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Impact of rice–fish–prawn culture on rice field ecology and productivity

RAJEEB K MOHANTY[1], A K THAKUR[2], S GHOSH[3] and D U PATIL[4]

Directorate of Water Management, Bhubaneswar, Orissa 751 023

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ABSTRACT

An on-farm experiment was carried out during 2005–07 to study the impact of fish and prawn rearing on rice field ecology and productivity in rice–fish–prawn system. Water *p*H, total alkalinity, total suspended solid, plankton and chlorophyll-*a* were significantly lower in the rice mono crop than the rice–fish–prawn system, where supplemental feed was provided. However increased phytoplankton and chlorophyll-*a* concentration in the rice–fish–prawn system did not help in maintaining higher dissolved oxygen levels compared to rice monocrop probably due to decreased autotrophic/ increased heterotrophic activity. Gut content analysis of the cultured species indicated plenty availability of planktonic, periphytic and benthic food to fish and prawn in the rice field (22.7–48.9%), that reduce the supplemental feed input. Rice grain yield of 3.04 tonnes/ha in the rice–fish–prawn system was 16.9% higher than the rice monocrop. In rice–fish–prawn system, when 50% area is devoted for fish and prawn culture, the net returns enhanced by 23-folds in comparison to rice monocrop. Significantly higher net returns of Rs 79 585/ha, net water productivity of Rs 7.66/m^3 and the higher ratio of the output value to the cost of cultivation (1.6) in the rice–fish–prawn system infers that rice–fish–prawn culture being more beneficial can be adopted and expanded in lowland/ waterlogged areas.

Key words: Feed intake pattern, Rice–field ecology, Rice–fish–prawn culture, Water productivity, Yield

For sustaining the self-sufficiency attained through green revolution, it is necessary to develop a suitable agricultural system for maintaining soil fertility and productivity through greater acceptance of biological principles. It is thus essential to look at the present farming practices with emphasis on an integrated concept of sustainable farming that enhances the quality of environment and natural resource base while ensuring increased productivity. The need of the hour is diversification of enterprises, which produces multiple foods from the same unit. A judicious mix of one or more enterprises that complement the cropping activity can result in increased farm income and recycling of farm residues. Rice–fish integration is therefore, a primary option when trying to develop ecological agriculture that exploit maximum benefit from the system, avoid harmful effects and strive for maximum output using available energy and materials (Mohanty *et al*. 2009). Although, several works have been carried out on different aspects of rice–fish farming (Lu and Li 2006, Mohanty *et al*. 2008), very little work has been done on the hydro-ecological aspect of rice–fish farming system. In this backdrop, an attempt was made to study the impact of fish and prawn rearing on rice field ecology, yield and yield components of rice, food availability, feed intake pattern of fish and prawn in the rice–fish–prawn system.

MATERIALS AND METHODS

To study the impact of fish and prawn on rice field ecology and productivity in rice–fish–prawn farming system, an on-farm experiment was conducted at Khentalo village (latitude 20° 15′ N and longitude 86° 03′ E) of Cuttack district, Orissa. The experiment continued for 3 crop cycles (2005 to 2007). A patch of waterlogged area was converted into 3 1-hectare units each of deepwater rice monocrop system and deepwater rice–fish–prawn system. Fifty per cent of the lands in the deepwater rice–fish–prawn system units were excavated up to a depth of 100 cm to create a refuge area of 5000 m^2 and the excavated soil was utilized for peripheral dyke construction up to a height of 2.5 m.

