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Economic viability of rice-fish integration with the on-farm reservoir of rainfed ecosystem in eastern India

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Abstract

The problems of the rainfed agriculture are more complex than the irrigated agriculture. *In situ* conservation of rainwater in the dyked cropped field and in the on-farm reservoir (OFR), harvesting of excess rainwater from the field in the OFR, use of harvested water for supplemental irrigation (SI) and diversified cropping (fish culture) are some of the options for rainwater storage and recycling processes for increasing the overall agricultural productivity of a region. For the selection of appropriate rainwater management strategies, water balance simulation model followed by field experimental verification were carried out during the monsoon season for sustainable production of rice (O*ryza sativa,* MW-10 Variety) and fish varieties such as rohu (*Labeo rohita*), catla *(Catla catla)* and mrigal *(Cirrhinus mrigala)* in the polyethylene lined and unlined OFRs with different weir heights (0, 5 and 10 cm) maintained at the inlet point of the excess rainwater from the field into the OFR. The average (1994-2003) volume of runoff generated from the rice field area (720 m^2) through the weir heights of 0, 5 and 10 cm were 170.51, 127.88 and 92.84 m^3, respectively. The average depth of storage required for the lined and unlined OFRs (10% of the rice field area) with 1:1 slope was 2.46 and 1.99 m, respectively. Hence, the constructed storage depth of the OFR was kept as 2.4 m for both the lined and unlined systems including the settlement allowance. The benefit cost ratio (BCR) obtained from rice-fish integration with the lined OFRs are 1.54 for 0 cm and 1.65 for 5 cm and 1.80 for 10 cm weir heights. Similarly, for unlined OFR system, the BCR are 2.83 for 0 cm, 2.70 for 5 cm and 2.66 for 10 cm weir heights. The pay back periods obtained for the lined OFR with 0, 5 and 10 cm weir heights are 21, 20 and 19 years, respectively, whereas for the unlined OFR system with 0, 5 and 10 cm weir heights, the pay back periods are 12, 13 and 13 years, respectively. The study revealed that rice-fish integration in the unlined OFRs is more economically viable than the lined system for increasing the agricultural productivity during the monsoon season of rainfed ecosystem.

Key words: Agricultural productivity, benefit cost ratio, eastern India, on-farm reservoir, rice-fish integration, payback period, rainfed ecosystem, rainwater harvesting, water balance simulation, weir height.

Introduction

Rainfed agriculture in India extends over 94 M-ha that constitutes nearly 70% of the net sown area. Yields under rainfed eco-system are low and show a high degree of instability due to the vagaries of monsoon [1-2]. Out of 42 million ha of rice cultivated land in India about 20 million ha is suitable for adoption of rice-fish integration system and only 0.23 million has presently under rice fish culture [3]. If these lands were brought under integrated rice-fish system, it would enhance the use of land and water resources without bringing about environmental degradation.

Rice-fish culture has attracted renewed interest over the past decade as a potentially viable means of producing additional food, particularly protein, and increasing the overall incomes from an integrated farming system. Though the integrated fish farming system is already well developed in China, Taiwan, Malaysia, Hungary and certain other European countries [4-5], little attention has been given in India. If the area under integrated rice–fish [6-7] and rice-vegetable-fish production system [8] increased, it would compensate the economic losses in rice production brought about by natural calamities and also enhance the use of land and water resources without bringing about environmental degradation [9].

The practice of rainwater storage in the On-Farm Reservoir (OFR) is quite common but still there is a need to improve its feasibility through simulation modeling and field experimental verification [10-2]. Simulation modeling techniques are now increasingly being used as an alternative to extrapolate the result of the field trials that can be transferred to the farmers. Simulation studies by daily water balance models help to develop appropriate strategies for the efficient management of the water resources for the sustainable production [11-13].

