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INTEGRATED AQUACULTURE WITHIN IRRIGATION OPTIONS- AN ECONOMIC ANALYSIS IN INDIAN CONTEXT

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ABSTRACT
Increased pressure on fresh water supply leads to a compromise between agriculture and fresh water aquaculture. An aquaculture option within the irrigation system is one of the attempts for efficient utilization of limited fresh water resource. Nine experimental ponds of average waterspread area of 145 m^2 each were stocked with Indian Major Carps (IMC) with stocking densities of 2, 3.5 and 5 numbers per square meter with three replications. The pond water quality was measured at regular intervals to determine the levels of NO_3, NO_2, NH_3 and PO_4 pollution and water exchange requirements. The 'so-called' polluted water for fish was used for irrigating vegetable crops grown in experimental plots of 30 m^2 size each. To study the response of crop growth using the fish pond waste water enriched in nutrients, Okra (*Abelmoschus esculentus* L.) cultivar Myhco F-10 and Tomato (*Lycopesicum esculentum* L.) cultivar MHTM-256 were grown during kharif and rabi seasons respectively. The yield of fish ranged from 3.65 to 6.48 t/ha for different stocking densities. The average yield of tomato obtained from the three treatments and control plots varied between 63.8 to 66.7 t/ha, whereas the average yield of okra varied form 8.76 to 11.38 t/ha. Water exchange interval varied between 20 to 45 days for different stocking densities. The comparison of different treatments under the integrated fish-vegetable cropping system showed significant increase in production due to higher stocking density of fish thereby increasing the profit margin. Therefore, the farmers with a source of water supply, fish ponds and crop lands can have a higher net benefit by adopting this system.

KEYWORDS: Integrated farming system, Irrigation efficiencies, Benefit-cost ratio

INTRODUCTION

Although the agricultural output of a country may potentially increase to meet the food demand for immediate future, the ultimate constraint in long term will be the availability of water and its optimal use. With an average annual precipitation of approximately 1200 mm, storage dams are continuously being constructed in the country to retain some of the surface runoff water to meet the increasing demand for domestic, industrial and agricultural use. However, recent estimates suggest that scope for further increase of the irrigated area in Asia may be exhausted in the next 20-30 years (Yudelman, 1994). Combined effects of population pressure, competition with urban and industrial users, and increased frequency of drought are making water a dwindling resource for irrigation. Integration of aquaculture with traditional agricultural practices in which the water can first be used to grow fish and then the same water is used to irrigate crops can be a much better option. Integrated agri–aquaculture systems (IAAS) involving various crops, livestock and aquaculture subsystems may help to provide income whilst rehabilitating the soil through better on-farm nutrient recycling (O'Donnell et al., 1994). Integrated agri–aquaculture systems in China and Vietnam are highly diversified, intensive and strongly integrated (Edwards, 1993; Luu, 2001; Luu et al., 2002). Integration of aquaculture and agriculture through the use of pond sediment organic matter as a crop fertilizer, and of pond water for irrigation, establishes linkages between aquaculture ponds and crops. The main objective of the integrated system is to enhance nutrient cycling and energy flow in the system to obtain maximum benefits in the production of food and fiber (Chan, 1993). The farm ponds mainly serve two purposes; it can be used to have fish culture as well as to supply irrigation for fruit and vegetables thus bringing a 'turning point' in the farm households. The farmers can move from traditional, mixed crop-livestock farming system to a more productive one. Increased adoption of new activities such as aquaculture into existing agro ecosystems calls for the application of simulation models to analyze and forecast consequences of new agro ecosystem designs (Elliot and Cole, 1989; Edwards et al., 1993). Integrated agri–horticulture systems (IAHS) involving cash crops and intensive aquaculture systems provided maximum yield in terms of crop and fish yield from unit area by multiple use of water for irrigation (Panigrahi et. al., 2007. Ray et. al., 2006).

Therefore, the present study was taken up with a view to evaluate the techno-economic feasibility of intensification of fish culture through water exchange and using the exchanged water for irrigation of vegetable crops.

Study Area

Field experiment was conducted at the aquaculture farm of Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, India. The farm is located on a gently sloping drainage basin situated at an altitude of 48 m above mean sea level and is intersected by 22^o19` N latitude and $87^o19$` E longitude. The climatic condition of the experimental site is humid subtropical with an average annual rainfall of 1500 mm and a large percent is concentrated during the months of June to October. Soil at the experimental site is lateritic with sandy loam texture, which is taxonomically grouped under the order ALFISOL (Oxyaquic haplustalf). Irrigation is essential for growing crop in the post-monsoon season.