'CR 683-123' deepwater rice variety was transplanted in the 100% area of rice monocrop plots and 50% unexcavated area (5000 m^2) of the rice–fish–prawn system units during third week of July in the first, second and third year of the study. Rice was transplanted with a spacing of 20 cm × 20 cm (between rows and plants). The fertilizers (urea, single superphosphate, and muriate of potash) were applied @ 80

[1]Senior Scientist (Fish and Fishery Science) (e mail: rajeebm@yahoo.com), [2]Scientist (Plant Physiology) (e mail: amod_wtcer@yahoo.com), [3]Scientist (Agricultural Extension) (e mail: ghosh_wtcer@yahoo.com), [4]Technical Officer (e mail: patildu_wtcer@yahoo.com).

kg N/ha, 40 kg P_2O_5/ha and 40 kg K_2O/ha. Fifty per cent of N and full dose of P and K was applied as basal dose and rest of N was applied at 2 equal splits during tillering and panicle-initiation stages. No pesticide was used in the experimental plots to prevent fish mortality. Grain yield and yield components were recorded at the time of harvest.

Seven days after pre-stocking refuge preparation (third week of July), fish fingerlings (3.0–4.8 g mean body weight) and prawn juvenile of *M. rosenbergii* (1.2 g mean body weight) were stocked @ 1,00,000/ha with a species composition of 25: 25: 15: 15: 20 (*Catla catla*: *Labeo rohita*: *Cirrhinus mrigala*: *Cyprinus carpio*: *Macrobrachium rosenbergii*) in the excavated refuge (5000 m^2) of the rice–fish–prawn system units. Supplemental feeding was provided with a ratio of 55: 35: 10 (rice bran: mustard oil cake: fish meal) at 6%, 5%, 4% and 2.5% of mean body weight, twice a day during first, second, third and fourth month till harvesting. Periodic manuring with raw cattledung @500 kg/ha and liming at 200 kg/ha were carried out in the refuge at every 15 days interval to maintain plankton population in the ecosystem. Fish and prawn rearing continued for 210 days. To study the food preference and feed intake pattern of cultured species, gut content analysis, degree of satiation (Mohanty 2003), frequency, abundance and matrix of dietary overlaps (Johnson 1999) were carried out. Weekly mean body weight, survival rate, biomass (kg), per cent feed used, feed requirement/day and apparent feed conversion ratio was estimated as described by Mohanty (1999).

Physico-chemical parameters of pond/ field water were monitored *in-situ* every day using standard method (APHA 1998, Biswas 1993). NH_4^+ was determined spectrophotometrically with indophenol blue method, while chlorophyll-*a* was determined using the acetone extraction method. Primary productivity, plankton estimation, nutrient analysis and monthly observations on soil quality (available N, available P, organic carbon and *p*H) were studied using standard methods (Biswas 1993).

To assess the output from the plot as a single unit, rice equivalent yield (REY) and ratio of the output value to the cost of cultivation (OV:CC ratio) of the integrated farming system was computed (Mohanty *et al.* 2008). The computation was carried out considering the farm gate selling price of rice, prawn and marketable fish at Rs 6, Rs 140 and Rs 60, respectively, and the proportional area devoted to rice and fish cultivation. The operational cost includes the cost of feed (Rs 18/kg), fish seed (Rs 250/1 000 early fingerling), prawn seed (Rs 0.5/ seed), raw cowdung (Rs 500/1 000 kg), labour (Rs 80/man-day), lime (Rs 5.50/kg) and other cost, such as cost of plant material, fertilizer etc. Economic indices of water productivity (net consumptive water use index (Rs/m^3) were estimated as suggested by James *et al.* (2005).

The data sets collected during 3 years of experimentation for the various parameters were statistically analyzed considering year as a source of variation and the main effect of year and interaction effect between year and practice were non-significant for all the parameters considered in the study. Consequently, means were compared by LSD-tests between the two practices at the 5% level of significance (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Impact of fish and prawn culture on rice field ecology

Soil analysis showed that textural class was clay having acidic *p*H (6.6–6.8) and the composition of sand, silt and clay was 36.6, 19 and 44.4%, respectively. With the advancement of the crop cycle, the initial levels of organic carbon (0.49–0.57%), available nitrogen (17.9–20.1 mg/100 g) and phosphorus (1.28–1.63 mg/100 g) in soil increased

Table 1 Water and soil quality parameters in rice monocrop and rice–fish–prawn systems

