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Economic feasibility of intensive aquaculture integrated with irrigation system

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ABSTRACT

The Indian major carps (IMC) *Catla catla*, *Labeo rohita*, and *Cirrhinus mrigala*, were cultured at three different stocking densities *viz.*, 20000 (St.D-2.0), 35000 and 50000 (St.D-5.0) fingerlings ha^{-1} for a period of 300 days with suitable management practices. The wastewater from the ponds was judiciously reused to irrigate crops. A comparative evaluation of economic feasibility (St.D-3.5) was made between (i) the actual study conducted within the irrigation system (WIS) and (ii) a hypothetical case of aquaculture performed alone (OIS). Significantly higher net present value (NPV) and internal rate of return (IRR) and lower value of payback period were estimated in WIS compared to OIS for all three stocking densities ($p<0.05$). Significantly higher values of NPV of ₹ 56,12,161/- and IRR of 82.86% were obtained in WIS compared to the NPV of ₹ 47,81,635/- and the IRR of 69.55% in OIS for the treatment, St.D-5.0. The results strongly established the effectiveness of aquaculture conducted within an irrigation system, from an economic point of view.

Keywords: Indian major carps, Intensive aquaculture, Internal rate of return, Irrigation system, Net present value

Introduction

The mainstay of Indian aquaculture is the composite farming of the Indian major carps *viz.,* catla, *Catla catla* (Hamilton, 1822); rohu, *Labeo rohita* (Hamilton, 1822) and mrigal, *Cirrhinus mrigala* (Hamilton, 1822) and these three species contribute more than 82% of the total inland aquaculture production in India. However, the average annual pond productivity in the country is still very low at 2.9 t ha^{-1} yr^{-1} (GOI, 2012). Though India is the second largest fish producer in the world, it contributes only around 7.76% of the total world aquaculture production whereas, China leads with 61.35% (FAO, 2012). Carp culture in China is characterised by semi-intensive, intensive and hyper-intensive methods (Dey *et al.*, 2005) whereas, extensive and semi-intensive pond carp production are the major culture practices in India (Bag, 2012). The annual growth rate of freshwater aquaculture in India is considerably low compared to the growth rate of many other developing countries like Vietnam, Bangladesh and Thailand. In this context, intensification of aquaculture is expected to meet the growing demand of aquaculture products in the context of increase in population of the country (Bag, 2012).

In an intensive aquaculture system, the fish yield is mostly determined by the quality of pond water and to maintain proper water quality, suitable management practices *viz.*, quality feeding, liming, aeration and water exchange should be emphasised. In an intensive pond production system, the concentration of major inorganic compounds is maintained within their critical limits by adequate water exchange. Many researchers have reported on the negative impacts of aquaculture pond effluents on the adjacent environment (Naylor *et al.*, 1998, 2000; Dominguez *et al.*, 2001; Read and Fernandes, 2003; Yokoyama, 2003; Banas *et al.*, 2007). On the other hand, scarcity of freshwater is a limiting factor in facilitating proper water exchange (Avnimelech, 2009). Hence it is necessary to manage water resources efficiently by adopting holistic approaches to ensure food security and environmental sustainability (Falkenmark, 2007).

Agriculture and aquaculture, the two major food sectors in India, must be addressed effectively for the food security of the ever increasing population of the country. The integration of aquaculture and irrigation (IAI) may be a useful tool for both the sectors with judicious management of freshwater. Different aspects of IAI system were studied by many researchers and the effectiveness of this system has been reported earlier (Hussain and Al-Jaloud, 1995; McIntosh and Fitzsimmons, 2003; Edwards, 2004; Castro *et al*., 2006; Ray *et al.*, 2006). Though, voluminous literature is available in connection with fish production in irrigated area, the most important aspect of economic feasibility of aquaculture conducted in this system has generally been ignored.

