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ARTICLE

# Conservation and efficient utilization of rainwater in the rainfed shallow lowland paddy fields of Eastern India

**A. Mishra · B. K. James · R. K. Mohanty · P. S. B. Anand**

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**Abstract** A two-stage rainwater conservation technique was intervened in the farmers field of rainfed shallow low land, in which, part of the rainwater is conserved in rice field up to the weir crest level and the remaining in a refuge for rearing of fish (*Catla catla*, *Labeo rohita*, *Cirrhinus mrigala* and *Cyprinus carpio*). The conserved rainwater in the refuge is also used for giving supplemental irrigation to rice crop during rainy season and growing a light duty crop in winter season. On-farm experiment was conducted in the farmer's field for three consecutive years to study the scope and feasibility of this technique in enhancing productivity and cropping intensity. Three different weir heights (15, 20 and 25 cm) were considered as treatments with two replications each. Refuge occupying areas of 5–8 % of the rice field with a depth of 1.75 m were constructed at the downstream side of each plot. As a result of this intervention, the mono-cropped area could be gradually brought under double cropping. The rice yield increased from 1.8 to 5.3 t/ha. Fish yield of as high as 1,693 kg/ha was obtained for a fish rearing period of about 6 months. The net water productivity increased from 3.76 to 7.38 Rs./m$^3$. The highest net return of Rs. 63,572 was recorded in 20 cm weir height plots with a benefit cost ratio of 2.60. The system generated employment opportunity, increased income for farmers and provided nutritional security.

**Keywords** Two-stage rainwater conservation · Rice-fish farming · Water productivity · Weir height · Rainfed rice lands

A. Mishra (✉) · B. K. James · R. K. Mohanty · P. S. B. Anand
Directorate of Water Management (ICAR), Chandrasekharpur, Bhubaneswar 751023, Odisha, India
e-mail: atmaramm@yahoo.com

## Introduction

Agriculture, the lifeline of Indian economy, contributes to nearly 16 % of the national GDP and sustains livelihood of about two-thirds of population. Presently, India has more than 17 % of world's population, 4.2 % of world's fresh water and 2 % of world's geographical area. This presents a grim picture of challenges and threats in relation to resources, their availability and utilization. In future, to meet the food requirement of burgeoning population, the food grain production has to increase considerably through increased productivity and cropping intensity. Thus, there is an urgent need for development of location-specific technologies for efficient conservation, management and judicious utilization of the natural resources such as land and water leading to increased agricultural production.

The eastern region of India is blessed with plenty of rainfall, about 80 % of which occurs in monsoon season (June to September). During this period, about 50 % of the annual rainfall comes from few intense storms. Water received from such intense storms is subjected to high runoff losses (Pal et al. 1994). Added to this, is the erratic nature of the onset, distribution and the withdrawal of rains, which increases the probability of water stress at various crop growth stages of rice (Bhuiyan and Goonasekera 1988). Therefore, the rainfed rice ecosystem has common characteristic of uncertain soil moisture regime. Field may have too much water, too little water or both within the same cropping season. This is one of the major reason for which the average productivity of rice crop of eastern region is lower than the country's average rice productivity (Mishra et al. 1998).

The eastern India has an average cropping intensity of about 143 %. Fallow, after rice in about 12–16 M ha of lands in eastern India due to poor water resource development for irrigation in dry season is an important issue of water management (Samra et al. 2004). Conservation of rainwater, sediment and nutrient through optimum dike height and improvement in rice yield has drawn attention of the researchers in the recent past (Islam and Mandal 1992; Mishra et al. 1998; Khepar et al. 2000). A study on in situ conservation of rainwater in rainfed rice fields revealed that weir height of 6 and 30 cm could store 57 and 99 % of the seasonal rainfall, respectively. Conservation of rainwater in rice fields minimizes supplemental irrigation requirement during dry spells, drainage need of the adjoining lowlands and improves the productivity (Mishra et al. 1998). Further, this region is prone to frequent occurrence of natural calamities such as flood, drought and cyclone, which repeatedly weakens the financial backbone of the farming community. Therefore, to ensure continuous flow of income throughout the year and minimize the risks associated with natural calamities affecting mono-cropping system, rice-based farming system coupled with rainwater conservation and multiple/cascading use of water seems to be promising and viable technological option. Rice-based integrated farming systems are less risky due to their efficiency, derived synergism among other components, their diversity of produce and environmental friendliness. In order to obtain increased productivity from unit volume of conserved rainwater, a two-stage rainwater conservation technique was conceptualized and experimented in the research farm of Directorate of Water Management, Bhubaneswar, India (Mishra and Mohanty 2004).

The research effort was focused here on conservation of rainwater and adoption of integrated rice-based farming system in the farmer's rainfed shallow low land rice fields. The objective of the intervention was to enhance the land and water productivity and cropping intensity through multiple use management of harvested rainwater. The rainwater immediately falling over the rice field is conserved through strengthening of dike height around rice field and providing a surplus weir at the down stream bund of the rice field at an optimal height. The excess rainwater spilling over the weir is further harvested through provision of a small refuge constructed in the rice field at its downstream portion. The harvested water in the refuge is utilized for providing supplemental irrigation in dry spells to rice crop in the monsoon season, rearing of a short-duration fish culture of about four to six months duration, cultivation of a light duty crops in winter season and growing of horticultural crops on the embankment of the refuge.

