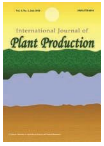

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Enhancing economic water productivity under on farm reservoirs in diversified rainfed cropping systems

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Abstract

A long term study was done to assess the impact of on farm reservoirs (OFR) on oil seed and cereal based cropping systems with vegetables (okra, tomato and carrot) in semi-arid alfisol of southern Telangana region. Two supplemental irrigation (SI) depths (30 and 50 mm) from OFR with raingun system were studied for assessing the water productivity and profitability of the technology in these cropping systems. Cropping system using sole crop of groundnut or maize, later was found to be more profitable (3 times) with 50 mm SI in 2 critical growth stages having annualized net benefit (ANB) of $ 971 - 998 / ha and economic productivity (EP) of 31 Cents / m^3 under different capacities of OFR (500-1500 m^3). In rainy season with single filling of OFR and deficit irrigation of 30 mm SI, maize+tomato was found to be more profitable (ANB: $ 1659 - 2325 / ha and EP: 37 - 51 Cents / m^3) as compared to sole crop or with okra. During rainy season and post-rainy season with second filling of OFR at SI depth of 30 mm, maize+tomato+carrot was the most profitable option (ANB: $ 2544 - 3012 / ha and EP: 37 - 45 Cents/ m^3) as compared to any other combination of the crops. The study revealed that the best economical crop combination under deficit irrigation of 30 mm will make the rainfed agriculture more remunerative with OFR technology with efficient use of surface water.

Keywords: On farm reservoirs; Supplemental irrigation; Economic productivity; Cropping system; Rainfed agriculture.

Introduction

Food production for a growing world population would increase the global water demand. 80% of the world's physical agricultural area is covered under rainfed system and contributes 62% of the world's staple food (FAOSTAT, 2005). Farm lands of 93% of Sub-Saharan Africa, 87% of Latin America, 67% of Near East and North Africa, 65% of East Asia and 58% of South Asia are rainfed (FAO, 2002a). Most countries depend primarily on rainfed agriculture for their grain food. Rainfed agriculture constitutes 55% of total net cultivable area in India and contributes to production of major coarse cereals, pulses and oil seeds. The environment of rainfed agriculture is enrolled with regular climate constraints like long dryspells, high intensity rainfall, high evaporation losses, soil degradation, etc. Moreover the annual average rainfall varies from less than 100 mm to 2500 mm in different rainfed agro-ecological regions of the country. Its distribution is erratic with CV varying from 30 to 80% during crop growth period which varies in both space and time. The present level of land productivity in rainfed agriculture in India is about 1 t/ha, however, globally it varies from 1-2 t/ha (FAO, 2002b). Therefore, all the above vagaries of the climate necessitates for immediate measures towards adaption of rainwater harvesting technologies for climate resilience in rainfed agriculture to manage the drought. Rainwater harvesting technologies like check dams, drop spillways, gabion structures, percolation tanks, sunken pits, etc. have been implemented across the rainfed regions in India as a drought mitigation measure in the watershed programmes. These technologies have resulted in the increase of recharge potential of shallow wells and tube wells. However, in the hard rock areas and long distances for access to water by the farmers in the watersheds, on-farm reservoirs (OFR) are the best option available for them to harvest rain water.

Rainwater harvesting is the collection and storage of excess runoff generated from small scale farmers land, ephemeral streams and hill slopes in rainy season for productive purposes (Wang et al., 2011; Kahinda et al., 2007; Ngigi et al., 2005). Small and marginal farmers with farm holding size of 1-2 ha constitute 80% of total farmers engaged in agricultural activities in India (Dev, 2012). Enhancing the water productivity in rainfed areas using supplemental small-scale irrigation is an important tool to increase green water flows (Fraiture et al., 2007). Many researchers around the world mentioned that, the rainwater harvesting concept has become key component in production technology to enhance livelihoods of rainfed farmers and reduce the yield gap between irrigated and rainfed agriculture with water scarcity under changing climate conditions (Oweis and Hachum, 2006; Gunnell and Krishnamurthy, 2003; Pandey et al., 2003).

The optimal design of rainwater storage structure, catchment command area ratio for giving supplemental irrigation to different cropping systems, depends on runoff potential of farm and the amount of water that is needed for supplemental irrigation at critical stages of rainy season crops and deficit irrigation to vegetable and post-rainy season crops. A challenge in design and construction of on-farm water storage structures is to minimize water losses (mainly due to seepage and evaporation) by way of lining (Ngigi et al., 2005). Evaporation rate and water spread area directly relates to evaporation losses and it also depends on type of soil, climate and underlying formation material. The limited runoff collected in OFR may not allow full irrigation in rainfed conditions but it permits supplemental irrigation to mitigate long dryspells during critical stages of most rainfed crops. Excellent responses to supplemental irrigation have been reported from several locations (Gunnell and Krishnamurthy, 2003). The yield responses of crops to supplemental irrigation in different locations indicated that one supplemental irrigation at the critical stages of crop growth considerably increased crop yields (Singh and Khan, 1999).

Efficient use of limited water available in the OFRs requires crop diversification for more profits to the farming community. Across the world, rainfed farming communities require localized storage of run off water and the efficient methodology of water application to mitigate the long dry spells as well as to promote the on farm water conservation protecting the land erosion and nutrient losses. Maize and groundnut are widely grown under rainfed conditions in south Asian and African countries. The information on catchment command area ratio, runoff coefficients for on farm rainwater harvesting on cropping system approach with net water availability, could be supported with supplemental irrigation. Different storage capacities of OFRs are seldom available for the design of the structures. Therefore, a systematic methodology and economic assessment under widely prevailing cropping system approach is presented in the paper.

