Available online at www.sciencedirect.com

SCIENCE DIRECT

Aquaculture 230 (2004) 125–135

Aquaculture

www.elsevier.com/locate/aqua-online

Performance evaluation of rice–fish integration system in rainfed medium land ecosystem

Rajeeb K. Mohanty*, H.N. Verma, P.S. Brahmanand

Water Technology Centre for Eastern Region, Indian Council of Agricultural Research (ICAR), At/PO-Chandrasekharpur, Bhubaneswar 751023, India

Received 22 October 2002; received in revised form 13 May 2003; accepted 15 May 2003

Abstract

This study was carried out for three successive years during 1999–2001 to evaluate growth and yield performance of fish, prawn and paddy under rice–fish integration system in rainfed medium land ecosystem. Irrespective of stocking density, faster growth rate was recorded for *Catla catla* followed by *Cyprinus carpio*, *Cirrhinus mrigala*, *Labeo rohita* and *Macrobrachium rosenbergii*. *C. carpio* and *C. mrigala* performed better growth rate against that of *L. rohita* probably due to the fact that being bottom dwellers, *C. carpio* and *C. mrigala* are more tolerant to fluctuation of oxygen concentration. Productivity of fish and prawn was, however, higher ($p < 0.05$) in refuges with 10-cm weir height plots, irrespective of stocking density, while overall yield performance was good at stocking density of 25,000 ha^{-1}. It was observed that, even with supplemental feeding, with increase in stocking density, biomass yield increased up to an optimum and then decreased. An average minimum and maximum yield of 906.6–1282.3 kg ha^{-1} of fish and prawn has been achieved, which was much higher than the earlier recorded productivity in a season under rice–fish integration system. Highest grain yield was recorded at 15-cm weir height plot (3629 kg ha^{-1}), probably contributed by higher number of panicles per square meter (235.5) and number of filled grains per panicle (121.7). Percentage increase in rice yield under rice–fish integration system was 7.9–8.6% against control, where paddy was cultivated without integration of fish and prawn probably due to better aeration of water, greater tillering effect and additional supply of fertilizer in form of leftover feed and fish excreta. Irrespective of stocking density, the overall rice equivalent yield (REY) of the system was high (4.22–4.55 tons ha^{-1}) at 12.5-cm weir height plots-cum-refuge, without using any pesticide, herbicide, etc.

Keywords: Rice–fish integration; Stocking density; Growth; Weir height; Rice equivalent yield

---

* Corresponding author.

E-mail address: rajeebm@yahoo.com (R.K. Mohanty).

doi:10.1016/S0044-8486(03)00423-X

1. Introduction

Indian agriculture, on supply side, has been subjected to tremendous pressure to provide food security due to stagnation in net cultivated area and increased population, which needs optimum utilization of land resources, in situ water conservation, multiple use of stored water and, finally, integrated farming practice to match the food demand in the coming years. Out of 42 million ha of rice cultivated land in India, about 20 million ha is suitable for adoption of rainfed rice–fish integration system (Rao and Ram Singh, 1998). However, only 0.23 million ha is presently under rice–fish culture (Mohanty and Mishra, 2003), where a productivity of 200–800 kg ha^{-1} of fish has been obtained (Mukhopadhyay et al., 1991). Experience has proved the beneficial aspects of rice–fish integration system, which combines the principles of water conservation, soil improvement and biological control and plays an important role in sustainable production. Unfortunately, the carrying capacity of these suitable lands in India have not been utilized to the fullest extent. However, if these lands are brought under an integrated rice–fish system, it would help to compensate the economic losses in rice production brought about by natural calamities. This will also optimize the water and land use without bringing about environmental degradation. As paddy fields are complex ecosystems where primary producers and consumers at different levels compete with rice for material and energy, it decreases the overall productivity. However, fish culture in paddy fields can turn and recycle the available material and energy into fish production, accelerate the productivity of paddy fields and enhance the production potential of traditional farming practice (Caguan et al., 2000) with increased net income (Halwart, 1998).