## Materials and methods

An on-farm experiment was carried out in farmers' fields, located in the shallow low lands at Sadeiberini village of Dhenkanal district, Odisha (latitude 20°58′N and longitude 83°51′E), India for three consecutive years (2001–2002 to 2003–2004). The total experimental area was approximately 14,410 $m^2$. The soil is predominantly sandy clay loam in texture. Each rice plot was provided with a brick masonry broad-crested rectangular weir at the partition dike between the refuge and the rice field. The length of the weir was kept at about 1–1.5 m. Three weir heights of 15 cm ($T_1$), 20 cm ($T_2$) and 25 cm ($T_3$) were considered as treatments with two replications each for in situ conservation of rainwater in the rice fields. During rainy season three rice varieties i.e. 'Saruchinamali' (farmer's choice, a traditional local variety), 'Jagannath' and 'Moti' (high yielding variety) were grown. Thus, in total there were eighteen experimental plots i.e. three weir heights (main plot treatment) × three rice varieties (sub plot treatment) × two replications. These eighteen plots belonged to five farmers. Split plot design was followed. Each experimental plot was adequately leveled so as to maintain a uniform depth of ponding. After each plot there was a natural drop/fall. However, considering the entire area, an average land gradient of 1.5 % was observed.

With the provision of surplus weir and refuge, a portion of rainwater was conserved in the rice field up to the weir crest level. The excess rainwater above the crest level was allowed to spill over the weir for further conservation in the refuge. Though the design area of the refuge was kept as 10 % area of the rice field, farmers initially did not spare that much area for refuge. Therefore, run-off collection refuge occupying approximately 5–8 % of the individual plot size was constructed at the downstream end of each plot to harvest the excess rainwater during heavy downpour. The average depth of the refuges was kept at 1.75 m with a side slope of 1:1. The top width of the embankment of the refuges was kept as 1 m. The excess water from the refuge was drained out through a hume pipe (fixed at weir crest level) with fine-meshed net to prevent escape of fish (Mishra et al. 2003). Schematic diagram of the refuge with rice field and surplus weir is shown in Fig. 1.

Transplanting of the rice was carried out during third to fourth week of July with a spacing of 20 × 10 cm. Chemical fertilizer was applied at the rate of 80:40:40 (N: $P_2O_5$: $K_2O$) kg/ha in three split doses along with bio-fertilizer, *Azosprillum*. On the embankment of the refuge, horticultural crops such as banana, papaya, drum stick, French bean etc. were grown. During winter season farmers grew crops such as winter rice ('Lalat' and 'MW-10'), ladies finger (*Hibiscus esculentus* L.), green gram (*Phaseolus radiatus* L.), black gram (*P. mungo* L), water melon etc. using the harvested rainwater from the refuge. Fish were reared in the refuge 7 days after first manuring and fertilization. Early fingerlings of <1.5 g size of *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala* and *Cyprinus carpio* were stocked with a species

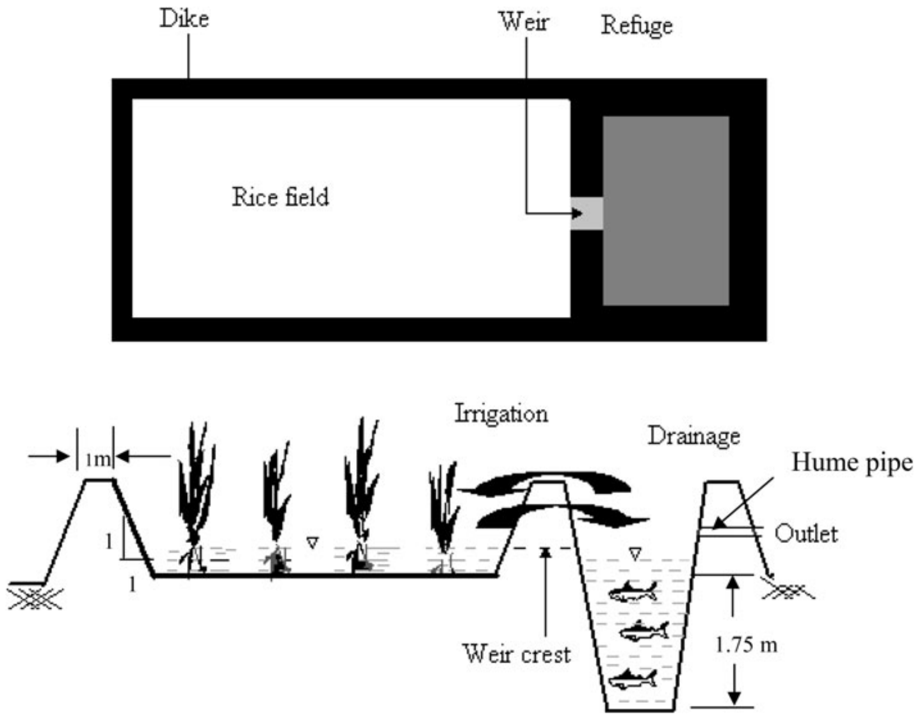



**Fig. 1** Schematic diagram of rainwater conservation in rice fields through optimum weir height and refuge in rainfed shallow low land