Material and Methods

Study area and climate

The field experiments were conducted from 2008 to 2015 in model rainwater harvesting through OFR in Gunegal Research Farm (GRF) of ICAR-Central Research Institute for Dryland Agricultural (CRIDA), Hyderabad, Telangana, India. The farm is located at 17º 2' N and 78º 40' E with mean sea level of 621 m. The daily climate data on rainfall, maximum and minimum temperature, solar radiation, relative humidity and wind speed were recorded from an automated weather station (AWS) installed at the farm. The average annual and seasonal rainfall of the study area is 701.87 and 478.05 mm, respectively. The average temperature of study area is 25.5 ºC with average minimum and maximum of 8.94 and 42.06 ºC, respectively. The land is relatively flat with a slope of 2 per cent or less and it has deep to moderately deep well drained red soils. Soil texture was sandy clay loam with Sand (70.96%), Clay (22.32%) and Silt (6.72%) with soil depth varying from 50 to 100 cm.

Rainfall runoff relation in semi arid alfisols

A rainfall and runoff relation was developed by using 7 years data of observations in the research farm on rainfall and runoff collected in the OFR with different catchment areas varying from 1.5 to 14.5 ha. The water balance was worked out for both lined and unlined OFRs considering the evaporation and seepage losses in unlined OFR upto 2010 and only evaporation losses in lined OFR with HDPE 500 micron geo-membrane sheet.

Cropping systems

The long term data generated through field experimentation has been used in the present analysis for two cropping systems i) oil seed based with major crop of groundnut (GN) + okra (O)/ tomato (T) in rainy and carrot (C) in post-rainy seasons and ii) cereal based with major crop of maize (M)+O / T in rainy and C in post-rainy seasons which are commonly grown by the farmers of rainfed region in peninsular India. The experiments were conducted at the research farm with different crops and the yield data were obtained. During 2008-11, the groundnut based cropping system was tested and maize based cropping system was tested during 2012-15 under OFR imposing supplemental irrigation (SI) depths of 30 and 50 mm at two critical stages of the main crops, i.e., tasseling (50 DAS) and silking (70 DAS), grain filling and development (100 DAS) in M; flowering (40 DAS), peg initiation (50 DAS) and pod development (70 DAS) in GN and weekly scheduling (Table 1) of deficit irrigation of 30 mm for vegetables in the alfisols.

Table 1. Command area under different combinations of cropping systems under differential rainfall and capacities of OFR.

Seasons	Storage/SI depths	500 m^3 (CA=2.55)		750 m^3 (CA=3.8)		1500 m^3 (CA=7.6)		Storage/SI depths	500 m^3		750 m^3		1500 m^3	
		30 mm	50 mm	30 mm	50 mm	30 mm	50 mm		30 mm	50 mm	30 mm	50 mm	30 mm	50 mm
		Cropping system (Oil seed based)							Cropping system (Cereal Based)					
Rainy season		Acreage (ha)							Acreage (ha)					
	GN	0.8	0.5	1.16	0.7	2.23	1.34	Maize	0.8	0.5	1.16	0.7	2.23	1.34
	No of irrigation	2	2	2	2	2	2	No of irrigation	2	2	2	2	2	2
	Irrigation time (hrs)	4	4.11	5.7	5.8	10.03	11.01	Irrigation time (hrs)	4	4.11	5.7	5.8	10.03	11.01
	Acreage (ha)								Acreage (ha)					
	GN	0.25	*	0.4	-	0.84	-	Maize	0.3	-	0.4	-	0.84	-
	Okra	0.25	*	0.3	-	0.5	-	Okra	0.2	-	0.3	-	0.5	-
		No of irrigation							No of irrigation					
	GN	2	*	2	-	2	-	Maize	2	-	2	-	2	-
	Okra	5	-	5	-	5	-	Okra	5	-	5	-	5	-
		Irrigation time (hrs)							Irrigation time (hrs)					
	GN	1.25	-	2	-	4.2	-	maize	1.5	-	2	-	4.2	-
	Okra	3.125	-	3.75	-	6.25	-	Okra	2.5	-	3.75	-	6.25	-
		Acreage (ha)							Acreage (ha)					
	GN	0.4	-	0.5	-	0.84	-	Maize	0.4	-	0.5	-	0.84	-
	Tomato	0.1	-	0.2	-	0.5	-	Tomato	0.1	-	0.2	-	0.5	-
		No of irrigation							No of irrigation					
	GN	2	-	2	-	2	-	Maize	2	-	2	-	2	-
	Tomato	6	-	6	-	6	-	Tomato	6	-	6	-	6	-
		Irrigation time (hrs)							Irrigation time (hrs)					
	GN	2	-	2.5	-	4.2	-	Maize	2	-	2.5	-	4.2	-
	Tomato	1.5	-	3	-	8.75	-	Tomato	1.5	-	3	-	8.75	-
		Carrot							Carrot					
Post-rainy season (Second Filling)	Acreage (ha)	0.2	-	0.3	-	0.55	-	Acreage (ha)	0.2	-	0.3	-	0.55	-
	No of irrigation	7	-	7	-	7	-	No of irrigation	7	-	7	-	7	-
	Irrigation time (hrs)	3.8	-	5.73	-	10.91	-	Irrigation time (hrs)	3.8	-	5.73	-	10.91	-

* Insufficient storage to irrigate in one filling of pond with combination of GN and vegetable; CA=Catchment Area in ha.