In the present study, the economic feasibility of aquaculture with the Indian major carps *viz.*, catla, rohu and mrigal at three different stocking densities of 20000, 35000 and 50000 fingerlings ha^{-1} in an irrigated area was evaluated. In this system, freshwater was used twice judiciously *i.e.,* first for aquaculture and then for agriculture. The economic analysis was also carried out for the intensive culture of these three species with similar stocking densities and management practices. A comparative evaluation of economic feasibility of the intensive farming of three Indian major carp species was made between: (i) the actual study conducted within the irrigation system and (ii) a hypothetical case of aquaculture performed alone.

Materials and methods

Study area

The study was carried out from 20 June, 2008 to 16 April, 2009 at the aquaculture farm of the Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India. The farm is located at an altitude of 48 m above mean sea level (22°19' N’, 87°19' E).

Pond preparation

The study was conducted within an irrigation system. A deep tubewell was constructed at one corner of the farm mainly for irrigating the agricultural crops. Whenever there was a need for water exchange, the required volume of pond water was discharged to the agricultural crop fields and the ponds were filled with the ground water lifted from the tubewell. The layout of the experimental farm used in the study is shown in Fig. 1.

Nine numbers of polythene lined ponds were constructed at the experimental farm to avoid high seepage loss at the experimental site. The pond bed was lined with a layer of loamy soil of 30 cm thickness to simulate the natural pond environment. The average water area, depth and water volume of the ponds were 0.015 ha, 1.2 m and 100 m^3 respectively. The area adjacent to the ponds was used for growing agricultural crops. The pond effluent was used to irrigate the crops. The bottom soil of all the ponds was treated with agricultural lime at the rate of 200 kg ha^{-1} and sun dried for about one week. Then the ponds were filled with water to the required depth. Subsequently ponds were fertilized with cowdung, single super phosphate and urea at the rate of 3000 kg ha^{-1}, 40 kg ha^{-1} and 40 kg ha^{-1} respectively as basal dose to develop a good and healthy natural aquatic environment before stocking the fish fingerlings.

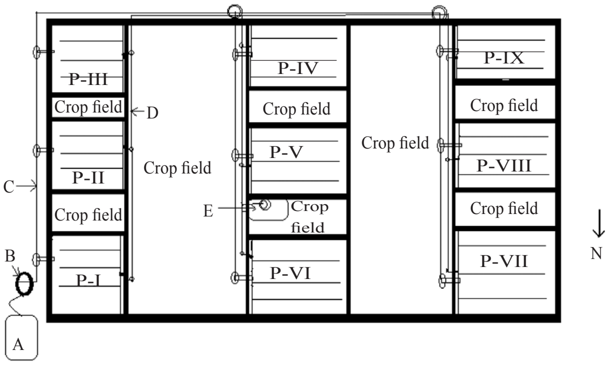

Fig. 1. Layout of experimental ponds and crop fields

Stocking of fish

The fingerlings of the Indian major carps were stocked in the experimental ponds at three different stocking densities *viz.*, St.D-2.0 with 20000 fingerlings ha^{-1}, St.D-3.5 with 35000 fingerlings ha^{-1} and St.D-5.0 with 50000 fingerlings ha^{-1} with catla forming 40%, rohu 30% and mrigal 30%, in triplicates. The mean initial weights of species stocked were 16.78 ± 1.84 g, 16.82 ± 1.69 g and 16.65 ± 1.83 g for catla, rohu and mrigal respectively.

Liming and feeding

The pH of water was maintained within ideal range (6.5 - 9.0) through intermittent application of agricultural lime. The fishes were fed with pelleted feed containing 35% crude protein. Proximate composition of ingredients and prepared diets are shown in Table 1.

The pelleted feed was provided at the rate of 5% of fish biomass up to 30 days, 3% up to 60 days, 2% up to 165 days, 1% up to 255 days (winter months) and 1.5% up to the rest of the experimental period. Fishes were sampled fortnightly and weighed to calculate the expected fish biomass and accordingly the daily ration was adjusted for the following two weeks.