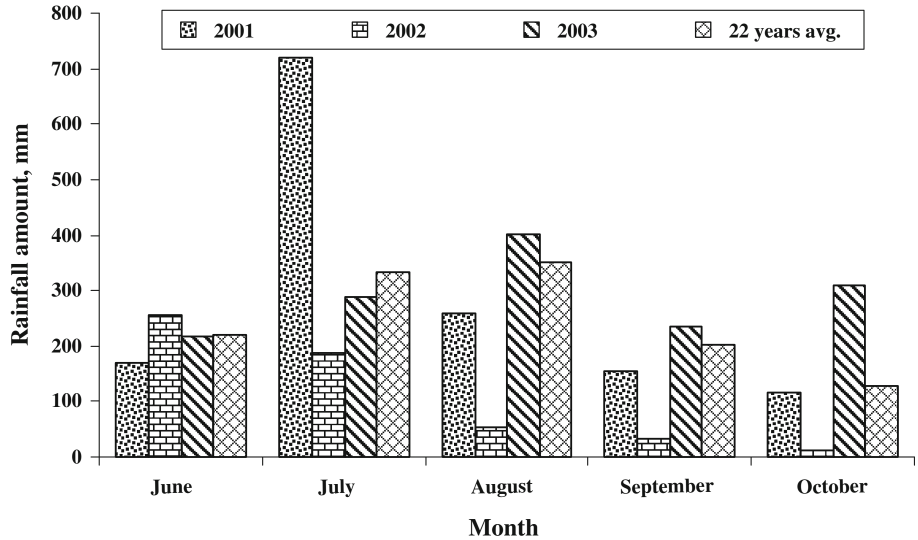
composition of 30:30:20:20, respectively. Before stocking, the refuge water was treated with raw cattle dung, lime and fertilizer (urea + single super phosphate) at the rate of 5,000 kg/ha; 750 kg/ha, and 3 ppm, respectively. Fish feed (rice bran and groundnut oil-cake, 1:1) at the rate of 10 % of body weight was given twice a day to fish in the first month which was gradually reduced to 2.5 % in the sixth month. Stocking density of 20,000 fingerlings/ha was maintained in all the treatments and rearing continued for about 180 days (third week of August–third week of February).

Daily depth on water in each refuge was measured. Monthly samplings of fish were carried out in early morning hours prior to feeding using cast net so that complete evacuation of the gut is ensured. Twelve number of each species were sampled for individual weight and length. This was carried out for assessment of mean body weight, per day increment, apparent feed conversion ratio, biomass and survival rate. Ponderal index or condition factor $\left(K_n = \frac{\text{Weight}, W}{\text{Length}, L^3} \times 100\right)$ was estimated that expresses the overall condition of a fish, such as the degree of well being, plumpness or fatness in numerical term (value >1.0 indicates better well being of the fish). Statistical analysis with regard to growth performance and yield between the treatments were tested through one-way ANOVA and means were compared using Duncan's Multiple Range Test to find out the difference at 5 % ($p < 0.05$) level (Duncan 1955). To evaluate the production performance with more precision, performance index (PI) was calculated (Zacharia and Kakati 2002). This index was calculated by combining the two responses such as growth and survival. PI = growth rate in g/day at the time of harvesting i.e. [(final mean body weight at harvesting in g − initial mean body weight in g)/(rearing duration)] × final survival rate in %. Production-size index (PSI) was also estimated to evaluate production performance of each species with respect to their size (Tidwell et al. 2003). PSI = production in kg/ha × mean body weight in g/1,000. Both PI and PSI were estimated after the final harvest.

Monthly observations on water quality parameters of refuge such as temperature, pH, dissolved oxygen, total alkalinity, transparency, primary productivity, total suspended solids, dissolved organic matter, nitrite, nitrate, ammonia, phosphate etc. were taken. Sediment and water samples were collected between 7.30 and 8.30 h and were analyzed using standard methods (APHA 1995 and Biswas 1993). Field test instruments were used to analyze in situ water pH (Checker-1, HANNA, USA), soil pH (DM-13, Japan) and dissolved oxygen (YSI-55, Yellow Springs, OH, USA). Plankton samples were collected at fortnightly intervals by filtering 50 l of water from each unit through plankton collection net (no. 25, mesh size 64 µm), preserved in 4 % formaldehyde solution and later analyzed for quantitative and qualitative estimation.

To assess the output from the plot in a single unit, rice equivalent yield (REY) was computed considering the selling price of rice and fish and the proportional area devoted to rice and fish cultivation. Economic indices of water productivity was estimated keeping the total volume

Fig. 2 Monthly rainfall during monsoon season at the experimental site




of water used (water contained in the harvested biomass + evaporation + deep percolation and seepage + average standing water volume + volume of water added from other source) into account (Boyd 2004). Economic indices of water productivity (net consumptive water use index, Rs./$m^3$) = (total economic value of produce − production cost)/total volume of water used.

Each component of water balance in the rice field was either estimated or measured. Depth of ponding in rice field was measured daily through measuring scales installed in each plot. The pan evaporimeter data were used to determine the daily evaporation rate. Lysimeters were used to measure daily evapotranspiration and seepage and percolation rate from rice fields. The supplemental irrigation applied using water from the refuge through a pumpset was also measured. Daily rainfall was measured through a rain gauge installed at the project site. Water content in the harvested rice grain was assumed as 14 % and the total water volume was computed by multiplying the total grain yield with 0.14. Similarly the water content in harvested rice straw was considered as 60 % and fish as 70 % for computation of water productivity.

