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Agricultural Water Management 79 (2006) 280–292
Agricultural water management
www.elsevier.com/locate/agwat

Effects of winter crop and supplemental irrigation on crop yield, water use efficiency and profitability in rainfed rice based cropping system of eastern India

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Accepted 13 March 2005
Available online 24 May 2005

Abstract

Soil moisture availability is the main limiting factor for growing second crops in rainfed rice fallows of eastern India. Only rainfed rice is grown with traditional practices during the rainy season (June–October) with large areas (13 m ha^{-1}) remaining fallow during the subsequent dry season (November–March) inspite of annual rainfall of the order 1000–2000 mm. In this study an attempt was made to improve productivity of rainfed rice during rainy season and to grow second crops in rice fallow during dry (winter) season with supplemental irrigation from harvested rainwater. Rice was grown as first crop with improved as well as traditional farmers' management practices to compare the productivity between these two treatments. Study revealed that 87.1–95.6% higher yield of rice was obtained with improved management over farmers' practices. Five crops viz., maize, groundnut, sunflower, wheat and potato were grown in rice fallow during dry (winter) season with two, three and four supplemental irrigations and improved management. Sufficient amount of excess rainwater (runoff) was available (381 mm at 75% probability level) to store and recycle for supplementary irrigation to second crops grown after rice. Study revealed that supplemental irrigation had significant effect ($P < 0.001$) on grain yield of dry season crops and with two irrigation mean yields of 1845, 785, 905, 1420, 8050 kg ha^{-1} were obtained with maize (grain), groundnut, sunflower, wheat and potato (tuber), respectively. With four irrigations 214, 89,

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doi:10.1016/j.agwat.2005.03.001

78, 81, 54% yield was enhanced over two irrigations in respective five crops. Water use efficiency (WUE) of 13.8, 3.35, 3.39, 5.85 and 28.7 kg ha^{-1} was obtained in maize, groundnut, sunflower, wheat, potato (tuber), respectively with four irrigations. The different plant growth parameters like maximum above ground biomass, leaf area index and root length were also recorded with different levels of supplemental irrigation. The study amply revealed that there was scope to improve productivity of rainfed rice during rainy season and to grow another profitable crops during winter/dry season in rice fallow with supplemental irrigation from harvested rainwater of rainy season.

Keywords: Rainfed rice ecosystem; Dry season crop; Runoff recycling; Eastern India; Double crops

1. Introduction

Major part of eastern India (Assam, West Bengal, Jharkhand, Orissa, Chhattisgarh and eastern UP) receives abundance rainfall (1000–2000 mm) but it is confined within four southwest monsoon months (June–September). Most of it is not accessed and put into beneficial use before it evaporates or flows into sinks and goes off as runoff. As a result rainfed area of eastern India is mono-cropped with low productivity (1.4–1.9 t ha^{-1}), dominated by rice during rainy season only. During dry (winter) season such lands are mostly kept fallow because of scarcity of water. But the land can be brought under double cropping through proper utilization of carry-over residual soil moisture and by providing supplemental irrigation to second crops from harvested rainwater of rainy season (Rathore et al., 1996; Panigrahi et al., 2001; Kar et al., 2004a; Kar et al., 2004b).

Increased water use efficiency (WUE) of field crops was possible through proper irrigation scheduling by providing only the water that matches the crop evapotranspiration and providing irrigation at critical growth stages (Norwood and Dumler, 2002; Eck, 1984; Wang, 1987; Turner, 1987; Hunsaker et al., 1996; Wang et al., 2001). Quantifying the root length growth is also necessary for knowledge about water and nutrient extraction pattern of different crops at different depths, (Merril, 1992; Merril et al., 2002). Some earlier workers (Sarker et al., 2000; Zaman et al., 2000; Das, 2001; Prasad et al., 2000) attempted to increase productivity and cropping intensity of rainfed rice area of eastern India with supplemental irrigation. Much is known about the crop water use or water use efficiency of major crops like rice, wheat, sorghum at various agro-ecological conditions of India (Prihar et al., 1976; Hundal and De data, 1984; Singh and Sinha, 1987; Singh, 1989; Tyagi et al., 2000). But still actual water use and water use efficiency of some dry season crops in rice fallow of eastern India are to be studied to explore possibility of double cropping on such land.