Parameter	Rice monocrop	Rice–fish–prawn system	LSD (*P*=0.05)
*p*H	7.52 (6.7–8.1)	7.31 (6.9–8.5)	0.12
Dissolved oxygen (ppm)	6.1 (4.4–8.9)	4.9 (3.3–8.4)	0.3
Temperature (°C)	28.7 (27.9–31.5)	28.4 (27.7–31.3)	NS
Total alkalinity (ppm)	83 (73–107)	94 (68–109)	4
Dissolved organic matter (ppm)	2.6 (0.55–3.6)	3.4 (1.45–4.8)	0.3
TSS (ppm)	177 (60–257)	225 (132–297)	14
NH_4^+ water (ppm)	0.59 (0.41–0.91)	0.68 (0.34–0.97)	0.05
Chlorophyll-a (mg/m^3)	22.3 (18.8–31.3)	41.1 (21.1–62.2)	8.1
Total plankton (units/l)	7.3×10^3 (9.4×10^2–1.8×10^4)	3.3×10^4 (2.9×10^3–6.7×10^4)	6.1×10^3
Nitrite – N (ppm)	0.033 (0.011–0.07)	0.037 (0.012–0.072)	NS
Nitrate – N(ppm)	0.36 (0.16–0.61)	0.37 (0.05–0.49)	NS
Phosphate – P (ppm)	0.26 (0.13–0.54)	0.21 (0.06–0.33)	NS
Available-N in soil (mg 100/g)	19.3 (20.1–21.9)	20.3 (17.9–21.6)	NS
Available-P in soil (mg 100/g)	2.11 (1.63–2.89)	2.23 (1.28–2.93)	0.4
Organic carbon in soil (%)	0.62 (0.57–0.75)	0.66 (0.49–0.82)	0.04
Soil *p*H	6.94 (6.6–7.1)	7.01 (6.8–7.1)	0.01

Values in parentheses represent range

(Table 1) in both the treatments, while the increments were significantly higher in the deepwater rice–fish–prawn system than in the rice monocrop system. This may be attributed to additional nutrients from fish feed and faeces (Mohanty *et al.* 2008) and fish grazing on the photosynthetic aquatic biomass and other components of the system which aids in nutrient recycling (Vromant *et al*. 2004) and also fish minimizes N losses and helps in P release from the sediment (Breukelaar *et al.* 1994). Oehme *et al*. (2007) also reported that when the rice field is stocked with fish, the nitrogen, phosphorous, and potassium (NPK) contents of the soil and water increases significantly.

In this experiment, the recorded mean minimum and mean maximum values of various water quality parameters are presented in Table 1. Total suspended solid (132–60ppm) and dissolved oxygen concentration (4.4–3.3ppm) showed a decreasing trend with the advancement of culture period (210 days) while, higher values of nitrite (0.07–0.072ppm), nitrate (0.49–0.61ppm), ammonium (0.91–0.97ppm) and total alkalinity (107–109ppm) were recorded towards the later part of the crop-cycle (during 170–210days) in the rice–fish–prawn system. Gradual increase in nitrite, nitrate, ammonia in the rice–fish–prawn system were attributed by intermittent fertilization, increased level of metabolite and decomposition of unutilized feed in absence of water replenishment (Mohanty *et al.* 2004).

The recorded mean values of water *p*H (7.31–7.52) and total alkalinity (83–94 ppm) in different treatments were within the desirable range and maintained due to periodic liming. Total alkalinity (94 ppm), total suspended solid (225 ppm), plankton (3.3×10^4) and chlorophyll-*a* (41.1 mg/m^3) were significantly higher in the rice–fish–prawn system when supplemental feed was provided. This agrees with the findings of Frei and Becker (2005). However, increased phytoplankton and chlorophyll-*a* concentration in the rice–fish–prawn system did not help in maintaining higher dissolved oxygen levels compared to rice monocrop. This was probably due to the decomposition of organic matter (feed and excreta), resulting in higher oxygen consumption. As the oxygen budget is strongly influenced by the balance/ dominance of autotrophic/ heterotrophic process, lower dissolved oxygen concentration might be attributed to the decreased autotrophic/increased heterotrophic activity (Mohanty *et al*. 2009).