## Results and discussion

### Hydrology and rainwater conservation

The average evapotranspiration rate from rice fields was observed as 3.4 mm/day. The average deep percolation and seepage rate was also determined as 2.4 mm/day. The average depth of ponding in rice plots with weir heights 15, 20 and 25 cm was recorded as 7.40, 8.58, and 8.90 cm, respectively. On an average, two supplemental irrigations of 6 cm depth each were provided from the respective refuges to rice plots with weir height of 15 and 20 cm and one irrigation of 6 cm depth to rice plots with weir height of 25 cm. The total rice plot area under 15, 20 and 25 cm weir heights were 3,202.4; 4,595.2 and 2,217.2 $m^2$, respectively. Thus, the average volume of water which was applied during monsoon season as supplemental irrigation to rice plots of 15, 20 and 25 cm weir heights was observed as 384.29, 551.42 and 133.03 $m^3$, respectively. The average evaporation rate in the refuges was observed as 1.8 mm/day. Similarly, the deep percolation and seepage rate was recorded as 3.6 mm/day.

The monthly rainfall pattern of the experimental site during monsoon season is presented in Fig. 2. In the year 2001, rainfall of 1,535 and 1,420 mm were received during the entire year and rainy season, respectively. In this year, an unusual rainfall during July amounting to 719 mm (2.2 times than that of 22 years average value) was experienced. In spite of heavy rainfall during July and subsequent scanty rainfall during August and September, water levels in the refuges were observed to be sufficiently high till end of February 2002 (Table 1). The year 2002 was a drought year. In this year rainfall amount of 728 and 543 mm were received during the entire year and rainy season, respectively. Similarly, in the year 2003, rainfall of 1572.5 and 1451.5 mm were received during the entire year and rainy season, respectively. Twenty years average annual rainfall and rainy season's rainfall were 1415 and 1226 mm, respectively. Thus, from rainfall point of view, the first and third years were excess rainfall years and the second year was a drought year. Amongst these two excess rainfall years, the monsoon rain was well distributed in 2003 and was poorly distributed in 2001. However, in all these extreme cases, the water levels in the refuges were observed to be sufficient enough (> 1 m most of the period) till end

**Table 1** Monthly average depth of standing water in the rice field refuges

| Weir height (treatment) | Years | Depth of standing water (m) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | August | September | October | November | December | January | February |
| 15 cm ($T_1$) | First year | 1.70 | 1.70 | 1.71 | 1.69 | 1.66 | 1.62 | 1.63 |
| | Second year | 1.10 | 1.08 | 1.07 | 1.05 | 1.02 | 1.03 | 1.02 |
| | Third year | 1.21 | 1.20 | 1.20 | 1.19 | 1.16 | 1.17 | 1.15 |
| | Average | 1.34 | 1.33 | 1.33 | 1.31 | 1.28 | 1.27 | 1.27 |
| 20 cm ($T_2$) | First year | 1.58 | 1.43 | 1.45 | 1.31 | 1.24 | 1.17 | 1.18 |
| | Second year | 1.28 | 1.24 | 1.09 | 0.89 | 0.79 | 0.74 | 0.65 |
| | Third year | 1.62 | 1.57 | 1.54 | 1.53 | 1.43 | 1.40 | 1.36 |
| | Average | 1.49 | 1.41 | 1.36 | 1.24 | 1.15 | 1.10 | 1.06 |
| 25 cm ($T_3$) | First year | 1.62 | 1.61 | 1.59 | 1.54 | 1.47 | 1.39 | 1.38 |
| | Second year | 1.22 | 1.16 | 1.05 | 0.93 | 0.87 | 0.81 | 0.74 |
| | Third year | 1.60 | 1.59 | 1.58 | 1.56 | 1.48 | 1.40 | 1.38 |
| | Average | 1.48 | 1.45 | 1.41 | 1.34 | 1.27 | 1.20 | 1.17 |

February (Table 1). This enables the farmers to carry out a short-duration fish culture for a period of about 6 months.

## Growth and yield of rice crop during monsoon season

Table 2 presents the treatment wise and variety wise average yield and yield attributes of rainy season's rice crop. The highest grain yield of 5.3 t/ha was obtained in 20 cm weir height plots. The highest panicle/m$^2$ was observed in 15 cm weir height plots followed by 20 cm weir height. Similarly, highest filled grains per panicle was obtained in 25 cm weir height followed by 20 cm. Yield attributes at different weir heights were found to be statistically non significant. Perusal of individual years yield data infers that due to sufficient rainfall in first and third years of experiment, maximum yield of rice was recorded in 20 cm weir height plot. However, in the second year (drought year) highest yield was recorded in 25 cm weir height plot because more amount of rainwater was conserved in the rice field. This clearly indicates the effect of in situ conservation of rainwater as a function of weir height on crop growth and yield. Among varieties, Jagannath recorded the highest grain yield (5.91 t/ha) followed by Moti (4.7 t/ha) and Saruchinamali (4.12 t/ha). This was primarily due to highest number panicles/m$^2$ and filled grains/panicle. The superiority of genotype in terms of higher plant biomass, yield components and economic yield of rice when exposed to similar edaphic environment and climatic factors were in confirmation with the findings of Verma and Srivastava (2004).

