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Research paper

Rainwater, soil and nutrients conservation for improving productivity of citrus orchards in a drought prone region

P. Panigrahi[a,*], A.K. Srivastava[b], D.K. Panda[a], A.D. Huchche[b]

[a] ICAR-Indian Institute of Water Management, Bhubaneswar-23, Odisha, India
[b] ICAR-Central Citrus Research Institute, Nagpur-10, Maharashtra, India

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ABSTRACT

The abundant surface runoff along with top fertile soil in rainy season, followed by sub-optimal soil water content (SWC) in root zone of the plants during post-rainy period is one of the major causes of low productivity and decline of citrus orchards in tropics. Keeping this in view, a study was conducted for seven years to evaluate the effects of different rainwater conservation techniques (RCTs) on runoff, soil and nutrients losses and yield of citrus orchard in Vertisols under a sub-humid tropical climate of central India. The RCTs: staggered trench (ST) and continuous trench (CT) with and without grass mulch (GM) were imposed in runoff plots (350 m^2 area) with 14 citrus plants across the slope (12%) and their performances were compared with without conservation measure (WCM) treatment. All the RCTs were effective in conserving rainwater, soil and nutrients (N, P, K, Fe, Mn, Cu and Zn), which imparted a favourable response on vegetative growth, leaf nutrient content, fruit yield and fruit quality of citrus plants. However, CT + GM produced the best response, conserving 49% runoff and 51% soil compared with WCM in the orchard. The available nutrients and organic carbon content in soil were significantly improved in mulched plots. The runoff generated made linear relations (R^2 = 0.82–0.91) with rainfall amount in treated plots, whereas this relationship was exponential (R^2 = 0.89) in WCM plot. However, the quantity of runoff made the linear relations with soil loss in both treated plots (R^2 = 0.76–0.89) and WCM (R^2 = 0.93). The rates of transpiration, photosynthesis and stomatal conductance of leaf and leaf water use efficiency of the citrus plants were higher under higher available SWC in CT + GM. The CT + GM produced 65% higher fruit yield with better quality fruits (higher juice content, TSS and ascorbic acid content with lower acidity) using 32% less irrigation water, resulting in 65% improvement in rainwater productivity and 143% improvement in irrigation water productivity compared with WCM. Citrus production with CT + GM was also found economically superior to other treatments, generating more annual net income (INR 125480 ha^{-1}) with higher benefit-cost ratio (3.1). Overall results of this study demonstrates that the conjunctive use of CT and GM could conserve substantial rainfall runoff, soil and nutrients, resulting higher yield and water productivity using less irrigation water in citrus orchard in clay soil.

1. Introduction

Citrus is the most widely cultivated fruit crop in world (Ladanyia, 2008). As an evergreen perennial fruit crop, citrus requires adequate water and nutrients for its annual life cycle (Davies and Albrigo, 1994). Deficiency of either water or nutrients reduces the plant growth and fruit yield and causes the permanent decline of citrus orchards (Ghosh, 2007).

Availability of water becomes a major constraint to citrus production globally (Singh and Srivastava, 2004). The problem of water scarcity is more acute in tropical and sub-tropical regions where rainfall is seasonal. In these regions, the loss of rainwater as runoff in rainy season (monsoon period) and plant water stress caused by inadequate soil water content (SWC) in root zone during post-monsoon period is a common trend in citrus orchards. Moreover, the loss of bulk amount of top fertile soil through surface runoff not only reduces the orchard efficiency of citrus groves, but pollutes the surface water bodies in the regions (Huchche et al., 1999). In that scenario, soil and water conservation in orchards through rainwater harvesting is essential for sustainable citriculture.

Rainwater harvesting *in situ* through mechanical measures (bunds and trenches) is suitable for the areas having land slope less

* Corresponding author.
E-mail addresses: pravukalyan@rediffmail.com, pra73_nag@yahoo.co.in (P. Panigrahi).

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than 15% (Suresh, 1997). Moreover, mulching is an effective *in situ* soil water conservation practice in crop production. Mulches could improve the yield and quality of the produces by reducing plant water stress, creating favourable soil temperature and controlling weeds in crop fields (Kasirajan and Ngouajio, 2012). Commonly used mulches are synthetic (polyethylene) and organic (leaves, straws, grass, etc) in nature. Synthetic mulches are used to conserve soil water *in situ* during post-rainy season, whereas organic mulches could improve the soil water content by conserving rainfall runoff during rainy season and reducing evaporation from soil in post-rainy period. Therefore, the use of *in situ* rainwater harvesting technique alone or in combination with mulch may be one of the potential options for sustaining citrus cultivation in water scarce regions.