In this study an attempt was made to increase the productivity and cropping intensity of rainfed lowland rice ecosystem of eastern India through (i) enhancing the productivity of rainfed rice on such land during rainy season with improved management practices, (ii) growing of second crops during dry/winter season by providing supplemental irrigation at critical growth stages from harvested excess water of rainy season.

2. Materials and methods

2.1. Experimental site

The mean monthly maximum temperature of the study area (Lat. 20°50′ N, long. 86′ E, height 139 m above m.s.l.) ranged from 46.2 °C in May to 29.4 °C in December. On the other hand, mean minimum temperature varied between 24.6 °C in July and 9.0 °C in December. The mean total annual rainfall was 1440 mm and 80% of which occurred during southwest monsoon period (June–September). The reference evapotranspiration of the region varied from 8.7 mm in May to 3.3 mm in December. The pH of the soils was slight acidic and no salt problem was detected in the soil profile. The organic carbon content of the soil was 0.60%. Available water capacity of the soils varied between 0.120 and 0.162 $m^3 m^{-3}$.

2.2. Management practices adopted in rice based cropping system

2.2.1. Management practices for growing rice (first crop) during rainy season

The rice (*Oryza sativa* L.) variety 'Lalat' (120 days duration) was grown during rainy season on 20th July 1999 and 19th July 2000 (two study years) following both improved and traditional farmers' management practices to visualize the enhancement of yield through improved practices over farmers' practices (experimental layout is given in Fig. 1). The farmers' practices consisted of broadcasting sowing, no control of pest and diseases, no intercultural operation or gap filling and application of basal dose of 30:30:0 fertilizer (N:P:K) etc. Whereas, under improved practices transplanting was done with the spacing of 20 cm × 15 cm and gap filling was done at 20 days after transplanting. Weed was

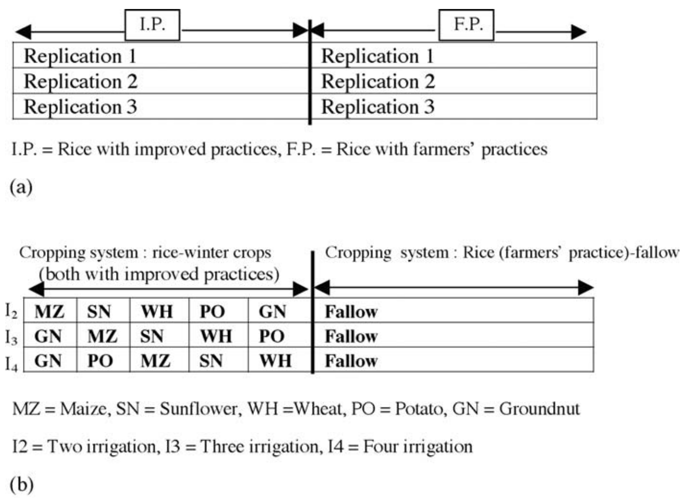

Fig. 1. (a) Layout of the experimental plot during rainy season. IP = rice with improved practices; FP = rice with farmers' practices. (b) Layout of the experimental plot during winter/dry season. MZ = maize; SN = sunflower; WH = wheat; PO = potato; GN = groundnut. I2 = two irrigation; I3 = three irrigation; I4 = four irrigation.

controlled through integrated weed management technique (Butachlor @ 1.5 l ha^{-1} at 5 days after transplanting (DAT) + one hand weeding at 35 DAT). Fertilizer was given in the ratio of 60:40:40 (N:P:K), 50%N and full dose of P and K were applied as basal and rest 50%N was applied during maximum tillering stage. Need-based plant protection measures were also taken.

2.2.2. Growing of second crops during subsequent dry (winter) season in rice fallow

The second crops were sown in the third week of November in two study years (1999–2000 and 2000–2001) as early as possible after harvesting rice to enable these to make full use of carry-over residual profile soil moisture. Five crops viz., maize (*Zea mays* cv. Novjyot), groundnut (*Arachis hypogea* L. cv. TMV-2), sunflower (*Helianthus annus* L. cv. BSH-1), wheat ((*Triticum aestivum* L. cv. Sonalika), potato (*Solanum tuberosum* L. cv. Kufri Jyoti) were grown with supplemental irrigation at critical growth stages (Table 1). The experiments were conducted in split plot design with main plots as irrigation treatments and subplots as crops (Fig. 1). There were three replications with the individual subplot size being 6 m × 4 m. The package of practices of growing the second crops in rice fallow is given in (Table 2). Plots were bordered to prevent runoff while irrigating the crops.