Adoption and practice of rice–fish culture in India dates back almost 1500 years. The original system of integrated rice–fish farming, introduced to Southeast 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 much works have been carried out on different aspects of fish integration system (Likangmin, 1988; Lightfoot et al., 1992; Huazhu, 1994; Fernando and Halwart, 2000; Kurup and Ranjeet, 2002), very little information are available on soil and water chemistry in relation to yield, impact of stocking density, design and management strategy to enhance unit yields. Keeping these in view, an attempt has been made to evaluate rice–fish integration system in rainfed medium land ecosystem with special reference to stocking density, growth performance of cultured species, system's rice equivalent yield and impact of weir height on system's overall performance.

2. Materials and methods

The present study was carried out at Deras Research Farm of WTCER, Bhubaneswar, India (Lat. 20°30′ N and Long. 87°48′10″ E), during 1999–2001 for three successive years. Nine plots of 30 × 10 m size were selected for the proposed study. Three different weir heights (10, 12.5 and 15 cm) were maintained as treatment in triplicate along with peripheral trench of 0.5-m wide and 0.3-m deep. A slope of 0.5% was provided at the trench bottom towards the downstream side. Each plot was connected to adjacent refuge ($R_1 = 45$ m^2 with 10-cm weir height; $R_2 = 35$ m^2 with 12.5-cm weir height; and $R_3 = 15$ m^2 with 15-cm weir height) of 1.75-m deep. The sizes of the refuges were determined as per guidelines given by Mishra et al. (1998) to collect all the excess runoff. The excess water from the rice field was spilled out into the refuge over the fixed weir. When water level recedes in rice field, fish and prawns move to the peripheral trench and then to the refuge through the inlets. Two regulated inlets (pipes) were provided to each refuge at the bottom surface of the trench. The excess water from the refuge was spilled out through the surface drainage system provided with fine-meshed net to prevent escape of fish.

After 2 years of varietal trial among *MW-10*, *Swarna* and *Lalat*, *Swarna* was selected as the best variety on the basis of comparative yield potential and was tried in each plot of the present study at a spacing of 20 × 10 cm (between rows and plants) during second week of July each year. The seed and fertilizer (granular) application rate was 50 kg ha^{-1} and 80:40:40 (N/P/K) ha^{-1}, respectively. Only 50% of N and full dose of P and K were given as basal at the time of transplanting. The rest of nitrogen was given in two equal splits during tillering (20 days after transplanting) and panicle initiation stage (45 days after transplanting). Crop growth and yield parameters were recorded at regular intervals. However, no pesticide was used during the experiment.

After proper refuge preparation, liming at the rate of 2000 kg ha^{-1}, manuring with raw cattle dung at the rate of 5000 kg ha^{-1} and fertilization (urea + SSP, 1:1) at the rate of 3 ppm were 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 with a species composition of 30:30:15:15:10, respectively. The stocking densities of fry were 15,000, 25,000 and 35,000 ha^{-1} for the 1st, 2nd and 3rd year of experiment, respectively, and rearing was continued for 120 days. Supplemental feed (rice bran + groundnut oil cake, 1:1) at the rate of 10%, 8%, 6% and 4% of mean body weight (MBW) was given twice a day, during the 1st, 2nd, 3rd and 4th month to harvesting, respectively. Periodic manuring at the rate of 500 kg ha^{-1} and liming at the rate of 200 kg ha^{-1} were carried out at every 15-day interval to maintain plankton population in the ecosystem.

Phyto- and zooplankton estimation, weekly observations on water quality (temperature, pH, DO, total alkalinity, transparency, total suspended solids, dissolved organic matter, nitrite, nitrate, ammonia, phosphate, etc.) and monthly observations on soil quality (pH, available N,P and organic carbon) were recorded using standard methods (APHA, 1989; Biswas, 1993). Field test instruments were also used to analyze in situ water pH (Checker-1, HANNA, USA), soil pH (DM-13, Japan) and dissolved oxygen (YSI-55, USA). The sediment, nitrogen and potassium losses through runoff from rice field was estimated as per guidelines given by Mishra et al. (1997). Crop performance, fish/prawn growth parameters, survival rate, condition factor of fish and prawn, and the apparent feed conversion ratio were estimated using standard methods (Mohanty, 1999). To compare the effect of fish and prawn on rice yield, three fields of equal size with different weir heights

Table 1
Growth performance in rearing of fry to advanced fingerlings of fish and prawn in rice–fish integration system at a stocking density of 15,000 ha^{-1}

