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Rainwater Conservation and Rice-fish Integration for Enhancing Land and Water Productivity

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FOREWORD

Rainwater conservation in rainfed medium lands and its utilization for rice-fish integration system is gaining importance in the new millenium particularly in high rainfall region. Significant research and development works have been done at Water Technology Centre for Eastern Region, since last one decade on various aspects of rainwater, soil and nutrient conservation in rice fields and subsequent integration of fish and prawn culture with rice crop. Rainwater conservation in rice field and refuge has significantly enhanced the overall productivity, cropping intensity and rice equivalent yield of the system due to integration of fish and prawn. This eco-friendly and easily adaptable system encourages synergism between components and recycles the wastes of one another leading to enhancement in grain yield. Further, this system generates employment opportunity and provides nutritional security to the resource poor farming community.

I congratulate the team leader and his associates for their outstanding contribution in the field of rainwater conservation and rice-fish integration. I sincerely hope that their efforts in bringing out this bulletin will be helpful for all those engaged in rice-fish integration and its management. This will also serve as a source of information to farmers, policy makers, entrepreneurs, researchers and extension workers as training guide. I would also like to thank Dr. S. D. Sharma, Dean, Post-Graduate Studies and Extension Education, OUAT, Bhubaneswar, for critically reviewing this manuscript and offering valuable suggestions.

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1.0 INTRODUCTION

Indian agriculture is subjected to tremendous pressure of fulfilling the food requirements of increased population. In one hand there is stagnation of net cultivated area and in other there is increasing demand for irrigation water. Thus, optimum utilization of land resource and multiple use of water resource through integrated farming practice are the present need to enhance the overall agricultural production from unit area of land and unit volume of water.

The eastern region of the country is blessed with plenty of rainfall most of which occurs during June to September. Rice is, therefore, the predominant crop of this region during monsoon. During this period (June to September), about 50% of the annual rainfall come from few intense storms. Water received from such intense storms results into high runoff losses. Added to this is the erratic nature of onset, distribution and withdrawal of monsoon rains which increases the probability of water stress at various stages of the rice crop. The crop suffers from moisture stress either due to excess water during heavy downpour (Pande, 1976) or due to shortage during long drought spell (BRRI, 1984 and Zamen, 1986). Due to this, the productivity of rainfed rice is quite lower than that of the irrigated rice. To improve the rice yield of eastern region, which has almost half of its acerage under rainfed ecosystem, rainwater conservation and management, is highly essential. To achieve the same, farmers try to store maximum rainwater in the rice fields by strengthening the dikes around the field and raising their height. Thus, in rainfed rice lands, dike height around rice fields play a crucial role in conserving rainwater *in-situ*. Optimum dike height for conservation of rainwater, sediment, nutrient and improvement in rice yield has drawn attention of the researchers in recent past (Islam and Mondal, 1992; Mishra *et al.*, 1998 and Khepar *et al.*, 2000). A dike height of 20-25 cm is recommended only for *in-situ* conservation of rainwater, sediment and nutrient for Bhubaneswar region (Mishra *et al.*, 1998). *In-situ* conservation of rainwater also minimizes the supplemental irrigation requirement during dry spells and drainage need of the catchment.

Instead of conserving all the rainwater *in-situ*, it would be beneficial to conserve a part of it in the rice field and the remaining to spill over the weir from rice field and harvested in a refuge for rearing of fish and prawns in addition to its utilization for supplemental irrigation. To obtain increased production from unit volume of rainwater, there is a need to judiciously decide the quantum of water that has to be conserved in the field and the quantum to be harvested in the refuge. Thus, the optimum dike height for conservation of rainwater *in-situ* and harvest of excess water for fish culture in the refuge needs determination. Further, a majority of population, particularly small and marginal farmers with poor purchasing power is forced to eat only rice, thus, getting unbalanced diet. Hence, the rice based cropping system needs crop diversification to provide balanced nutrition. Therefore, rice fish integration can be a suitable option to be taken up in the rainfed medium lands along with rainwater conservation measures to alleviate malnutrition and provide a better nutritional security.

Out of 42 million ha of rice cultivated land in India, about 20 million ha is suitable for adoption of rice-fish integration system (Rao and Ramsingh, 1998) and only 0.23 million ha is presently under rice-fish culture (Radhey Shyam, 1998). Unfortunately, the carrying capacity of these suitable lands has not been utilized to the fullest extent. If these lands were brought under integrated rice-fish system, it would help to compensate the economic losses in rice production brought about by natural calamities. Further, it will also enhance the use of land and water without bringing about environmental degradation. In addition to enhanced productivity, this system could further generate employment opportunity and increased income for farmers.

Adoption and practice of rice-fish culture in India dates back almost 1500 years. The original system of integrated rice-fish farming introduced to South-East Asia from India, has flourished and developed from the low input-based to intensive systems (Ali, 1990). However, despite great advances, several technical and production constraints are yet to be resolved such as yield gap between experimental and field models, inconvenience in pesticide application and development of suitable design. It is also important to study the mechanism of rice-fish culture and the relationship among rice, fish and other factors such as soil, water, fertilization etc. in the rice field. Although lot of research have been carried out on different aspects of rice-fish integration system (Khoo and Tan, 1980; Likangmin, 1988; Lightfoot *et al.*, 1992; Huazhu, 1994 and Sinhababu, 2001), very little information is available on species composition and stocking density, food preference and intake pattern of cultured species, soil and water chemistry in relation to yield, and management strategy to enhance unit yields. Though some exotic designs of integrated rice-fish system developed in neighbouring countries have been demonstrated and evaluated in India (CRRI, Cuttack and CICFRI, Barackpore), not much emphasis has been given to improve the design aspect for better efficiency and increased productivity. A need is thus felt to investigate efficient, productive and location specific rice-fish system for developing viable rice-fish farming packages. In some areas of the region, a thumb rule to have a tank at the lower end of rice field to harvest runoff for supplemental irrigation being propagated by NGOs also needs improvement in engineering design. The quantum of rainwater to be conserved *in-situ* for better growth and yield of rice, *ex-situ* for longer duration rearing of fish/prawn and thereby decision regarding optimum weir height and size of the refuge is essential and linked with the fish culture component.

Keeping the above stated points in view, attempt has been made here to determine the optimum weir height for *in-situ* conservation of rainwater for rice crop as well as refuge size to harvest the runoff water for fish culture. Attempt has also been made to evaluate rice-fish integration system in medium land ecosystem with special reference to stocking density, food preference and intake pattern of cultured species, and soil and water chemistry in relation to yield.