OFR technology

Three dug out OFRs having top dimensions of 17×17×3 m, 20×20×3 m and 26×26×3 m for the capacities of 500, 750 and 1500 m^3, respectively (considering suitability to small farm of less than 1.0 ha, medium farm of 2-4.0 ha and large farm of more than 4.0 ha, respectively in the rainfed areas) were considered in the present study with lining of HDPE 500 microns thick geo-membrane film. The structures were provided with inlet spill way, silt trap (1.5×1.5×1 m) and rectangular outlet (1×1 m). The depth of maximum storage was of 3 m with side slopes of 1.5:1. On an average the evaporation losses were observed at 3 mm/day in rainy season and 5 mm/day in post-rainy season. The net water availability for critical irrigation in different OFRs were calculated by reducing the evaporation losses up to the critical stage of the groundnut and maize. The yield data for rainfed as well as SI were considered for two irrigation depths of 30 and 50 mm. The details of SI, acreage and cropping systems under different capacities of OFRs are given in Table 1. It was observed that, there is a chance of two fillings of OFRs for three out of five years after lining in 2010. Similarly, there is a chance of single filling of the OFR, four out of five years. It indicates that, the risk level is 20% for single filling and 40% for two fillings of OFRs. Post-rainy season crop was grown only after second filling of OFR. In single filling, the water available is sufficient to provide two critical irrigations for groundnut and maize along with vegetables (tomato/okra) with 30 mm of irrigation depth weekly once.

Catchment-Command Area (CCA) Ratio

A 30 year seasonal rainfall data has been subjected to probability analysis by using Weibulls technique (Crichley and Siegert, 1991) as given below.

$$p = \frac{(m-0.375)}{(n+0.25)} \qquad (1)$$

p = probability % of m^{th} rank
m = rank of the observation
n = total number of observations

It is estimated that, the seasonal rainfall at 75 % probability of occurrence was 375 mm and taken as design rainfall (Reddy et al., 2012) for the experimental site. The average runoff coefficients and runoff efficiency were taken as 0.07 (7%) and 0.75 (75%) (micro-catchments) respectively for the alfisols which have good drainage, infiltration meeting the hydrological group B conditions. The catchment areas for 500, 750 and 1500 m^3 capacities of OFRs, are calculated by using the formula as given below:

$$Q = \frac{(A_{ca} \times RO_c \times RO_e \times R_d)}{1000} \qquad (2)$$

Where,

Q = OFR capacity, m^3
A_{ca} = catchment area, m^2
RO_c = runoff coefficient, (fraction)
RO_e = runoff efficiency, (fraction)
R_d = design rainfall, mm

The CCA ratios were calculated under different OFR capacities and cropping systems with different SI depths of 30 and 50 mm using equation 2 and the acreage as given in Table 1.

OFR construction and lining

The economics of OFR construction involves earth excavation, slope stabilization, digging of field channels, silt trap, inlet and outlet structures along with bund formation. Beside the earth excavation for digging of OFR, an extra of earth removal of 22%, 20% and 17% were added for 500, 750 and 1500 m^3, respectively. Based on the field experience of digging the OFR using machinery with big bucket having capacity of 1 m^3 can cost Rs. 30/m^3 as per the recent market prices of hiring the machinery. Lining of OFR with 500 micron HDPE black thick film is about Rs.100/m^2 plus labor charges for anchoring and laying of the film in the trench along the side bund of the OFR. The costs of the lining were: Rs. 30000, Rs.41500 and Rs.70000 for 500, 750 and 1500 m^3, respectively. The life of the lining film is taken as 5 years. The costs of the earth excavation were: Rs. 18300, Rs. 27000 and Rs. 52650 for 500, 750 and 1500 m^3 capacities of OFRs, respectively. These above fixed cost are annualized for 20 years of life of the structures by using the formula given below:

$$Annualized\ cost = p\frac{r(1+r)^{n}}{(1+r)^{n}-1} \quad (3)$$

Where,

P = loan amount, Rs
r = interest rate (9%)
n = amortization period, years.

Water Application system cost

The cost of the water application system was estimated using two rainguns with one full circle and one half circle at an operating head of 30 m with 50% over lapping in the spray pattern and the discharge rate of 150 lph. One full circle would cover an area of 1258 m^2 by Hidra model of raingun. The life of the system was taken as 15 years for the 5hp monoblock diesel pumpset, HDPE pipes with accessories for 1 ha irrigation at a time (50 HDPE pipes at 4kgcm^{-2}). A plot size of 100×100 m^2 was assumed for all calculations of irrigation cost. The system was operated on shifts immediately after meeting the irrigation depth criterion. The time of irrigation estimated for 30 and 50 mm depths were 2.5 hr and 4.2 hr, respectively. The total market price of the system was estimated as [**]Rs 80,000/-. It is proposed to run the system on custom hiring basis with 100% benefit on annualized cost with 9% bank interest rate for loan repayment by the entrepreneur. The annual operation and maintenance cost of the system was taken as 12% over the annualized cost of the system including transport, etc. It is presumed that the system will be in operation for 840 hrs in the field in a year taking care of rainy season and post-rainy season irrigation from the OFR or any other water source in a cluster of 5-6 villages. The unit irrigation cost of the system was arrived at Rs. 350/hr.

[**] Prevailing conversion rate of rupees (Rs.) in US dollars (Rs. 67=1 US $).