Plankton density has always a profound effect on water quality having direct relationship with fish production (Yaro *et al.* 2005). In this experiment, fluctuating trend (increase and decrease) in plankton density (7.3×10^3–3.3×10^4 nos./l) was recorded in both treatments, which ultimately reflected the fish, rice and rice equivalent yield (Tables 2, 3). Mainly diatoms and green algae were dominated groups in the phytoplankton population, while copepods and rotifers dominated the zooplankton population. In all the treatments, average primary production in the first month of cultivation ranged between 87.6 and 137 mg C/m^3/hr, which improved further (407.5 ± 38.3 mg C/m^3/hr) with the advancement of crop-cycle. 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 (Mohanty 2003).

The most important factor limiting aquatic photosynthesis in rice fields is the shading by the growing rice biomass. Besides the competition for light, rice also competes with the field water's photosynthetic active biomass (PAB) for available nutrients, especially N, the most limiting nutrient in the rice fields (Mohanty *et al*. 2009). In rice–fish–prawn system, at the onset of the experiment (first month), the higher *p*H values (7.6–8.1), together with higher dissolved oxygen (6.6–7.7 ppm) and chlorophyll-*a* values (49–62.2 mg/m^3) suggest that an autotrophic pathway dominated within the

Table 2 Rice yield attributes in deepwater rice–fish–prawn system

Treatment	Rice yield (tonnes/ha)	Straw yield (tonnes/ha)	Panicles/ (m^2)	Filled grain/ panicle	Test weight (g)	Per cent increase in grain yield over rice monocrop
Rice monocrop	2.60	3.18	122.2	98.5	25.7	
Rice–fish–prawn system	3.04	3.61	130.2	106.2	25.6	16.9
LSD (*P*=0.05)	0.21	0.17	0.4	0.5	NS	

Table 3 Treatment-wise average crop and water productivity, rice equivalent yield, and ratio of the output value to the cost of cultivation (OV-CC)

Treatment	Rice yield (tonnes/ha)	Fish yield (tonnes/ha)	REY (tonnes/ha)	GWP (Rs/m^3)	NWP (Rs/m^3)	OV-CC ratio
Rice monocrop	2.60		2.6	0.96	0.46	1.28
Rice–fish–prawn system	3.04	6.1	35.5	10.92	7.66	1.60
LSD (*P*=0.05)	0.21		0.3	0.12	0.17	0.06

REY, Rice equivalent yield; GWP, gross water productivity; NWP, net water productivity aquatic phase of the rice fields. However, with the increase in rice biomass, the concentration of chlorophyll-*a* (21.1–33.6 mg/m^3), NH_4^+ (0.34–0.41 ppm), *p*H (6.9–7.3) and dissolved oxygen (3.3–4.6ppm) decreased which indicate a reduced aquatic photosynthesis and suggest that the autotrophic pathway lost importance. As a result, in rice–fish–prawn system, surface feeder (*Catla catla*) and column feeder (*Labeo rohita*) fish gradually switched from feeding on plankton/ algal biomass to supplemental feed and to a diet primarily composed of detritus (Table 4), a process that results in inter-specific competition (Table 5) with bottom feeders (*C. mrigala*, *C. carpio* and *M. rosenbergii*) which agrees to the findings of Vromant *et al*. (2004).

Yield and yield components of rice

The higher rice grain yield recorded in the rice–fish–prawn system was significantly superior to that of rice monocrop (Table 2). This was mainly contributed by higher number of panicles/ m^2 (130.2) and number of filled grains/ panicle (106.2). Percentage increase in grain yield over rice monocrop was also higher in rice–fish–prawn system (16.9%). Lesser panicles (122.2/m^2) and number of filled grain (98.5/panicle) in rice monocrop was probably due to the absence of fish and prawn in the field which helps in improving soil fertility, recovering lost energy, adjusting energy flow by consuming plankton, weeds, insect and bacteria that compete with rice for nutrient (Mohanty 2003).