MATERIALS AND METHODS

Layout of experimental site

Nine dugout ponds were constructed with about 1.5 m depth in the experimental farm and were lined with 250-micron polyethylene sheets to check seepage. Below the lining material, 30 cm thickness of sand cushioning was provided to avoid rupture. Over the lining, loamy soils were provided to a depth of 30-45 cm to provide suitable environment for the growth of zooplankton and phytoplankton to be used by the fish as feed. Lined ponds were filled with tubewell water to culture three different species of Indian major carps. Adjacent to the ponds, a total of 36 experimental plots of 5 m × 6 m size each were laid out.

Culture of fish

The experimental ponds were stocked with 20,000 fingerlings of IMC in the first group (STD-2), 35,000 per hectare in the second group (STD-3.5) and 50,000 per hectare in the third group (STD-5). Fingerlings of Indian Major Carp, *Catla catla* (Hamilton), *Labeo rohita* (Hamilton) and *Cirrhinus mrigala* (Hamilton) were used for the experiment with a stocking ratio of 4:3:3 (Catla: Rohu: Mrigal). Fish sampling was carried out at every fifteen days interval to evaluate the growth status of the fish at different level of stocking densities. Complete artificial pelleted fish feed having 35% crude protein was supplied in three different water depths. Total ammonia-nitrogen, nitrite-nitrogen, nitrate-nitrogen, orthophosphate, total organic carbon and total suspended solid were measured following the standard methods given by APHA (1998) to record the status of the water quality. Different cost components for culture of fish is presented in Table-1. It is seen from Table-1 that the cost of culture of fish are Rs.1,04,761.6, Rs.1,46,740.4 and Rs. 2,05,066.0 per ha for stocking densities of 20000, 35000 and 50000 per ha respectively.

Crop

To evaluate the effect of intensively stocked aquacultural pond water and fertilizer dose on yield attributes of crops, Okra (*Abelmoschus esculentus* L.) cultivar Myhco F-10 during kharif and Tomato (*Lycopesicum esculentum* L.) MHTM-256, suparna during rabi were grown at a planting geometry of 60 cm × 75 cm in 36 plots of 30 m^2 size each prepared adjacent to the ponds. Soil moisture was monitored at an interval of 2 days after irrigation/rainfall at 15, 30, 45 and 60 cm depths from the ground surface using gravimetric method. Irrigation scheduling was done by soil moisture depletion method. All the plots received 100 kg P_2O_5 ha^{-1} as single super phosphate and 100 kg K_2O ha^{-1} as muriate of potash and 10 ton ha^{-1} farm yard manure as basal application. Four different doses of nitrogen fertilizer was applied for four different treatments, viz. 100% (150 kg N ha^{-1}) as treatment-1, 85% as treatment-2, 70% as treatment-3 and 55% as treatment-4. Nitrogen was applied in two equal splits, one as basal dose and another 21 days after planting of the crop.

RESULTS AND DISCUSSION

Temporal Variation in Water Quality

The pH of water was maintained between 7.0 and 8.5 and dissolved oxygen in pond water was maintained between 5 to 6 ppm for optimum growth of fish. Details of other water quality parameters are discussed below.

Temporal variation in total ammonia-N (TAN)

The temporal variation of ammonia-N in different ponds is presented in Fig-1. TAN value varied in the range of 0.1 ppm to 1.0 ppm. It can be seen from the figure that the fluctuation of ammonia-N is higher in ST.D-5 followed by ST.D-3.5 and ST.D-2. During the rainy season upto September, the increase in TAN was very low due low growth of fish and dilution of NH_4-N with rain water. The optimum level of ammonia was maintained through water exchange by addition of fresh water from a tubewell. Whenever water exchange in the range of 10 to 25% was carried out, the TAN values dropped much below the critical level.

Temporal variation in Nitrate-N

Nitrate-N value varied in the range of 0.1 to 0.7 ppm. The fluctuation of nitrate-N was higher in STD-5 followed by STD-3.5 and STD-2. In most of the cases, the highest value was within the permissible limit of 0.5 mg/l. Only in two cases, in STD-5 the nitrate-nitrogen level reached above the critical imit. However, NO_3-N was not the critical parameter as it was automatically controlled when water exchange was done to control the NH_4-N.