The cost of SI at two critical stages of crop growth at different levels of irrigation depths of 30 mm and 50 mm of water application was worked out as Rs 1900/ha and Rs 3204/ha, respectively under the custom hiring module using rainguns. It includes hiring charges of irrigation system and diesel cost with consumption of 0.5 l/hr of operation. On an average, the cost of the diesel was taken as Rs 60/litre.

Production economics

Cost of land use for OFR construction consists of production loss under rainfed conditions for the three selected volumes of 500, 750 and 1500 m^3 capacities. These losses are considered for GN and M only as these are the main crops grown under rainfed conditions. The area losses were estimated to be 0.03, 0.04 and 0.07 ha under 500, 750 and 1500 m^3 capacities of OFR, respectively. The corresponding net production losses were Rs. 150, 200 and 350, respectively for GN and Rs. 1182, 1576 and 2758 for M, which accounts for only 3-7% monetary loss. These values were considered for calculating annual net benefits and economic productivity for different cropping systems.

The selected crops GN, M, O, T and C were treated with 30 and 50 mm SI depths at 2 critical stages of the crop growth period. The average yields, costs of cultivation, market price are given in Table 2. In the present analysis, the cereal crop maize and oil seed crop, groundnut were taken as primary crops as commonly grown by the farmers of rainfed areas in southern region of India. The economic analysis was carried out in the combination of vegetables (O and T) with single filling and carrot in post-rainy season with second filling of the OFR. The analysis into the systems like monocrop M, M+O, M+T, during rainy season and M+C, M+O+C, M+T+C during rainy season and post-rainy season both spread over 2 seasons of the year, were carried out. Similarly, the second systems with oil seed crop, GN with the above combinations were tried in the experiment.

Table 2. Average yield and cost details of different crops under different irrigation depths.

Crops	Cost of cultivation (Rs/ha)	Present market price (Rs/kg)	Average crop yield (kg/ha)		
			50 mm	30 mm	Rainfed
Groundnut	23000	40	1200	875	700
Maize	25000	23	4600	3930	2800
Okra	40600	20	8500	5950	-
Tomato	61000	15	40000	28000	-
Carrot	35600	20	25000	17500	-

The sole crop of M and GN were experimented with both the SI depths of 30 and 50 mm at two critical stages (silking and tasseling, grain filling and development in M; flowering, peg initiation and pod development in GN). The combination of sole crop with vegetables like O and T were tested with 30 mm deficit irrigation from OFR as vegetable requires minimum 5-7 irrigations during its growth period. In the post-rainy season, C was grown with 7 irrigations of 30 mm from the OFR. The analysis was considered for three different capacities of 500, 750 and 1500 m^3. Under rainfed conditions, the average yields of GN and M are 700 and 2800 kg/ha with a cost of cultivation of Rs. 23000 and 25000/ha, respectively. In addition to the GN seed yield, the haulm of the GN added a benefit of Rs. 12500/ha under rainfed and Rs. 19000/ha under SI.

Economic productivity of different cropping systems were estimated under different SI depths for all the three OFR capacities. For estimating total water use for different cropping combinations, the effective rainfall at 75% probability of seasonal rainfall of 375 mm was considered by taking 57% of it as effective rainfall based on long term observations in the Alfisols. The SI depths applied for different crops as per Table 1 were also added to the effective rainfall for estimating economic productivity which is the ratio of annualized net benefit (Rs/ha) and total crop water use (m^3) by the system.

Results and Discussion

Rainfall and Runoff Relationship (RRR)

The relationship between rainfall and runoff in rainfed alfisols was developed through the regression analysis by using the data collected during experimental period and presented in Figure 1. From the all years of experimental data, it was observed that, there was a quadratic relation between rainfall and runoff with a coefficient of R^2=0.82 in rainfed alfisols. Though the alfisols has high infiltration characteristics, the soils have the crust formation immediately after sowing having the runoff coefficient of 2 to 12% depending upon the antecedent moisture conditions of the catchment area and the rainfall intensity and its duration.

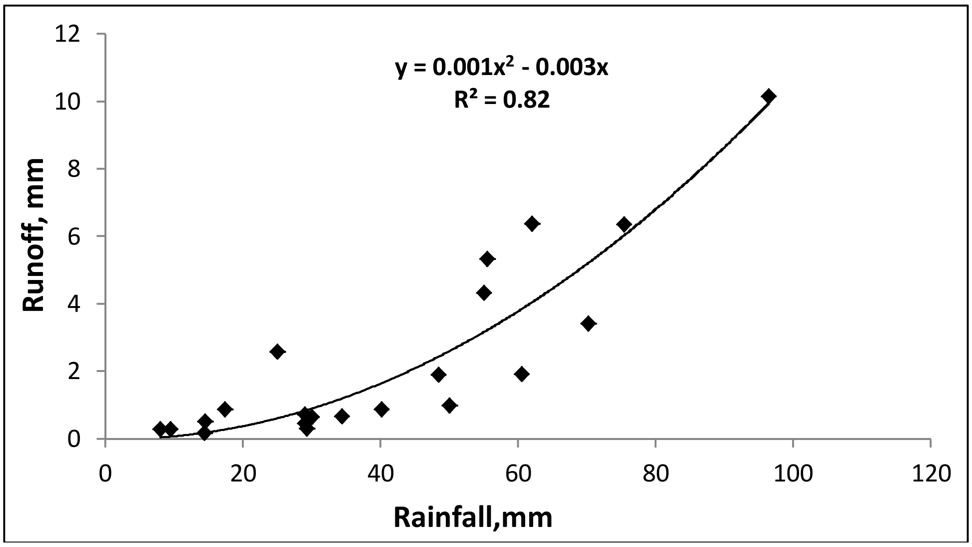

Figure 1. Rainfall and runoff relationship in rainfed alfisols during experimental period.