2.0 THEORETICAL CONSIDERATIONS

2.1 Water balance model for diked rice field

Irrigation and drainage requirements of a rice field can be estimated by means of a water balance study. The water balance (input-output = change in storage) of a diked rice field can be expressed in terms of water depth and a time units of a day of 24 hours may be considered suitable for simulation. Different components of the water balance in a rice field are shown in Fig. 1. The mass balance equation can be expressed as:

$$WL_e = WL_b - ET - DP + RF + IR - DR \quad (1)$$

where, WL_e = water level at the end of the day, WL_b = water level at the beginning of the day, ET = actual evapotanspiration during the day, DP = deep percolation and seepage loss during the day, RF = total rainfall during the day including possible inflow from other areas, IR = irrigation water required/supplied during the day, and DR = runoff water from the paddy field during the day.

In order to perform the daily water balance computation it is necessary to specify boundary conditions and to make some assumptions. WL_{max} and WL_{min} are defined as the maximum possible and minimum required water levels in the field. For $WL>WL_{max}$, runoff ($DR = WL-WL_{max}$) will occur and for $WL<WLmin$, irrigation ($IR = IAD-WL$) will take place, where WL is the water level at a particular time and IAD is the irrigation application depth.

The model computes the depth of standing water in the rice field, the volume of water that spills out and irrigation water to be applied daily, if any for the crop growth period for bunded rice fields with various weir heights.

Analysis of historical climatic data of the study site (Bhubaneswar) reveals that 17 June and 29 October are the mean dates of onset and withdrawal of effective monsoon, respectively. On an average, two to three dry spells of mean 18 days duration occur in a year (Upadhyaya and Singh, 1996). Therefore, on an average the seeding of rice is assumed to start on 17 June. Considering a nursery of 25-30 days old suitable for transplanting, 15th July is assumed as the transplanting date. Thus, the crop growth period (transplanting to harvesting) for the purpose of the water balance study is considered to be from 15 July to 15 November.

The weir height of the bunded rice fields for simulations were kept as 6 cm to 30 cm at an interval of 4 cm. These weir heights are considered as WL_{max} values for simulation. Daily rainfall data at Bhubaneswar for the period 1960-1991 were used for present study. Daily ET rate of rice crop was estimated for the same period by a modified penman method using data on the daily maximum temperature, minimum temperature, relative humidity, wind velocity and sunshine hours. Deep percolation and seepage, which are the vertical movement of water beyond the root zone to the water table and the lateral movement of subsurface water respectively, are often inseparable (Wickham and Singh, 1978). Hence, the daily water loss due to deep percolation and seepage was calculated using the relationship obtained from experimental field observation (Mishra *et al.*, 1997) which is as follows:

$$DP = -0.164 + 0.079D, \quad R^2 = 0.865 \tag{2}$$

Where, DP is the rate of water loss (cm/day) due to deep percolation and seepage and D is the average depth of water stored in the rice field (cm). Equation (2) implies that deep percolation and seepage rate is zero up to the average depth of 2.08 cm. This is probably due to the deposition of a fine layer of soil on the surface on account of puddling. Puddling induces non-Darcian flow at lower hydraulic gradients (Sinha *et al.*, 1981). Thus, the hydraulic gradient corresponding to 2.08 cm depth of ponding is the threshold value after which the deep percolation and seepage take place.

In the rainfed system, where there is no provision of irrigation water, it becomes essential to know the quantum of water required for supplemental irrigation. Further, it is decided to irrigate the rice field just a day after the complete disappearance of standing water from the land surface. Hence, for the model study, WL_{min} is considered at the land surface or zero depth. The runoff amount (DR) from various weir height plots as predicted by the model has been presented below (Table 1) for deciding the refuge size (Table 2).

2.2 Estimation of runoff and refuge size at different weir heights

Based on the experimental study (Mishra *et al.*, 1998) and water balance model study as stated above by inputting the climatic data of Bhubaneswar (Mishra, 1999), weir height of 20 to 25 cm is considered optimum only from *in-situ* resource conservation angle in the medium land rice ecosystem of the study region. With this weir height of 20 to 25 cm, about 96.74% to 98.68% of rainwater could be conserved directly in the rice field. To have a more productive use of rainwater, it is decided to conserve a portion of rainwater directly in the rice field and the remaining portion in a refuge (primarily meant for fish culture) constructed in the down stream pocket of rice field. For this purpose a detailed experimental study of three years duration with three weir heights of 10 cm, 12.5 cm and 15 cm was proposed. Thus, in these proposed weir heights, rainfall amount of 80.07% to 91.94% is expected to be retained in the field. The remaining portion of the rainfall from rice plot will spill over the weir and get stored in the refuge.

Table 1 shows fortnightly runoff, which is expected to spill out from 10, 12.5 and 15 cm weir height rice fields. This was obtained through daily water balance simula-

Table 1 Fortnightly runoff in mm (mean of 32 years) from rice plots with various weir heights

Weir height (cm)	July 2nd half	Aug. 1st half	Aug. 2st half	Sept. 1st half	Sept. 2st half	Oct. 1st half	Oct. 2st half	Nov. 1st half
10	45.54	46.76	40.40	32.63	21.32	14.98	15.96	6.19
12.5	32.07	31.50	30.36	23.29	15.16	8.38	10.89	4.42
15	20.95	18.62	3.86	8.75	5.42	0.77	1.72	1.69

Table 2. Refuge size and computed fortnightly water depth (m) in the refuge

Weir height (cm)	Area of the refuge as (%) of rice field	July 2nd half	Aug. 1st half	Aug. 2st half	Sept. 1st half	Sept. 2st half	Oct. 1st half	Oct. 2st half	Nov. 1st half
10	12%	0.44	0.88	1.26	1.54	1.73	1.81	1.89	6.85
12.5	9%	0.42	0.82	1.2	1.47	1.65	1.7	1.77	4.73
15	4%	0.60	1.12	1.4	1.62	1.76	1.74	1.78	1.73

