Aquaculture Research

Aquaculture Research, 2010, **41**, 1402–1412 doi: 10.1111/j.1365-2109.2009.02432.x

# Performance evaluation of concurrent rice–fish–prawn culture with and without cull harvesting

**Rajeeb K Mohanty, Amod K Thakur, Souvik Ghosh, Silabhadra Mohanty & Dhiraj U Patil**

Directorate of Water Management, Indian Council of Agricultural Research, Chandrasekharpur, Bhubaneswar, Orissa, India

**Correspondence:** R K Mohanty, Directorate of Water Management, Indian Council of Agricultural Research, Chandrasekharpur, Bhubaneswar, Orissa 751 023, India. E-mail: rajeebm@yahoo.com

## Abstract

This study was carried out in farmers' fields for three experimental culture cycles to evaluate the performance of rice–fish–prawn culture. The treatments carried out were deepwater rice mono-cropping (R), and rice–fish–prawn culture with cull harvesting (R–FC) and without cull harvesting (R–F). Water pH and total alkalinity were significantly higher ($P < 0.05$) in R–FC than in R–F, while the concentrations of total suspended solids, plankton and chlorophyll *a* were higher in R–F. Cull harvesting in R–FC had no marked influence on the concentrations of dissolved oxygen, $NH_4^+$, nitrite, nitrate and phosphate compared with the R–F treatment. The significantly higher fish and prawn yields ($P < 0.05$) and species-wise faster individual growth performance in R–FC than in R–F were probably due to periodic cull harvesting, which minimized the competition for food and space as well as physiological stress at reduced density. The paddy yield and percentage increase in paddy yield over rice mono-crop was significantly higher ($P < 0.05$) in R–FC (25%), followed by R–F (16.9%), probably due to lower chlorophyll *a* (36.7 mg m$^{-3}$) and plankton density ($1.4 \times 10^4$ L$^{-1}$), which minimized the competition for nutrients with rice plants. The highest rice equivalent yield (38.5), output value–cultivation cost ratio (1.56) and enhanced net return (28%) in deepwater rice–fish culture were recorded when cull harvesting was practiced.

**Keywords:** concurrent rice–fish–prawn culture, Indian major carps, growth performance, cull harvesting, water quality

## Introduction

Rice–fish farming provides a sustainable alternative to rice monoculture and is practiced in 28 countries on six continents (Suloma & Ogata 2006). Two types of growing periods, concurrent with the rice and rotational after the rice, are usually followed. The major differences in these farming systems are mainly due to the variations in field design, species composition, stocking density, sizes, crops, crop rotation, etc. Concurrent rice–fish farming is ecologically sound and is a good method of diversification, where fish improve the soil fertility. Significant work on rice–fish farming has been carried out in many countries such as Philippines (Sevilleja 1992), Indonesia (Koesoemadinata & Costa-Pierce 1992), Bangladesh (Gupta, Sollows, Mazid, Rahman, Hussain & Dey 1998; Frei, Razzak, Hossain, Oheme, Dewan & Becker 2007; Oehme, Frei, Razzak, Dewan & Becker 2007; Kunda, Azim, Wahab, Dewan, Roos & Thilsted 2008; Rohul Amin & Salauddin 2008; Wahab, Kunda, Azim, Dewan & Thilsted 2008), Vietnam (Cagauan, Branckaert & Van Hove 2000), Thailand, Malaysia (Ali 1990), etc. Although the practices of rice–fish farming differ from country to country, they all follow the same principle of utilizing or recycling farm resources for production. Rice–fish farming systems, as part of an integrated ecosystem in line with the local cultural, environmental and economic conditions, are composed of complementary sub-agricultural ecosystems and play important ecological service roles (Fernando 1993), such as bio-control, nitrogen fixation and landscape combination. The highest fish yield per crop reported from a rice–fish system so far is 7.03 t ha$^{-1}$ (Chen, Ying & Shui 1995), while the recorded maximum fish yields per crop from these systems are 1.7 t ha$^{-1}$ in India (James, Mishra, Mohanty, Brahmanand, Nanda, Das & Kannan 2005), 2.5 t ha$^{-1}$ in China, 2.2 t ha$^{-1}$ in Vietnam, 0.98 t ha$^{-1}$ in Bangladesh, 0.9 t ha$^{-1}$ in Thailand and 0.8 t ha$^{-1}$ in Indonesia (Haroon & Pittman 1997). However, in most countries, rice–fish farming is characterized by intensive rice culture and extensive fish culture, where fish yields are usually very low, about 300 kg ha $^{-1}$ (Nhan, Duong & Rothuis 1998).

In India, during the last two decades, experiments have been conducted in several states to improve the production potential of fish/prawn in rice fields. Presently, most research activities in rice–fish culture are confined to medium lands and deep-water rice fields in both freshwater and coastal rice fields. The average fish yields from different rice–fish farming systems in India are usually very low, about 600 kg ha $^{-1}$ (Sinhababu 2008). However, the experimental results are much better than the farmers' practice. Generally, two types of fish farming systems are practiced in these rice fields: a capture-based system or a culture system. The culture-based system is practiced mainly in lowland rice-growing areas with construction of pond refuge and trenches. The fish farming practices in this system are almost similar to the conventional methods, except for restricted use of chemicals and pesticides required for rice crops.

In rainfed lowlands and waterlogged areas, farmers mostly grow mono-crop traditional rice with very low inputs and poor management due to various adverse situations such as excess water, flash flood, cyclone, drought, pest and diseases. The productivity, as a result, is very low (< 1.5 t rice ha $^{-1}$) as compared with the national average of 2.1 t ha $^{-1}$ (Mohanty, Jena, Kumar, Sahoo & Roy Chowdhury 2008). This underutilized, otherwise high potential area, however, provides excellent scope for rice–fish farming to enhance productivity and income through a suitable farming approach. Against this backdrop, an attempt was made to enhance the productivity of rice–fish systems based on management strategies like high-density initial stocking, followed by selective/cull harvesting when the growth curve of fish/prawn starts to slow down and to study the subsequent impact on water quality and growth. Although limited studies have been reported on the impact of selective/cull harvesting on fish (Heaps 1995; Coltman 2008) and prawn (Keppeler & Valenti 2006), its application in short-duration aquaculture mainly in the rice–fish system has not been reported. Because the rice–fish system provides a viable opportunity for mass-scale fry to advanced fingerling rearing in a 5–6-month period, the high-density initial stocking approach was adopted with the aim of fulfilling the local demand for advanced fingerlings for grow-out pond culture through cull/selective harvesting (the desired stocking programme suffers mainly due to non-availability of adequate land-based nursery ponds and financial constraints in developing new infrastructure facilities).