Water exchange and aeration

Water exchange was carried out to maintain the inorganic nutrients within their permissible limits. The exchanged waste water from the ponds was used to irrigate the crops. As the aquaculture operation was conducted

Table 1. Proximate composition of feed ingredients and prepared feed

Ingredients/feed	Crude protein (%)	Crude fat (%)	Ash (%)	Moisture (%)	% in diet
Fish meal	56	8.5	17	8	21.40
GOC	40	6	9	8	42.9
MOC	25	7	11	10	12.35
Rice bran	13	14	6	8	12.35
Wheat flour	11	4	8	8	10.00
Vit & min mix	-	-	-	-	1.00
Formulated feed	34.94	7.39	11.40	8.16	-

GOC : ground nut oil cake: MOC; mustard oil cake: Vit & min mix: Vitamin and mineral mixture; Energy content of formulated feed: 15.76 kJ g^{-1}.

within irrigation system, no additional expenditure was incurred for water exchange. One deep tubewell was constructed at one corner of the farm and all the nine ponds were connected through a network of underground pipe lines. Suitable valve arrangements were made to regulate the flow to individual pond. To maintain the desirable level of dissolved oxygen (DO) concentration of the pond water (above 4 mg l^{-1}), a network of compressed air lines was also laid at the site. A 5.0 HP compressor (Air-O-matic air compressor, Model-MS-500, RPM-750, Sl.No-1756) and a 3.0 HP compressor (Air compressor, Model-D003, RPM-400 and Sl.No-004/86) with suitable regulators in the air lines were used for air supply. Three perforated 12 mm diameter air hose pipes were distributed evenly at the bottom of the water spread area for release of compressed air. Flexible hose pipes were used to connect the perforated pipes with the main air supply line.

Water quality monitoring

Water samples collected between 08.00 and 09.00 hrs at an interval of 3 days were analysed to estimate water temperature, pH, dissolved oxygen (DO), total ammonia nitrogen (TAN), nitrite-nitrogen, nitrate-nitrogen and orthophosphate. For estimation of temperature and DO, a portable DO meter (Oxi 330i) was used. The pH was measured using a pH meter (Systronics, 802). TAN, nitrite-nitrogen, nitrate-nitrogen and orthophosphate were estimated using spectrophotometric (Spectrophotometer; DR/2500, HACH, USA) method following APHA (1998).

Fish growth parameters

On termination of the experiment, the fishes were harvested by repeated netting and subsequently by complete draining of the pond water and counted species-wise. Species-wise final mean weight, survival rate, production and feed conversion ratio (FCR) were estimated.

Economic analysis

Different economic parameters *viz.*, initial outlay, recurring expenditure, income, profit, payback period, net present value (NPV), profitability index (PI) and internal rate of return (IRR) were calculated for one hectare farm both for actual as well as hypothetical study based on the costs involved in 0.015 ha experimental farm used in the study. Considering the durability of the polythene lining and other machineries, the life time of the project (n) was assumed as 10 years. Depending on the recurring expenditure and income from the present study, cash flows (CF) for 10 years were decided considering a discount (k) rate of 10%. The profit, payback period, NPV, PI and IRR were calculated using the following formulae:

Profit = Income - operating cost

Payback period = Initial outlay/cash flow

$$\text{NPV} = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t} - IO$$

where, CF = cash flow over the life of the project; IO = initial outlay; k = discount rate or cost of capital and n = life time of the project

$$\text{PI} = \frac{\sum_{t=0}^{n} \frac{CF_t}{(1+k)^t}}{\text{IO}}$$

IRR was calculated by determining the value of discount rate at which NPV becomes zero.

Statistical analysis

The various economic parameter data obtained from the three different treatments of the two systems *viz.*, (i) aquaculture practiced within the irrigation system (WIS) and (ii) aquaculture practiced alone (OIS) were analysed by one-way ANOVA. Post-hoc comparisons were made using Duncan's new multiple range test (Duncan, 1955) to detail the significant differences between the WIS and OIS ($p < 0.05$). All the statistical analyses were carried out using SPSS version 17.

Results and discussion

Water quality

The mean values of different water quality parameters are presented in Table 2.