tion of 32 years rainy season (using the developed water balance model described above). The predicted runoff values from the model are found to be in close agreement with the observed experimental values (Mishra *et al.*, 1997). Perusal of the Table 1 reveals that in case of 15 cm weir height plot, there is drastic reduction in runoff values just after 1st half of August. Hence, for the study area, weir height of more than 15 cm will not be suitable for fish culture by harvesting runoff in the refuge. Further, it is decided to maintain a depth of 1.5 to 1.75 in the refuges for fish culture. Keeping this depth of storage in mind the area to be brought under the refuge for various weir heights are calculated and shown in Table 2. It is found that rice fields with weir heights of 10 cm, 12.5 cm and 15 cm need about 12%, 9% and 4% of the rice field area for construction of refuge, respectively. The average depth of water, which will be standing after taking into account, the losses are also shown in Table 2. Possibility of utilizing the harvested water either for fish culture or for irrigation during dry spells to maximize the return from the system can be explored through experimental study. The estimated depth of standing water in the refuge at the end of 1st half of November (during harvesting of rice) reveals that there will be more than 1.7 m of water in all three sizes of refuge. Thus, with a stored water depth of 1.7 m, rearing of fish/prawns can be successfully carried out till end of December. On an average 20 cm of water is estimated to be required for supplemental irrigation. The figures in Table 2 are given considering that there is an alternative source for giving supplemental irrigation. In the rainfed system, if the supplemental irrigation is to be given from the refuge, the fish may be harvested by 15th of December. After the harvest of fish, the water remaining in the refuge can be utilized as a pre-sowing/life saving irrigation for a light duty *rabi* crop.

3.0 EXPERIMENTAL LAYOUT

This study is a follow up of the experimental study made by Mishra *et al.*, 1997 on determination of optimum dike height for rainwater, soil and nutrient conservation *in-situ* without integrating fish culture component. The present experiment was carried out at WTCER research farm, Deras, Bhubaneswar, India (Lat. 20°30′ N and Long. 87°48′10″ E) during 1999-2001 for three successive years. Plots of 30 x 10 m size were selected for the proposed study. Three different weir heights (10 cm, 12.5 cm and 15 cm) were chosen as treatments with three replications each. Each rice field was provided with a peripheral trench of 0.5 m wide and 0.3 m deep on three sides (Fig. 1). A slope of 0.5% was provided at the trench bottom towards downstream side. When water level recedes in the rice field, fish and prawns move to the peripheral trench and finally to the refuge through the regulated inlets. Ref-

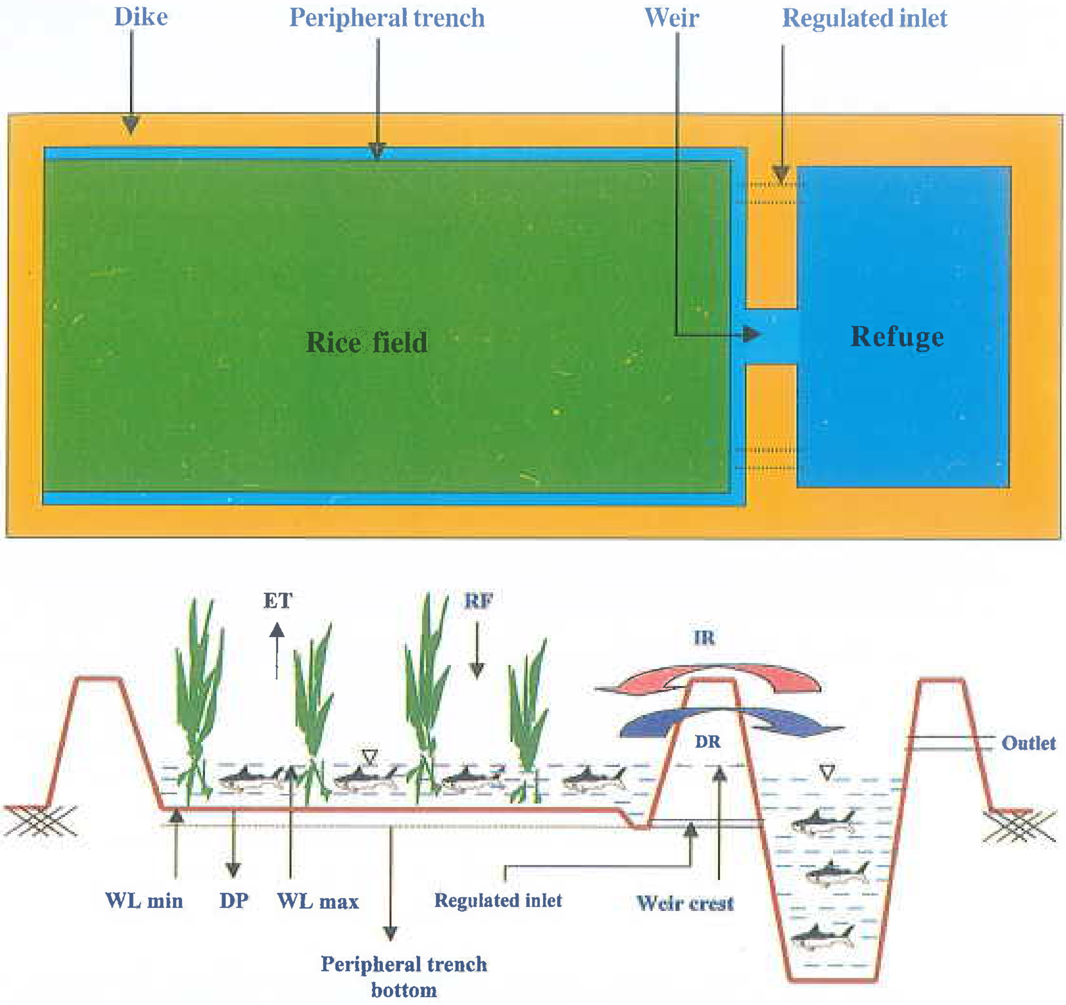

Fig. 1 Layout of rice-fish system in rainfed medium lands with water balance components

uges were constructed at the down stream end of each plot as per the size determined above (Table 2). The area of the refuges was 45 m^2, 35 m^2 and 15 m^2 for 10, 12.5 and 15 cm weir heights plots, respectively. The depth of the refuges from weir crest to bottom of refuge was kept at 1.75 m. The excess rainwater spilling over the weir was harvested in the refuge. Two regulated inlets (pipes) were provided to each refuge at the bottom surface of the trench. These inlets remain closed most of the time. Only when the water level in the rice field recedes, they are opened to allow the fish and prawns to come to the refuge from the rice field. Further, each refuge was provided with an outlet (hume pipe fitted with fine meshed net) to dispose of the excess water above 2.00 m in the event of heavy down pour.