## Materials and methods

This experiment was carried out for three experimental culture cycles in farmers' fields at Kishor Nagar (latitude 20°15′N and longitude 86°03′E) of Cuttack district, Orissa, India, during 2004–2005 to 2006–2007. A patch of waterlogged area was selected for this study and rice–fish–prawn culture was evaluated in three treatments in triplicate of one hectare each with a randomized block design, i.e. R–FC: rice–fish culture with selective/cull harvesting, R–F: rice–fish culture without cull harvesting and R: deepwater rice only. In R–FC and R–F, 50% of the land was excavated up to a depth of 100 cm for construction of a refuge, and the excavated soil was utilized for the construction of a peripheral dyke up to a height of 2.5 m.

The deepwater rice variety *Durga* (CR 683-123) was transplanted in the unexcavated land (50% area, 5000 m $^2$) of R–FC and R–F, and in the whole area of R plots during the third week of July in all the 3 years of the study. Rice was cultivated by following the standard practices of deep water rice cultivation (ICAR 1997) and three seedlings were transplanted with a spacing of 20 cm × 20 cm. The fertilizer application rate was 80 kg N ha $^{-1}$, 60 kg $P_2O_5$ ha $^{-1}$ and 40 kg $K_2O$ ha $^{-1}$ for urea, single super phosphate (SSP) and muriate of potash respectively. Fifty per cent of the N and the full dose of P and K were applied as a basal dose at the time of transplanting. The remaining nitrogen was applied in two equal doses during the active tillering stage and the panicle initiation stages (30 and 60 days after transplanting). No pesticide was used in the experimental plots to prevent fish mortality. Grain yield and yield attributes of crops were recorded at the time of harvest. Crops in an area of 5 m $^2$ from each replication were harvested excluding the border effect for determination of yield per unit area and the test weight (1000 – grain weight) at 14.5% seed moisture content. Yield components like panicle number per unit area and number of filled grains per panicle for each replication were determined.

The pre-stocking refuge preparation in R–FC and R–F included horizontal and longitudinal ploughing, followed by application of lime ($CaCO_3$) at the rate of 750 kg ha $^{-1}$, raw cattle dung (RCD) at 7000 kg ha $^{-1}$

 

as the basal dose and fertilizer (urea:SSP∷1:1) at 3 ppm. Seven days after refuge preparation (third week of July), hatchery-produced early fish fingerlings [3.0–4.8 g mean body weight (MBW)] and prawn juveniles of *Macrobrachium rosenbergii* (1.2 g MBW) were stocked in the excavated refuge (5000 $m^2$) at the rate of 100 000 $ha^{-1}$ with a species composition of 25:25:15:15:20 (*Catla catla*:*Labeo rohita*:*Cirrhinus mrigala*:*Cyprinus carpio*:*M. Rosenbergii*∷ 12 500:12 500:7500:7500:10 000). Supplemental feeding was only provided in the refuge, twice a day, at a ratio of 55:35:10 (rice bran:mustard oil cake:fish meal) on a dry wet basis at the rate of 5%, 4%, 3% and 2.5% of MBW, respectively, during the first, second, third and fourth month of harvesting respectively. Periodic manuring with RCD at the rate of 500 kg $ha^{-1}$ and liming at 100 kg $ha^{-1}$ were carried out at every 15-day interval to maintain the plankton population in the refuge.

The major physico-chemical parameters of refuge water, e.g. temperature, pH, total alkalinity, total suspended solids and $CO_2$ were monitored *in situ* every week between 07:00 and 08:00 hours using standard methods (Biswas 1993; APHA 1995). Dissolved oxygen (DO) and turbidity were recorded using a Multi-Parameter Water Analyzer (YK-611, Yeo-Kal Electronics Pty., New South Wales, Australia). $NH_4^+$ was determined spectrophotometically using the indophenol blue method, while chlorophyll *a* was determined using the acetone extraction method (Strickland & Parsons 1972). Primary productivity was analysed using the 'Oxygen method' (APHA 1995), while nutrient analysis was performed using standard methods (Biswas 1993). Plankton samples were collected at fortnightly intervals by filtering 50 L of water from each unit through a silk net (no. 25, mesh size 64 μm), preserved in 4% formaldehyde and later analysed for quantitative and qualitative estimation. Water exchange/replenishment was not undertaken during the study period. Sediment samples were collected twice from the refuge and paddy grown area during each crop period (i.e. before stocking and after harvest of fish) and analysed for pH, available nitrogen (De 1962), available phosphorus (Troug 1930) and organic carbon (Walkley & Black 1934).

In R–FC, phased/selective harvesting of advanced (large-sized) fish fingerlings and prawn (mainly females above 30 g and blue-clawed male) was undertaken twice, after 120 and 165 days of stocking (DAS). Fish and prawn rearing continued for 210 days. The weekly growth study was carried out before feeding, so that complete evacuation of the gut was ensured. Weekly MBW, daily increment, survival rate (SR%), biomass (kg), feed requirement, % feed used, feed requirement per day and apparent feed conversion ratio (AFCR) were estimated as described by Mishra and Mohanty (2004). All the data were statistically analysed using analysis of variance (ANOVA) to test for the effect of treatments (Gomez & Gomez 1984). When a significant treatment effect was observed by ANOVA ($P<0.05$), Duncan's multiple range test was used to compare all possible pairs of treatment means at a 5% level of significance. All statistical analyses were carried out using MSTAT-C version 2.10 software (Michigan State University, East Lansing, MI, USA).

To assess the output from the plot as a single unit, the rice equivalent yield (REY) was computed (James *et al.* 2005) considering the farm gate selling price of rice, fish fingerling, prawn and marketable fish as Rs. 5.00 $kg^{-1}$, Rs. 2.50 $piece^{-1}$, Rs. 120.00 $kg^{-1}$ and Rs. 50.00 $kg^{-1}$, respectively, and the proportional area devoted to rice and fish cultivation. The ratio of the output value to the cost of cultivation (OV–CC ratio) of the integrated farming system was estimated (Mohanty *et al.* 2008). The cost of excavated refuge/pond, considering the life span up to 15 years, which is a fixed cost, was added (depreciated cost) to the yearly variable cost of cultivation. The cost of excavated refuge/pond was estimated to be Rs. 135 000 $ha^{-1}$. The operational cost includes: the cost of feed (Rs. 14.00 $kg^{-1}$), fish seed (Rs. 200.00 per 1000 early fingerling), prawn seed (Rs. 0.5 $seed^{-1}$), raw cow dung (Rs. 500.00 per 1000 kg), labour (Rs. 70.00 per man day), lime (Rs. 4.50 $kg^{-1}$) and other costs such as the cost of plant material, fertilizer, etc.