Treatment	Species reared	Initial MBW (g)	Final MBW (g)	ADG (g)	SR (%)	Yield (kg ha^{-1} 4 $months^{-1}$)
10-cm weir height plot with refuge	*C. catla*	0.84 ± 0.07	123.6 ± 4.8	1.02	78.9	1026.7
	L. rohita	0.92 ± 0.03	88.4 ± 7.1	0.73	84.2	
	C. mrigala	0.97 ± 0.08	92.8 ± 6.8	0.76	70.0	
	C. carpio	0.88 ± 0.11	94.6 ± 4.3	0.78	60.0	
	M. rosenbergii	0.04 ± 0.01	24.8 ± 1.2	0.21	66.6	
12.5-cm weir height plot with refuge	*C. catla*	0.84 ± 0.07	121.0 ± 8.2	1.0	73.3	962.8
	L. rohita	0.92 ± 0.03	79.2 ± 4.9	0.65	80.0	
	C. mrigala	0.97 ± 0.08	84.0 ± 6.3	0.69	87.7	
	C. carpio	0.88 ± 0.11	87.1 ± 6.3	0.71	62.5	
	M. rosenbergii	0.04 ± 0.01	24.3 ± 0.8	0.2	77.8	
15-cm weir height plot with refuge	*C. catla*	0.84 ± 0.07	113.8 ± 5.8	0.94	71.4	906.6
	L. rohita	0.92 ± 0.03	73.0 ± 5.2	0.6	71.4	
	C. mrigala	0.97 ± 0.08	78.5 ± 3.8	0.64	75.6	
	C. carpio	0.88 ± 0.11	79.2 ± 4.4	0.65	50.0	
	M. rosenbergii	0.04 ± 0.01	24.3 ± 0.8	0.2	66.6	

MBW—mean body weight; ADG—average daily growth; SR—survival rate.

of 10, 12.5 and 15 cm were taken as control, where only the *Swarna* variety of rice was grown without integration of fish and prawn. 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/prawn as Rs.40.00 per kilogram (1 US$ = Rs.47.00 approx.). Statistical analysis was carried out through one-way ANOVA. Means were

Table 2
Growth performance in rearing of fry to advanced fingerlings of fish and prawn in rice–fish integration system at a stocking density of 25,000 ha^{-1}

Treatment	Species reared	Initial MBW (g)	Final MBW (g)	ADG (g)	SR (%)	Yield (kg ha^{-1} 4 $months^{-1}$)
10-cm weir height plot with refuge	*C. catla*	0.82 ± 0.03	103.8 ± 4.1	0.85	58.8	1243.1
	L. rohita	0.88 ± 0.03	76.9 ± 5.2	0.63	61.7	
	C. mrigala	0.92 ± 0.06	88.8 ± 6.8	0.73	58.8	
	C. carpio	0.88 ± 0.09	90.2 ± 4.3	0.74	58.8	
	M. rosenbergii	0.04 ± 0.01	24.1 ± 1.4	0.2	60.0	
12.5-cm weir height plot with refuge	*C. catla*	0.82 ± 0.03	98.2 ± 6.1	0.81	57.6	1156.5
	L. rohita	0.88 ± 0.03	76.2 ± 4.9	0.63	61.5	
	C. mrigala	0.92 ± 0.06	87.7 ± 6.3	0.72	61.5	
	C. carpio	0.88 ± 0.09	90.2 ± 6.8	0.74	46.1	
	M. rosenbergii	0.04 ± 0.01	22.8 ± 0.8	0.19	50.0	
15-cm weir height plot with refuge	*C. catla*	0.82 ± 0.03	90.2 ± 5.3	0.74	50.0	1036.6
	L. rohita	0.88 ± 0.03	68.1 ± 5.2	0.56	66.6	
	C. mrigala	0.92 ± 0.06	74.6 ± 3.2	0.61	50.0	
	C. carpio	0.88 ± 0.09	74.8 ± 5.0	0.62	50.0	
	M. rosenbergii	0.04 ± 0.01	20.3 ± 1.1	0.17	33.3	

MBW—mean body weight; ADG—average daily growth; SR—survival rate.