Irrigation scheduling of different cropping systems

Under three different capacities of OFRs with two levels of SI depths, an irrigation schedule was calculated based on the net water availability in the OFR at the time of critical stages of sole crop and for different combinations of O, T in rainy season and C in post-rainy seasons and the results are presented in Table 1.

For sole oilseed based cropping system, the GN can be irrigated in 0.8 and 0.5 ha with the SI depths of 30 and 50 mm for 4 and 4.11 hrs of irrigation time, respectively with the designed rain gun irrigation system under the OFR capacity of 500 m^3 with two critical irrigations. Similarly, for 750 m^3 capacity of OFR, GN can be grown in 1.16 and 0.7 ha with 30 and 50 mm critical irrigation depths for 5.7 and 5.8 hrs, respectively. For 1500 m^3 capacity of OFR, the areas under GN cultivation could be 2.23 and 1.34 ha with irrigation depths of 30 and 50 mm for 10.03 and 11.01 hrs of irrigation duration, respectively.

For the combination of GN and O, the areas under which GN could be irrigated with net available water are 0.25, 0.4 and 0.84 ha with 30 mm SI depth for the irrigation time of 1.25, 2.0 and 4.2 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively. The areas under O are 0.25, 0.3 and 0.5 ha with five irrigations for duration of 3.13, 3.75 and 6.25 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively in combination with GN.

For the combination of GN and T, the areas under which GN grown are 0.4, 0.5 and 0.84 ha with 30 mm SI depth for the irrigation time of 2.0, 2.5 and 4.2 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively. The areas under T are 0.1, 0.2 and 0.5 ha with six irrigations for duration of 1.5, 3.0 and 8.75 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively in combination with GN.

In post-rainy season, C crop was grown in addition to the above combination of crops in rainy season with the second filling of OFR. The area under C are 0.2, 0.3 and 0.55 ha with 30 mm SI depth and seven irrigations with duration of 3.8, 5.7 and 10.9 hrs under 500, 750 and 1500 m^3 OFR capacities, respectively. Except sole crop, the combination of crops are not possible with 50 mm level of irrigation depth under the OFRs looking into the water requirements of vegetables like O and T in rainy season and C in post-rainy season and the evaporative demand in the rainfed areas of semi-arid tropics.

Similar schedules were calculated for the M based cropping system with similar combination of vegetables like O, T in rainy season and C in post-rainy season (Table 1).

Catchment command area (CCA) ratio

The catchment areas estimated for alfisols with 7% average run-off coefficient are 2.55, 3.8 and 7.6 ha for 500, 750 and 1500 m^3 OFR capacities, respectively. In both the cropping systems with GN and M as sole crops, the CCA ratio was found to be same with progressive increase in OFR capacities from 500 to 1500 m^3. In 30 mm SI depth, both GN and M have the CCA ratio of 3.19-3.41 and it was 5.1-5.67 at 50 mm SI depth (Figure 2). In the GN-based cropping system, when C is planned in post-rainy season after second filling of the OFR, the minimum of CCA ratio was observed when both O/T in rainy season and C in post-rainy season are considered with 30 mm SI depth (Figure 2) and it ranged from 2.13 to 2.28. The CCA ratio of growing sole GN at 50 mm SI depth was similar to GN+vegetables (O/T) at 30 mm SI depth, which indicates that crop diversification benefits can be fetched using OFR. The same holds true for the M based cropping system too. While comparing both the cropping systems, the CCA ratio in GN+O/T+C under 30 mm SI depth (CCA=2.13-2.28) is less than M based system (CCA=3.64-4.02) as evidenced by 71.43, 76, 76.19% increase in M based cropping system over the GN in OFR capacities of 500, 750 and 1500 m^3, respectively (Figure 2).

The analysis of CCA ratio under different capacities of OFR indicates that for low sloppy land (less than 5%) particularly in the alfisols, the run-off coefficients are less, however, the CCA values may further decrease with increase in run-off coefficients in the moderate to high sloppy lands (more than 5%) in alfisols.