## Results

### Soil and water quality

Soil analysis shows that the textural class is clay having an acidic pH (6.6–6.8). The composition of sand, silt and clay was 36.6%, 19% and 44.4% respectively. The organic carbon (%), available N and P in soil (mg 100 $g^{-1}$) ranged between 0.16 and 0.19, 7.9 and 10.1, and 1.28 and 1.63, respectively, at the initial stage of intervention, which improved further (Table 1) with the advancement of the crop period. A significant variation in available N was recorded in different treatments, while there was no such variation in soil pH. The sediment characteristics of the different treatments indicate that the soil is of medium productivity.

Differences in the water-quality parameters among treatments are presented in Table 1. Various hydro-biological parameters in the different treat-

**Table 1** Variations in water and sediment quality parameters in the different treatments

| Parameters | Rice–fish system with cull harvesting (R–FC) | Rice–fish system with out cull harvesting (R–F) | Only rice (R) |
|---|---|---|---|
| Water quality parameters | | | |
| Water pH | 6.7–8.6 | 6.9–8.5 | 6.7–8.1 |
| Dissolved oxygen ($mg\,L^{-1}$) | $5.1 \pm 1.1^{b}$ | $4.9 \pm 1.3^{b}$ | $6.1 \pm 0.8^{a}$ |
| Temperature (°C) | $28.4 \pm 0.5$ | $28.4 \pm 0.3$ | $28.7 \pm 0.6$ |
| Total alkalinity ($mg\,L^{-1}$) | $106 \pm 7^{a}$ | $94 \pm 10^{b}$ | $88 \pm 8^{c}$ |
| Dissolved organic matter ($mg\,L^{-1}$) | $3.2 \pm 0.3^{a}$ | $3.4 \pm 0.4^{a}$ | $2.6 \pm 0.2^{b}$ |
| Total suspended solids ($mg\,L^{-1}$) | $213 \pm 10^{b}$ | $225 \pm 13^{a}$ | $177 \pm 17^{c}$ |
| $NH_4^+$ water ($mg\,L^{-1}$) | $0.65 \pm 0.02^{ab}$ | $0.68 \pm 0.03^{a}$ | $0.59 \pm 0.03^{b}$ |
| Chlorophyll *a* ($mg\,m^{-3}$) | $36.7 \pm 4.1^{b}$ | $41.1 \pm 3.2^{a}$ | $22.3 \pm 5.3^{c}$ |
| Total plankton ($\times 10^3\,U\,L^{-1}$) | $14 \pm 1.3^{b}$ | $33 \pm 1.1^{a}$ | $7 \pm 1.4^{c}$ |
| Nitrite-N ($mg\,L^{-1}$) | $0.03 \pm 0.01$ | $0.04 \pm 0.01$ | $0.03 \pm 0.00$ |
| Nitrate-N ($mg\,L^{-1}$) | $0.36 \pm 0.09$ | $0.37 \pm 0.06$ | $0.36 \pm 0.08$ |
| Phosphate-P ($mg\,L^{-1}$) | $0.21 \pm 0.04^{b}$ | $0.21 \pm 0.03^{b}$ | $0.26 \pm 0.04^{a}$ |
| Sediment quality parameters* | | | |
| Available N in soil ($mg\,100\,g^{-1}$) | $19.8 \pm 0.2^{b}$ | $19.3 \pm 0.3^{c}$ | $20.3 \pm 0.3^{a}$ |
| Available P in soil ($mg\,100\,g^{-1}$) | $2.21 \pm 0.06^{a}$ | $2.23 \pm 0.08^{a}$ | $2.11 \pm 0.07^{b}$ |
| Organic carbon in soil (%) | $0.61 \pm 0.01^{b}$ | $0.64 \pm 0.01^{a}$ | $0.63 \pm 0.01^{a}$ |
| Soil pH | 6.6–7.1 | 6.8–7.1 | 6.8–7.1 |

All values are mean ± SD.
Values with different superscripts in a row differ significantly ($P < 0.05$).
*Sediment quality parameters were recorded once before commencement of the experiment and after harvest of each crop cycle.

ments were within the optimum ranges for fish growth and survival and did not fluctuate drastically. Total suspended solids and DO concentration showed a decreasing trend with the advancement of the rearing period. In the present study, the DO level did not decline below 3.3 ppm in any treatment and a significantly higher DO concentration was recorded in treatment R.

Cull harvesting in treatment R–FC had no marked influence on the concentrations of dissolved organic matter, $NH_4^+$, nitrite, nitrate and phosphate (Table 1). Water pH and total alkalinity were significantly higher in R–FC than in R–F, while the concentration of total suspended solid, plankton and chlorophyll *a* was higher in R–F, followed by R–FC and R. In this experiment, a significantly higher plankton density was recorded in R–F, followed by R–FC and R. Phytoplankton was mainly dominated by diatoms and green algae and zooplankton by copepods and rotifers. In all the treatments, the average primary production in the first month of cultivation ranged between 87.6 and 137 $mg\,C\,m^{-3}\,h^{-1}$, which improved further ($407.5 \pm 38.3\,mg\,C\,m^{-3}\,h^{-1}$) with the advancement of the rearing period.

## Growth and yield performance of fish and prawn

A faster growth rate in terms of weight gain was recorded for *C. catla*, followed by *C. carpio* and *C. mrigala* (Table 2) in R–FC, while in R–F, a faster growth rate was recorded for *C. carpio*. Similarly, the growth performance of *M. rosenbergii* was much faster in R–FC than in R–F. The impact of cull harvesting on the overall growth performance and yield of fish and prawn (Table 3) was reflected in the faster growth of all species after 120 days of rearing and higher yield in R–FC (14.1% increase over R–F). Fish and prawn yield in R–FC was significantly higher than that in R–F. Similarly, a higher SR and a lower AFCR were also recorded in R–FC than in R–F. The condition factor of the cultured species was $< 1.0$ (0.87–0.97) in the initial 3 weeks of rearing (monsoon phase) and improved thereafter (1.06–1.27) with the gradual improvement in water quality (post-monsoon) in both R–FC and R–F.