2.3. Soil water depletion studies

The soil water depletion was measured gravimetrically once a week from 0 to 0.15, 0.15 to 0.30, 0.30 to 0.45, 0.45 to 0.60, 0.60 and 0.90 to 1.20 m soil layers.

The actual water use (AWU) was estimated as per the equation:

$$\mathrm{AWU} = \mathrm{ER} + \mathrm{I} + \Delta S + \int_{t2}^{t1} F_x \,\mathrm{d}t \qquad (1)$$

where, ER = effective rainfall (mm), calculated using USDA soil conservation services methods, I = irrigation (mm), ΔS = change in soil moisture storage.

Soil water upward flux (F_x) was negligible because of existence of deep water table (>3.0 m) in the study area. The runoff was nil because crops were grown in small-boarded plots during winter/dry season and irrigation was applied at critical growth stages only.

2.4. Computation of runoff for assessing water harvesting potential

The SCS runoff curve number method has been employed for computing runoff depth to assess water harvesting potential in the region. The runoff was collected during rainy season from upper catchments of existing pond for providing supplemental irrigations to second crops during winter/dry season, grown in rice fallow below the pond (Table 3). Study revealed that at highly assured probability level (75%), 381 mm rainfall was predicted. During the study years in four southwest monsoon months (June–September), 432 and 451 mm runoff were computed in 1999 and 2000, respectively.

Table 1
Irrigation scheduling at different growth stages of winter crops (maize, groundnut, sunflower, wheat, potato) during 1999–2000 and 2000–2001

Irrigation treatments	Crops				
	Maize	Groundnut	Sunflower	Wheat	Potato
Two	Tassel initiation + grain filling	Peg initiation + pod development	50% flowering + grain filling	Crown root initiation stage (CRI) + jointing	Stolonization + tuberization
Three	Early vegetative + Tassel initiation + grain filling	Flowering + pod development + grain filling	Bud initiation + 50% flowering + seed development	Crown root initiation stage (CRI) + jointing + milking stage	Stolonization + tuberization + tuber bulking
Four	Early vegetative + Tassel + silking + grain filling + Maturity	Peg initiation + pod development + seed filling + branching	Secondary branching + Bud imitation + 50% flowering + seed development	Crown root initiation stage (CRI) + tillering + jointing + milking	Early vegetative + tuberization + 50%tuber formation + tuber bulking

Table 2
Package of practices for growing second crops

Crop	Variety	Spacing (cm × cm)	Fertilizer dose (N:P:K)	Date of sowing		Date of harvest	
				1999–2000	2000–2001	1999–2000	2000–2001
Maize	Novjot	60 × 30	80:40:40	22.11.99	19.11.00	18.03.00	16.03.01
Groundnut	TMV-2	30 × 20	20:40:20	22.11.99	19.11.00	23.03.00	20.03.01
Sunflower	BSH-1	45 × 30	60:60:30	22.11.99	19.11.00	26.03.00	25.03.01
Wheat	Sonalika	20 × 10	80:50:40	22.11.99	19.11.00	20.03.00	16.03.01
Potato	Kufri Jyoti	45 × 20	120:60:120	22.11.99	19.11.00	10.03.00	07.03.01

2.5. Crop growth observations

Two main crop growth parameters viz., above ground dry biomass and leaf area index were measured weekly throughout the crop growth period. The biomass was measured using oven–dry method and a leaf area meter (LICOR 3200) was used to measure leaf area index. Maximum rooting length was measured by digging trench profile near the crop. The root length density was measured using modified line intersection method (Tennant, 1975).

The five plant samples from each plot in each replication were selected randomly for leaf area and biomass measurement. The sampling was done at 7 days interval. The green leaf portions were separated and the area of the leaves was measured using leaf area meter (LI-3100). Mean value per plant was used in calculating the LAI, which was derived using the formula:

$$\mathrm{LAI} = \frac{\text{Measured leaf area per plant }(\mathrm{cm}^2)}{100 \times 100\,(\mathrm{cm}^2)} \times \text{No. of plants}/\mathrm{m}^2 \qquad (2)$$

The collected plant samples were oven dried at 80 °C for more than 48 h till constant weight of the samples was observed.