Further, fish helps in enhancing carbon available to plant by releasing carbon dioxide and break the soil surface, oxidize layers of soil that increases the supply of oxygen to promote root growth and tillering capability of rice plant (Mohanty *et al*. 2009). Since fish in rice field also helps in improving the physico-chemical properties of the arable layer soil of paddy field (Mohanty 2003), enhancing the growth period of rice, increasing dry matter and leaf area index at different growth stages, increasing area of top 3 leaves which improves photosynthesis rate and grain filing (Yang *et al.* 2006); growth and yield performance of rice was enhanced in rice–fish–prawn system than rice monocrop. In this experiment, rice yield irrespective of treatments, was not more than 3.04 tonnes/ha in presence of fish and 2.6 tonnes/ha in monocrop, probably due to higher water levels that decreased the number of panicles/m^2 and rice yield. Vromant *et al*. (2002) also reported that increase in water levels lower the rice yield at a rate of 0.06 tonnes/ha/cm.

Growth and yield performance of fish and prawn in rice–fish–prawn system

Faster growth rate was recorded for *C. carpio* (217.8 g), followed by *C. mrigala* (185.5 g), *C. catla* (178.5 g), *L. rohita* (101.0 g) and *M. rosenbergii* (43.5 g) in the rice–fish–prawn system. The fish and prawn yield (6.1 tonnes/ha/210 days (Table 3) was contributed by *C. mrigala* (1.59 tonnes/ha) followed by *C. catla* (1.47 tonnes/ha), *L. rohita* (1.35 tonnes/ha), *C. carpio* (1.2 tonnes/ha) and *M.rosenbergii* (0.49 tonnes/ha). Condition factor (ponderal index) of cultured species was less than 1.0 (0.87–0.97) during initial 3 weeks of rearing (monsoon phase) and improved thereafter (1.06–1.27) with gradual improvement in water quality (post-monsoon). Species-wise survival rate was 36.4%, 57.3%, 32.9%, 53.8% and 46.7% for *C. carpio*, *C. mrigala*, *C. catla*, *L.rohita* and *M. rosenbergii*, respectively, while the apparent feed conversion ratio was 1.77. Bottom feeders (*C. carpio* and *C. mrigala*) registered better growth rate than that of *C. catla* (surface feeder) and *L. rohita* (column feeder) probably due to their superior feed utilizing capability and high degree of tolerance to fluctuation of dissolved oxygen and total suspended solid concentration (Mohanty *et al*. 2004). Faster growth rate of bottom feeders were attributed to effective utilization of ecological niches and rich detrital food web that was maintained through periodic manuring, liming and fertilization in the refuge.

Food availability and feed intake pattern of fish and prawn in the rice field ecosystem

Phytoplanktons and zooplanktons were most preferred food items for *C. catla* and *L. rohita*, while mud and detritus were highly preferred by *C. mirgala*, *C. carpio* and *M.rosenbergii* in rice fish integration system (Table 4). However, quantity-wise most consumed food item was artificial supplemental feed. Among bottom dwellers (*C.mrigala*, *C. carpio* and *M.rosenbergii*), *M. rosenbergii*

Table 4 Average% of individual gut content volume (abundance) and% of analyzed species in which mentioned food components were found (frequency) in rice field ecosystem