Table 3
Growth performance in rearing of fry to advanced fingerlings of fish and prawn in rice–fish integration system at a stocking density of 35,000 ha^{-1}

Treatment	Species reared	Initial MBW (g)	Final MBW (g)	ADG (g)	SR (%)	Yield (kg ha^{-1} 4 $months^{-1}$)
10-cm weir height plot with refuge	*C. catla*	0.91 ± 0.07	86.3 ± 8.4	0.71	52.0	1245.3
	L. rohita	0.9 ± 0.08	54.4 ± 5.3	0.44	62.5	
	C. mrigala	0.95 ± 0.04	57.1 ± 6.7	0.47	66.6	
	C. carpio	0.87 ± 0.09	57.7 ± 9.3	0.47	54.1	
	M. rosenbergii	0.04 ± 0.01	21.6 ± 1.2	0.18	50.0	
12.5-cm weir height plot with refuge	*C. catla*	0.91 ± 0.07	90.8 ± 8.8	0.75	55.5	1282.3
	L. rohita	0.9 ± 0.08	55.5 ± 5.9	0.45	61.1	
	C. mrigala	0.95 ± 0.04	56.4 ± 6.9	0.46	66.6	
	C. carpio	0.87 ± 0.09	58.1 ± 6.3	0.47	61.1	
	M. rosenbergii	0.04 ± 0.01	22.4 ± 0.9	0.18	40.0	
15-cm weir height plot with refuge	*C. catla*	0.91 ± 0.07	84.2 ± 7.8	0.69	43.7	984.6
	L. rohita	0.9 ± 0.08	46.7 ± 5.9	0.38	50.0	
	C. mrigala	0.95 ± 0.04	51.7 ± 8.8	0.42	62.5	
	C. carpio	0.87 ± 0.09	53.3 ± 5.4	0.43	50.0	
	M. rosenbergii	0.04 ± 0.01	21.3 ± 0.6	0.17	40.0	

MBW—mean body weight; ADG—average daily growth; SR—survival rate.

compared using Duncan's Multiple Range Test to find the difference at 5% ($p < 0.05$) levels (Duncan, 1955).

3. Results

The recorded minimum and maximum values of various water quality parameters during the experimental period were: water temperature, 27.5–30.2 °C; water pH, 6.9–

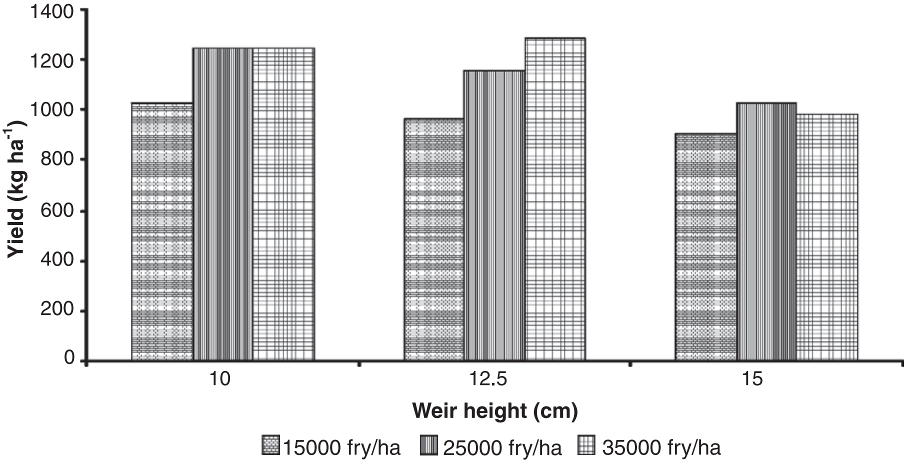

Fig. 1. Effect of stocking density on fish and prawn yield in different weir height plot-cum-refuge.

Table 4
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 (2756.0)[a]	3572.0
12.5-cm weir height	3595.0 (3309.0)[a]	4303.0
15-cm weir height	3629.0 (3362.0)[a]	4420.0
CD ($p < 0.05$)	157.08	160.39

[a] Grain yield in control (only rice) plots are shown in parenthesis.