An interesting trend in the growth performance of *M. rosenbergii* was observed when grown together with fish in the rice–fish system. The data of the weight distribution (%) and heterogeneity size of the *M. rosenbergii* between treatments are presented in Table 4. At 120 days after stocking, about 60% of the population had an MBW below 20 g in both treatments. While at 210 DAS the proportion of population below 20 g was reduced to 7.3% in R–FC, in R–F the reduction was only to 23.7%. Similarly, at 210 DAS, 12.5% population attained $> 80$ g MBW in R–FC while none reached this target in R–F (Table 4).

 

**Table 2** Details of cull harvesting at different days after stocking (DAS) in a rice–fish–prawn system

| Species composition | Cull harvesting | | | | | | Final survival (%) | |
|---|---|---|---|---|---|---|---|---|
| (25:25:15:15:20) | MBW (g) at 1st cull (120 DAS) | | MBW (g) at 2nd cull (165 DAS) | | MBW (g) at final harvesting (210 DAS) | | | |
| | R–FC | R–F | R–FC | R–F | R–FC | R–F | R–FC | R–F |
| *Catla catla* | 66.7 ± 4.3[a] (4000*) | 53.5 ± 4.6[b] | 192.6 ± 10.2[a] (2000†) | 122.5 ± 8.8[b] | 387.5 ± 15.2[a] (1008†) | 178.5 ± 18.8[b] (4113†) | 56.1 ± 4.2[a] | 32.9 ± 3.3[b] |
| *Labeo rohita* | 39.6 ± 5.1[a] (3000*) | 27.2 ± 5.5[b] | 98.4 ± 6.6 (3000*) | 89.5 ± 7.2 | 205.0 ± 11.5[a] (1690†) | 101.0 ± 20.2[b] (6720†) | 61.5 ± 4.1[a] | 53.8 ± 5.2[b] |
| *C.mrigala* | 44.0 ± 2.2 (2000*) | 43.3 ± 1.5 | 145.0 ± 3.5[a] (1500†) | 115.0 ± 8.1[b] | 275.0 ± 14.2[a] (1807†) | 185.5 ± 17.7[b] (4297†) | 70.8 ± 2.8[a] | 57.3 ± 3.3[b] |
| *C. carpio* | 57.7 ± 2.6 (1000*) | 58.0 ± 2.3 | 175.5 ± 5.7[a] (1500†) | 140.2 ± 9.5[b] | 340.0 ± 15.8[a] (833†) | 217.8 ± 19.1[b] (2734†) | 44.4 ± 4.8 | 36.5 ± 6.2 |
| *M. rosenbergii* | 28.8 ± 1.1 (1500‡) | 27.3 ± 1.0 | 52.2 ± 1.5[a] (3500‡) | 43.5 ± 3.3[b] | 78.2 ± 5.8[a] (630‡) | 53.0 ± 9.2[b] (4669‡) | 56.3 ± 2.2[a] | 46.7 ± 3.1[b] |

Mean body weight (MBW) values are mean ± SD.
Values with different superscripts between treatments within a row differ significantly ($P < 0.05$).
Figures in parentheses represent the number of fish/prawn harvested.
*Sold as fingerling at Rs. 2.50 piece$^{-1}$.
†Sold in market at Rs. 50 kg$^{-1}$.
‡Sold in market at Rs. 120 kg$^{-1}$ (1 USD = 47 INR for the year 2009).

**Table 3** Impact of cull harvesting on individual daily growth performance and yield of fish and prawn in a rice–fish–prawn system

| Species | | Daily Increment in weight (g) in R–FC | | | Yield (t) from refuge (5000 m$^2$) | | AFCR | |
|---|---|---|---|---|---|---|---|---|
| stocked | Initial MBW (g) | 120 DAS | 120–165 DAS | 165–210 DAS | R–FC | R–F | R–FC | R–F |
| *C. catla* | 3.7 ± 0.1 | 0.52 ± 0.07 | 2.8 ± 0.1 (438.4) | 4.33 ± 0.3 (54.6) | 1.042 ± 0.02[a] | 0.734 ± 0.01[b] | 1.77 ± 0.9[b] | 2.24 ± 0.13[a] |
| *L. rohita* | 3.0 ± 0.2 | 0.30 ± 0.04 | 1.3 ± 0.06 (333.3) | 2.36 ± 0.07 (81.5) | 0.760 ± 0.02[a] | 0.678 ± 0.01[b] | | |
| *C. mrigala* | 4.8 ± 0.2 | 0.33 ± 0.04 | 2.24 ± 0.07 (578.7) | 2.88 ± 0.09 (28.5) | 0.802 ± 0.01 | 0.797 ± 0.02 | | |
| *C. carpio* | 4.0 ± 0.3 | 0.45 ± 0.05 | 2.62 ± 0.09 (482.2) | 3.65 ± 0.1 (39.3) | 0.604 ± 0.02 | 0.595 ± 0.02 | | |
| *M. rosenbergii* | 1.2 ± 0.04 | 0.23 ± 0.03 | 0.52 ± 0.02 (126.0) | 0.57 ± 0.06 (0.1) | 0.275 ± 0.01[a] | 0.247 ± 0.01[b] | | |
| | | | Total | Biomass = | 3.48 ± 0.02[a] | 3.05 ± 0.01[b] | | |

All values are mean ± SD.
Values with different superscripts between treatments within a row differ significantly ($P < 0.05$).
Figures in parentheses indicate percentage increase over previous PDI.
AFCR, apparent feed conversion ratio.

**Table 4** Weight distribution (%) and size heterogeneity of *Macrobrachium rosenbergii* with and without cull harvesting under a high-density culture in a deepwater rice–fish–prawn system

| Days after stocking (DAS) | Weight distribution (%) < 20 g R–FC | < 20 g R–F | 20–40 g R–FC | 20–40 g R–F | 40–60 g R–FC | 40–60 g R–F | 60–80 g R–FC | 60–80 g R–F | > 80 g R–FC | > 80 g R–F |
|---|---|---|---|---|---|---|---|---|---|---|
| First cull, 120 DAS | 61.0 ± 2.5 | 62.0 ± 2.6 | 39.0 ± 1.4 | 38.0 ± 1.1 | – | – | – | – | – | – |
| Second cull, 165 DAS | 30.0 ± 1.4[b] | 42.0 ± 3.9[a] | 33.0 ± 1.0 | 33.3 ± 1.5 | 34.0 ± 1.1[a] | 24.7 ± 1.6[b] | 3.0 ± 0.5 | – | – | – |
| Harvesting, 210 DAS | 7.3 ± 3.5[b] | 23.7 ± 7.3[a] | 16.2 ± 3.1[b] | 31.4 ± 5.7[a] | 28.5 ± 2.3 | 33.9 ± 3.1 | 35.5 ± 2.7[a] | 11.0 ± 1.1[b] | 12.5 ± 1.5 | – |

All values are mean ± SD.
Values with different superscripts between treatments within a row differ significantly ($P<0.05$).