In the high rainfall region weir height plays a greater role in creating a favourable depth of ponding in rice field in addition to the supplemental irrigation. In this process, 20 cm weir height has created a more congenial water regime which has resulted in higher yield and economy in comparison to other weir heights. Thus, from highest grain yield point of view, 20 cm weir height may be considered as the optimum height for the study site to have two-stage rainwater conservation.

**Table 2** Average yield attributes and yield of monsoon rice

| Weir height (treatment) | Panicles/m$^2$ | No of filled grains/panicle | Grain yield (t/ha) |
|---|---|---|---|
| 15 cm | 272.1 | 140.8 | 4.59 |
| 20 cm | 267.6 | 143.9 | 5.30 |
| 25 cm | 257.9 | 150.3 | 4.83 |
| CD (0.05) | NS | NS | 0.556 |
| Rice variety | | | |
| Saruchinamali | 238.4 | 131.2 | 4.12 |
| Moti | 272.3 | 147.4 | 4.70 |
| Jagannath | 286.8 | 156.4 | 5.91 |
| CD (0.05) | NS | NS | 0.382 |

## Performance of winter season crops

In the first year (2001–2002) two rice varieties i.e. 'MW-10' and 'Lalat' were grown and recorded yield of 2.34 and 2.70 t/ha, respectively. Ladies finger was also grown in the same year which resulted in productivity of 1.85 t/ha. In the second year rice variety 'MW-10' recorded 3.5 t/ha grain yield. In this year, ratooning was practiced in 'Savitri' and 'Durga' varieties of rice. 'Savitri' resulted in good productivity (2.73 t/ha). Pulses such as black gram and green gram were cultivated in second year, which registered pod yield of 0.34 and 0.45 t/ha, respectively. In the third year rice varieties 'MW-10' and 'Lalat' yielded 1.23 and 1.3 t/ha, respectively. The reason for higher rice yield during

**Table 3** Yield of winter crops grown using the harvested rainwater

| Crop | Yield (t/ha) | | |
|---|---|---|---|
| | First year | Second year | Third year |
| Rice (*MW-10*) | 2.34 | 3.50 | 1.23 |
| Rice (*Lalat*) | 2.70 | – | 1.30 |
| Rice (*Savitri*) | – | 2.73 | – |
| Rice (*Durga*) | – | 0.50 | – |
| Ladies finger | 1.85 | – | – |
| Black gram | – | 0.34 | 0.42 |
| Green gram | – | 0.45 | 0.56 |

second year though it was a drought year might be attributed to lower incidence of blast disease caused by *Pyricularia oryza* and yellow stem borer, *Scirpophaga incertulas*. In addition, Photosynthetic active radiation (PAR) was the main factor positively influencing the rice yield in second year. Similarly, the lower grain yield of MW-10 during third year was primarily due to higher pest incidence i.e. yellow stem borer and brown plant hopper, *Nilaparvata lugens*. Black gram and green gram were also grown in the third year which resulted in better yield compared to that of previous year (Table 3). In summer season, watermelon variety 'sugarbaby' was grown using stored water from the refuge which has resulted in fruit yield of 6.2 t/ha.

### Horticulture on the embankment

On the embankment of the refuge, dwarf variety of papaya, banana and drum stick were grown at a spacing of 1–1.5 m. Irrigation to these plants was given using the harvested rainwater from the refuges. Among these three horticultural plants, banana performed the best in terms of yield and survival. These plants (specifically drum stick) were damaged to some extent by cattle grazing during winter and summer as the adjacent fields were lying fallow in that locality. The yield of banana and papaya was recorded as 200 bunch/ha and 1,600 kg/ha, respectively. The fruit yield of drumstick was recorded as 5.6 t/ha. In the inter tree spaces, French bean was cultivated which resulted in the pod yield of 8.3 t/ha.

### Cropping intensity

Before intervention, the study site was a mono-cropped area, rice during monsoon season being the only crop grown. The harvested rainwater from the refuge was utilized for growing a second crop which has resulted in increasing the cropping intensity of the site from 100 to 131 %, 176 and 200 % in the first, second and third year of experiment, respectively. In the very first year of experiment, the farmer's were not much interested to go for a second crop. Motivation and benefit from the second crop, gradually aroused interest among the farmers to bring more area under cultivation during winter. That is how, in the third year of the experiment the entire area was brought under second crop.

### Performance of fish growth and yield

Irrespective of stocking density, faster growth rate was recorded for *C. carpio* followed by *C. catla* and *C. mrigala* during 180 days of culture. Comparative growth performance of all species in terms of per day increment or average daily growth rate decreased with increase in weir height that reduces water availability in the refuge. Higher performance index (PI) was recorded for *C. mrigala* while the lowest was recorded for *L. rohita* in all the treatments. Species-wise, significant variation in PI ($p < 0.05$) was recorded for *C. catla* (surface feeder) and *C. mrigala* (bottom feeder) between $T_1$ and $T_2$; and $T_1$ and $T_3$; while no such trend was observed between $T_2$ and $T_3$. However, no significant variation in PI was observed for *L. rohita* (column feeder) and *C. carpio* (exotic carp) among treatments. Overall production-size index (PSI) was significantly higher ($236.8 \pm 8.2$) in $T_1$ followed by $T_2$ and $T_3$ (Table 4). However, no trend in species-wise PSI was recorded among treatments. Overall survival rate (inclusive of all species) was high in $T_1$, while species-wise, no such trend was marked among treatments. Condition factor (Ponderal index) of fish was less than 1.0 (0.87–0.98) at the initial 3 weeks of rearing (monsoon phase) and improved thereafter (1.04–1.23) with gradual improvement in water quality (post-monsoon). Ponderal index value $> 1.0$ indicates better degree of well being of the cultured fish species indicating better length–weight relationship. Fish yield in 15 cm weir height refuge (1,693.6 kg/ha/180 days) was, however, significantly higher ($p < 0.05$) than the yield of 20 and 25 cm weir height refuges. However, there was no significant variation between yields (Table 5) of refuges of 20 cm (1,265.3 kg/ha/180 days) and 25 cm weir height (1,279.4 kg/ha/180 days).