2.6. Harvesting of crops

Grain yields of groundnut, wheat, sunflower and tuber yield of potato were harvested by hand harvesting from two rows of the center of each plot. The maize was harvested both as

Table 3
Predicted runoff at different probability levels with actual runoff

Month	Runoff at probability (mm)				Actual runoff (mm) during study years	
	10%	25%	50%	75%	1999	2000
June	150	131	89	81	145	104
July	153	169	129	101	153	145
August	201	153	139	97	123	99
September	195	161	141	102	153	102
Total	699	614	498	381	432	451

grain and cob from the same maize treatment. The samples were weighed after grain yields were corrected to 15.5 g kg^{-1} moisture.

2.7. Computation of net return

The net return was computed in Indian rupees (one Indian rupees ≈0.0229 USD) by subtracting fixed cost (interest on land) and operational expenses of cultivation (seeds, irrigation, fertilizers, ploughing and cost of other agro inputs) from gross income of the produce.

2.8. Crop water use efficiency

Overall water use efficiency of different crops was determined by dividing the grain yield by the water used (sum of soil water at planting—soil water at harvest + irrigation water + effective rainfall) and expressed as kg ha^{-1} mm^{-1}. The soil upward flux was negligible because of deep ground water table (>3.0 m). The deep drainage was nil because limited irrigation was applied only at critical growth stages.

2.9. Meteorological data

Daily meteorological data viz., rainfall, evaporation, relative humidity, maximum and minimum temperatures etc. were recorded from nearby meteorological observatory of Central Rubber Board Regional Station, Dhenkanal, Orissa.

3. Results and discussion

3.1. Enhancement of rice yield during rainy season with improved practices over farmers' practices

Study revealed that (Fig. 2) rice yield of 4.51 and 4.01 t ha^{-1} yield was obtained under improved management practices in 1999 and 2000, respectively. On the other hand under

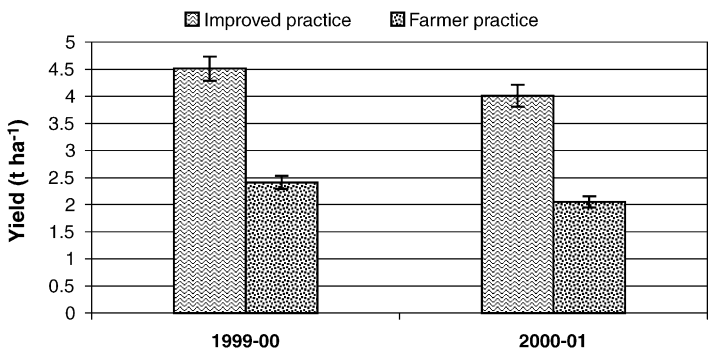

Fig. 2. Yield of rice under improved and farmers' management practices.

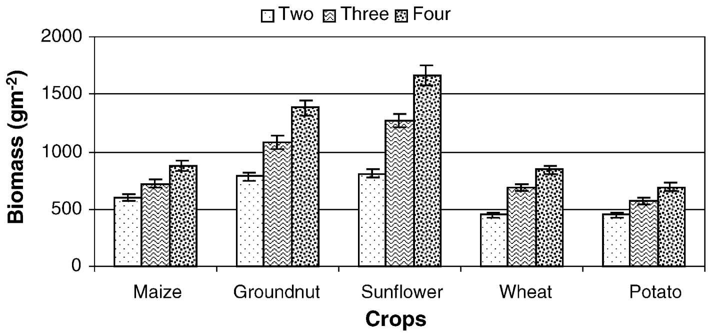

Fig. 3. Maximum biomass of different crops with supplemental irrigation.

farmers' practices 2.41 and 2.05 t ha^{-1} yield was achieved in two respective years. It was revealed that 87.1–95.6% higher yield was obtained with improved practices over farmers' practices. It was also observed due to dry spell in 2000, rice yield was adversely affected, as a result 12.4 and 17.5% less yield was obtained under improved and farmers practices, respectively in that year (Fig. 2).