In the present study, the water balance simulation (1994-2003) and field studies in the rainfed ecosystem of the experimental farm of Agricultural and Food Engineering Department, Indian Institute of Technology (IIT), Kharagpur, India were carried out during the monsoon season of 2003 for sustainable production of rice (O*ryza sativa,* MW-10 Variety) and fish varieties such as Rohu (*Labeo rohita*), catla *(Catla catla)* and mrigal *(Cirrhinus mrigala)* in the polyethylene lined and unlined OFRs with different weir heights (0, 5 and 10 cm) maintained at the inlet point of the OFR. In addition the economic viability of the rice-fish farming with the OFR system at different weir heights was also studied.

Material and Methods

Quantification of runoff : Rice grown in rainfed eco-system may have alternate wetting (saturated) and drying (unsaturated) phases depending on the amount and distribution of rainfall. Under ponding phase (when soil moisture content is greater than the saturation moisture content), the generalized daily soil water balance model in the effective root zone of rice ignoring upward flux because of capillary rise from groundwater was used for estimation of soil moisture status [11, 14, 15]. Similarly, under unsaturated condition, mass balance approach also used considering inflows and outflows to determine the soil moisture content in the effective root zone of rice [16, 17]. Initially soil moisture content is assumed to be at wilting point at the time of sowing. Germination period for rice is about 5 days.

Water was not allowed to stand in the rice field during first 10 days after germination and last 10 days before harvesting. During this period surface runoff can be estimated by using the following equation:

$$sr_i = smc_{i-1} + p_i - sat \quad (1)$$

where, *smc* = soil moisture content (mm); *p* = rainfall (mm), *sr* =surface runoff (mm); sat = saturation moisture content (mm) and *i* stands for time index (day). The average value of saturation soil moisture content in 45 cm of soil layer was found 170 mm.

For the rest of the period, the excess surface runoff over the fixed weir height (*wh*) maintained as per requirement can be estimated as:

$$sr_i = smc_{i-1} + p_i - sat - wh \quad (2)$$

***Quantification of the OFR storage**:* Daily OFR storage depends on previous day storage as well as different components of the OFR water balance model. Surface runoff from the field and direct rainfall in to the OFR is the input components whereas evaporation and seepage is the output components. Assuming the water utilization by the fish varieties as negligible, the daily water balance model of the OFR can be expressed as:

$$V_{storage_i} = V_{storage_{i-1}} + VP_i + VQ_i - VS_i - VE_i \quad (3)$$

where $V_{storage}$ = storage volume in the OFR (m^3); VP_i = volume of direct rainfall on the OFR (m^3); VQ_i = surface runoff volume from the field to the OFR (m^3); VS_i = seepage volume from the OFR (m^3); and VE_i = volume of evaporation from the OFR (m^3). The input parameters of the OFR water balance model were estimated based on the plot size, OFR bottom width, slope and water depth[2, 18, 19].

Farming system and stocking density: The integrated farming system was set up under split plot design where the type of OFR (polyethylene lined and unlined) and the weir heights (0, 5 and 10 cm) were considered as main and sub main factors for the design. So, the field experiment was carried out in the 21 plots of size 800 m^2 (40 m x 20 m) (average plot size of the region) at the Agricultural and Food Engineering Department, IIT, Kharagpur, India. Nine polyethylene lined and nine unlined OFRs constructed at one corner of the individual plots and 3 plots were kept as buffer plot (rainfed). Based on the availability of field setup and simulation results [18, 19], the area of each OFR was kept 80 m^2 (8.94 m x 8.94 m) i.e. 10% of the total plot area (800 m^2) and side slope of the OFR as 1:1. The depth of storage in the OFR for different sizes of the OFR (% of plot size) was simulated based on the average volume of runoff generated from each plot over the weir heights. The different weir heights (0, 5 and 10 cm) were maintained artificially by a metal sheet at the inlet point of the OFR to maintain the desired ponding depth in the rice plot.