Food component	Abundance (%)					Frequency (%)				
	M.rosenbergii	*L.rohita*	*C.catla*	*C.carpio*	*C.mrigala*	*M.rosenbergii*	*L.rohita*	*C.catla*	*C.carpio*	*C.mrigala*
Supplemental feed	61.7$^+$	49.3$^+$	56.7$^+$	46.1$^+$	45.8$^+$	77.8	77.8	72.2	88.8	83.3
Phytoplankton	4.3$^-$	5.1$^-$	11.2$^-$	2.7$^-$	2.3$^-$	72.2	83.3	94.4	66.6	55.6
Zooplankton	1.6$^-$	4.3$^-$	5.9$^-$	1.9$^-$	1.4$^-$	44.4	83.3	88.8	72.2	44.4
Detritus+mud	21.0$^-$	15.4$^-$	5.6$^-$	32.1$^+$	29.1$^+$	77.8	22.2	11.1	88.9	94.4
Benthos	16.4$^-$	1.0$^-$		12.2$^-$	12.2$^-$	61.1	5.5		55.6	44.5

$^+$ more than; $^-$ less than

Table 5 Matrix of dietary overlap(s) and estimated degree of satiation (F_i) of fingerling to advanced fingerling stage of fish and prawn in rice field ecosystem

Species	Matrix of dietary overlap(s)					Estimated degree of satiation (F_i)	
	C.catla	*L.rohita*	*C.mrigala*	*C.carpio*	*M.rosenbergii*	Fingerling stage	Advanced fingerling stage
C. catla		0.70	0.52	0.52	0.42	5.9 ± 0.5	2.7 ± 0.4
L. rohita			0.56	0.52	0.45	5.1 ± 0.3	4.1 ± 0.5
C. mrigala				0.85	0.83	4.7 ± 0.3	4.2 ± 0.3
C. carpio					0.90	6.2 ± 0.5	5.3 ± 0.4
M. rosenbergii						5.2 ± 0.4	4.7 ± 0.1

F_i , w × 100/W; where w, weight of gut content and W, weight of individual fish/ prawn.

preferred more phytoplankton (72.2%) and benthos (61.1%) while *C. carpio* and *C. mrigala* preferred detritus (88.9–94.4%). Omnivorous feeding behaviour was observed in case of each species except *C. catla*, while the degree of omnivorous feeding behaviour was high in case of *M. rosenbergii.* Frequency distribution of available food items in the gut content of the cultured fish and prawn species (Table 4) indicated plenty availability of planktonic, periphytic and benthic food to fish and prawn in the rice-field, which can help, reduce the supplemental feed input.

Estimated degree of satiation (index of gut fullness) at fingerling stage was high in case of *C. carpio*, followed by *C. catla*, and *M. rosenbergii* (Table 5). Comparative degree of satiation, indicated a distinct declining trend from fingerling 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. Matrix of dietary overlap(s) of cultured species under deepwater rice-fish integration system (Table 5) revealed that degree of food preference was more similar between *C. carpio* and *M. rosenbergii* (0.9), while it was poorly overlapped between *C. catla* and *M. rosenbergii* (0.42). This high similarity index between bottom dwellers established a stronger possibility of competition for food among each other.

System's economic evaluation

Significantly higher REY (Table 3) was recorded in rice–fish–prawn system (35.5) than by rice monocrop (2.6). In rice–fish–prawn system, when 50% area is devoted for fish and prawn culture, the net returns enhanced by 23-folds in comparison to rice monocrop. Higher net returns of Rs 3 510/ha and Rs 79 585/ha was estimated in rice monocrop and rice–fish–prawn system, respectively. The economic indices of net water productivity were Rs 0.46/m^3 and Rs 7.66/m^3 for rice monocrop and rice–fish–prawn system, respectively (Table 3). Similarly, the ratio of the output value to the cost of cultivation (OV-CC ratio) of the integrated farming system (rice–fish–prawn) was significantly higher than that of the rice monocrop (Table 3). This infers that rice–fish–prawn culture is more beneficial than traditional deepwater rice monocropping.

Thus, it may be concluded that integration of fish to the rice field ecology not only enhances production and helps in achieving higher economic returns but also improves/ benefits rice field ecology. This eco-friendly and highly beneficial production system (rice–fish– prawn) that generate lucrative returns, can be adopted and expanded in unproductive or low productive lowlands and waterlogged areas.

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