8.8; dissolved oxygen, 3.9–8.1 ppm; total alkalinity, 49–119 ppm; transparency, 16–57 cm; dissolved organic matter, 0.6–4.7 ppm; nitrite-N, 0.006–0.071 ppm; nitrate-N, 0.06–0.52 ppm; ammonia, 0.01–0.31 ppm; total suspended solid, 89–319 ppm; phosphate-P, 0.06–0.34 ppm; water level/depth, 89–174 cm; and total plankton count, 2.4×10^2–9.1×10^3 nos/l. Similarly, recorded minimum and maximum values of various soil quality parameters during the experimental period were: soil pH, 6.6–7.0; available N in soil, 7.9–10.7 mg 100 g^{-1}; available P in soil, 0.29–0.67 mg100 g^{-1}; and organic carbon in soil, 0.16–0.53%. Most of the parameters were within/nearly optimum ranges throughout the culture period. The average maximum sediment, nitrogen and potassium losses through runoff water from rice field were 120.31, 3.19 and 1.39 kg ha^{-1} at 10-cm weir height, and the minimum were 65.7, 0.7 and 0.35 kg ha^{-1} at 15-cm weir height, respectively.

Faster growth rate was recorded for *C. catla* followed by *C. carpio*, *C. mrigala*, *L. rohita* and *M. rosenbergii* during 120 days of culture, at stocking density of 15,000, 25,000 and 35,000 ha^{-1} (Tables 1–3). Comparative growth performance (Tables 1–3) of all species in terms of average daily growth rate decreased with increase in stocking density from 15,000 to 35,000 fry ha^{-1}. Species-wise overall survival rate was high at stocking density of 15,000 ha^{-1} (*C. catla*, 71.4–78.9%; *L. rohita*, 71.4–84.2%; *C. mrigala*, 70.0–87.7%; *C. carpio*, 50.0–62.5%; and *M. rosenbergii*, 66.6–77.8%), which decreased with increase in stocking density (Tables 1–3). The condition factor (Ponderal index) of fish and prawn was less than 1.0 (0.82–0.98) at the initial 3 weeks of rearing and improved thereafter (1.02–1.38) with gradual improvement in water quality. Yield in terms of production (kg ha^{-1} 4 $months^{-1}$) of fish and prawn was, however, higher ($p < 0.05$) in refuges with 10-cm weir height plots, irrespective of stocking density, while, overall yield performance was good at a stocking density of 25,000 ha^{-1} (Fig. 1).

The highest grain yield was recorded at 15-cm weir height (3629 kg ha^{-1}), which was significantly superior ($p < 0.05$) to that of 10-cm weir height (2988 kg ha^{-1}). However, its

Table 5
Rice yield attributes in different weir height plots under rice–fish integration system

Treatment	Number of panicles/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 ($p < 0.05$)	15.32	7.24	NS

Test weight = weight of 1000 rice grains; NS = not significant.

Table 6
System's rice equivalent yield (REY) at different stocking densities

Stocking density (nos ha^{-1})	Weir height (cm)	Total area (m^2)	Yield (tons ha^{-1})		REY (tons ha^{-1})
			Rice	Fish	
15,000	10.0	345	2.988	1.026	3.93
	12.5	335	3.595	0.962	4.22
	15.0	315	3.629	0.906	3.88
25,000	10.0	345	2.988	1.243	4.21
	12.5	335	3.595	1.156	4.43
	15.0	315	3.629	1.036	3.95
35,000	10.0	345	2.988	1.245	4.22
	12.5	335	3.595	1.282	4.55
	15.0	315	3.629	0.984	3.92

REY = rice equivalent yield; selling price of rice at Rs.4.00 per kilogram; selling price of fish and prawn at Rs.40.00 per kilogram.

superiority over 12.5-cm weir height was not statistically significant. The similar trend was also followed in case of straw yield (Table 4). However, the test weight (weight of 1000 grains) has not been affected significantly at different weir heights (Table 5). Percentage increase in rice yield under rice–fish integration system was 7.9–8.6% against control, where paddy was cultivated without integration of fish and prawn (Table 4). The overall rice equivalent yield (REY) of the system (Table 6) was higher (4.22–4.55 tons ha^{-1}) at 12.5-cm weir height plots-cum-refuge, which was significantly superior ($p < 0.05$) to that of 15-cm weir height plots-cum-refuge (3.88–3.95 tons ha^{-1}). Statistical significance of REY was, however, not recorded between 12.5- and 10.0-cm weir height plots-cum-refuge. REY was comparatively low (3.88–4.22 tons ha^{-1}) at a stocking density of 15,000 ha^{-1} and improved further (3.95–4.43 tons ha^{-1}) when stocking density increased to 25,000 ha^{-1}. However, no significant increase in REY (3.92–4.55 tons ha^{-1}) was recorded thereafter when stocking density increased further by 10,000 ha^{-1}, from 25,000 to 35,000 ha^{-1}.