The effect of weir height on production performance (production-size index, PSI) was highly significant ($p < 0.05$) between $T_1$ and $T_2$; and $T_1$ and $T_3$; while there was no significant variation of PSI between $T_2$ and $T_3$. This indicates optimum production performance at lower weir height, $T_1$, where yield is significantly higher ($p < 0.05$) than yield at $T_2$ and $T_3$. In fact, under crowded condition at lower water depth, fish suffers stress due to aggressive feeding interaction and eat less resulting in a retardation of growth (Mohanty et al. 2009). Further, as highest and lowest performance index (PI) was recorded for *C. mrigala* and *L. rohita* in all the treatments, manipulation in species composition for stocking is essential. Increase and decrease in the stocking rate of

**Table 4** Performance index, production-size index and apparent feed conversion ratio of cultured fish species

| Treatment | Species reared | Yield (kg) | Performance index (PI) | Species-wise production-size index (PSI) | Overall PSI | AFCR |
|---|---|---|---|---|---|---|
| $T_1$ | *C. catla* | 5.3 | 56.9 ± 2.9 | 99.5 ± 3.1 | 236.8 ± 8.2 | 1.68 ± 0.18 |
| | *L. rohita* | 2.6 | 28.1 ± 3.7 | 22.7 ± 4.6 | | |
| | *C. mrigala* | 4.2 | 68.2 ± 1.6 | 72.8 ± 3.7 | | |
| | *C. carpio* | 2.3 | 37.4 ± 2.2 | 47.9 ± 4.9 | | |
| $T_2$ | *C. catla* | 5.9 | 36.8 ± 2.5 | 50.4 ± 5.4 | 159.1 ± 7.7 | 1.74 ± 0.57 |
| | *L. rohita* | 3.6 | 21.8 ± 4.0 | 16.9 ± 2.2 | | |
| | *C. mrigala* | 4.6 | 42.5 ± 2.9 | 37.7 ± 6.9 | | |
| | *C. carpio* | 4.5 | 41.9 ± 2.6 | 57.4 ± 1.8 | | |
| $T_3$ | *C. catla* | 3.7 | 37.2 ± 1.8 | 49.5 ± 4.7 | 141.4 ± 4.8 | 1.79 ± 0.22 |
| | *L. rohita* | 2.8 | 27.5 ± 2.3 | 20.8 ± 2.2 | | |
| | *C. mrigala* | 3.2 | 47.4 ± 2.4 | 41.2 ± 4.7 | | |
| | *C. carpio* | 2.0 | 29.9 ± 3.3 | 29.2 ± 4.1 | | |

**Table 5** Year-wise fish yield (kg/ha) in the rice field refuges

| Weir height (cm) | First year | Second year | Third year | Pooled |
|---|---|---|---|---|
| 15 | 1,232.40 | 1,988.80 | 1,859.60 | 1,693.60$^{a}$ |
| 20 | 1,004.80 | 1,553.00 | 1,238.10 | 1,265.30$^{b}$ |
| 25 | 1,109.90 | 1,478.35 | 1,250.00 | 1,279.40$^{b}$ |

Means having different superscripts in a column differed significantly by DMRT ($p < 0.05$)

*C. mrigala* and *L. rohita*, respectively, would definitely enhance the fish yield from unit water area in short-duration culture.

### Variation of water quality parameters in the refuges

Various hydro-biological parameters prevailing in different treatments were within optimum ranges and did not show any distinct trend among the treatments (Table 6). This was probably due to similar levels of input in all the treatments in the form of organic manure, inorganic fertilizer and periodic liming. Total suspended solid and dissolved oxygen concentration showed a decreasing trend with the advancement of rearing period, while slightly higher values of nitrite, nitrate, ammonia and total alkalinity were recorded towards the latter part of the experiment. The decreasing trend of dissolved oxygen in all the treatments with the advancement of rearing period attributed to fluctuation in plankton density and gradual increase in biomass, resulting in higher oxygen consumption. Gradual increase in nitrite, nitrate and ammonia in all the treatment were attributed by intermittent fertilization, increased level of metabolites and decomposition of unutilized feed in the absence of water replenishment. At any given point of time, other water quality parameters and plankton population did not register any specific trend among the treatments.