After two years of varietal trial amongst *MW-10*, *Swarna* and *Lalat* (Fig. 2); *Swarna* was selected as the best variety and was grown in each plot of the present study (Figs. 3 and 4) with a spacing of 20 x 10 cm (between rows and plants). Transplanting was usually carried out during 2nd week of July. The seed and fertilizer application rate was 50 kg ha^{-1} and 80:40:40 (N:P:K) ha^{-1} , respectively. 50% of N and full dose of P and K were given as basal dose at the time of transplanting. The rest of the Nitrogen was applied in two equal splits during tillering (20 days after transplanting) and panicle initiation (45 days after transplanting) stages. Crop growth and yield parameters were recorded at regular intervals. No pesticide was used in the experimental plots to prevent fish mortality.

Fig 2. Verietal trial of paddy in rice-fish integration system

Refuge preparation with application of lime @ 2000 kg ha^{-1}, raw cattle dung @ 5000 kg ha^{-1} and fertilizers (Urea:SSP :: 1:1) @ 3 ppm was carried out prior to stocking. Seven days after refuge preparation, fry of *Catla catla, Labeo rohita, Cirrhinus mrigala, Cyprinus carpio* and post larvae (PL$_{3-5}$) of freshwater prawn *Macrobrachium rosenbergii* were stocked in the refuge during 4th week of July –1st week of August with a species composition of 30:30:15:15:10, respectively. Stocking density of fry was kept at 15000, 25000 and 35000 ha^{-1} (refuge area only) during 1st, 2nd

Fig 3. View of rice-fish integration system

Fig 4. Series of refuge with adjacent rice fields

and 3rd year of experimental study, respectively and rearing was continued for 120 days. Initially, the fry and post-larvae were released both in the rice field and refuge. In the event of heavy down pour, when the water level of rice field and refuge rises above the weir crest and becomes equal, movement of fish/prawns takes place in either direction between the refuge and rice field. Supplemental feed (rice bran:groundnut oil cake :: 1:1) @ 10%, 8%, 6% and 4% of mean body weight (MBW) was given twice a day, during 1st, 2nd, 3rd and 4th month to harvesting, respectively. Periodic manuring @ 500 kg ha^{-1} and liming @ 200 kg ha^{-1} were carried out at every 15 days interval to maintain plankton population in the eco-system.

Plankton estimation, weekly observation on water quality and monthly observations on soil quality was recorded using standard methods (APHA, 1989 and Biswas, 1993). Field test instruments were also in use to analyze *in-situ* water pH (Checker-

Fig 5. Harvested fish and prawn from rice-fish integration system

1, HANNA, USA), Soil pH (DM-13, Japan), and dissolved oxygen (YSI-55, USA). Crop performance, fish/prawn growth parameters, condition factor of fish and prawn, feed conversion ratio were measured/estimated. To estimate the food preference and feed intake pattern of cultured species, gut content analysis, degree of satiation (Mohanty *et al.*, 2000), indices of electivity of different food components (Ivlev, 1961), frequency, abundance and matrix of dietary overlaps (Johnson, 1999 and Mohanty *et al.*, 2000) were carried out. Every year, during the experiments, 12 numbers of each species were sacrificed for this purpose. To compare the effect of fish and prawn on rice yield, three fields of equal size and different weir heights of 10, 12.5 and 15 cm were taken as control, where only *Swarna* variety of rice was grown without integration of fish and prawn.

4.0 RESEARCH FINDINGS

4.1 Soil and water quality

Water quality, changes in response to daily and seasonal climatic rhythms while, fish/prawn can adapt to this natural fluctuations to a certain level and fails thereafter due to stress. In this experiment, various hydrobiological parameters did not show any distinct trend between the treatments except in the cases of total suspended solid, dissolved oxygen and total alkalinity. The recorded minimum and maximum values of various water and soil quality parameters were: water temperature 27.5 - 30.2^{0}C; water pH 6.9 - 8.8; dissolved oxygen 3.9 - 8.1ppm; total alkalinity 69 - 129 ppm; dissolved organic matter 0.6 - 4.7 ppm; nitrite –N 0.006 - 0.071 ppm; nitrate-N 0.06 - 0.52 ppm; ammonia 0.01 - 0.21 ppm; total suspended solid 89 - 319 ppm; phosphate-P 0.06 - 0.34 ppm; water depth 89 - 175 cm; soil pH 6.6 - 7.0; available-N in soil 7.9 - 10.7 mg 100^{-1}g; available P in soil 0.29 - 0.67 mg 100^{-1}g ; organic carbon in soil 0.16 - 0.53% and total plankton count 2.4 x 10^2 – 9.1 x 10^3 nos/ l. Most of the parameters were fluctuated within / near the optimum range (Table-3). The dissolved oxygen content showed a decreasing trend with the advancement of rearing period, attributed to gradual increase in biomass, resulting in higher oxygen consumption. Increased level of water and concentration of total suspended solid was observed in refuge with 10 cm weir height plots, followed by 12.5 and 15 cm weir height plots, probably due to more volume of runoff from the rice field along with sediment and other nutrients. Turbidity caused by suspended soil particles has usually no direct effect on fish (Pillay, 1992) but as it restricts light penetration, photosynthesis and natural food availability becomes limited (Mohanty, 1996). Poor growth performance of cultured species takes place at pH < 6.5 (Mount, 1973) while, higher values of total alkalinity (>90ppm) indicates a better productive ecosystem (Banerjea, 1967) and increased plankton density reflects higher nutrient status of the water body. The availability of CO_2 for phytoplankton growth is related to total alkalinity, while water having 20-150 ppm total alkalinity produce suitable quantity of CO_2 to permit plankton production (Boyd and Pillai, 1985). However, the recorded minimum and maximum range of total alkalinity during the experimental period was 69 and 129 ppm respectively, which was maintained due to periodic liming. Decreased level of transparency, increased level of ammonia and total suspended solids were probably due to entry of runoff water

Table 3. Minimum and maximum values (average of three replications) of water and soil quality parameters in the experimental refuges