4. Discussion

As rainfall and hydrograph of ponding in the rice fields are stochastic, substantial damage to crop and yield due to submergence or long dry spell at critical stages of crop growth takes place. This ultimately needs to determine the optimum weir/dyke height, so that there is maximum utilization of rainwater without any adverse effect on crop growth and yield. In our earlier experiment (Mishra et al., 1997), prior to this experiments, it was observed that deep percolation and seepage losses were increased with the increase in weir height from 6 to 30 cm, while sediment and nutrient loss increased with decrease in weir height from 30 to 6 cm. Jhingran et al. (1998), however, reported that the average depth of water in paddy plots should be about 15 cm. Keeping these factors and water requirement of medium land rice varieties in view, weir heights of 10, 12.5 and 15 cm were considered for this experiment where sediment (120.31–65.7 kg ha^{-1}), nitrogen (3.19–0.7 kg ha^{-1}) and potassium (1.39–0.35 kg ha^{-1}) loss have been minimized to a considerable extent. The lost sediment and nutrients from rice field was, however, retained in the refuge.

Water quality changes in response to daily and climatic rhythms, while fish and prawn can adapt to this natural fluctuations to a certain level and fails thereafter due to stress. In this experiment, various hydrobiological parameters, however, did not show any distinct trend between the treatments, except in the cases of total suspended solid and water level/depth. Poor growth performance of cultured species takes place at $pH < 6.5$, while higher values of total alkalinity (>90 ppm) are indicative of a productive ecosystem (Mohanty and Mishra, 2003) and increased plankton density reflects better 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 were 49 and 119 ppm, respectively, which was probably maintained due to periodic liming. 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 (Mohanty, 1995). 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 increased spill out of water supply from the rice field along with sediment and other nutrients. Concentration of ammonia also showed an increasing trend as the days of culture increased, probably due to higher metabolic deposition and organic load (Mohanty, 1999).

Bottom feeders (*C. carpio* and *C. mrigala*) showed better growth rates 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 tolerant to fluctuation of oxygen concentration (Vijayan and Verghese, 1986). Moreover, the faster growth rate of *C. catla* and bottom dwellers were attributed to the effective utilization of ecological niches and the rich detrital food web that was maintained through periodic manuring, liming and fertilization, which agrees to the findings of Mohanty (1995). Observations on apparent feed conversion ratio (AFCR) also supports the conclusion of effective utilization of ecological niches, as minimum and maximum AFCR were 0.96–1.23, 0.94–1.13 and 0.9–0.97 at stocking densities of 35,000, 25,000 and 15,000 ha^{-1}, respectively. AFCR increased with increase in stocking density, probably due to inadequate availability of natural food, higher degree of metabolic deposition/organic load (Mohanty, 1999), low dissolved oxygen concentration and increased level of ammonia towards the latter stage of rearing attributed by gradual increase in biomass.

The comparative growth performance (Tables 1–3) of all species in terms of average daily growth rate decreased with increase in stocking density from 15,000 to 35,000 fry ha^{-1}, probably due to mutual competition for food and space that cause physiological stress (Wedemeyor, 1976) and relatively degraded water quality (Smart, 1981) due to increased density and biomass (Trzebiatowski et al., 1981). *C. catla* and *L. rohita* showed a distinct declining trend in survival rate with increase in stocking density from 15,000 to 35,000 ha^{-1}, while no such trend was marked in the case of *C. mrigala*, *C. carpio* and *M. rosenbergii*. This was probably due to mutual competition for food among these three bottom-dweller species at the lower level of the food web. Growth, survival rate and yield performance of cultured species improved with decrease in weir height of rice field, probably due to increased spill out of water supply to refuge with increased quantity of nutrients (Mishra et al., 1997), increased natural food availability and less fluctuation of physicochemical parameters (Mohanty et al., 2001). The yield in terms of productivity (kg ha^{-1} 4 $months^{-1}$) of fish and prawn was, however, higher ($p < 0.05$) in refuges with 10-cm weir height plots (Fig. 1), irrespective of stocking density, while overall yield performance was good at a stocking density of 25,000 ha^{-1}. An increase in stocking density from 25,000 to 35,000 ha^{-1}, however, recorded a negligible maximum increase of 125.8 kg ha^{-1} 4 $months^{-1}$ in fish/prawn yield in refuges with 12.5-cm weir height plots, while total yield decreased by 4.5% in refuges with 15-cm weir height plots. It was observed that, even with supplemental feeding, with increase in stocking density, biomass yield increased up to an optimum and then decreased. In fact, by increasing the stocking density beyond the optimum rate, the total demand for oxygen increases with drastic fluctuation of other physicochemical parameters and density-dependent growth occurs (Zonneveld and Fadholi, 1991; Bjoernsson, 1994) with no substantial increase in yield.