Plankton has a profound effect on water quality and is the major source of productivity in aquatic ecosystem, having a direct relationship with fish production. However, no perceptible trend in the total plankton density ($6.6 \times 10^2$–$1.3 \times 10^4$ units/l) was observed among treatments attributable to the regular fertilization schedule at monthly intervals. Low primary production (88.8–141 mg C/m$^3$/h) in the initial phase of rearing was probably due to fixation of nutrient ions by suspended soil/clay particles as well as rich organic matter (Mohanty 2003). Sediment characteristics of different treatments (pH, organic carbon and available phosphorus) were, however, indicative of a medium productive soil group.

### Rice equivalent yield

Considering the sale price of rice as Rs. 10.00/kg and fish as Rs. 80.00/kg in the year 2011 (one US dollar = Rs. 52) the rice equivalent yield (REY) for all three treatments was calculated (Table 7). The highest REY was recorded in 20 cm weir height plots (5.59 t/ha) followed by 25 cm weir height plots (5.25 t/ha). The bench mark survey of study site revealed that before interventions the average yield of rice was 1.8 t/ha. Thus, there is about 3.1 fold increase in the land productivity due to efficient and multiple uses of conserved rainwater and scientific crop management practices. There are mainly two reasons which have attributed to the land productivity to become triple than before intervention. The first one is the effect of the intervention which has almost changed the rainfed situation to irrigated one with assured availability of irrigation water in the refuge for giving supplemental irrigation to monsoon rice during dry spells. The second reason is the adoption of 'scientific crop management practices' for cultivation of rice which includes high yielding varieties, application of recommended doses of fertilizers,

**Table 6** Variation in water and sediment quality parameters in rainwater storage refuges

| Parameters | $T_1$ | $T_2$ | $T_3$ | Acceptable range |
|---|---|---|---|---|
| Water pH | 7.2–7.8 (7.5) | 7.6–8.2 (7.8) | 7.5–8.3 (7.8) | 7.3–8.5 |
| DO (ppm) | 3.6–9.3 (5.5) | 3.3–8.8 (6.1) | 3.7–9.2 (4.9) | >4.0 |
| Temperature (°C) | 26.8–31.2 (28.4) | 26.7–31.3 (28.3) | 26.8–31.3 (28.4) | 26–32 |
| Total alkalinity (ppm) | 69–121 (98) | 68–131 (118) | 73–139 (106) | 90–170 |
| DOM (ppm) | 0.3–4.5 (3.2) | 0.5–4.8 (3.6) | 1.1–5.2 (4.1) | 2–8 |
| TSS (ppm) | 81–282 (213) | 72–277 (225) | 55–256 (187) | <400 |
| Nitrite N (ppm) | 0.01–0.07 (0.03) | 0.01–0.07 (0.04) | 0.01–0.04 (0.03) | <0.05 |
| Nitrate N (ppm) | 0.3–0.5 (0.4) | 0.3–0.4 (0.4) | 0.2–0.6 (0.4) | <10 |
| Phosphate P (ppm) | 0.1–0.6 (0.3) | 0.2–0.7 (0.4) | 0.1–0.6 (0.3) | |
| Total plankton (units/l) | $1.0 \times 10^3$–$4.3 \times 10^3$ ($3.04 \times 10^3$) | $2.4 \times 10^3$–$1.3 \times 10^4$ ($5.3 \times 10^3$) | $6.6 \times 10^2$–$3.7 \times 10^3$ ($2.07 \times 10^3$) | >200 |
| Available-N (mg/100 g soil) | 8.1–11.1 (9.3) | 7.9–11.6 (9.8) | 9.3–12.2 (10.6) | 35–90 |
| Available-P (mg $P_2O_5 - P$/100 g soil) | 1.8–3.3 (3.0) | 1.8–3.6 (3.2) | 1.9–3.5 (3.2) | 20–50 |
| Organic carbon in soil (%) | 1.2–1.5 (1.41) | 1.4–1.6 (1.5) | 1.5–1.6 (1.5) | |
| Soil pH | 6.8–7.1 (7.0) | 7.0–7.1 (7.0) | 6.7–6.9 (6.9) | 7–8.5 |

Figures in parentheses indicate average values

*DO* dissolved oxygen, *DOM* dissolved organic matter, *TSS* total suspended solid, *OC* organic carbon

**Table 7** Treatment-wise rice equivalent yield (REY)

| Weir height (treatment) | Rice area ($m^2$) | Refuge area ($m^2$) | Total area ($m^2$) | Rice yield (t/ha) | Fish yield (kg/ha) | REY (t/ha) |
|---|---|---|---|---|---|---|
| 15 cm ($T_1$) | 3,202.4 | 171 | 3,373.4 | 4.59 | 1,694 | 5.06 |
| 20 cm ($T_2$) | 4,595.2 | 294 | 4,889.2 | 5.30 | 1,265 | 5.59 |
| 25 cm ($T_3$) | 2,217.2 | 184 | 2,401.2 | 4.83 | 1,279 | 5.25 |

micro nutrients such as $ZnSO_4$, bio fertilizers and pesticides at right time and maintaining the optimum crop geometry.

## Water productivity

The total water utilized per hectare (average of three treatments) was estimated as 8,204.5 $m^3$ after summing up the water utilized in the rice field and refuge. Considering one hectare experimental area, the rice area was taken as 9,200 $m^2$ and refuge area was taken as 800 $m^2$. The total water utilized in the rice field was computed as 6,146.03 $m^3$ which includes evapotranspiration of 3,597.2 $m^3$, deep percolation and seepage of 2,539.2 $m^3$, and water content in the harvested biomass of all the crops as 9.631 $m^3$. The total water utilized in the refuge was computed as 2,058.47 $m^3$ which includes average standing water volume of 1,021.6 $m^3$, evaporation of 345.6 $m^3$, deep percolation and seepage of 691.2 $m^3$, and water content in the harvested biomass of fish as 0.0784 $m^3$.