Temporal variation in Nitrite-N

The value varied in the range of 0.02 - 0.08 ppm. The fluctuation of nitrite-N was also higher in ST.D-5 followed by STD-3.5 and STD-2. Although the nitrite-N is the most critical parameter for fish mortality, the maximum level of nitrite-N was always below the critical limit of 0.25 mg/l which did not warrant any water exchange. However, water exchange was required to maintain the optimum level of TAN and nitrate-N.

Temporal variation in orthophosphate

The fluctuation of orthophosphate was higher in ST.D-5 followed by ST.D-3.5 and ST.D-2. Initially, the orthophosphate level in pond water was higher and it gradually decreased with water exchange and phytoplankton growth. Also the pond bottom mud acted as the sink for orthophosphate to reduce its concentration in water. Therefore, no water exchange was required to reduce the level of orthophosphate.

Water Exchange

Water exchange is essential when the concentrations of nutrients in water exceed their permissible limit beyond which water is considered as the polluted water that adversely affects the fish growth. The Aquaculture Authority of India (1998) prescribed the permissible limit of different water quality parameters. From practical operation point of view, some specific concentrations values were fixed for upper limit of different nutrient parameters for water exchange. No water exchange was required upto September as the total biomass was low and the water was diluted due to rainfall. From October onwards water exchange at the rate of about 15% of the volume of water was carried out at intervals of 45, 30 and 20 days in STD-2, 3.5 and 5 respectively. In a period of about 6 months they are equal to 4, 6 and 9 times in the respective ponds.

Fish Yield

Variations in fish growth at different periods due to various stocking densities were observed (fig-2). The average individual fish growth was the highest in ST.D-2 (182.8 g) followed by ST.D-3.5 (135.9 g) and ST.D-5 (129.7 g). Corresponding average production values were 3.656 ton/ha, 4.756 t/ha and 6.486 t/ha in STD-2, STD-3.5 and STD-5 respectively (Table-2). Although the growth of individual fish is less in higher stocking densities, but the total biomass production is much higher due to more number of fishes. Value of feed conversion ratio (FCR) ranged from 2.09 to 2.11. This high value may be due to the use of pelleted feed prepared in the laboratory. Slight fish mortality in STD-5 was recorded which may be due to higher level of Total Available Nitrogen (TAN) value as a result of high stocking density.

The yields are only relative yields as the pond sizes are small as compared to any commercial ponds where the sizes may range from 0.2 to 1.0 ha. Moreover, the experimental ponds are lined as otherwise water can not be retained in this locality due to highly porous soil. Therefore, availability of natural feed such as phytoplankton, algae etc are very limited which also might have reduced the fish growth.

The fish was sold @ Rs.50 per kg and thereby the gross returns for different treatments are: Rs.1, 82,800, Rs.2, 37,800 and Rs.3, 24,300 for STD-2, STD-3.5 and STD-5 respectively. Therefore, net returns from fish culture from the respective treatments are: Rs.78, 038.4, Rs.91, 059.6 and Rs.1, 19,234.00. Corresponding BCR values are 1.7449, 1.6205, 1.5814 and net BCR values are 0.7449, 0.6205 and 0.5814 respectively. It is seen from Table-2 that for higher stocking densities, the benefit cost ratio reduces but the net return is much higher. Therefore, a farmer with availability of more capital should go for higher stocking density of about 50,000 per ha for higher net return.

Crop Yield

Crops were grown both in the kharif and in the rabi season. Okra was grown in the kharif season with different doses of nitrogen. But no irrigation to the crop or water exchange from the ponds was required as there was sufficient rainfall to meet the moisture need of the crop and the pond water was sufficiently diluted. As a result the control plot with 100% N gave the highest yield of 11.38 t/ha followed by other treatments with yields of 10.66, 9.34, and 8.76 t/ha. However, the kharif season crop is not included in the economic analysis as it became independent of the fish culture. Only the benefit accrued from the rabi season crop, tomato is included.

Yield of tomato crop

The treatment plots received irrigation mainly from nine ponds with three different fish stocking densities, whereas, the control plots received irrigation directly from the tubewell only. Also 100% N (150 kg/ha) was applied to the control plots, whereas, only partial dose was applied to the treatment plots. Details cost of cultivation of tomato is presented in Table-3. The tomato yields obtained from different treatments are shown in Fig-3 and Table-4. There is no significant difference in yields (63.8 to 66.7 t/ha) obtained either from the three treatment plots or the control plots. However, the yield obtained from the control plot is the highest (66.7 t/ha) which may be due to availability of full dose of nitrogen.