Short duration (110 days) rice (variety MW-10) was sown as dry seeded in line spacing of 20 cm before the onset of monsoon. The seed and FYM was applied at the rate of 100 and 5000 kg ha^{-1}, respectively. The fertilizers of N, P and K were applied in the form of urea, single super phosphate and muriate of potash, at the rate of 60, 45 and 45 kg ha^{-1}, respectively. Nitrogen fertilizer was applied in two equal splits, one at the time of sowing with P and K fertilizers and the other at the booting stage of rice. In addition, the fish varieties selected for the study are catla (*Catla catla),* rohu (*Labeo rohita)* and mrigal (*Cirrhinus mrigala)* for both the lined and unlined OFRs based on their feeding habits in different layers of the OFR water.

When depth of water in the OFRs was attained at one meter then the OFRs were treated with lime (250 kg ha^{-1}) prior to the trial [20]. On day five, fresh cow manure, urea and triple super phosphate were applied at the rate of 4500, 150, 150 kg ha^{-1}, respectively. On 12th day, Rohu of 30 g weight and length 11 cm, catla of 40 g weight and length 10.5 cm, mrigal of 25 g weight and length 10 cm, were released into the OFR. The OFR were stocked at the rate of 15,625 fingerlings ha^{-1} with four different species rohu 40, catla 25 and mrigal 35% for all the lined and unlined OFRs. The fish varieties were harvested when the water storage depth depleted to 50 cm or after the harvesting of rice which ever is earlier.

Water quality parameters such as temperature, dissolved oxygen (DO), pH, nitrate-N (NO_3-N), potassium (K^+), chloride (Cl^-), turbidity, electrical conductivity (EC) and total dissolved solids (TDS) were monitored in the laboratory using Horiba Water Quality W-23 instrument and maintained within the standard limits prescribed for aquaculture. Secchi depth transparency (SD) was monitored using Secchi disk. Temperature, DO and pH were monitored on daily basis, while other chemical and physical water quality parameters were measured on weekly basis.

The fish were feed at a rate of 2-6% of their body weight per day[21] based on fish samples taken from the OFR periodically over the entire growing season. The conversion of feed to fish termed as the OFR conversion value or S-value is calculated as follows:

$$S = \frac{Feed\ applied}{Net\ production} \quad (4)$$

Fish harvesting for sampling purpose was carried out at an intervals of 10 days. Each OFR was seined to collect at least 10% of each variety fish population for the measurement of individual weight and length determination. As proposed [18] the specific growth rate (SGR) was estimated as:

$$SGR = \frac{[\ln(final\ weight) - \ln(initial\ weight)]}{Cultural\ period\ (days)} \times 100 \quad (5)$$

Economic analysis: As proposed [2, 22, 23] a present worth analysis was used to evaluate the economics of the OFR. The present worth of the benefits (PW_b) of the OFR was calculated as follows:

$$PW_b = \sum_{t=1}^{n} \frac{P_t}{(1+r)^t} \quad (6)$$

where, P is the benefit, r is the interest rate and n is the life span of the OFR. The present worth of the total annual costs (PW_{ac}) was calculated as follows:

$$PW_{ac} = \sum_{t=1}^{n} \frac{A_t}{(1+r)^t} \quad (7)$$

where A is the annual cost . The present worth of total costs (PW_c) was calculated as follows:

$$PW_c = I_{inv} + PW_{ac} \quad (8)$$

where, I_{inv} is the initial investment. For the economic analysis, 12% interest rate and 25 years economic life of the OFR are assumed. The net profit (NP) of the OFR was given by:

$$NP = PW_b - PW_c \quad (9)$$

Benefit cost ratio (*BCR*) was the present worth of benefits divided by present worth of costs. Project is worth considering if BCR > 1.

$$BCR = \frac{PW_b}{PW_c} \quad (10)$$

Results and Discussion

Seasonal surface runoff and OFR size: The major contributions of water in the OFRs are the direct rainfall and runoff from the rice field through different weirs (0, 5 and 10 cm). Based on different treatment of weir heights, seasonal surface runoff was simulated for ten years (1994-2003) (Fig.1). The maximum runoff was generated in the year 2000 and the minimum during the 1998. Runoff generated from the rice field to the OFR was decreasing with the increase in weir heights from 0 to 10 cm. Considering the average size of plot (800 m^2) the rainfall and runoff volume contribution from the rice field at different weir heights to different sizes of the OFR starting from 8 to 15% of plot size were also simulated and presented in Fig. 2.