3.2. Crop growth of second crops during dry season with supplemental irrigation

The main crop growth parameters like above ground dry biomass and leaf area index were measured and pooled data of two study years are presented in Figs. 3 and 4, respectively. Study revealed that with two irrigations, peak above ground biomass of 600, 785, 808, 448 and 446 g m^{-2} was achieved in maize, groundnut, sunflower, wheat and potato, respectively (pooled data of two years). The 20.0, 37.1, 56, 53 and 28% maximum above ground biomass was enhanced in respective five crops when three irrigations were applied over two irrigation. With four irrigations at 45.2, 75.3, 105.0, 87.3 and 54.3% biomass was increased over two irrigations in maize, groundnut, sunflower, wheat and potato, respectively.

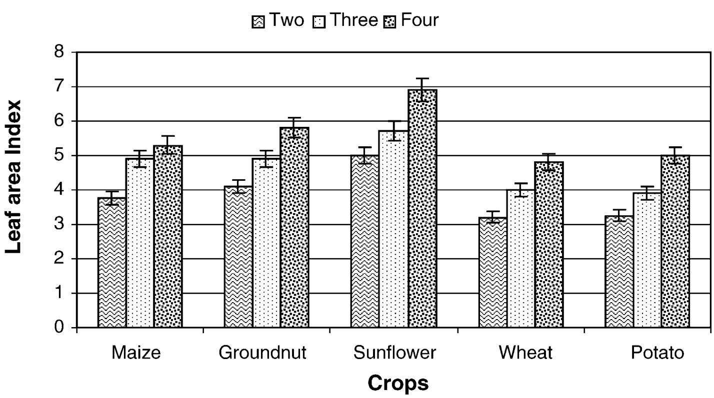

Fig. 4. Maximum leaf area index of different crops with supplemental irrigation.

Table 4
Yield and water use efficiency (pooled data of two years) of different crops with limited irrigation scheduling during 1999–2000 and 2000–2001

	Treatments	Maize	Groundnut	Sunflower	Wheat	Potato
Crop yield (kg ha^{-1})	I_2	1845 c	785 c	905 c	1420 c	8050 c
	I_3	2950 b	1020	1205 b	2250 b	9650 b
	I_4	5805 a	1590 a	1715 a	2780 a	12400 a
	LSD $_{(0.01\%)}$	158.3	206.9	433.3	283.3	4327.8
Water use (mm)	I_2	334 c	348 c	395 c	348 c	355 c
	I_3	385 b	395 b	429 b	390 b	394 b
	I_4	438 a	444 a	476 a	440 a	432 a
	LSD $_{(0.01\%)}$	67.33	67.33	0.44	40.44	50.78
Water use efficiency (kg ha^{-1} mm^{-1})	I_2	4.95 c	2.24 c	2.29 c	4.08 c	22.7 c
	I_3	7.25 b	2.58 b	2.60 b	6.31 a	24.5 b
	I_4	13.8 a	3.35 a	3.39 a	5.85 b	28.7 a
	LSD $_{(0.01\%)}$	0.027	0.022	0.022	0.026	0.096

Values within a column followed by the same letter are not significantly different at <0.01 using Dunken's multiple range test.

Highest leaf area index was observed with four irrigations with the mean values being 5.3, 5.8, 6.9, 4.8 and 5.0 in maize, groundnut, sunflower, wheat and potato, respectively. The 69, 65, 78, 81 and 84% maximum leaf area index was enhanced with the application of four irrigations over two irrigations in the respective five crops. With three irrigations, the maximum LAI of 4.9, 4.9, 5.7, 4.0 and 3.9 was observed in respective five crops.

3.3. Yield of second crops with supplemental irrigation

Supplemental irrigation had a significant effect ($P < 0.01$) on grain yield of winter crops (Table 4) and with two supplemental irrigation, mean yield of 1845, 785, 905, 1420, 8050 kg ha^{-1} was obtained in maize (grain), groundnut, sunflower, wheat and potato (tuber), respectively. The 59, 29, 33, 58 and 19% higher yield was obtained in the five respective crops when three irrigations was applied. With increase of another irrigation i.e., with four supplemental irrigation 214, 89, 78, 81 and 54% yield was enhanced in maize, groundnut, sunflower, wheat and potato, respectively over two irrigations.