The yields of tomato were 63.8, 64.8, 64.7 and 66.7 t/ha from treatments T_1, T_2, T_3 and control plots respectively. In case of tomato, there will be handling losses to the tune of 15%. About 85% can be marketed. Therefore, respective marketable quantities will be 54.23, 55.08, 54.995 and 56.695 tons. During the peak production season, the tomato is sold in the farmers' fields @Rs.3.00 per kg. Therefore, gross returns from the respective plots will be Rs.1, 62,690, Rs.1, 65,240, Rs.1, 64,985 and Rs.1, 70,085. The corresponding net benefits will be Rs.97, 340.4, Rs.1, 00,159.35, Rs.1, 00,173.33 and Rs. 1, 04,466.45 with BCR values of 2.4895, 2.5390, 2.5456 and 2.5920 respectively. The respective net BCR values are 1.4895, 1.5390, 1.5456 and 1.5920. In this case, either the net benefits or the benefit cost ratios are statistically non-significant.

Economic Analysis

An Economic analysis was also made for the integrated fish crop farming system. The cost analysis for individual pond and corresponding treatment plots were carried out considering separate production costs incurred for each crop treatment and fish culture. The details of the cost analysis are presented in Table-5. It can be seen from Table-5 that the costs of production of crop varied only marginally due to application of different doses of nitrogen. There was not much variation in the total cost of production as all other inputs remained same. The production of tomato was also almost same from all the treatments. It shows that the pond effluent did not affect the yield much. The control plot with 100% nitrogen produced a slightly better yield of tomato.

As the stocking density of fish was increased, the production cost also increased due to higher cost of fingerlings, feed, aeration, water exchange and labour. However, net return was also higher for higher stocking density due to production more fish biomass. The net benefit of the integrated agri-aquaculture system increased with the increase in stocking density mainly due to increase in income from fish culture as the crop yielded almost same return irrespective of whether it was irrigated by water from ponds with different stocking densities or directly from the tubewell (control plot).

The BCR and the net BCR values reduced with the increase in stocking density. But the net benefit increased with the increase in stocking density. Control plot crop was irrigated directly by the tubewell water and was provided with 100% nitrogenous fertilizer. It was presumed that the other plots will receive substantial amount of N from the effluent water and were supplied with 55% to 85% nitrogenous fertilizer. In reality it did not happen. Only 5 to 10% of N was available from the effluent water. As a result, the treatment plots suffered some loss of yield as compared to the control plot. Therefore, nitrogenous fertilizer can be cut down to a maximum of 10% in the plots irrigated by pond effluent water. As a whole the system works well as the polluted water of the pond water does not pollute the environment, rather it supplies nitrogen rich water to the crop. Therefore, a farmer owning fish pond, water source and agriculture land at one location should go for the above type of intensification for optimum utilization of resources, better income and environment friendly development.

CONCLUSION

It can be concluded from the above study that integrated agri-aquaculture is a viable and environment friendly option for increase of a farmer's income through increased stocking density of IMC culture. Although the benefit-cost ratio reduces slightly due to intensification of IMC culture, but the net benefit increases substantially. Therefore, a farmer owning fish pond, water source and agricultural land at one location should go for the above type of intensification for optimum utilization of resources, better income and ecologically sustainable development.

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FIGURE-1 Temporal variation in ammonia-nitrogen concentration in ponds with different stocking densities