The rainfall and runoff contribution from the rice field at different weir heights to the OFR size of 8% of the plot size were found the variation from 81.10 and 18.90% for 0 cm, 76.34 and 23.66% for 5 cm and 70.03 and 29.97 % for 10 cm weir heights, respectively. Whereas, the rainfall and runoff contribution from the rice field at different weir heights to the OFR size of 15% of the plot size were found 67.89 and 32.11% for 0 cm, 61.09 and 38.91% for 5 cm and 53.82 and 46.18% for 10 cm weir heights, respectively. Based on the availability of experimental field setup and previous simulation study the OFR of 10% of plot size was considered for the present study. The average volume of runoff contributed from the rice field area (720 m^2) at the weir heights of 0, 5, and 10 cm were 170.51, 127.88 and 92.84 m^3, respectively.

The lined and unlined OFR specifications considered for the simulation are square shaped pyramidal shape with 1:1 side slope. Figs. 3 and 4 present the simulated maximum depth of storage required at different sizes of lined and unlined OFR (% of plot size) with different weir heights. The OFR depth of storage decreases with increase in depth of weir height and the OFR size due to the variation of rainfall and runoff contribution. From the simulation, the maximum storage depths obtained for the lined OFR (10% of plot size) with 0, 5 and 10 cm weir heights were 2.75, 2.41 and 1.96m, respectively. Whereas for the unlined OFR (10% of plot size) with 0, 5 and 10 cm weir heights, the maximum storage depths were 2.23,1.92 and 1.80 m, respectively.

The average depth of storage required for the lined and unlined OFR at three-weir heights was 2.46 and 1.99 m, respectively. The settlement depth for the unlined OFR was given as 40 cm. So, for the field experimental study the storage depth was kept 2.4 m for the lined and unlined OFRs size (10% of the plot size) with 1:1 slope.

During the growing period of rice in 2003, it was observed that only eight times runoff from the rice field contributed to the OFR. The maximum runoff generated through the 0, 5 and 10 cm weir heights were 44.15, 39.68 and 37.91 mm, respectively. Total runoff generated from the rice fields during the growing period with 0, 5 and 10 cm weir height was 240.84, 181.14 and 131.14 mm, respectively.

The observed and simulated depths of storage for the lined and unlined OFRs were presented in Figs 5 and 6, respectively. The depth of storage in the lined and unlined OFRs with different weir heights shows the significant difference due to the variation of inflow and outflow components of the OFR. During the experiment the observed average depth of water in the lined and unlined OFRs was found 1.80 and 1.05 m, respectively. Standard deviations for the depth of storage in the lined and unlined OFR were found as 0.13 and 0.30 m, respectively. During the study period minimum depth of storage for the lined and unlined OFR were observed as1.50 and 0.80 m respectively. So, the OFRs can be used for fish culture during the crop-growing period.

Specific growth rate of fish: Specific growth rate (SGR) is used to evaluate the effect of the lined and unlined OFRs on fish growth. SGR values for three fish species in the lined and unlined OFR are shown in Fig. 7. The SGR of catla, rohu and mrigal in the lined OFR were found as 1.56, 1.53 and 1.57 (% body weight ((bw)/day), respectively. The SGR values in the unlined OFR were found 1.53, 1.4 and 1.23 (% bodyweight (bw/day), respectively. The SGR value shows little variation due to the variation of water storage depth with the same shape and size of the OFR.

OFR conversion value: The conversion of feed to fish is termed as the OFR conversion value (S-value). The S-value for catla, rohu, and mrigal were found 1.8, 1.6 and 1.76 in the lined and 1.67, 1.72 and 1.85 in the unlined OFR, respectively. Although the S-values are suitable for economic evaluation but they are misleading for water quality considerations.