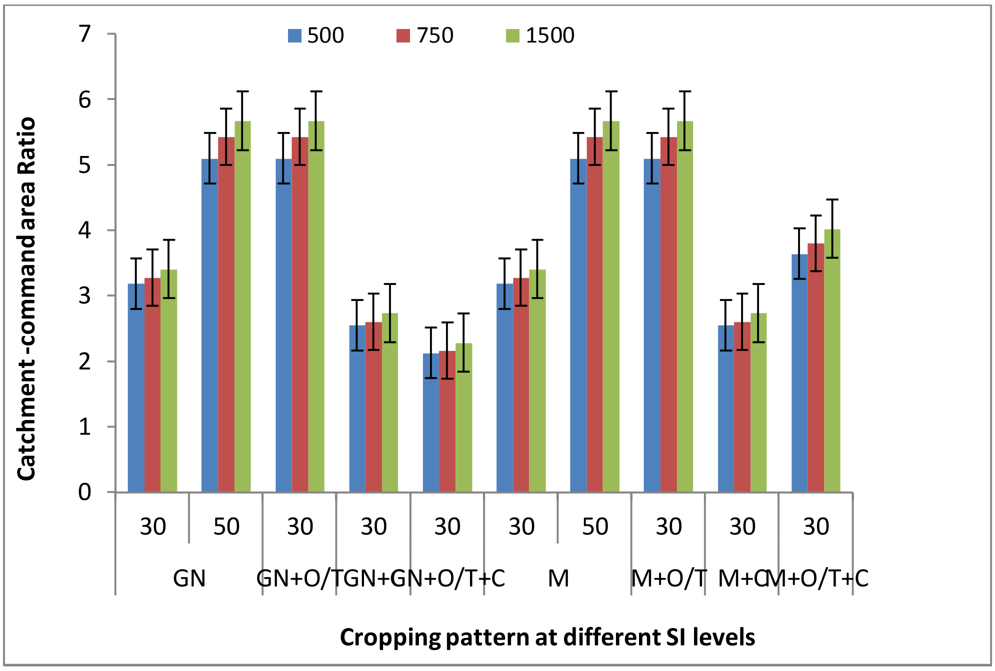

Figure 2. Catchment command area ratio for different cropping systems and OFR capacities.

Production dynamics under different SI

Average yield of the GN obtained were 1200 and 875 kg/ha under different irrigation levels of 50 and 30 mm, respectively. The corresponding rainfed yield was 700 kg/ha with average seasonal rainfall of 436 mm. For M, average yields were 4600 and 3930 kg/ha under 50 and 30 mm critical SI depths, respectively. The rainfed M yield was 2800 kg/ha. The average yields of O with five irrigations were 8500 and 5950 kg/ha under 50 and 30 mm depths, respectively (Table 2). For T, the average yields were 40000 and 28000 kg/ha under 50 and 30 mm depths, respectively with six irrigations. The post-rainy season C yields were 25000 and 17500 kg/ha under 50 and 30 mm depths of irrigation, respectively for seven irrigations.

SI showed a large potential to improve yield potential especially in semi-arid cropping systems with uneven rainfall variability and high intra seasonal dry spell occurrence (Pandey et al., 2003; Barron, 2004). Research results in Tigray (Araya et al., 2011) also showed that more than 80% of yield reduction and more than 50% of crop failure can be avoided when SI is employed during the critical growth stages of the crops. The importance of SI for different crops at critical growth stages is supported by various researchers in the world. In similar way SI was stated as one of the good crop water management options aimed to improve water availability and hence increase transpiration (Rockstorm and Barron, 2007). SI is a key strategy, still underused, for unlocking rainfed yield potential and water productivity (Rockstorm et al., 2010).

Economic assessment of OFR technology

The economic analysis has been done for two situations, viz., single filling of OFR with a risk of 20% (4 successful events out of 5 years) in rainy season and second filling of OFR with a risk of 40% (3 successful events out of 5 years) in post-rainy season in semi-arid regions with major soil group of alfisols. With the single filling in the oil seed based cropping system, three combinations using GN as a sole crop with 30 and 50 mm SI depths at two critical stages and GN+O or GN+T with the vegetable in the rainy season with the SI depth of 30 mm was considered. Similarly, with the second filling of OFR, the carrot crop was taken in addition to the above combinations in post-rainy season with 30 mm SI depth.

While comparing the annualized net benefit with single filling of OFR in rainy season, it was observed that the net benefits with GN as a sole crop ranged from Rs. 11672 to 13156 per ha under the SI depth of 30 mm (Figure 3). However, there was an increase in the net benefit ranging from Rs. 21297 to 22818 per ha under the SI depth of 50 mm. Under the sole GN crop system, though the area increased (Table 1) with 30 mm SI depth, the response of crop yield is much more under 50 mm SI depth with less area giving increased net benefits. Under the cropping system of GN+O with 30 mm SI depth, the net benefits ranged from Rs. 24435 to 29249 per ha which is almost two times more than the net benefits with sole crop of GN. When T is taken instead of O, the net benefits ranged from Rs. 74301 to 128484 per ha which is five times more than the GN sole crop with the same SI depth of 30 mm. Also, when GN+T are compared with GN+O, the net benefits were increased by 2-5 times under different capacities of OFR with the same SI depth. Therefore, under oil seed based cropping system, GN+T is the best option followed by GN+O in the rainy season with the single filling of OFR.