### Rice yield performance: with and without fish

The highest grain yield was recorded in R–FC, which is significantly higher than that of treatment R. The higher grain yield was mainly due to the higher number of panicles $m^{-2}$ (139.5) and number of filled grains per panicle (111.5). The percentage increase in grain yield over rice mono-crop was 25% higher in R–FC than in R–F (Table 5).

### System's REY and economic output

The highest REY (Fig. 1) was recorded in R–FC (38.5), followed by R–F (35.5) and R (2.6). Although there was not much variation in R–FC and R–F, both these treatments were much better than treatment R with respect to REY. The OV–CC ratio had a higher value (1.56) in rice–fish culture when cull harvesting was practiced (Table 6). In R–FC, the net income was Rs. 71 535.00 while in R–F it was Rs. 55 997.00 (1 USD = 47 INR approximately).

## Discussion

### Soil and water quality

With the advancement of the culture season, the initial levels of organic carbon and available nitrogen and phosphorus in soil increased. This may be attributed to (1) additional nutrients from fish feed and fish faeces (Mohanty *et al*. 2008), (2) fish grazing on the photosynthetic aquatic biomass and other components of the system, which aids in nutrient recycling (Vromant, Nam, Chau & Ollevier 2004), and (3) minimization of N losses (Cagauan 1995) and facilitation of P release from the sediment (Breukelaar, Lammens, Breteler & Tatrai 1994).

Various hydro-biological parameters prevailing in different treatments did not fluctuate drastically probably due to similar levels of inputs in all the treatments in the form of organic manure, inorganic fertilizer and periodic liming. In this experiment, the DO level did not decline below 3.3 ppm and a significantly higher DO concentration was recorded in treatment R. The decreasing trend of DO in the treatments with fish was mainly due to the decomposition of organic matter (feed) that requires additional oxygen, fluctuation in plankton density and a gradual increase in biomass, resulting in higher oxygen consumption. A similar observation was also made by Frei and Becker (2005), who reported that fish decrease the DO and pH value compared with rice

**Table 5** Rice yield attributes in a deepwater rice–fish–prawn system

| Treatments | Rice yield ($t\,ha^{-1}$) | Straw yield ($t\,ha^{-1}$) | Number of panicles $m^{-2}$ | Number of filled grains $panicle^{-1}$ | Test weight* (g) |
|---|---|---|---|---|---|
| Rice mono-crop (R) | $2.6 \pm 0.26^{c}$ | $3.18^{c}$ | $122.2 \pm 6.1^{c}$ | $98.5 \pm 6.2^{c}$ | $25.7 \pm 0.3^{a}$ |
| Rice–fish without cull harvesting (R–F) | $3.04 \pm 0.18^{b}$ (16.9) | $3.61^{b}$ | $130.2 \pm 4.6^{b}$ | $106.2 \pm 3.4^{b}$ | $25.6 \pm 0.2^{a}$ |
| Rice–fish with cull harvesting (R–FC) | $3.25 \pm 0.24^{a}$ (25.0) | $3.94^{a}$ | $139.5 \pm 3.7^{a}$ | $111.5 \pm 2.7^{a}$ | $25.8 \pm 0.3^{a}$ |

All values are mean ± SD.
Mean values with different superscripts in a column differ significantly ($P < 0.05$).
*Test weight represents the weight of 1000 grains with a 14.5% moisture content.
Figures in parentheses represent the percentage increase in grain yield over rice mono-crop.

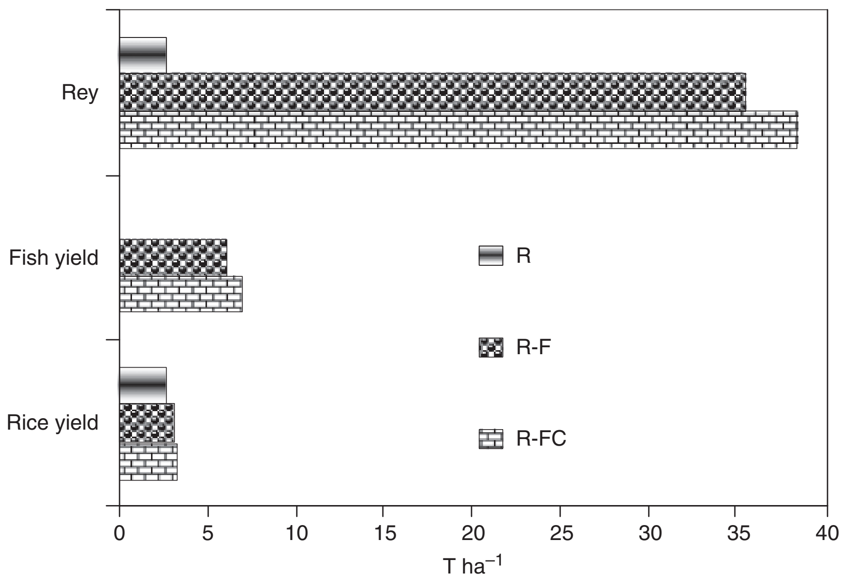


**Figure 1** Treatment-wise rice, fish and rice equivalent yield (REY) in concurrent rice–fish–prawn system.

**Table 6** Ratio of the output value (OV) to the cost of cultivation (CC) of the integrated farming system (average of three experimental years)

| Treatment | Output value (Rs. $ha^{-1}$) | Cultivation cost (Rs. $ha^{-1}$) | Net return (Rs. $ha^{-1}$) | OV–CC ratio |
|---|---|---|---|---|
| $T_3$: Deep water rice mono-crop | 13 000 | 10 900 | 2100 | 1.19 |
| $T_2$: Rice–fish: without cull harvesting | 180 095 | 124 098 | 55 997 | 1.45 |
| $T_1$: Rice–fish: with cull harvesting | 200 220 | 128 685 | 71 535 | 1.56 |

1 USD = 47 INR approximately for the year 2009.

mono-crop, especially when supplemental feed is given. Yaro, Lamani and Oladimeji (2005) reported that most warm water fish species require a minimum DO level of 1 ppm for survival, 3 ppm for comfort and 5 ppm for ideal growth and maintenance. Cull harvesting in R–FC, however, had no marked influence on the concentrations of DO (Table 1).