Table 2. Different water quality parameters (Mean±SD) recorded in different treatments

Parameter	Treatments		
	St.D-2.0	St.D-3.5	St.D-5.0
Temp (°C)	27.38 ± 0.06	27.37 ± 0.13	27.37 ± 0.19
pH	7.26 ± 0.03	7.20 ± 0.03	7.16 ± 0.02
DO (mg l^{-1})	7.02 ± 0.22	5.84 ± 0.12	5.32 ± 0.08
TAN (mg l^{-1})	0.65 ± 0.01	0.76 ± 0.04	0.85 ± 0.02
NO_3-N (mg l^{-1})	0.32 ± 0.01	0.42 ± 0.03	0.47 ± 0.01
NO_2-N (mg l^{-1})	0.05 ± 0.00	0.06 ± 0.01	0.07 ± 0.01
PO_4-P (mg l^{-1})	0.11 ± 0.00	0.14 ± 0.01	0.16 ± 0.00

Temp. - temperature; DO - dissolved oxygen; TAN - total ammonia nitrogen. Data are means (± SD) of three replicates.

Temperature mostly ranged between 24° to 32°C during the culture period, except from December to first fortnight of February which is optimum for good growth of carps. Water pH was maintained within its ideal range of 6 to 9 in all the three treatments by applying agricultural limestone as per requirement. To ensure a minimum dissolved oxygen level of 4.0 mg l^{-1}, supplementary aeration was provided mainly during night hours for 721, 1300 and 1492 h in St.D-2.0, St.D-3.5 and St.D-5.0 respectively.

Total ammonia nitrogen (TAN) is considered to be a major factor limiting fish biomass and stocking density in intensive culture systems (Thurston *et al*., 1983; Cai and Summerfelt, 1992; Forsberg and Summerfelt, 1992; Leung *et al.*, 1999). According to Crab *et al.* (2007), TAN is toxic to commercially cultured fish at concentrations above 1.5 mg l^{-1}. In the present study, the TAN concentration was always maintained below 1.5 mg l^{-1} by water exchange. The total volume of exchanged water varied significantly among the three different treatments and the highest value was recorded in St.D-5.0 (718%) followed by St.D-3.5 (434%) and St.D-2.0 (183%). The values of nitrite-nitrogen, nitrate nitrogen and orthophosphate in different treatments were found to be within safe levels for carps (Meade, 1985; Banerjee and Lal, 1990; Jena and Das, 2006; Lyssenko and Wheaton, 2006).

Fish growth

The mean values of few selected fish growth parameters are presented in Table 3. High survival rates of all the species ranging from 91.52 to 94.73% were recorded in all the treatments. The highest total fish production of about 15 t ha^{-1} 10 $months^{-1}$ was recorded in St.D-5.0 followed by St.D-3.5 (10.9 t ha^{-1} 10 $months^{-1}$) and St.D-2.0 (6.8 t ha^{-1} 10 $months^{-1}$). According to De Silva and Anderson (1995), the feed cost is the greatest operating expense in aquaculture enterprises. So efforts were made for full utilisation of feed to maximise the growth and feed conversion. Value of feed conversion ratio of less than 2.00 or very close to 2.00 is considered to be good in aquaculture. FCR values recorded in different treatments ranging from 2.19 to 2.28 were very close to the desirable range.

Economic analysis

The details of initial outlay and the input costs are presented in Tables 4 and 5 respectively. The fixed

Table 3. Fish growth parameters recorded in different treatments (Mean±SD)

Parameters	Species	Treatments		
		St.D-2.0	St.D-3.5	St.D-5.0
Final mean weight (g)	Catla	379.20 ± 5.85	332.15 ± 4.06	318.88 ± 3.76
	Rohu	349.37 ± 7.37	338.00 ± 5.52	326.00 ± 4.02
	Mrigal	343.07 ± 2.85	327.33 ± 4.03	316.32 ± 4.67
	Average	357.21 ± 5.35	332.50 ± 4.10	320.40 ± 4.12
Survival rate (%)	Catla	94.29 ± 0.78	92.56 ± 0.28	91.52 ± 1.19
	Rohu	94.73 ± 1.11	93.59 ± 0.45	92.81 ± 0.42
	Mrigal	94.15 ± 1.60	94.41 ± 0.48	93.55 ± 0.40
	Average	94.39 ± 1.07	93.52 ± 0.29	92.63 ± 0.23
Gross production (kg ha^{-1} $crop^{-1}$)	Catla	2860.36 ± 48.69	4304.35 ± 48.03	5836.38 ± 7.78
	Rohu	1985.68 ± 37.24	3321.38 ± 41.34	4538.72 ± 65.66
	Mrigal	1938.2 ± 43.97	3244.61 ± 23.47	4438.79 ± 84.54
	Total	6784.24 ± 128.33	10870.34 ± 102.22	14813.89 ± 142.87
FCR	Catla	2.19 ± 0.03	2.21 ± 0.01	2.28 ± 0.05
	Rohu	-	-	-
	Mrigal	-	-	-
	Average	-	-	-