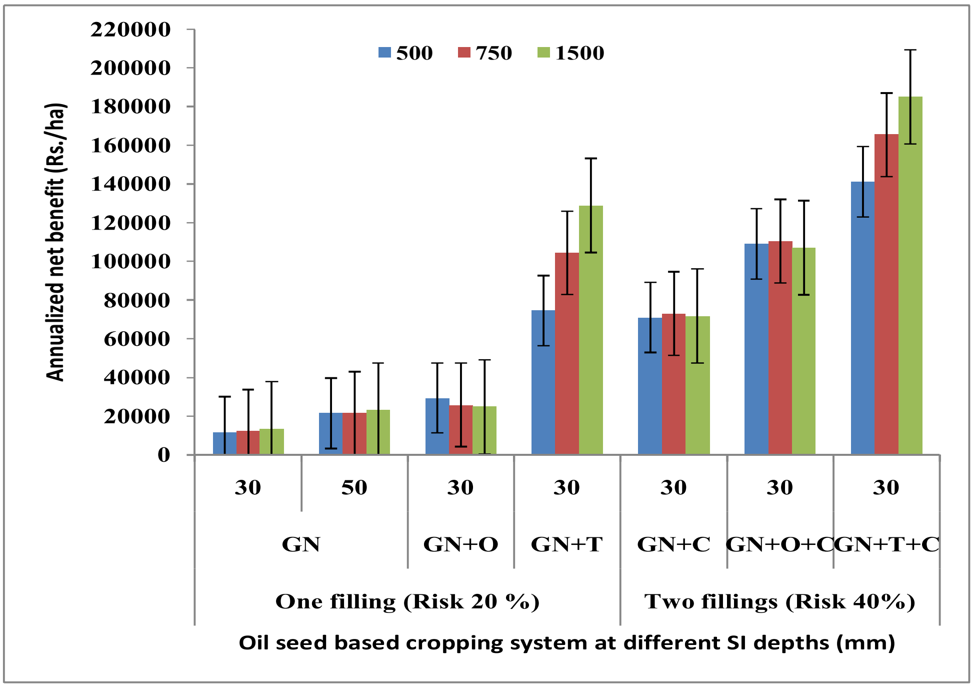

Figure 3. Annualized net benefits from oil seed based cropping system under different irrigation depths and OFR capacities.

In both the rainy and post-rainy seasons with second filling of OFR, the analysis was done for GN+C, GN+O+C, GN+T+C with the 30 mm SI depth and observed net benefits ranged from Rs. 70858 to 71312 per ha, Rs. 106693 to 108777 per ha and Rs. 140958 to 184590 per ha, respectively. It indicates that GN+T+C was the most profitable cropping system with two fillings of the OFR followed by GN+O+C.

In the cereal based cropping system with M as sole crop, net benefits ranged from Rs. 58011 to 58118 per ha, Rs. 65910 to 66893 per ha under 30 and 50 mm SI depths, respectively (Figure 4). With the introduction of O in the cropping system, the net benefits ranged from Rs. 49547 to 52210 per ha under 30 mm SI depth which is less than the sole crop as M. The decreases in net benefits were observed due to reduction in the cropping area and yield.

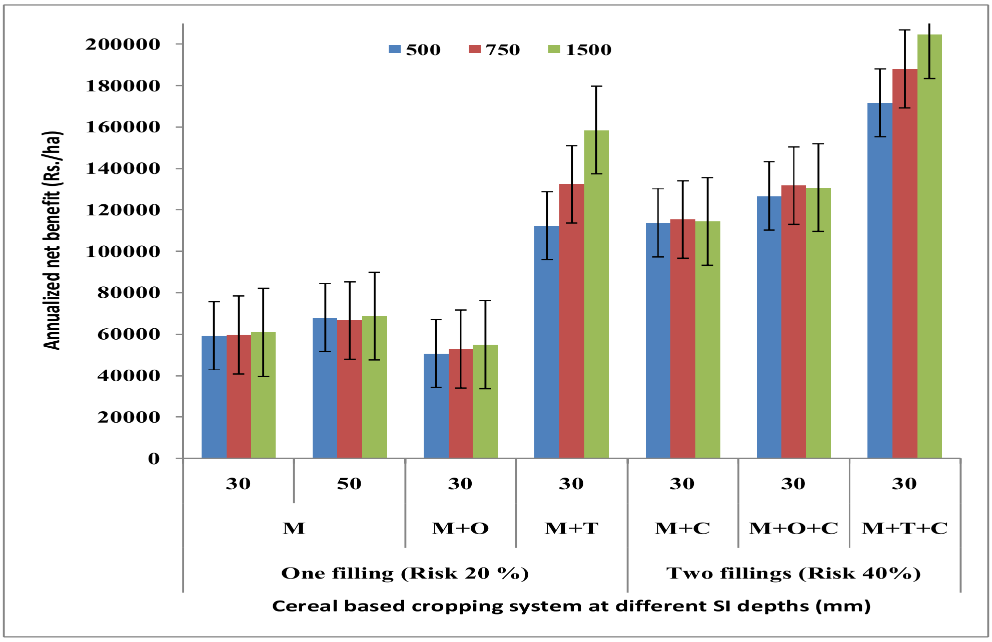

Figure 4. Annualized net benefits from cereal based cropping system under different irrigation depths and OFR capacities.

With the second filling of OFR, the net benefits ranged from Rs. 111731 to 113780 per ha, Rs. 125561 to 130143 per ha and Rs. 170434 to 201784 per ha for M+C, M+O+C and M+T+C, respectively. It indicates that M+T+C were the most profitable cropping system with two fillings of the OFR followed by M+O+C with 30 mm SI depth.

The economic productivity (EP) for different cropping systems were calculated by considering the total water used per ha by the system from the OFRs along with effective rainfall of 2138 m^3 and the annualized net benefits, Rs/ha of the cropping systems under different OFR capacities and SI depths of 30 and 50 mm. In GN based cropping system, the sole GN has the EP ranging from 4.26 to 4.80 Rs/m^3, 6.79 to 7.27 Rs/m^3, respectively under 30 and 50 mm SI depths (Figure 5). EP in GN+O declined from 6.90 to 5.77 Rs/m^3 as the capacity of OFRs increased. GN+T had the maximum EP over GN+O and sole GN ranging from 16.37 to 28.31 Rs/m^3.

When both farming seasons are taken into account with C in post-rainy season, GN+O/T in rainy season with 30 mm SI depth, GN+T+C had the maximum EP ranging from 21.23 to 27.81 Rs/m^3 over the OFR capacities of 500-1500m^3 followed by GN+O+C and GN+C with a declining trend as the OFR capacity increases.