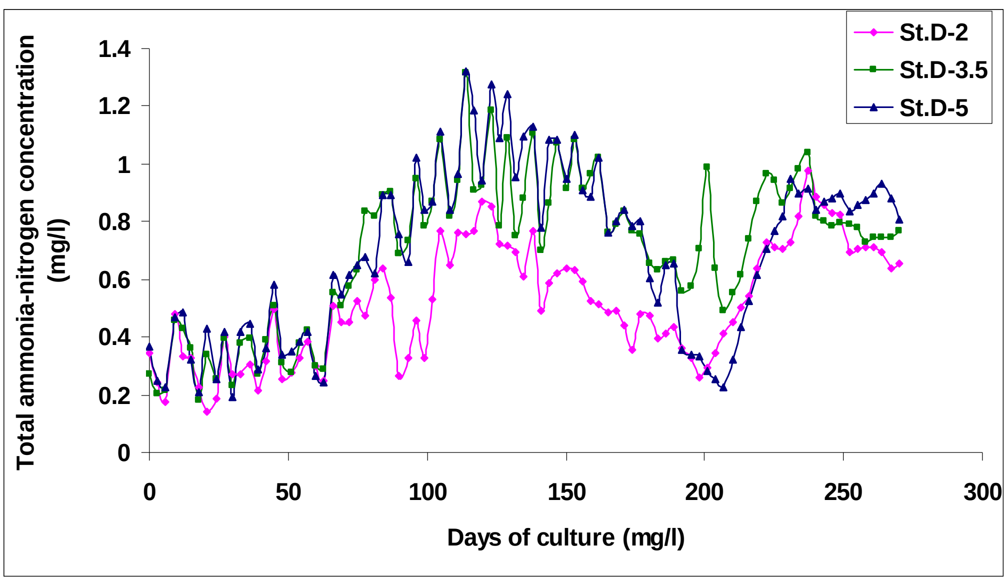

FIGURE-2 Growth of fish during culture period

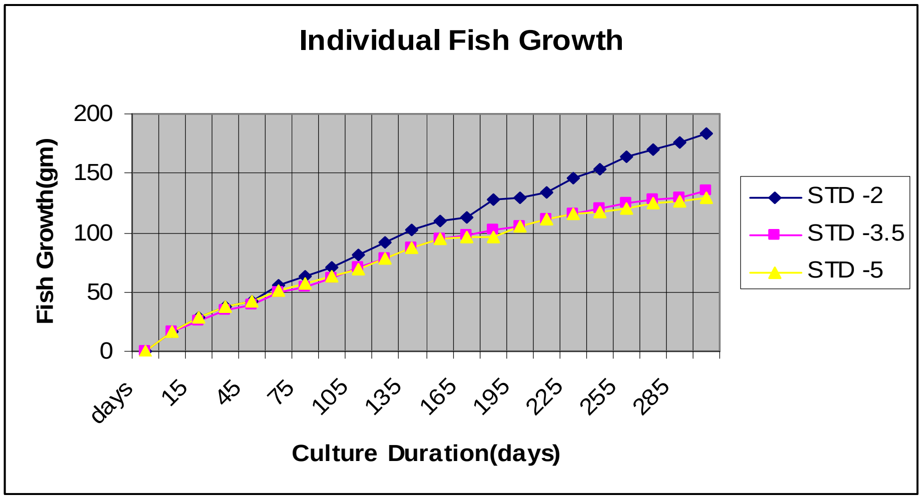

FIGURE-3 Yield of tomato obtained from three treatments and control plots

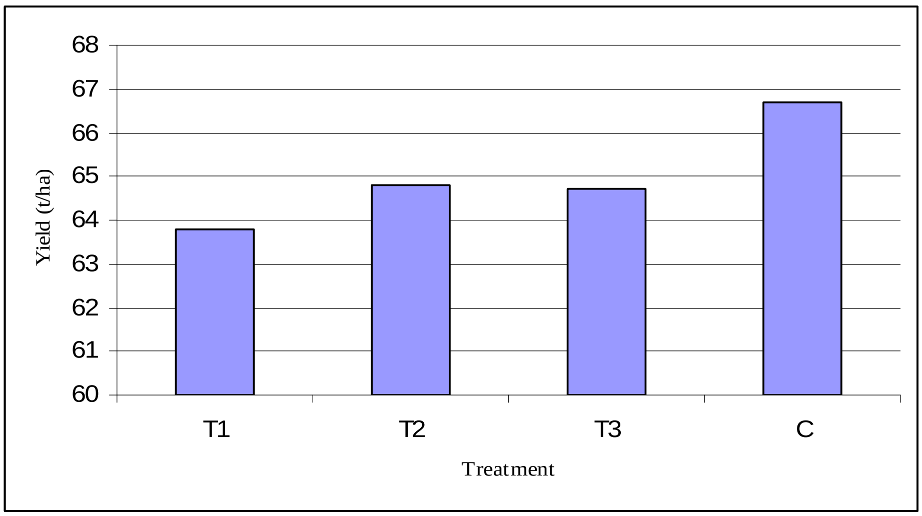

TABLE-1 Investment for Fish Culture with Different Stocking Densities

Inputs	Pond-1 (STD-2)		Pond-2 (STD-3.5)		Pond-3 (STD-5)	
	Quantity, kg/ha	Cost, Rs/ha	Quantity, kg/ha	Cost, Rs/ha	Quantity kg/ha	Cost Rs/ha
Urea	160	880	160	880	160	880
SSP	80	440	80	440	80	440
FYM	16,000	1600	16,000	1600	16,000	1600
Lime	500	2500	500	2500	500	2500
Feed	7714.16	77141.6	9940.04	99400.4	13620.6	136206
Fingerling	200	10000	350	17500	500	25000
Water Exchange	6000 m^3	7200	9000 m^3	10800	13500 m^3	16200
Aeration cost	---	Nil	2 aerators 180 h	6120	2 aerators 360 h	12240
Labour	Lumpsum	5,000.00	Lumpsum	7,500.00	Lumpsum	10,000
Total		1,04,761.6		1,46,740.4		2,05,066.0

TABLE-2 Cost-Benefit Analysis of Fish Culture

Treatment	Cost of culture, Rs	Yield, kg	Total return, Rs	Net benefit, Rs	BCR	Net BCR
STD-2	1,04,761.6	3656	1,82,800	78, 038.4	1.7449	0.7449
STD-3.5	1,46,740.4	4756	2, 37,800	91, 059.6	1.6205	0.6205
STD-5	2,05,066.0	6486	3, 24,300	1,19,234	1.5814	0.5814

TABLE-3 Investments for Tomato Cultivation

Input	Treatment-I		Treatment-II		Treatment-III		Control plot	
	Quantity	Cost (Rs/ha)	Quantity	Cost (Rs/ha)	Quantity	Cost (Rs/ha)	Quantity	Cost (Rs/ha)
Land preparation	Lumpsum	5000	Lumpsum	5000	Lumpsum	5000	Lumpsum	5000
Urea	277.1 kg	1524.05	228.2 kg	1255.10	179.3 kg	986.15	326 kg	1793
SSP	625 kg	4718.75	625 kg	4718.75	625 kg	4718.75	625 kg	4718.75