FCR - Feed conversion ratio. The values of total fish production bearing different superscripts (a, b, c) in three stocking densities differ significantly ($p < 0.05$). Data are means (± SD) of three replicates cost of construction of tubewell and the operating cost of electricity consumption for pumping of the ground water were included in the irrigation cost. If the study is not conducted along with the irrigation system, the cost of the above two items need to be included in the fish production cost. As a result, a sum of ₹9,90,700/- was estimated to be the capital expenditure for aquaculture within an irrigation system (WIS), whereas a sum of ₹10,65,700/- was the initial outlay for practicing aquaculture alone (OIS). An additional operating expenditure of ₹21,000/-, ₹50,000/- and ₹83,000/- is to be invested for the purpose of water exchange in St.D-2.0, 3.5 and 5.0 respectively which will lead to significant increase of input cost and decrease of profit in OIS compared to WIS for all the three treatments ($p<0.05$). Different economic parameters estimated in the experiment are presented in Table 6. The highest values of profit, net present value (NPV), profitability index (PI) and internal rate of return (IRR) and the lowest value of payback period were recorded in St.D-5.0 followed by St.D-3.5 and St.D-2.0. Significantly higher values of NPV, PI and IRR and lower value of payback period were estimated in WIS compared to OIS ($p<0.05$).

Significantly higher values of the NPV of ₹56,12,161/- and the IRR of 82.86% were obtained in WIS compared to the NPV of ₹47,81,635/- and the IRR of 69.55% in OIS for the treatment St.D-5.0. The results of the study strongly indicate the economic effectiveness of aquaculture practiced within an IAI system.

In the experiment, a huge volume of pond effluent of about 1.80 ha-m in St.D-2.0, 4.30 ha-m in St.D-3.5 and 7.20 ha-m in St.D-5.0 was estimated to be discharged for maintaining TAN within its safe level. As the pond

Table 4. Initial outlay for construction of one hectare farm for three treatments

Particulars	Amount	Rate (₹)	Total in WIS (₹)	Total in OIS (₹)
Soil excavation	14300 m^3	27 m^{-3}	386100	386100
Polythene sheet	10400 m^2	34 m^{-2}	353600	353600
Brick	3200 nos.	5 no^{-1}	16000	16000
Sand	1000 m^3	70 m^{-3}	70000	70000
Labour for different works	500 mandays	80 $man\text{-}day^{-1}$	40000	40000
Aerators with accessories	4 nos. (1.12 kW)	25000 no^{-1}	100000	100000
Miscellaneous expenditure (water pipe line/water channel, net, handi and hapa	L.S.		25000	25000
Tubewell with accessories	L.S.		-	75000
Total			990700	1065700

WIS - within irrigation system; OIS - outside irrigation system; L.S. - lump sum; ₹ 44.5 = 1 $ (Approximate)

Table 5. Input costs in three different treatments

	Treatments					
Particulars	St.D-2.0		St.D-3.5		St.D-5.0	
	WIS	OIS	WIS	OIS	WIS	OIS
Lime	2250	2250	3150	3150	3600	3600
Cowdung	1500	1500	1500	1500	1500	1500
Urea	180	180	180	180	180	180
SSP	160	160	160	160	160	160
Fingerlings	20000	20000	35000	35000	50000	50000
Fish feed	179878	179878	288853	288853	407733	407733
Aeration cost	36050	36050	65000	65000	74600	74600
Water exchange	-	21181	-	50270	-	83102
Netting	8000	8000	8000	8000	8000	8000
Prophylactics	4000	4000	6000	6000	8000	8000
Labour for monitoring, feeding, water exchange and aeration	30000	30000	30000	30000	30000	30000
Maintenance	14797	14797	19329	19329	24191	24191
Total input costs (₹ ha^{-1} $crop^{-1}$)	296815 $\pm 3087^{a}$	317996 $\pm 1674^{b}$	457172 $\pm 3622^{a}$	507442 $\pm 9769^{b}$	607964 $\pm 12708^{a}$	691066 $\pm 6538^{b}$