3.4. Field water use and water use efficiency of second crops

The amount of water use is directly proportional to the amount of water available in the soil profile. The total water use of 334, 348, 395, 340 and 355 mm was measured by maize groundnut, sunflower, wheat and potato, respectively when only two irrigations was applied. With four irrigations, the total water use was 438, 444, 476, 440 and 432 mm in respective five crops. Among all the crops the highest water was used by sunflower crop. It might be due to its deep root system as compared to other crops. Study revealed that (Table 4) with two supplemental irrigation water use efficiency (pooled data of two years) of 4.95, 2.24, 2.29, 4.08 and 22.7 kg ha^{-1} mm^{-1} was achieved by maize, groundnut, sunflower, wheat and potato, respectively.

The WUE increased drastically by 46, 14, 22, 38, and 7% when three irrigation was applied over two irrigation in maize, groundnut, sunflower, wheat and potato, respectively. With four supplemental irrigations, WUE of 13.8, 3.35, 3.39, 5.85 and 28.7 kg ha^{-1} mm^{-1} was obtained in five respective crops.

3.5. Maximum rooting depth studies and water extraction pattern of second crops

The characterization of maximum rooting depth is necessary to appraise the water and nutrition uptake pattern of different crops. The maximum rooting depth of different crops in rainfed rice fallow was measured and the average results of two years are presented in Fig. 5. The water uptake of different crops from different depths was also studied and the percentage of total water use extracted along with distribution of root length density at different depths has been given in Table 5. Of the five crops studied, sunflower was found to be the deep-rooted and withdraw 30–40 mm more water than other crops. Sunflower, with its tap root-organized root growth system, was found the most deeply rooted of the crops and has the capability of extracting subsoil water at greater depths than all other crops studied. This crop extracted 18–20 and 14–16% of total water use at 60–90 and 90–120 cm depth, respectively. Results of two years revealed that greatest total rooting length was more with four irrigations, which was interpreted as response to availability of soil water.

With four irrigations the average maximum rooting depths were 92, 98, 155, 133 and 91 cm in maize, groundnut, sunflower, wheat and potato, respectively, which was, 16, 13, 6, 13 and 21% higher than that of twice irrigated crops because of wetter subsoils and decrease of soil strength. The variation of rooting depth in different crops was positively correlated with soil water extraction during both the years.

3.6. Economics of rice based cropping system with limited irrigation to second crops

The net returns from first and second crop were computed (in Indian rupees) and are presented in Table 6. Since maize cob was more remunerative and had better market

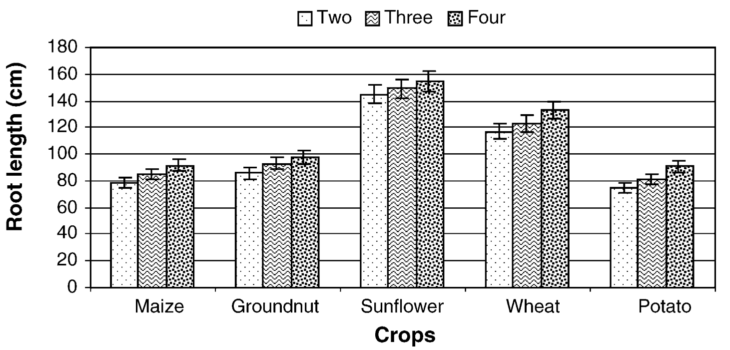

Fig. 5. Maximum rooting depth of different crops with supplemental irrigation.

Table 5
Percentage (%) of total extracted water at different soil depths by different corps (pooled data of 1999–2000 and 2000–2001)