Slightly higher values of the nitrogenous compound and total alkalinity were recorded towards the later part of the experiment. Gradual increases in the nitrogenous compound could be attributed to intermittent fertilization, increased level of metabolite and decomposition of unutilized feed in the absence of water replenishment (Mohanty, Verma &

Brahmanand 2004). The higher concentration of phosphate-P in treatment R compared with R–F and R–FC was probably due to poor nutrient uptake by the rice plants in the absence of fish and prawn (Breukelaar *et al.* 1994). In general, poor growth performance of cultured species takes place at $pH < 6.5$ (Mount 1973), while higher values of total alkalinity ($> 90$ ppm) indicate a better productive eco-system and increased plankton density, and reflect higher nutrient status of the water body (Mohanty 2003). The recorded values of pH and mean total alkalinity in different treatments during the experimental period (Table 1) were within the desirable range and were maintained due to periodic liming. Water pH and total alkalinity were significantly higher in R–FC while the concentration of total suspended solid, plankton and chlorophyll *a* was higher in R–F when supplemental feed was provided. This agrees with the findings of Frei and Becker (2005), who reported that fish stimulate the growth of phytoplankton and chlorophyll *a* in an integrated rice–fish culture. However, increased phytoplankton and chlorophyll *a* concentration in R–F and R–FC did not help in maintaining higher DO levels compared with R. This was probably due to the decomposition of organic matter (feed and excreta), resulting in higher oxygen consumption. As the oxygen budget is strongly affected by the balance/dominance of autotrophic and heterotrophic processes (Asaduzzaman, Wahab, Verdegem, Mondal & Azim 2009), the lower DO concentration can be attributed to the decreased autotrophic/increased heterotrophic activity. Plankton density always has a profound effect on water quality, having a direct relationship with fish production (Smith & Piedrahita 1988; Yaro *et al.* 2005). The 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).

One of the most important factors limiting aquatic photosynthesis in rice fields is the shading by the growing rice biomass (Mustow 2002). Besides competition for light, rice also competes with the field water's photosynthetic active biomass for available nutrients, especially N, the most limiting nutrient in the rice fields (Heckman 1979; Kropff, Cassman, Vanlaar & Peng 1993). At the onset of the experiment, the slightly alkaline pH values, together with high DO and chlorophyll *a* values, suggest that an autotrophic pathway dominated within the aquatic phase of the rice fields. However, with the increase in rice biomass, the chlorophyll *a* concentration, $NH_4^+$, pH and DO decreased, which indicates a reduced aquatic photosynthesis and suggests that the autotrophic pathway lost importance. With increasing rice biomass, the surface (catla) and column feeder fish (rohu) gradually switch over from feeding on plankton/algal biomass to supplemental feed and to a diet primarily composed of detritus (Mohanty *et al.* 2008), a process that results in interspecific competition with the bottom feeders (mrigal, common carp, prawn).

## Effects of cull harvesting on the growth and yield performance of fish and prawn

In both R–FC and R–F treatments, bottom feeders (*C. carpio* and *C. mrigala*) showed a better growth rate than that of *L. rohita* (column feeder) probably due to its higher feed-utilizing capability and high degree of tolerance to fluctuations in DO and TSS concentration (Mohanty 2003). Among bottom feeders, the growth performance of *C. carpio* appears to be much better than *C. mrigala* in both R–FC and R–F. The faster growth rates of *C. catla* (surface feeder), *C. carpio* and *C. mrigala* (bottom feeder) can be attributed to effective utilization of ecological niches and the rich detrital food web that was maintained through the periodic manuring, liming and fertilization.

Faster growth was recorded in R–FC than R–F due to periodic harvesting after 120 days of rearing (Table 2). The slower growth and lower SR in R–F were probably due to the fact that, under crowded conditions, fish undergo physiological stress (Montero, Izquierdo, Tort, Robaina & Vergara 1999; Mohanty 2004) due to aggressive feeding interaction and eat less, resulting in a retardation of growth (Zonneveld & Fadholi 1991; Bjoernsson 1994). The significantly higher yield and species-wise faster individual growth performance in R–FC than R–F was due to periodic cull harvesting, which minimized the competition for food and space among the cultured species. Heterogeneous growth is known to be common in crustaceans and occurs in *M. rosenbergii* (Ra'anan & Cohen 1985). In this species, sexually mature male populations consist of distinct morphotypes that differ in size, morphology, physiology and behaviour (Karplus, Malecha & Sagi 2000). The removal of first-growing individuals of *M. rosenbergii* in R–FC improved the prospects of other smaller prawn individuals to achieve their individual growth potential. This step also disrupted the continuation of the socially induced differential growth rates, resulting in a wide variation in size within the population over time.

### Rice yield performance: with and without fish

The recorded grain yield was significantly higher in R–FC than in R and R–F. The less number of panicles (122.2 $m^{-2}$) and number of filled grains (98.5 $panicle^{-1}$) in rice mono-crop (Table 5) was probably due to the absence of fish and prawn in the field, which helps improve soil fertility (Mohanty *et al.* 2004), recover lost energy and adjust energy flow by consuming plankton, weeds, insect and bacteria that compete with rice for nutrient (Mishra & Mohanty 2004). Furthermore, fish helps enhance carbon available to plant by releasing carbon dioxide and breaking the soil surface, oxidizing layers of soil that increases the supply of oxygen to promote root growth and the tillering capability of the rice plants (Mohanty *et al.* 2008). Fish in rice fields help in improving the physico-chemical properties of soil's arable layer. Further, they help in enhancing the growth period of rice, increasing the dry matter and leaf area index of different growth stages (mainly the top three leaves). Because this helps in improving the photosynthesis rate and grain filing and preventing the degeneration of leaves' function (Yang, Zhang, Hu, Dai & Zhang 2006), the growth and yield performance of rice was enhanced in R–FC and R–F.