WIS - within irrigation system; OIS - outside irrigation system; SSP - single super phosphate; ₹ 44.50 = 1.00 $ (Approximate). The values of total input costs bearing different superscripts in column (a, b) under two systems for three St.Ds differ significantly ($p <0.05$). Data are means (± SD) of three replicates.

Table 6. Fish production and different economic parameters recorded in three different stocking densities in one hectare aquaculture farm within and outside irrigation system

Parameters	System	Treatments		
		St.D-2.0	St.D-3.5	St.D-5.0
Income (₹)	WIS	610581 ± 11550^{x}	978331 ± 9200^{x}	1334224 ± 11291^{x}
	OIS	610581 ± 11550^{x}	978331 ± 9200^{x}	1334224 ± 11291^{x}
Profit (₹)	WIS	313766 ± 9346^{x}	521159 ± 5596^{x}	726260 ± 8833^{x}
	OIS	292585 ± 9979^{y}	470889 ± 11644^{y}	643158 ± 5220^{y}
Payback (Year)	WIS	3.16 ± 0.09^{x}	1.90 ± 0.02^{x}	1.36 ± 0.01^{x}
	OIS	3.64 ± 0.12^{y}	2.27 ± 0.06^{y}	1.66 ± 0.01^{y}
Net present value (₹)	WIS	1861933 ± 84967^{x}	3747463 ± 50876^{x}	5612161 ± 80304^{x}
	OIS	1594367 ± 90728^{y}	3215428 ± 105868^{y}	4781635 ± 47457^{y}
Profitability index	WIS	2.88 ± 0.08^{x}	4.78 ± 0.05^{x}	6.66 ± 0.08^{x}
	OIS	2.49 ± 0.08^{y}	4.02 ± 0.10^{y}	5.49 ± 0.05^{y}
Internal rate of return (%)	WIS	38.51 ± 1.10^{x}	61.47 ± 0.59^{x}	82.86 ± 0.90^{x}
	OIS	33.49 ± 1.14^{y}	52.50 ± 1.18^{y}	69.55 ± 0.51^{y}

WIS - within irrigation system; OIS - outside irrigation system; ₹ 44.50 = 1.00 $ (Approximate). The values bearing different superscripts in columns (x, y) differ significantly ($p < 0.05$). Data are means (± SD) of three replicates

effluent was reused as an irrigation source, a huge volume of valuable freshwater was judiciously managed which also helped to reduce environmental pollution. Moreover, the pond effluents supplied approximately 20, 51 and 96 kg inorganic nitrogen in the form of ammonia, nitrite and nitrate and 2, 6 and 10 kg phosphorus in the form of orthophosphate from one hectare pond area for the field crops (Table 6).

The usefulness of IAI system has been evaluated by many researchers (Hussain and Al-Jaloud, 1995; Gooley *et al.*, 2000; Ingram *et al.*, 2000; McIntosh and Fitzsimmons, 2003; Edwards, 2004; Castro *et al.*, 2006; Ray *et al.*, 2006; Nhan *et al.*, 2008). In this system, the water is used initially for aquaculture and then for irrigation. The water from the aquaculture ponds with high concentration of different inorganic nutrients can safely be used as an important enriched irrigation source for different agricultural crops. Hence, from environmental as well as economical point of view, the IAI system proves to be highly beneficial. The economic benefit realised from the present study has been found to be significant and this may encourage wide acceptance of IAI system. The system has been adopted by many countries particularly those with less availability of freshwater resources. Many perspectives of the IAI system have been well identified and results of the present investigation has supported its economic profitability.

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