Roy et al. (1990) reported that in traditional deepwater rice–fish system in India, the yield of rice in a season range between 1.0 and 1.5 tons ha^{-1} and fish production between 50 and 200 kg ha^{-1}, while application of cow dung enhance the productivity of rice and fish to 3.1 and 0.67 tons 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 cow dung at 5000 kg ha^{-1}, which was much higher than the earlier recorded productivity in a season. This high productivity of fish under rice–fish integration system 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).

Rice variety *Swarna* was tested under three different weir heights of 10, 12.5 and 15 cm with four replications each. The highest grain yield at 15-cm dyke height was probably contributed by higher number of panicles per square meter (235.5) and number of filled grains per panicle (121.7). Percentage increase in rice yield under rice–fish integration system was probably due to introduction of fish and prawn in rice field, where frequent locomotary movement of fish and prawn helps in improving dissolved oxygen level and stirring up soil nutrients, making them more available for rice. Further, these cultured species help in enhancing soil organic matter/nutrient status by adding faecal matter; it also controls plankton population/macro- and microaquatic insects/bacteria/organic detritus that compete with rice for material and energy. Hora and Pillay (1962) also reported 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 the form of leftover feed and fish excreta.

Taking all the aforementioned aspects into account, it is recommended that in rainfed medium land ecosystem, rice–fish integrated farming can be undertaken. However, the stocking density of fish fry and prawn post-larvae should not go beyond 25,000 ha^{-1}, which results density-dependent growth with no substantial increase in yield. Moreover, weir height of 12.5 cm is more beneficial from both paddy and fish yield point of view, where rice equivalent yield of the system can be increased up to 4.43 tons ha^{-1} in a season, without using any pesticide, herbicide, etc.

Acknowledgements

I warmly thank Dr. H.N. Verma, Director, WTCER (Indian Council of Agricultural Research), for providing me the necessary facilities for this experiment and Dr. S.K. Mohanty, Fisheries Consultant, Chilika Development Authority, Orissa, India, for reviewing the manuscript.

References

Ali, A.B., 1990. Rice/fish farming in Malaysia: a resource optimization. Ambio 19 (8), 404–408.

APHA, 1989. Standard Methods for Examination of Water and Waste Water. American Public Health Association, Washington DC, USA. 1647 pp.

Biswas, K.P., 1993. Fisheries Manual. Bhagabat Press and Publishers, Cuttack, Orissa, India. 436 pp.

Bjoernsson, B., 1994. Effect of stocking density on growth rate of halibut (*Hippoglossus hippoglossus* L.) reared in large circular tanks for three years. Aquaculture 123, 259–271.

Boyd, C.E., Pillai, V.K., 1985. Water Quality Management in Aquaculture. Special Publication, vol. 22. CMFRI (ICAR), Cochin, India. 96 pp.

Caguan, A.G., Branckaert, R.D., VanHove, C., 2000. Integrating fish and azolla into rice–duck farming in Asia. Naga, ICLARM Q. 23 (1), 4–10.

Duncan, D.B., 1955. Multiple range and multiple *f*-test. Biometrics 11, 1–42.

Fernando, C.H., Halwart, M., 2000. Possibilities for integration of fish farming into irrigation system. Fish. Manage. Ecol. 7 (1–2), 45–54.

Halwart, M., 1998. Trends in rice–fish farming. FAO Aquacult. Newsl. 18, 3–11.

