	-0.12^{b}	+0.07^{b}	-0.06^{b}	-0.11^{b}
CT	-0.05^{c}	+1.30^{c}	+0.08^{c}	+2.10^{c}	-0.10^{c}	+0.06^{c}	-0.06^{c}	-0.10^{c}
ST + GM	+0.04^{d}	+3.36^{d}	+0.27^{d}	+3.07^{d}	-0.06^{d}	+0.03^{d}	-0.04^{d}	-0.07^{d}
CT + GM	+0.07^{e}	+3.61^{e}	+0.30^{e}	+3.01^{e}	-0.07^{e}	+0.03^{e}	-0.03^{e}	-0.04^{e}
WCP	-0.07^{a}	+0.70^{a}	+0.05^{a}	+1.70^{a}	-0.14^{a}	+0.07^{a}	-0.07^{a}	-0.15^{a}

Data within a column followed by different letters differ significantly at $P<0.05$; Values within the years were statically at par

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Table 3 Yield and quality of fruits and water use efficiency under different treatments in Nagpur mandarin #

Treatment	Yield parameter			RWUE (kg/m^3)	IWUE (kg/m^3)	Fruit quality parameters			
	No. of fruits/ plant	Fruit weight (g)	Total yield (t/ha)			Juice content (%)	Total soluble solids (^{0}Brix)	Acidity (%)	Ascorbic acid (mg/100 ml juice)
ST	508^b (272^d)*	93.32^b	13.18^b	1.64^b	7.74^b	36.55^b	7.21^b	7.57^d	29.04^b
CT	558^c (230^c)	96.82^c	15.02^c	1.87^c	9.52^c	37.22^c	7.55^c	7.32^c	29.65^b
ST + GM	601^d (203^b)	108.31^e	18.10^d	2.26^d	13.33^d	41.31^d	8.18^e	6.85^a	29.88^c
CT + GM	690^e (104^a)	102.54^d	19.66^e	2.45^e	16.00^e	43.06^e	7.98^d	7.11^b	30.24^d
WCP	504^a (305^{ab})	91.71^a	12.84^a	1.60^a	7.18^a	34.31^a	6.87^a	7.80^e	28.17^a

Data within a column followed by different letters differ significantly at $P<0.05$; Values within the years were statically at par.