Soil depth (cm)	Maize			Groundnut			Sunflower			Wheat			Potato		
	I2	I3	I4	I2	I3	I4	I2	I3	I4	I2	I3	I4	I2	I3	I4
0–30	43.2 (63.1)	38.9 (64.5)	42.1 (62.9)	39.8 (60.1)	40.7 (62.3)	40.3 (63.1)	30.8 (41.2)	32.1 (42.3)	32.3 (40.8)	39.0 (54.2)	39.5 (57.8)	40.3 (54.2)	39.5 (58.2)	41.2 (57.8)	45.2 (56.8)
30–60	35.0 (23.9)	36.1 (21.8)	37.9 (22.1)	32.1 (24.8)	32.7 (21.8)	35.1 (21.8)	29.7 (27.8)	28.8 (28.8)	28.9 (26.8)	34.8 (23.9)	35.3 (21.8)	35.9 (23.8)	34.7 (24.1)	36.3 (23.8)	35.2 (21.8)
60–90	16.9 (8.3)	17.9 (9.3)	15.4 (8.1)	22.5 (10.1)	32.4 (9.3)	21.8 (8.4)	20 (16.8)	20 (17.1)	21.9 (16.8)	17.1 (13.2)	17.7 (12.8)	17.6 (14.1)	17.9 (10.1)	15.3 (11.3)	14.0 (10.3)
90–120	4.8 (8.7)	7.0 (4.4)	4.4 (6.9)	5.5 (5.0)	4.1 (6.6)	2.9 (6.7)	19.1 (11.2)	19.1 (12.3)	16.5 (12.5)	9.0 (8.7)	7.4 (7.6)	6.2 (7.9)	7.7 (7.6)	7.1 (7.1)	5.5 (11.1)

The number mentioned in the parenthesis indicates the mean of percent root length density (mm mm^{-3}).

Table 6
Net return from different crop combinations (pooled data of 1999–2000 and 2000–2001)

Rice based cropping system	Net return from first crop (Rs/ha)	Net return from second crop (Rs ha^{-1})			Total return (Rs ha^{-1})			LSD (0.01%)
		I2	I3	I4	I2	I3	I4	
Rice–maize (grain)	13540*	1225	6250	20025	14765 c	19790 b	23565 a	1865.0
Rice–maize (cob)	13540*	4600	13000	34400	18140 c	26540 b	47940 a	954.0
Rice–groundnut	13540*	1990	7780	15260	15530 c	21320 b	28800 a	1476.9
Rice–sunflower	13540*	5095	7875	17110	18635 c	21415 b	30650 a	1036.2
Rice–wheat	13540*	-	2500	4120	13540 c	15940 b	17340 a	1460.9
Rice–potato	13540*	6100	8800	13800	19640 c	22340 b	27340 a	2286.2
Rice (farmers' practice)	6920*	–	–	–	6920	6920	6920	-

* The net return includes the straw yield of rice.

prospects, economics of rice (improved)–maize (cob) was also computed from same maize treatment. Study revealed that from first crop rice (pooled data of two years) Rs 13540 and 6930 ha^{-1} net return was obtained with improved and farmers' practices, respectively. With two irrigation to second crops Rs 14765, 18140, 15530, 18635, 15540 and 19640 ha^{-1} net return was obtained from rice–maize(grain), rice–maize(cob), rice–groundnut, rice–sunflower, rice–wheat, rice–potato, respectively when rice was grown with improved management. With four irrigation Rs 33565, 47940, 28800, 30650, 17660 and 27340 ha^{-1} net return was obtained from rice–maize (grain), rice–maize (cob), rice–groundnut, rice–sunflower, rice–wheat and rice–potato, respectively. Therefore, with four supplemental irrigation the net return was obtained in the order of sole rice (farmers' practices) < sole rice (improved practices) < rice–wheat < rice–potato < rice–groundnut < rice–sunflower < rice–maize (grain) < rice–maize (cob).

4. Conclusion

The study revealed that there is a scope to improve productivity of rice yield with improved management practices. Supplemental irrigation had a significant effect ($P < 0.01$) on grain yield of winter or dry season crops. Among different crops grown in rice fallow during the dry season, rice–maize (cob) was the most profitable, followed by rice–sunflower (grain) and rice–groundnut (Kernel). With four supplemental irrigation, WUE of 13.8, 3.35, 3.39, 5.85 and 28.7 kg ha^{-1} mm^{-1} was obtained in maize (grain), groundnut, sunflower, wheat and potato (tuber), respectively. Among the crops studied sunflower with its tap root system was found the most deeply rooted of the crops and had the capability of extracting subsoil water at greater depths.

Acknowledgements

Authors take this opportunity to extend our gratitude to District Magistrate & Collector and DDA, Dhenkanal., B. D. O., Kamakhyanagar, KVK, Dhenkanal, Central Rubber Board, Dhenkanal, Meteorological Centre, IMD, Govt. of Orissa for their support to undertake the programme in Dhenkanal district and for providing necessary information to carry out the study.