Hora, S.L., Pillay, T.V.R., 1962. Handbook on fish culture in the Indo-Pacific region. Fish. Biol. Tech. Pap., vol. 14. FAO, Rome.

Huazhu, Y., 1994. Integrated rice–fish culture. Developments in Aquaculture and Fisheries Science, vol. 28. Elsevier, pp. 368–385.

Jhingran, V.G., Ahmad, S.H., Singh, A.K., 1998. Retrospect and prospects of integrated aquaculture–agriculture–animal husbandry farming in India. In: Ahmad, S.H. (Ed.), Advances in Fisheries and Fish Production. Hindustan Publishing Corporation, New Delhi, India. 309 pp.

Kurup, B.M., Ranjeet, K., 2002. Integration of freshwater prawn culture with rice farming in Kuttanad, India. Naga, World Fish Cent. Q. 25 (3–4), 16–19.

Lightfoot, C., Costa-Pierce, B.A., Bimbao, M.P., Delacruz, C.R., 1992. Introduction to rice–fish research and development in Asia. In: Delacruz, C.R., et al. (Eds.), Rice–Fish Research and Development in Asia. ICLARM, Philippines, pp. 1–10.

Likangmin, 1988. Rice–fish culture in China: a review. Aquaculture 71, 173–186.

Mishra, A., Ghorai, A.K., Singh, S.R., 1997. Effect of dike height on water, soil and nutrient conservation and rice yield. Research bulletin No-5, Water Technology Centre for Eastern Region (ICAR), Bhubaneswar, India. 19 pp.

Mishra, A., Panda, R.K., Nanda, P., Mohanty, R.K., 1998. Enhancing agricultural productivity of medium and lowland rice ecosystem—a strategic approach. J. Indian Soc. Coast. Agric. Res. 16 (2), 89–96.

Mohanty, U.K., 1995. Comparative evaluation of growth and survival of Indian Major Carp fry in aerated vis-à-vis non-aerated ponds under different stocking densities. MFSc thesis, Orissa University of Agriculture and Technology, Bhubaneswar, India. 123 pp.

Mohanty, R.K., 1999. Growth performance of *Penaeus monodon* at different stocking density. J. Inland Fish. Soc. India 31 (1), 53–59.

Mohanty, R.K., Mishra, A., 2003. Successful rice–fish integrated farming adopting rainwater conservation measures. Fish. Chimes 22 (10–11), 97–99.

Mohanty, R.K., Verma, H.N., Brahmanand, P.S., 2001. Rice–fish integration for enhancing land and water productivity. Annual report, 2000–2001, Water Technology Centre for Eastern Region (ICAR), India, pp. 70–74.

Mukhopadhyay, P.K., Das, D.N., Roy, B., 1991. Deepwater rice–fish farming. Research Bulletin, Deepwater Rice Project, Rice Research Station, Chinsura, West Bengal, India.

Rao, A.P., Ram Singh, 1998. Rice–fish farming system. In: Ahmad, S.H. (Ed.), Advances in Fisheries and Fish Production. Hindustan Publishing, New Delhi, India. 309 pp.

Roy, B., Das, D.N., Mukhopadhyay, P.K., 1990. Rice–Fish–Vegetable Integrated Farming: Towards a Sustainable Ecosystem. Naga, ICLARM, Philippines, pp. 17–18. October.

Smart, G.H., 1981. Aspects of water quality producing stress in intensive fish culture. In: Pickering, A.D. (Ed.), Stress and Fish. Academic Press, London, pp. 277–293.

Trzebiatowski, Fillpiak, J., Jakubowski, R., 1981. On effect of stocking density on growth and survival of rainbow trout. Aquacult. J. 22, 289–295.

Vijayan, M.M., Verghese, T.J., 1986. Effect of artificial aeration on growth and survival of Indian Major Carps. Proc. Indian Acad. Sci., Anim. Sci. 95 (4), 371–378.

Wedemeyor, G.A., 1976. Physiological response of juvenile Coho Salmon (*Oncorhynchus* Kisutch) and rainbow trout (*Salmo gairdneri*) to handling and crowding stress in intensive fish culture. J. Fish. Res. Board Can. 33, 2699–2702.

Zonneveld, N., Fadholi, R., 1991. Feed intake and growth of red tilapia at different stocking densities in ponds in Indonesia. Aquaculture 99, 83–94.