Parameter	Refuges with 10 cm weir height plot		Refuges with 12.5 cm weir height plot		Refuges with 15cm weir height plot	
	Min	Max	Min	Max	Min	Max
pH	6.9	8.3	7.2	7.9	6.9	8.8
Dissolved oxygen (ppm)	4.2	7.6	4.5	8.1	3.9	7.2
Temp. (^{0}C)	27.5	30.1	27.6	29.9	27.5	30.2
Total alkalinity (ppm)	76	129	69	116	88	117
Dissolved organic matter (ppm)	0.6	4.7	0.8	4.7	0.6	4.2
Nitrite-N (ppm)	0.006	0.071	0.007	0.063	0.006	0.058
Nitrate-N (ppm)	0.06	0.52	0.06	0.47	0.06	0.39
Amonnia (ppm)	0.01	0.21	0.02	0.16	0.01	0.19
TSS (ppm)	116	319	95	260	89	246
Phosphate-P (ppm)	0.07	0.33	0.07	0.31	0.06	0.34
Water depth (cm)	121	175	98	175	89	175
Soil pH	6.8	7.0	6.6	6.8	6.7	6.9
Available - N in soil (mg/100g)	8.9	10.7	8.4	10.1	7.9	9.4
Available - P in soil (mg/100g)	0.32	0.67	0.36	0.64	0.29	0.45
Organic carbon in soil (%)	0.19	0.53	0.16	0.51	0.21	0.38

from the rice field along with sediment and other nutrients, periodic manuring, decomposition of weeds, metabolic deposition and organic load (Mohanty, 1999). Average primary production in the first month of rearing ranged between 93 – 117 mgC m^{-3} h^{-1}, which improved further (514.5 ± 89.4 mgC m^{-2} h^{-1}) with the advancement of rearing period. Low primary production 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. In general, water reaction process is low during monsoon (July – August) due to dilution of alkaline substances or dissolution of atmospheric CO_2.

4.2 Growth and yield of rice

Rice variety *Swarna* was grown under three different weir heights plots of 10 cm, 12.5 cm and 15 cm. Table 4 presents the biometric parameters for different treatments. Highest number of panicles/m^2 (235.5) was recorded in 15 cm weir height plots followed by 12.5 cm weir height plots (233.2). Similar trend was observed for number of filled grains/panicle. However, highest test weight (weight of 1000 grains) was recorded in 12.5 cm weir height plots. The test weight was not significantly different amongst treatments.

Table 5 presents the grain and straw yield of rice under various treatments. Highest grain yield was recorded at 15 cm weir height (3629 kg ha^{-1}) which was significantly superior to that of 10 cm weir height (2988 kg ha^{-1}). However, its superiority over 12.5cm weir height was not statistically significant. The similar trend was also followed in case of straw yield. The highest grain yield at 15 cm weir height was probably contributed by higher number of panicles/m^2 (235.5) and number of filled grains/panicle (121.7).

Table 6 shows the grain yield of rice in rice-fish integrated plots and control (rice was grown without fish and prawn) plots. Perusal of the Table reveals that in all the treatments, yield of rice in rice-fish integrated plots was higher than that of control plots. On an average, 8.33% of increase in rice yield was obtained in the rice –fish integrated plots. This increase in rice yield is possibly due to introduction of fish and prawn in rice field where, frequent locomotary movement of fish and prawn improves the dissolved oxygen level and soil organic matter/ nutrient status by adding faecal matter. Introduction of fish and prawns also controls plankton population/ macro and micro aquatic insects/ bacteria/ organic detritus that compete with rice for material and energy resulting in enhanced rice yield. Similar findings of Hora and Pillay (1962) also reveals that, introduction of fish has increased paddy yield by 15% in the Indo-Pacific countries due to better aeration of water, greater tillering effect and additional supply of fertilizer in form of leftover feed and fish excreta.

Table 4. Rice yield attributes in different weir height plots under rice-fish integration system

Treatment	Number of panicle / m^2	Number of filled grain / Panicle	Test weight (g)
10 cm weir height	204.2	110.2	19.5
12.5 cm weir height	233.2	118.0	19.9
15 cm weir height	235.5	121.7	19.3
CD (0.05)	*15.32*	*7.24*	*NS*

Table 5. Grain and straw yield of rice as influenced by weir height in rice-fish integration system

Treatment	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
10 cm weir height	2988.0	3572.0
12.5 cm weir height	3595.0	4303.0
15 cm weir height	3629.0	4420.0
CD (0.05)	*157.08*	*160.39*

Table 6. Rice yield enhancement as influenced by introduction of fish and prawn in the rice field

Weir height (cm)	Grain yield of rice (kg ha^{-1})		Percent increase (%)
	Rice-fish integration system	Only rice (control)	
10	2988.0	2756.0	8.42
12.5	3595.0	3309.0	8.64
15	3629.0	3362.0	7.94

4.3 Growth, survival and yield of fish and prawn

Absolute growth of *Catla catla, Labeo rohita, Cirrhinus mrigala, Cyprinus carpio* and *Macrobrachium rosenbergii* was 122.76, 87.48, 91.83, 93.72 and 24.76 g in refuges with 10 cm weir height; 120.16, 78.28, 83.03, 86.22 and 24.26 g in refuges with 12.5 cm weir height and 112.96, 72.08, 77.53, 78.32 and 24.26 g in refuges with 15 cm weir height, respectively, at stocking density of 15,000 ha^{-1} (Table 7). Faster growth rate was recorded for *Catla catla* followed by *C. carpio, C.mrigala, L.rohita* and *M. rosenbergii* during 120 days of culture. Similar trend of growth performance was also recorded at stocking density of 25,000 and 35,000 ha^{-1} (Tables 8 and 9). Bottom feeders (*C. carpio* and *C. mrigala*) performed better growth rate against that of *L. rohita,* probably due to the fact that being surface and column dweller, *L. rohita* is more sensitive to oxygen depletion, while being bottom dwellers *C. carpio* and *C. mrigala* are more telerant to fluctuation of oxygen concentration (Vijayan and Verghese, 1986). Moreover, faster growth rate of *Catla catla* and bottom dwellers were attributed to effective utilization of ecological niches and rich detrital food web that was maintained through periodic manuring, liming and fertilization, which agrees to the findings of Mohanty (1995). Observations on feed conversion ratio (FCR) also supports the conclusion of effective utilization of ecological niches, as minimum and maximum FCR was 0.96 - 1.23, 0.94 - 1.13 and 0.9 - 0.97 at stocking density of 35000, 25000 and 15000 ha^{-1}, respectively. FCR increased with increase in stocking density, probably due to inadequate availability of natural food, high degree of metabolic deposition / organic load (Mohanty, 1999), low dissolved oxygen concentration and increased level of ammonia towards latter stage of rearing attributed by gradual increase in biomass.