Between R–FC and R–F, a comparatively higher rice yield was recorded in R–FC (3.25 t $ha^{-1}$) probably due to (1) the higher number of panicles $m^{-2}$ and filled grains per panicle (Table 5) and (2) the lower chlorophyll *a* and plankton density (Table 1), which minimized the competition for nutrients with rice plants, which agrees with the findings of Heckman (1979) and Kropff *et al* (1993). In this experiment, rice yield was not more than 3.25 t $ha^{-1}$ in the presence of fish and 2.6 t $ha^{-1}$ in mono-crop, probably due to the high water levels in this system, which decreased the number of panicles $m^{-2}$ and rice yield. Vromant, Duong and Ollevier (2002) also reported that the increased water levels reduced the rice yield at a rate of 0.06 t $ha^{-1}$ $cm^{-1}$.

### System's REY and economic out put

The significant increase in REY, OV–CC ratio and net return was probably due to periodic cull harvesting and selling of harvested fingerlings. This indicates that cull harvesting in rice–fish culture is more beneficial, which enhances the growth rate of the remaining standing crop, yield and finally the net return.

## Conclusion

In rainfed lowland/waterlogged areas, *in situ* conservation of rainwater and short-duration aquaculture with rice seems to be a viable solution for increasing the income of small and marginal farmers. This eco-friendly dual-production system (rice and fish) helps in generating additional income, employment opportunity and nutritional security. Moreover, under the best possible management practice at the farmer's level, income in this system can be enhanced further if high-density initial stocking, followed by cull harvesting of fish/prawn is practiced. Because this management strategy improves the net return by 28% in the shortest possible time and there is ample scope for adoption and development of this integrated deep-water rice–fish system, its potential for expansion in the country with regard to an agrarian economy in general and agricultural economy in particular is high.

## Acknowledgments

The authors would like to thank Ashwani Kumar, Director, WTCER (ICAR), for his helpful comments during the experiment, and Dr Edna Antony, Senior Scientist, for reviewing the draft of this manuscript. Comments of two anonymous reviewers certainly improved the quality of this manuscript.

## References

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

APHA (1995) *Standard Methods for Examination of Water and Waste Water*, 19th edn. American Public Health Association, Washington, DC, USA, 874pp.

Asaduzzaman M., Wahab M.A., Verdegem M.C.J., Mondal M.N. & Azim M.E. (2009) Effects of stocking density of freshwater prawn *Macrobrachium rosenbergii* and addition of different levels of tilapia *Oreochromis niloticus* on production in C/N controlled periphyton based system. *Aquaculture* **286**, 72–79.

Biswas K.P. (1993) *Fisheries Manual*. Bhagabat Press and Publishers, Cuttack, Orissa, India.

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.

Breukelaar A.W., Lammens E.H.R.R., Breteler J.G.P.K. & Tatrai I. (1994) Effects of benthivorous bream (*Abramis brama*) and carp (*Cyprinus carpio*) on sediment resuspension and concentrations of nutrients and chlorophyll-*a*. *Freshwater Biology* **32**, 113–121.

Cagauan A.G. (1995) Overview of the potential roles of pisciculture on pest and disease control and nutrient management in rice fields. In: *The Management of Integrated Freshwater Agro-Piscicultural Ecosystems in Tropical Areas* (ed. by J.J. Symoens & J.C. Micha), pp. 203–244. RAOS & CTA, Wageningen, the Netherlands.

Cagauan A.G., Branckaert R.D. & Van Hove C. (2000) Integrating fish and Azolla into rice-duck farming in Asia. *Naga, The ICLARM Quarterly* **23**, 4–10.

Chen D., Ying H. & Shui M. (1995) Rice–azolla–fish in rice fields. In: *Rice–Fish Culture in China* (ed. by K.T. MacKay), pp. 169–176. International Development Research Centre (IDRC), Ottawa, ON, Canada.

Coltman D.W. (2008) Evolutionary rebound from selective harvesting. *Trends in Ecology and Evolution* **23**, 117–118.

De S.K. (1962) *Methods of Soil Analysis*. Narayan Publishing House, Allahabad, India.

Fernando C.H. (1993) Rice field ecology and fish culture – an overview. *Hydrobilogia* **259**, 91–113.

Frei M. & Becker K. (2005) A green house experiment on growth and yield effects in integrated rice–fish culture. *Aquaculture* **244**, 119–128.

Frei M., Razzak M.A., Hossain M.M., Oheme M., Dewan S. & Becker K. (2007) Performance of common carp, *Cyprinus carpio* L. and Nile tilapia, *Oreochomis niloticus* L. in integrated rice–fish culture in Bangladesh. *Aquaculture* **262**, 250–259.

Gomez K.A. & Gomez A.A. (1984) *Statistical Procedures for Agricultural Research*. John Wiley and Sons, New York, NY, USA.

Gupta M.V., Sollows J.D., Mazid A., Rahman A., Hussain M.G. & Dey M.M. (1998) *Integrating aquaculture with rice farming in Bangladesh: feasibility and economic viability, its adoption and impact*. ICLARM Technical Reports 55, 90pp.

Haroon A.K.Y. & Pittman K.A. (1997) Rice–fish culture: feeding, growth and yield of two size classes of *Puntius gonionotus* Bleeker and *Oreochromis* spp. in Bangladesh. *Aquaculture* **154**, 261–281.

Heaps T. (1995) Density dependent growth and the culling of farmed fish. *Marine Resource Economics* **10**, 285–298.

Heckman C.W. (1979) *Rice Field Ecology in Northeastern Thailand: The Effect of Wet and Dry Seasons on a Cultivated Aquatic Ecosystem. Monographiae Biologicae*, Vol. 34. Junk Publishers, The Hague, the Netherlands.

ICAR (1997) *Handbook of Agriculture*. Indian Council of Agriculture Research, New Delhi, India, 1303pp.

James B.K., Mishra A., Mohanty R.K., Brahmanand P.S., Nanda P., Das M. & Kannan K. (2005) *Management of excess rainwater in medium and lowlands for sustainable productivity*. Research Bulletin 24, WTCER, Indian Council of Agricultural Research, Orissa, India, 24pp.

Karplus I., Malecha S. & Sagi A. (2000) The biology and management of size variation. In: *Freshwater Prawn Culture: The Farming of Macrobrachium rosenbergii* (ed. by M.B. New & W.C. Valenti), pp. 254–289. Blackwell, Oxford, UK.