Economic viability of rice-fish farming: In the economic analysis, the different costs considered for the rice-fish farming system were initial investment for the OFR construction, the annual maintenance cost. Initial investments of the OFR system considered were the construction cost and lining cost. The annual cost comprised of repair and maintenance cost and land lease

Table 1. Summary of rice-fish production with the lined and unlined OFRs and buffer plots.

Parameters		Lined			Unlined			Buffer plot
		Weir heights (cm)			Weir heights (cm)			
		0	5	10	0	5	10	
Average yield	Rice (kg/ha)	3815	4016	4310	3846	3756	3756	2930
	Fish (kg/ha)	2705	2685	2665	2685	2655	2625	
Return from yield	Rice (Rs. /plot)	1236	1301	1396	1246	1216	1217	949
	Rice straw (Rs./plot)	124	130	139	124	121	122	105
	Fish (Rs. /OFR)	1082	1074	1066	1074	1062	1050	0.00
Total return	Rice-fish farming (Rs/plot)	2442	2505	2602	2444	2400	2389	1055
Benefits over buffer plot (Rs)		1387	1450	1547	1389	1345	1334	-

1 US $ = Rupees 46.

Table 2. Economics of the OFR (80m^2) system for rice-fish integration.

Parameter	Lined OFR			Unlined OFR		
	Weir heights (cm)			Weir heights (cm)		
	0	5	10	0	5	10
Cost of construction of OFR (Rs.)	2168	2168	2168	2100	2100	2100
Cost of LDPE sheets to line OFR (Rs.)	5400	5400	5400	-	-	-
Labour cost for lining of OFR (Rs.)	200	200	200	-	-	-
Total investment (Rs.)	7768	7768	7768	2100	2100	2100
Total annual cost (Rs.)	165	165	165	52	52	52
Present worth value of annual costs (Rs.)	2811	2811	2811	884	884	884
Present worth of total cost (Rs.)	10579	10579	10579	5795	5795	5795
Present worth of benefit (Rs.)	16330	17403	19050	16375	15622	15429
Net profit (Rs.)	5751	6824	8471	10580	9827	9634
Benefit cost ratio	1.54	1.65	1.80	2.83	2.70	2.66
Pay back period (years)	21	20	19	12	13	13

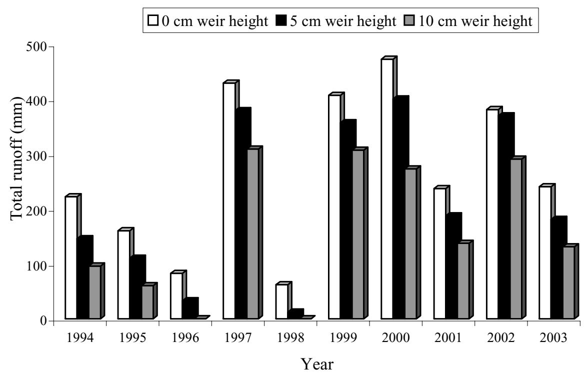

Figure 1. Total seasonal runoff contributed to the OFR from the rice field through the different weir heights

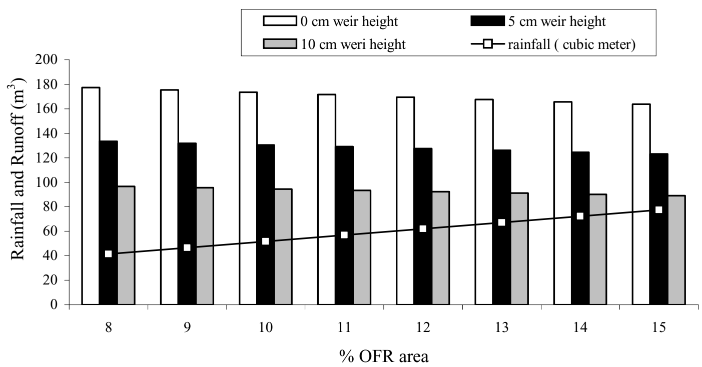

Figure 2. Contribution of direct rainfall and runoff volume from the rice field to the OFRs.