MOP	166.7 kg	666.8	166.7 kg	666.8	166.7 kg	666.8	166.7 kg	666.8
FYM	10 t	1000	10 t	1000	10 t	1000	10 t	1000
Seed	200 g	4240	2 00 g	4240	2 00 g	4240	2 00 g	4240
Plant protection	Lumpsum	1000	Lumpsum	1000	Lumpsum	1000	Lumpsum	1000
Irrigation	60 ha-cm	7200	60 ha-cm	7200	60 ha-cm	7200	60 ha-cm	7200
Labour	500 man-days	40000	500 man-days	40000	500 man-days	40000	500 man-days	40000
Total		65,349.60		65,080.65		64,811.70		65,618.55

TABLE-4 Cost-Benefit Analysis of Tomato Cultivation

Treatment	Cost of cultivation, Rs	Yield*, kg	Total return, Rs	Net benefit, Rs	BCR	N BCR
Crop treatment-I	65,349.60	63800	1, 62,690	97, 340.4	2.4895	1.4895
Crop treatment-II	65,080.65	64800	1, 65,240	1,00,159.35	2.5390	1.5390
Crop treatment-III	64,811.70	64700	1, 64,985	1,00,173.33	2.5456	1.5456
Crop treatment-IV	65,618.55	66700	1, 70,085	1, 04,466.45	2.5920	1.5920

*Only 85% of the total yield of tomato can be effectively sold due to spoilage of 15% yield.

TABLE-5 Cost-Benefit Analysis of the Integrated System (Fish + Rabi crop)

Integrated system	Investment, Rs		Return, Rs.		Net Benefit, Rs	BCR	Net BCR
	Fish/crop	Total	Fish/crop	Total			
Pond –I	1,04,761.6	1,70,111.2	1,82,800	3,45,490	1,75,378.8	2.0310	1.0310
Crop treatment –I	65,349.60		1, 62,690				
Pond –II	1,46,740.4	2,11,821.05	2, 37,800	4,03,040	1,91,218.95	1.9027	0.9027
Crop treatment –II	65,080.65		1, 65,240				
Pond –III	2,05,066.0	2,69,877.7	3, 24,300	4,89,285	2,19,407.3	1.8130	0.8130
Crop treatment –III	64,811.70		1, 64,985				
Control crop	65,618.55	65,618.55	1, 70,085	1, 70,085	1,04,466.45	2.5920	1.5920