Keppeler E.C. & Valenti W.C. (2006) Effects of selective harvest of the Amazon River prawn, *Macrobrachium amazonicum* on pond water, sediment and effluent. *Acta Limnologica Brasiliensis* **18**, 109–119.

Koesoemadinata S. & Costa-Pierce B.A. (1992) Development of rice–fish farming in Indonesia: past, present and future. In: *Rice–Fish Research and Development in Asia. ICLARM Conference Proceedings*, Vol. 24 (ed. by C.R. Dela Cruz, et al.), pp. 45–62. ICLARM, Manila, Philippines.

Kropff M.J., Cassman K.G., Vanlaar H.H. & Peng S. (1993) Nitrogen and yield potential of irrigated rice. *Plant Soil* **156**, 391–394.

Kunda M., Azim M.E., Wahab M.A., Dewan S., Roos N. & Thilsted S.H. (2008) Potential of mixed culture of freshwater prawn (*Macrobrachium rosenbergii*) and self-recruiting small species mola (*Ambypharyngodon mola*) in rotational rice-fish/prawn culture system in Bangladesh. *Aquaculture Research* **39**, 506–517.

Mishra A. & Mohanty R.K. (2004) Productivity enhancement through rice–fish farming using a two-stage rainwater conservation technique. *Agricultural Water Management* **67**, 119–131.

Mohanty R.K. (2003) Feed intake pattern and growth performance of Indian Major Carps and freshwater prawn in a rice-fish integration system. *Journal of Asian Fisheries Science* **16**, 307–316.

Mohanty R.K. (2004) Density-dependant growth performance of Indian major carps in rainwater reservoirs. *Journal of Applied Ichthyology* **20**, 123–127.

Mohanty R.K., Verma H.N. & Brahmanand P.S. (2004) Performance evaluation of rice–fish integration system in rainfed medium land ecosystem. *Aquaculture* **230**, 125–135.

Mohanty R.K., Jena S.K., Kumar A., Sahoo N. & Roy Chowdhury S. (2008) *Rice–fish culture: an ingenious agricultural heritage system*. Research Bulletin 42, Water Technology Centre for Eastern Region, Indian Council of Agricultural Research, Bhubaneswar, India, 54pp.

Montero D., Izquierdo M.S., Tort L., Robaina L. & Vergara J.M. (1999) High stocking density produces crowding stress altering some physiological and biochemical parameters in gilthead seabream, *Sparus aurata*, juveniles. *Fish Physiology and Biochemistry* **20**, 53–60.

Mount D.I. (1973) Chronic exposure of low pH on fathead minnow's survival, growth and reproduction. *Water Research* **7**, 987–993.

Mustow S.E. (2002) The effects of shading on phytoplankton photosynthesis in rice–fish fields in Bangladesh. *Agriculture, Ecosystems and Environment* **90**, 89–96.

 

Nhan D.K., Duong L.T. & Rothuis A. (1998) Rice–fish farming system research in the Vietnamese Mekong Delta: identification of constraints. *Naga* **20**, 107–111.

Oehme M., Frei M., Razzak M.A., Dewan S. & Becker K. (2007) Studies on nitrogen cycling under different nitrogen inputs in integrated rice-fish culture in Bangladesh. *Nutrient Cycling in Agroecosystems* **79**, 181–191.

Ra'anan Z. & Cohen D. (1985) Ontogeny of social structure and population dynamics in the giant freshwater prawn, *Macrobrachium rosenbergii* (De Man). In: *Crustacean Issues 2: Crustacean Growth* (ed. by A. Wenner & F.R. Schram), pp. 277–311. A.A. Balkema, Rotterdam, the Netherlands.

Rohul Amin A.K.M. & Salauddin M. (2008) Effect of inclusion of prawn and mola on water quality and rice production in prawn–fish–rice culture system. *Turkish Journal of Fisheries and Aquatic Sciences* **8**, 15–23.

Sevilleja R.C. (1992) Rice–fish farming development in the Philippines: past, present and future. In: *Rice–Fish Research and Development in Asia* (ed. by C.R. Dela Cruz, et al.), pp. 77–89. ICLARM, Philippines.

Sinhababu D.P. (2008) Scope and status of rice–cum–fish culture in Orissa. In: *Trainer's Training Manual on 'Freshwater Aquaculture for Rural Development'* (ed. by N. Sarangi, J.K. Jena, Kuldeep Kumar, T.K. Behera, G.S. Saha & D. Samantray), pp. 97–103. CIFA (ICAR), Bhubaneswar, India.

Smith D.W. & Piedrahita R.H. (1988) The relation between phytoplankton and dissolved oxygen in fish ponds. *Aquaculture* **68**, 249–265.

Strickland J.D.H. & Parsons T.R. (1972) *A Practical Handbook of Seawater Analysis*. Fisheries Research Board of Canada, Ontario, Canada.

Suloma A. & Ogata Y. (2006) Future of rice–fish culture, desert aquaculture and feed development in Africa: the case study of Egypt as the leading country in Africa. *Japan Agricultural Research Quarterly* **40**, 351–360. Available at http://www.jircas.affrc.go.jp

Troug E. (1930) the determination of readily available phosphorus of soils. *Journal of American Society of Agronomy* **23**, 874–882.

Vromant N., Duong L.T. & Ollevier F. (2002) Effect of fish on the yield and yield components of rice in integrated concurrent rice–fish system. *Journal of Agricultural Science* **138**, 63–71.

Vromant N., Nam C.Q., Chau N.T.H. & Ollevier F. (2004) Survival rate and growth performance of *Cyprinus carpio* L. in intensively cultivated rice fields. *Aquaculture Research* **35**, 171–177.

Wahab M.A., Kunda M., Azim M.E., Dewan S. & Thilsted S.H. (2008) evaluation of freshwater prawn – small fish culture concurrently with rice in Bangladesh. *Aquaculture Research* **39**, 1524–1532.

Walkley A. & Black I.A. (1934) An examination of the Degtjareff method for determination of soil organic matter and a proposed modification of the cromic acid titration method. *Soil Science* **34**, 29–38.

Yang Y., Zhang H., Hu X., Dai Q. & Zhang Y. (2006) Characteristics of growth and yield formation of rice in rice–fish farming system. *Agricultural Sciences in China* **5**, 103–110.

Yaro I., Lamani S.L. & Oladimeji A.A. (2005) Effect of different fertilizer treatments on water quality parameters in rice–cum–fish culture system. *Journal of Applied Ichthyology* **21**, 399–405.

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