Comparative daily growth performance (Tables 7, 8 and 9) was moderate to good as periodic organic manuring and inorganic fertilization was a regular practice that improved primary productivity (514.5 ± 89.4 mgC m^{-2}h^{-1}) which enhanced the growth rate. Similar observation was also made by Noriega-Curtis (1979). Average daily growth rate of all species (Table 7, 8 and 9) decreased with increase in stocking density from 15000 to 35000 ha^{-1}, which may be due to mutual competition for food and space causing physiological stress (Wedemeyor, 1976) and degraded water quality (Smart, 1981) because of increased biomass (Trzebiatowski, *et al.*, 1981). Sinha and Ramachandran (1985) also reported that, under crowded condition at higher stocking density, fish suffer stress due to aggressive feeding interaction, eat less and grow slowly. Further, in static ecosystem (during post monsoon period), too much of excretory products of the fish suppress their own growth rate.

Species-wise overall survival rate was high at stocking density of 15000 ha^{-1} (*Catla catla* 71.4 -78.9%; *Labeo rohita* 71.4 - 84.2%; *Cirrhinus mrigala* 70.0 - 87.7%; *Cyprinus carpio* 50.0 -62.5% and *M.rosenbergii* 66.6 - 77.8%) which decreased with increase in stocking density (Tables 7, 8 and 9). *Catla catla* and *Labeo rohita* showed a distinct declining trend in survival rate with increase in stocking density from 15000 to 35000 ha^{-1} while, no such trend was marked in case of *C. mrigala, C. carpio* and *M.*

Table 7. Growth performance of fish and prawn in rice-fish integration system at stocking density of 15000 ha^{-1}

Refuge of different treatments	Species reared	Initial MBW (g)	Final MBW (g)	ADG (g)	Min.-Max. Ponderal index (K_n)	SR (%)	Productivity (kg ha^{-1}4 months^{-1})
Refuge 1 (10 cm weir height)	*C.catla*	0.84 ±0.07	123.6 ±4.8	1.02	0.91-1.27	78.9	1026.7
	L.rohita	0.92 ±0.03	88.4 ±7.1	0.73	0.82-1.11	84.2	
	C.mrigala	0.97 ±0.08	92.8 ±6.8	0.76	0.96-1.38	70.0	
	C.carpio	0.88 ±0.11	94.6 ±4.3	0.78	0.96-1.18	60.0	
	M.rosenbergii	0.04 ±0.01	24.8 ±1.2	0.21	1.01-1.44	66.6	
Refuge 2 (12.5 cm weir height)	*C.catla*	0.84 ±0.07	121.0 ±8.2	1.0	0.9-1.31	73.3	962.8
	L.rohita	0.92 ±0.03	79.2 ±4.9	0.65	0.84-1.2	80.0	
	C.mrigala	0.97 ±0.08	84.0 ±6.3	0.69	0.92-1.17	87.7	
	C.carpio	0.88 ±0.11	87.1 ±6.3	0.71	0.92-1.22	62.5	
	M.rosenbergii	0.04 ±0.01	24.3 ±0.8	0.2	0.99-1.38	77.8	
Refuge 3 (15 cm weir height)	*C.catla*	0.84 ±0.07	113.8 ±5.8	0.94	0.88-1.19	71.4	906.6
	L.rohita	0.92 ±0.03	73.0 ±5.2	0.6	0.97-1.14	71.4	
	C.mrigala	0.97 ±0.08	78.5 ±3.8	0.64	0.97-1.16	75.6	
	C.carpio	0.88 ±0.11	79.2 ±4.4	0.65	0.91-1.23	50.0	
	M.rosenbergii	0.04 ±0.01	24.3 ±0.8	0.2	0.96-1.22	66.6	

MBW-mean body weight, ADG-average daily growth, SR- survival rate.

rosenbergii. This might be due to mutual competition for food among the bottom dweller species at the lower level of food web. Growth, survival rate and yield performance of cultured species improved with decrease in weir height of rice fields. This is possibly due to more volume of runoff water with higher quantity of nutrients (Mishra *et al.*, 1998) causing increased natural food availability and minimal fluctuation of physico-chemical parameters of refuge water (Mohanty *et al.*, 2000). Condition factor (Ponderal index) of fish and prawn (Tables 7, 8 and 9) was less than 1.0 at the initial three weeks of rearing and improved thereafter with gradual improvement in water quality.

Productivity of fish and prawn (kg ha^{-1} 4months^{-1}) was higher in refuges with 10cm weir height plots, irrespective of stocking density while, overall yield performance was good (Fig. 5) at stocking density of 25000 ha^{-1} (Table 10). An increase in stocking density from 25000 to 35000 ha^{-1} has recorded increase in yield of fish and prawn by 2.2 and 125.8 kg ha^{-1} 4months^{-1} in refuges with 10 and 12.5 cm weir height plots, respectively, while the yield decreased by 46 kg ha^{-1} 4months^{-1} (4.5%) in refuges

Table 8. Growth performance of fish and prawn in rice-fish integration system at stocking density of 25000 ha^{-1}

Refuge of different treatments	Species reared	Initial MBW (g)	Final MBW (g)	ADG (g)	Min.-Max. Ponderal index (K_n)	SR (%)	Productivity (kg ha^{-1}4 months^{-1})
Refuge 1 (10 cm weir height)	*C.catla*	0.82 ±0.03	103.8 ±4.1	0.85	0.99-1.24	58.8	1243.1
	L.rohita	0.88 ±0.03	76.9± 5.2	0.63	0.84-1.15	61.7	
	C.mrigala	0.92 ±0.06	88.8 ±6.8	0.73	0.96-1.21	58.8	
	C.carpio	0.88 ±0.09	90.2 ±4.3	0.74	0.94-1.16	58.8	
	M.rosenbergii	0.04 ±0.01	24.1 ±1.4	0.2	1.04-1.24	60.0	
Refuge 2 (12.5 cm weir height)	*C.catla*	0.82 ±0.03	98.2 ± 6.1	0.81	0.93-1.22	57.6	1156.5
	L.rohita	0.88 ±0.03	76.2 ±4.9	0.63	0.84-1.17	61.5	
	C.mrigala	0.92 ±0.06	87.7 ±6.3	0.72	0.97-1.27	61.5	
	C.carpio	0.88 ±0.09	90.2 ±6.8	0.74	0.93-1.2	46.1	
	M.rosenbergii	0.04 ±0.01	22.8 ±0.8	0.19	0.99-1.33	50.0	
Refuge 3 (15 cm weir height)	*C.catla*	0.82 ±0.03	90.2 ±5.3	0.74	0.98-1.19	50.0	1036.6
	L.rohita	0.88 ±0.03	68.1 ±5.2	0.56	0.91-1.13	66.6	
	C.mrigala	0.92 ±0.06	74.6 ±3.2	0.61	0.97-1.26	50.0	
	C.carpio\	0.88 ±0.09	74.8 ±5.0	0.62	0.95-1.21	50.0	
	M.rosenbergii	0.04 ±0.01	20.3 ±1.1	0.17	0.96-1.12	33.3	

MBW-mean body weight, ADG-average daily growth, SR- survival rate.

with 15 cm weir height plots. It may thus be inferred that, even with supplemental feeding, by increasing the stocking density, biomass yield increased up to an optimum level and then decreased which lends support to the findings of Sinha and Ramachandran (1985). In fact, by increasing the stocking density beyond the optimum level, the total demand for oxygen increases with drastic fluctuation of other physico-chemical parameters and density dependent growth occurs with no substantial increase in yield. Therefore, stocking density and stocking ratio should be on the basis of quantity of water available, amount of oxygen production and availability of natural food.