References

Das, J.C., 2001. Rainwater harvesting and utilization for supplemental irrigation to crops. Compendium on state level collaboration training programme on land and water management form 6th to 10th February 2001, pp. 85–92.

Eck, H.V., 1984. Irrigated corn yield response to nitrogen and water. Agron. J. 76, 421–428.

Hundal, S.S., De data, S.K., 1984. Water table and tillage effects on root distribution, soil water extraction and yield of sorghum grown after wetland rice in a tropical soil. Field Crop Res. 9, 291–303.

Hunsaker, D.J., Kimball, B.A., Pinter Jr., P.J., La Morte, R.L., Wall, G.W., 1996. Carbon dioxide enrichment and irrigation effects on wheat evapotranspiration and water use efficiency. Trans. ASAE 39 (4), 1345–1355.

Kar, G., Singh, R., Verma, H.N., 2004a. Spatial variability of soil hydro-physical properties using GIS for sustainable crop planning of watershed of eastern India and it's testing in portion of rainfed rice area. Aust. J. Soil Res. 42 (4), 369–379.

Kar, G., Singh, R., Verma, H.N., 2004b. Alternative cropping strategies for assured and efficient crop production in upland rainfed rice areas of eastern India based on rainfall analysis. Agric. Water Manage. 67 (1), 47–62.

Merril, S.D., 1992. Pressurized-wall minirhizotron for field observation of root growth dynamics. Agron. J. 84, 755–758.

Merril, S.D., Tanaka, D.L., Hanson, J.D., 2002. Root length growth of eight crops species in Haplustoll soils. Soil Sci. Soc. Am. J. 66, 913–923.

Norwood, C.A., Dumler, T.J., 2002. Transition to dry land agriculture. Limited irrigation versus dryland corn. Agron. J. 94, 310–320.

Panigrahi, B., Panda, S.N., Mull, R., 2001. Simulaiton of water harvesting potential in rainfed rice lands using water balance model. Agric. Syst. 69 (3), 165–182.

Prasad, U.K., Yadav, V.K., Prasad, T.N., Kumar, A., Prasad, S.M., 2000. Effects of levels of irrigation and nitrogen on oil percent, yield, moisture depletion and water use efficiency of winter sunflower (*Helianthus annus*). Indian J. Agron. 45 (4), 147–152.

Prihar, S.S., Cheri, K.I., Sandhu, K.S., Sandhu, B.S., 1976. Comparison of irrigation schedules based on pan evaporation and growth stages of winter wheat. Agron. J. 60, 650–653.

Rathore, A.L., Pal, A.R., Sahoo, R.K., Choudhury, J.L., 1996. On-farm rainwater and crop management for improving productivity of rainfed areas. Agric. Water Manage. 31 (3), 253–267.

Sarker, S., Singh, S.R., Singh, Y., 2000. Effective use of harvested water in relation to productivity and water use pattern of barely and rajmash as intercrop. J. Indian Soc. Soil Sci. 824–826.

Singh, R.D., Sinha, H.N., 1987. Water management practices for wheat. Indian J. Soil Conserv. 15, 101–106.

Singh, P., 1989. Water stress and plant parameters for wheat. Indian Soc. Agric. Eng. 85, 34–40.

Tennant, D., 1975. A test modified line interest method of estimating root length. J. Ecol. 63, 995–1001.

Turner, N.C., 1987. Crop water deficits: a decade of progress. Adv. Agron. 39, 1–51.

Tyagi, N.K., Sharma, D.K., Luthra, S.K., 2000. Evapotranspiration and crop coefficient of wheat and sorghum. J. Irrig. Drain. Eng. 126, 215–222.

Wang, H., Zhang, L., Dawes, W.R., Liu, C., 2001. Improving water use efficiency of irrigated crops in the North China plain-measurements and modeling. Agric. Water Manage. 48, 151–167.

Wang, S.T., 1987. Water use efficiency of plant and dryland farming production. Agric. Res. Arid Areas 2, 67–80.

Ray, G.B., Saha, D., Dutta, D.K. (Eds.), 2000. Effect of mulching on water use and grain yield of wheat under different irrigation regions in lateratic soil. Principles and Practices of Soil and Water Conservation.