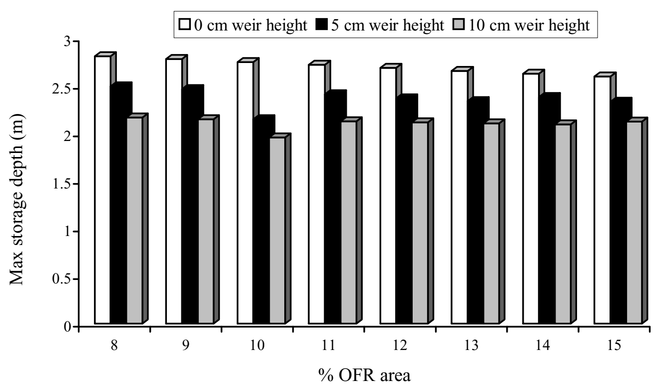

Figure 3. Maximum simulated storage depth variation with the different sizes of the lined OFR.

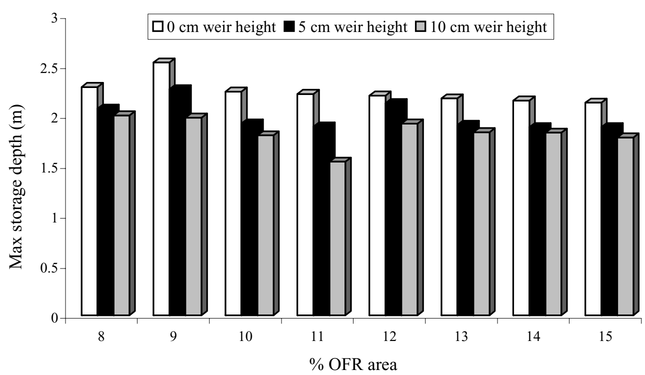

Figure 4. Maximum simulated storage depth variation with the different sizes of the unlined OFR.

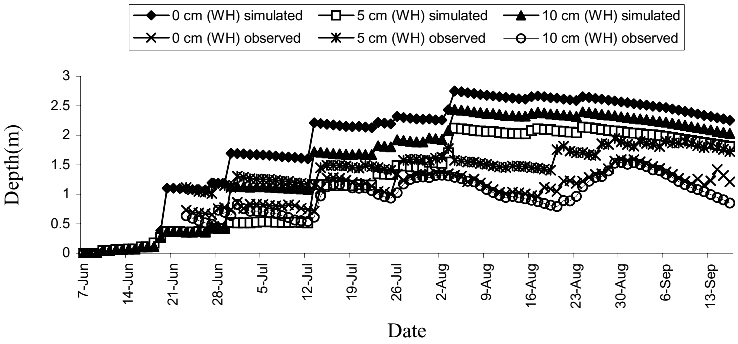

Figure 5. Simulated and observed depths in lined OFR.

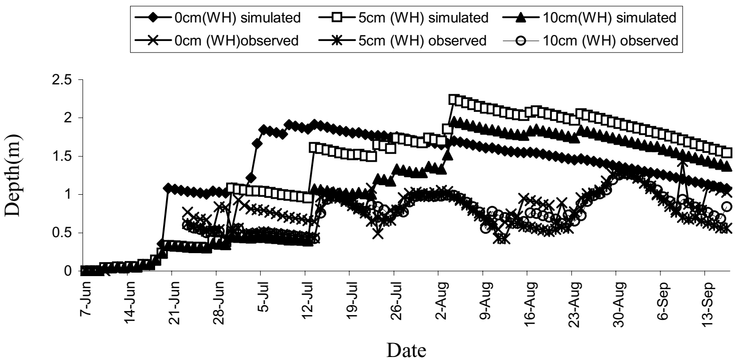

Figure 6. Simulated and observed depths in unlined OFR.