Roy *et al.*, (1990) reported that, in traditional deepwater rice-fish system in India, yield of rice in a season range between 1.0-1.5 t ha^{-1} and fish production between 50-200 kg ha^{-1}, while application of cowdung enhance the productivity of rice and fish to 3.1 and 0.67 t ha^{-1}, respectively. However, in the present study, an average productivity of 906.6 - 1282.3 kg ha^{-1} of fish and prawn has been achieved with application of cowdung @ 5000 kg ha^{-1}, which is much higher than the earlier recorded productivity in a season. This high productivity of fish was however, low in comparison to composite fish culture, probably due to shorter rearing duration and comparably less favourable environment as that in ponds (Rao and Ram Singh, 1998).

Table 9. **Growth performance of fish and prawn in rice-fish integration system at stocking density of 35000 ha^{-1}**

Refuge of different treatments	Species reared	Initial MBW (g)	Final MBW (g)	ADG (g)	Min.-Max. Ponderal index (K_n)	SR (%)	Productivity (kg ha^{-1} 4 $months^{-1}$)
Refuge 1 (10 cm weir height)	*C.catla*	0.91 ±0.07	86.3 ±8.4	0.71	0.9-1.22	52.0	1245.3
	L.rohita	0.9 ±0.08	54.4 ±5.3	0.44	0.84-1.14	62.5	
	C.mrigala	0.95 ±0.04	57.1 ±6.7	0.47	0.93-1.28	66.6	
	C.carpio	0.87 ±0.09	57.7 ±9.3	0.47	0.96-1.14	54.1	
	M.rosenbergii	0.04 ±0.01	21.6 ±1.2	0.18	1.0-1.25	50.0	
Refuge 2 (12.5 cm weir height)	*C.catla*	0.91 ±0.07	90.8 ±8.8	0.75	0.9-1.19	55.5	1282.3
	L.rohita	0.9 ±0.08	55.5 ±5.9	0.45	0.88-1.2	61.1	
	C.mrigala	0.95 ±0.04	56.4 ±6.9	0.46	0.9-1.22	66.6	
	C.carpio	0.87 ±0.09	58.1 ±6.3	0.47	0.94-1.22	61.1	
	M.rosenbergii	0.04 ±0.01	22.4 ±0.9	0.18	0.95-1.31	40.0	
Refuge 3 (15 cm weir height)	*C.catla*	0.91 ±0.07	84.2 ±7.8	0.69	0.88-1.29	43.7	984.6
	L.rohita	0.9 ±0.08	46.7 ±5.9	0.38	0.98-1.16	50.0	
	C.mrigala	0.95 ±0.04	51.7 ±8.8	0.42	0.97-1.26	62.5	
	C.carpio	0.87 ±0.09	53.3 ±5.4	0.43	0.94-1.24	50.0	
	M.rosenbergii	0.04 ±0.01	21.3 ±0.6	0.17	0.96-1.27	40.0	

MBW-mean body weight, ADG-average daily growth, SR- survival rate.

Table 10. **Effect of stocking density on fish and prawn yield at different weir heights**

Stocking density (nos ha^{-1})	Fish and prawn yield (kg ha^{-1})		
	10.0 cm	12.5 cm	15.0 cm
15000	1026.7^{b}	962.8^{c}	906.6^{c}
25000	1243.1^{a}	1156.5^{b}	1030.6^{a}
35000	1245.3^{a}	1282.3^{a}	984.6^{b}

Values are means of three replications. Means having different superscript(s) in a column by DMRT differed significantly ($p<0.05$).

4.4 Food and feeding habit

Phytoplankton and zooplankton were most preferred food item for *C. catla* and *L. rohita*, while mud and detritus were highly preferred by *C. mrigala*, *C. carpio* and *M. rosenbergii* in rice fish integration system (Table 11). However, quantity-wise most consumed food items were artificial supplemental feed of rice bran and groundnut oil cake. Among bottom dwellers (*C. mrigala, C. carpio* and *M. rosenbergii*), phytoplankton and benthos were preferred more by *M. rosenbergii* while zooplankton and detritus by *C. Carpio* and *C. mrigala*, respectively. Among bottom feeders, growth performance of *C. Carpio* appeared to be much better than *C. mrigala* probably due to their superior feed utilizing capability (Sinha, 1998). Omnivorous feeding behaviour was observed in case of each species except *Catla catla*, while the degree of omnivorous feeding behaviour was high in case of *M. rosenbergii* which agrees to the findings of Lee *et al.*, (1980). Estimated degree of satiation (index of gutfulness) at juvenile /fry stage was high in case of *Cyprinus carpio* followed by *Catla catla, Labeo rohita, Cirrhinus mrigala* and *M. rosenbergii.* While, high degree of satiation index was observed for *Cyprinus carpio* and lowest in case of *Catla catla* at advanced fingerling stage (Table 12). Comparative degree of satiation, indicated a distinct declining trend from fry/juvenile stage to advanced fingerling stage in case of each species. This was probably due to relatively low nutritional value of the ingested matter (mud and debris) and comparatively less preference to artificial feed at the initial stage of rearing that lend support to the findings of Spataru (1976). The intestine index ($I.I. = L_I / SL$; where L_I=Length of intestine and SL= standard length of fish) values of all analyzed fish varied from 6.7 to 9.8 and no correlation was found with standard length. These higher values of intestine index are typical to planktivorous, detritivorous or phytobenthophagous fishes.