However, the other cropping systems with M under different capacities of OFRs and SI depths, the EP increased 5 times more than that of sole GN based system (Figures 5 and 6) in rainy season except in the case of M+O with 2-fold increase. The maximum EP with progressive increase from 24.5 to 34.33 Rs/m^3 was obtained in case of M+T in rainy season with 30 mm SI depth (Figure 6). The EP was almost constant (23.09-23.52 Rs/m^3) in case of M+C with both cropping seasons under two fillings of OFR; however, M+T+C had the maximum EP (25.68-30.4 Rs/m^3) as compared to M+O+C and M+C when both the seasons are considered.

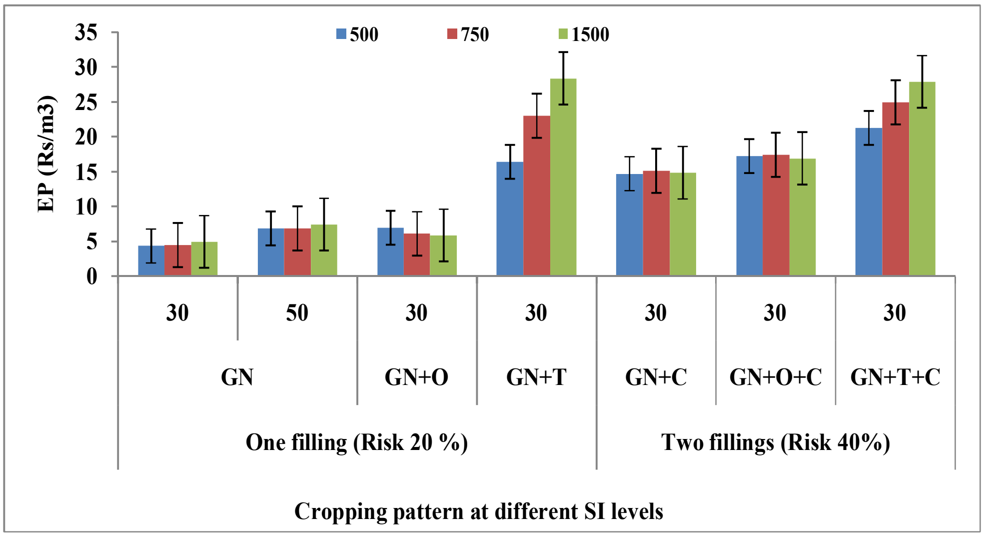

Figure 5. Economic productivity of oil seed based cropping system under different irrigation depths and OFR capacities.

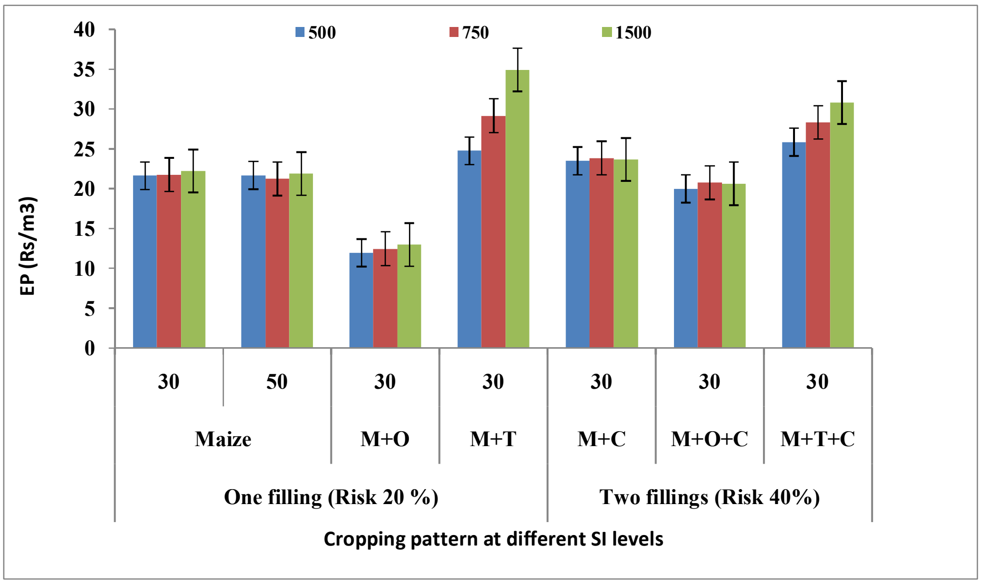

Figure 6. Economic productivity of cereal based cropping system under different irrigation depths and OFR capacities.

Conclusions

OFR technology with different capacities and crop diversification will lead to reduce the yield gaps between irrigated and rainfed. Due to changing climate and rainfall patterns, principles of rainwater harvesting through OFRs within the farmers fields has the potential of enhancing the economic productivity of different crops in the rainfed regions without exploiting the groundwater in hard rock regions like southern Telangana. Among the selected cropping systems with combination of different vegetables in rainy season and post-rainy season under two SI depths of 30 and 50 mm, the maize based cropping system with vegetables particularly tomato in rainy season and carrot in post-rainy season was found to be more profitable with high economic returns to the farmers. SI depth of 50 mm was found to be more profitable in the sole crop of M and GN; however, SI depth of 30 mm is not sufficient to induce the crop response to the profitable yield in the soils like alfisols which are thirsty with low water holding capacity leading to underutilization of soil nutrients as per the requirement of the crop. But, in the case of crop diversification with vegetables, like O, T and C with 5-7 irrigations, 50 mm SI depth can't be supported with the limited water storage in the OFRs upto 1500 m^3. Besides improving the economic productivity, OFR contribute intangible benefits of controlling soil loss and the nutrients from the farmers' fields and the limitation is only the area loss for construction of OFR within the farm field to an extent of less than or equal to 10% upto the capacity of 1500 m^3.

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