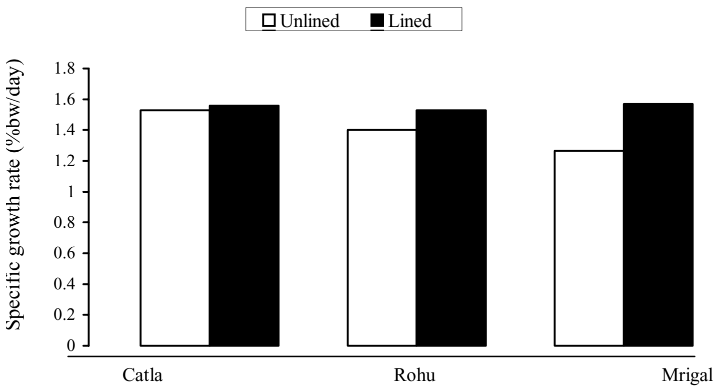

Figure 7. Fish specific growth rate in the lined and unlined OFRs.

cost for the construction of the OFR. Repair and maintenance cost was assumed to be 2% of initial investment. Considering 12% interest rate and 25 years life span of the OFR, present worth value of annual cost was computed for the lined and unlined OFR system with different weir heights for rice-fish integration during monsoon season in rainfed ecosystem. The benefit obtained from the yield of rice-fish with the lined and unlined OFR system over the buffer plot (without OFR) was used for benefit cost ratio (BCR) analysis. Summary of rice-fish production with the OFR and buffer plots are given in Table 1 and the economics of the OFR (80 m^2) system for rice-fish integration are presented in Table 2. The selling price of the yield and byproducts considered based on the market price as Rs. 4.5/kg for rice, Rs. 30/100kg for rice straw and Rs. 50/kg for fish.

Economic analysis revealed that 10% size of the unlined OFR is economically viable for rice (MW-10) and fish (catla, rohu and mrigal) integration with BCR of 2.83, 2.70 and 2.66 whereas the lined OFR shows BCR of 1.54, 1.65 and 1.80, with 0, 5 and 10 cm weir heights, respectively. It was observed that, the net profit and BCR of the lined OFR system was increased with the increase in depth of weir heights but in case of unlined OFR system the net profit was decreased with the increase in weir height due to the reduction of yield of rice-fish with weir heights and the effect of water availability for rice-fish farming. The pay back period (when BCR is equivalent to 1.0) period obtained for rice-fish integration with the lined OFR system and 0, 5, and 10 cm weir heights are 21, 20 and 19 years, respectively. Whereas for unlined OFR system with 0, 5, and 10 cm weir heights are 12, 13 and 13 years, respectively. Hence it can be said that OFR system is the only alternative to increase the overall productivity of the rainfed ecosystem.

Conclusions

The field study and simulation modeling for rainwater harvesting in the lined and unlined OFR with different weir heights (0, 5 and 10 cm) for rice-fish integration of rainfed ecosystem in eastern India, revealed that the lined and unlined On-Farm Reservoirs (OFR) are one of the alternatives to water harvest excess runoff generated from individual rice field during the monsoon season and can be used for sustainable production of fish varieties to increase the overall agricultural productivity and as supplemental irrigation to rainfed rice during the critical growth stage or pre-sowing irrigation to winter crops. The storage depths of 2.4 m from the field level and 1:1 side slope for the lined and unlined OFRs (10% of the plot size) with 0, 5 and 10 cm is the maximum depth required for the harvesting the direct rainfall and surface runoff spillover the weir height as overland flow. The lined and unlined OFRs of aforementioned dimensions are economically viable for rice (MW-10) and fish (catla, rohu and mrigal) farming with the BCR of 1.54, 1.65 and 1.80, for the lined OFR and 2.83, 2.70 and 2.66 for the unlined OFR at 0, 5 and 10 cm weir heights, respectively. The pay back period (BCR is equivalent to 1.0) period for rice-fish integration with the lined OFR system at 0, 5, and 10 cm weir heights are 21, 20 and 19 years, whereas for unlined OFR system with 0, 5, and 10 cm weir heights are 12, 13 and 13 years, respectively. Thus farmers may be suggested to adopt the rice-fish farming with the unlined OFR in the rainfed ecosystem for increasing their economic return and employment opportunities.

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