Previous researchers had emphasized on quantification of runoff, soil and nutrients loss and the agronomic strategies to conserve those in citrus orchards. Nishimura et al. (2002) studied the nitrogen and phosphorus concentration in runoff from citrus grove and concluded that the rainfall pattern widely changed the runoff characteristics and concentrations of N (25–45 mg L^{-1}) and P (0.1–0.8 mg L^{-1}) in runoff. He et al. (2004) quantified the transport of heavy metals in surface runoff from citrus fields and concluded that annual loads of dissolved metals in the runoff varied widely among the years and their concentrations in the surface runoff were associated with their accumulation in the soils. Zhang et al. (2004) studied the water quality (NH_4, NO_3, P and heavy metals) in drainage ditches within citrus groves of Florida, USA and indicated that nutrients and heavy metals in runoff was significantly varied with season and highly influenced by fertilizer application. Cerdà et al. (2009) quantified the soil and water losses from newly planted citrus orchards growing on sloped (8–14%) soils in the western Mediterranean basin through rainfall simulation studies and observed that soil erosion rate was 2.4 Mg ha^{-1} h^{-1} with sediment concentration of 10.4 g L^{-1} under 5-year return period rainfall. They concluded that the soil erosion rates in new citrus orchards on slopes are neither tolerable nor sustainable. The studies conducted by Wang et al. (2010) on effects of various alley crops (*Paspalum notatum*, *Hemerocallis citrina*, *Arachis hypogaea*) on soil and nutrient losses through surface runoff in young citrus orchards on 15–32% slope indicated that all the alley crops were effective in trapping the soil and nutrients with best performance under *Paspalum notatum*. Liu et al. (2012) evaluated the effects of straw mulch on surface runoff and soil erosion with that under conventional treatment (without mulching) for 2 years in citrus orchards on sandy soil with 15% slope. They reported that straw mulch reduced runoff volume, sediment yield and nutrients (N and P) losses significantly without affecting the fruit yield and fruit quality of citrus plants compared with that in conventional treatment.

Acid lime (*Citrus aurintofolia* Swingle), one of the commercial citrus cultivars, is mainly cultivated in tropical and sub-tropical regions of world. The fruit is rich in ascorbic acid (vitamin C). India is the top most acid lime producing country in world with total annual production of 2.83 M t from 0.28 M ha (NHB, 2014). The crop is predominantly grown in cracking clay (35–60%) soil (Vertisols) in rainfed eco-region of central India. The uneven distribution of rain in space and time in conjunction with high clay content in soil causes abundant runoff and soil erosion from the orchards during monsoon season (June–September). The sub-optimal SWC in root zone of the plants during post-monsoon period causes low productivity and decline of citrus orchards (Huchche et al., 1999; Panigrahi et al., 2009). Supplemental irrigation in critical stages of the crop (flowering, fruit setting and fruit growth) during January–June using groundwater is a common practice to improve yield of citrus in this region. The area under the crop is exponentially increasing each year due to its favourable production economics and suitability in the region (Gangwar et al., 1997). However, in recent years, limited irrigation water availability caused by overexploitation of groundwater becomes a threat to citrus production in central India (Singh and Srivastava, 2004). The introduction of drip irrigation has encouraged the establishment of citrus orchards on sloppy ($10–15^0$ slope) and undulating lands in large scale which are prone to soil erosion and land degradation in this region. In this scenario, adoption of suitable soil and water conservation measures could improve the soil fertility and fruit yield with reduced irrigation water supply in citrus orchards.

Grass mulch (GM) had proved its effectiveness in conserving *in situ* soil water in citrus orchards during post-monsoon period (Mohanty et al., 2002). In central India, nut grass (*Cyperus rotundus* L.) is easily available during post-monsoon season as it grows abundantly on upland areas and near the drainage channels of the region in monsoon season (Mohanty et al., 2002). The rainwater harvesting through bunds between the tree rows was not found suitable in citrus orchards in high clay content soil, as the standing water behind the bunds damages the tree stem by causing a dreadful dieses *'phytopthora'* in the crop (Huchche et al., 1999). Therefore, the rainwater harvesting through inter-row trenches (continuous trench/staggered trench) may be an option for water conservation in citrus orchards. However, the information on the effects of trenches alone or in combination with GM on rainwater, soil and nutrients conservation and productivity of citrus orchards in clay soils are limited worldwide. Moreover, the quantification of runoff and soil and nutrients losses in different seasons and annually through overland flow would give a better understanding of hydro-nutritional behaviour of citrus orchards under different conservation practices in the study region. This information could guide in planning and designing integrated water resource development and nutrient management strategies for sustainable production of citrus. With this background, an experiment was conducted for seven years to evaluate the response of citrus orchard to rainwater conservation in trenches with and without GM in a Vertisol under a hot sub-humid tropical climate of central India. The regressive models for prediction of runoff and soil loss from the citrus orchards were also developed and tested for this region.

2. Materials and methods

2.1. Experimental site

The field experiment was conducted at Research Farm of National Research Centre for Citrus, Nagpur (latitude 21^0 08′45″ N, longitude 79^0 02′15″ E, 340 m above mean sea level), Maharashtra state, India. The study was initiated in 10 year-old acid lime orchard (0.7 ha) with 5 m × 5 m plant spacing and same plantation was used for seven years (2004–2010) for the experiment.

The soil texture of the experimental orchard was clayey (31.65% sand, 23.6% silt, and 44.8% clay) with alkaline (pH, 8.1) nature. The basic infiltration rate of soil measured using double ring infiltrometer at the initiation of the study was 3.5 mm h^{-1}. The field capacity (−33 kPa) and permanent wilting point (−1500 kPa) of the soil were 24.8% and 15.7% (weight basis), respectively, with 1.2 g cm^{-3} bulk density. The organic carbon (OC) and available N, P, K, Fe, Mn, Cu and Zn in experimental soil (0–0.15 m) were 0.42%, 197.8 mg kg^{-1}, 25.8 mg kg^{-1}, 298.95 mg kg^{-1}, 15.7 mg kg^{-1}, 8.2 mg kg^{-1}, 0.8 mg kg^{-1} and 0.6 mg kg^{-1}, respectively. The experimental orchard had 12% land slope which was a representative of the citrus orchards of the region.

The weather data were collected at the meteorological observatory of the Research Centre which was present at 800 m away from the experimental site. The climate is characterized as sub-humid tropical, with hot and dry summers. Mean air temperature varies from 14.1 °C in winter to 35.7 °C in summer. However,