Considering the selling price of rice, fish, banana, papaya, black gram, green gram and ladies finger as Rs. 10/kg, Rs. 80/kg, Rs. 90/bunch, Rs. 7/kg, Rs. 33/kg, Rs. 35/kg and Rs. 12/kg (in the base year 2011), respectively, the net return from mono-crop rice, rice + fish, rice + fish + embankment horticulture and rice + fish + embankment horticulture + winter crop was calculated. The economic index of gross water productivity was computed as 5.98, 6.45, 10.01 and 12.20 Rs./$m^3$ for mono-crop rice, rice + fish, rice + fish + embankment horticulture and rice + fish + embankment horticulture + winter crops, respectively (Fig. 3). Similarly, the economic index of net water productivity for different farming system was computed as 3.76, 3.93, 6.90 and 7.38 Rs./$m^3$ for mono-crop rice, rice + fish, rice + fish + embankment horticulture and rice + fish + embankment horticulture + winter crops, respectively (Fig. 3). The percentage increase in net water productivity for rice + fish, rice + fish + embankment horticulture and rice + fish + embankment horticulture + winter crop over mono-cropped rice was 4.52, 83.5 and 96.2 %, respectively. Thus, the highest water productivity in rice + fish + embankment horticulture + winter crop combination indicates the most efficient and multiple use of conserved rainwater which has almost doubled water productivity over mono-cropped rice.

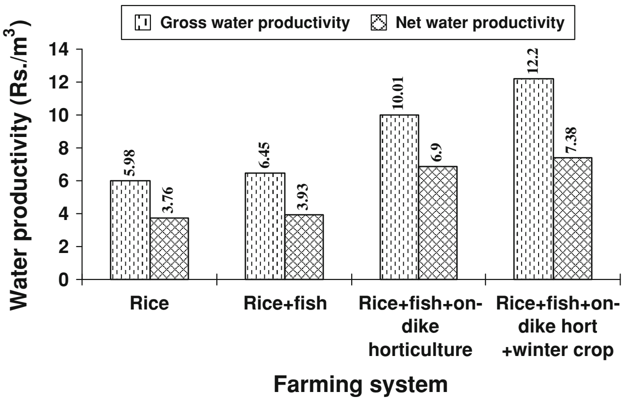



**Fig. 3** Gross and net water productivity in the rice-based farming system using two-stage rainwater conservation technique

**Table 8** Benefit cost (B:C) ratio of the farming system (3 year's average)

| Weir height (treatment) | Gross return (Rs./ha) | Cost of cultivation (Rs./ha) | Net return (Rs./ha) | B:C ratio |
|---|---|---|---|---|
| 15 cm ($T_1$) | 97,969 | 39,772 | 58,197 | 2.46 |
| 20 cm ($T_2$) | 1,03,344 | 39,772 | 63,572 | 2.60 |
| 25 cm ($T_3$) | 99,864 | 39,772 | 60,092 | 2.51 |

One US dollar = Rs. 52

### Economics

The highest gross returns of Rs. 1,03,344 and net returns of Rs. 63,572 were recorded in 20 cm weir height plots followed by 25 cm weir height plots (Table 8). The highest benefit cost ratio of 2.60 was obtained in 20 cm weir height plots followed by 2.51 in 25 cm weir height plots. The difference in cost of construction of weirs at different heights was negligible; hence was not taken into consideration. The gross returns were calculated by adding the returns generated from monsoon season rice, fish and winter season crops. The returns from banana and papaya were also included. The market rate per unit quantity of different crops was taken into consideration while estimating the gross returns. The cost of cultivation of all these crops and rearing of fish was also added. The above cost benefit was calculated for the base year of 2011. The net return was estimated by subtracting cost of cultivation from gross returns. Considering highest net income and benefit cost ratio, 20 cm weir height is recommended as optimum weir height for the study region for the system under consideration.

Further, irrespective of rice variety, 20 cm weir height plots proved to be the best treatment in terms of overall grain yield of rice, rice equivalent yield and net return. Again, Jagannath variety of rice has out performed over other varieties in terms of grain yield (6.0, 5.95 and 5.72 t/ha in first, second and third years of experiment, respectively) in the best weir height treatment of 20 cm. Therefore, keeping the best weir height (20 cm) and best variety (Jagannath) in consideration, the gross return (Rs. 1,08,884), net return (Rs. 69,112) and benefit cost ratio (2.73) were obtained.

## Conclusion

In the rainfed shallow low land of eastern India, in situ and *ex-situ* conservation of rainwater was found to be a viable solution for increasing the income of small and marginal farmers. The conserved water can be utilized in meeting the supplemental irrigation requirement of monsoon rice crop during dry spells, short-duration pisciculture in the refuge, integration of horticulture on the embankment and growing light duty winter crops. The dual production system (rice and fish) in rainy season, perennial horticulture and light duty winter crops generate additional income, employment opportunity and nutritional security. In addition, this also minimizes the risk of crop damages due to natural calamities. The system is eco-friendly and promotes synergism among different components.

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