Positive indices of electivity were observed for phytoplankton in monsoon-winter, while it was negative for zooplankton during the same period. Negative indices of electivity for zooplankton (-0.14 to - 0.46) in case of all species were recorded during monsoon-winter (August-November) and improved thereafter. This was probably due to rich detrital food web in the initial phase of rearing where raw cattle dung was applied @ 5000 kg ha^{-1} for refuge preparation prior to stocking. However, positive indices of electivity for zooplankton were observed during December, only in case of *C. catla, L. rohita* and *C. carpio*. Similarly, positive indices of electivity (0.02 - 0.31) for phytoplankton was observed in case of all species during August - October (monsoon) while it was negative thereafter probably due to increased density of zooplankton. Matrix of dietary overlap(s) of cultured species under rice-fish integration system (Table 13) reveled that degree of food prefer-

Table 11. Average frequency and abundance of cultured fish and prawn species in rice-fish integration system

Food component	Frequency (%)					Abundance (%)				
	1	2	3	4	5	1	2	3	4	5
Phytoplankton	94.4	83.3	55.6	66.6	72.2	<11.2	<5.1	<2.3	<2.7	<4.3
Zooplankton	88.8	83.3	44.4	72.2	44.4	<5.9	<4.3	<1.4	<1.9	<1.6
Mud+Detritus	11.1	22.2	94.4	88.9	77.8	<5.6	<15.4	>29.1	>32.1	<21.0
Benthos	-	5.5	44.5	55.6	61.1	-	<1.0	<12.2	<12.2	<16.4
Artificial feed	72.2	77.8	83.3	88.8	77.8	>56.7	>49.3	>45.8	>46.1	>61.7

1- *Catla catla*, 2- *Labeo rohita*,3- *Cirrhinus mrigala*, 4- *Cyprinus carpio*, 5- *Macrobrachium rosenbergii*;

Frequency = percent of analyzed fish and prawn in which mentioned food component was found;

Abundance = Percent of individual gut content volume

Table 12. Estimated degree of satiation (F_i) of cultured fish and prawn species in rice-fish integrated system

Cultured species	F_i	
	Fry/Juvenile stage	Advanced fingerling stage
Catla catla	6.3 ± 0.6	2.4 ± 0.3
Labeo rohita	6.1 ± 0.2	5.1 ± 0.3
Cirrhinus mrigala	5.9 ± 0.3	5.1 ± 0.6
Cyprinus carpio	7.2 ± 0.4	6.4 ± 0.4
Macrobrachium rosenbergii	5.9 ± 0.3	5.0 ± 0.1

Fi = w x 100/W; where, w- weight of gut content and W- weight of individual fish/ prawn.

ence was more similar between *C.carpio* and *M.rosenbergii* (0.89), while, it was poorly overlapped between *C.catla* and *M.rosenbergii* (0.41). This high similarity index between bottom dwellers established a stronger possibility of competition for food among each other. However, there is a need to study closely the habit of fish movement from rice field to refuge and vice versa to relate natural food availability and feeding preference of cultured species.

Table 13. Matrix of dietary overlap(s) of fry to advanced fingerling stage of fish and prawn in rice-fish integration system

Species	*Catla catla*	*Labeo rohita*	*Cirrhinus mrigala*	*Cyprinus carpio*	*Macrobrachium rosenbergii*
Catla catla	-	0.71	0.53	0.52	0.41
Labeo rohita	-	-	0.55	0.52	0.45
Cirrhinus mrigala	-	-	-	0.86	0.84
Cyprinus carpio	-	-	-	-	0.89
Macrobrachium rosenbergii	-	-	-	-	-

4.5 System's rice equivalent yield

To assess the return from the system as a single unit, Rice Equivalent Yield (REY) was calculated considering the base price of rice as Rs. 4.00 per kilogram and fish as Rs. 40.00 per kilogram and is presented in Table 14. The highest REY was recorded in 12.5 cm weir height plots with 35000 stocking density of fish and prawn.

Table 14. System's rice equivalent yield (REY) at different weir heights and stocking densities

Stocking density (nos ha^{-1})	Weir height (cm)	Area and yield of rice		Area and yield of fish		System's REY (t ha^{-1})
		Rice area, m^2	Yield, t ha^{-1}	Refuge area, m^2	Yield, t ha^{-1}	
15000	10.0	300	2.988	45	1.026	3.93
	12.5	300	3.595	35	0.962	4.22
	15.0	300	3.629	15	0.906	3.88
25000	10.0	300	2.988	45	1.243	4.21
	12.5	300	3.595	35	1.156	4.43
	15.0	300	3.629	15	1.036	3.95
35000	10.0	300	2.988	45	1.245	4.22
	12.5	300	3.595	35	1.282	4.55
	15.0	300	3.629	15	0.984	3.92

REY = Rice Equivalent Yield, Selling price of rice @ Rs.4.00 per kg , Selling price of fish and prawn @ Rs.40.00 per kg

Further, in all three years, highest rice equivalent yield was recorded in 12.5 cm weir height plots. The REY of 12.5 cm weir height plots (4.22-4.55 t ha^{-1}) was significantly superior to that of 15 cm weir height plots (3.88-3.95 t ha^{-1}). Statistical insignificance of REY was observed between 12.5 and 10.0 cm weir height plots.

REY was comparatively low (3.88-4.22 t ha^{-1}) at stocking density of 15000 ha^{-1} and improved to (3.95-4.43 t ha^{-1}) when stocking density increased from 15000 to 25000 ha^{-1}. However, no significant increase in REY (3.92-4.55 ha^{-1}) was noticed thereafter when stocking density increased further by 10000 ha^{-1} i.e., from 25000 to 35000 ha^{-1}.

5.0 CONCLUSIONS

In the medium land rainfed ecosystem, dike height around the rice fields plays an important role in conserving rainwater, soil, nutrients and increasing rice yield. This minimizes the supplemental irrigation requirement during the dry spells and also reduces the drainage need of the catchment by increasing ground water recharge. In order to increase the productivity from unit volume of rain water and unit area of land, conservation of rainwater both *in-situ* and *ex-situ* and integration of fish/prawn culture is found to be a viable, low input based and easily adaptable technology for small and medium farmers. For this system, weir height of 12.5 cm with refuge area of 9% of the rice field has resulted in highest return (4.22 to 4.55 t ha^{-1} REY) without using any pesticide. Stocking density of fish and prawn @ 25,000 ha^{-1} is recommended for this short duration (about 120 days) fry to fingerling stage of rearing. Rice–fish integration not only helps to compensate the economic losses in rice production brought about by natural calamities but also enhances the land and water productivity without bringing about environmental degradation. This system could generate employment opportunity, increase income for farmers and provide nutritional security.

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