Indian J. Fish., 71 (4): 63-69, 2024
doi:10.21077/ijf.2024.71.4.115967-08
Available online at: epubs.icar.org.in/index.php/IJF

Fish-based intensive integrated farming system for resource recycling, enhanced productivity and livelihood improvement in the lowlands of the middle Indo-Gangetic plains

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Keywords:
Economics, Integrated fish farming, Intensification, Livelihood, Pond dyke, Poultry fish and duck rearing, Resource recycling

Received : 25.09.2021
Accepted : 11.12.2024

Abstract

Integrated farming systems (IFSs) enhance economic yield per unit area and time through intensification, diversification and integration of location-specific components while promoting resource recycling and reducing dependency on external inputs. This approach is particularly effective for eastern India, especially in wetlands, where underutilised pond dykes can be efficiently utilised for growing vegetables, fruits integrating with poultry or duckery, providing significant benefits in production, income, nutrition and employment opportunities to farm families. In this study, components like field crops, vegetables, fruits, mixed carp culture, poultry and duckery were integrated at the main research farm of ICAR Research Complex for Eastern Region, Patna, India. The results were highly encouraging, showing significant improvements in production and income compared to the conventional rice-wheat and sole fish production systems. Integration of fish, poultry, duck with sequential vegetable and fruit production on pond dykes resulted in 333.14% higher relative production efficiency and higher daily income (₹443 day^{-1}) compared to rice-wheat and sole fish production system (₹95.1 day^{-1}). This model also generated 300% more employment opportunities over rice-wheat and sole fish production system. In addition to these benefits, it helped to contribute an ample amount of nutrients (N:P:K, 169.9:91.5: 81.9 kg per acre, respectively) to the farm soil, significantly reducing the reliance on chemical fertilisers. The present IFS model (rice-wheat and fish + poultry/duckery on pond dykes) proved to be highly productive, remunerative which can be easily adopted by small and marginal farmers in the middle Indo-Gangetic plains (MIGP).

Introduction

Integrated farming system (IFS) is an interdependent, interrelated often interlocking production systems based on few crops, animals and related subsidiary enterprises to maximise the utilisation of nutrients of each system and minimise the negative effect of these enterprises on environment. The interrelated, inter-dependent-interlocking nature of IFS involves the utilisation of primary produce and secondary produce of one system, as basic input of the other system, thus making them mutually integrated as one whole unit. Throughout the country, efforts were made to develop low-cost farming systems suitable for Indian conditions, based on the principles of productive utilisation of farm wastes and fuller utilisation of available resources and manpower. Due to progressive shrinkage of farm holding, maintaining food production for ever increasing population is one of the major challenges. To obtain maximum output from the available land holding, adoption of mixed farming system with crop, livestock and fish are becoming popular in low land, wet land and watershed areas of the country. India has 757,060 wetlands covering about 15.26 million ha area, which is around 4.63% of the total geographical area of the country (Arya *et al*., 2020). In Bihar about 4032 km^2 area lies under wetland ecosystem which is about 4.4% of its total geographical area which needs proper agricultural management to make it productive (Singh, 2018). The sustained research efforts have resulted in the development of integrated farming systems involving fish culture, livestock and crops. Integrated fish farming involves farming of fish along with livestock or/and agricultural crops. This farming system yields great efficiency in resource utilisation, waste recycling and utilisation of available farming space. The rising cost of protein-rich fish food and chemical fertilisers are of general concern for energy conservation. This system ensures the utilisation of rice and other crops as well as livestock wastes as a direct/indirect source of feed in fish culture operations (Ramanathan *et al.,* 2020). This farming system also yields higher income and increases the productivity in small land holdings in comparison to the system which uses only single crop for farming. There are various fish-based integrated farming systems. Ducks can be raised in ponds and the pond bunds can be used for cultivating horticultural crops. Integrated fish farming can be broadly classified into two, namely: Agriculture-fish and Livestock-fish systems. Agri-based systems include various combinations such as rice-fish integration, horticulture-fish system, mushroom-fish system and seri-fish system. Similarly, livestock-based systems include cattle-fish, pig-fish, poultry-fish, duck-fish, goat-fish and rabbit-fish systems. Among these, rice-fish farming, horticulture-fish, poultry-fish (ducks/Chicken), pig-fish and cattle fish systems are the most commonly practiced integrated farming models. These systems offer diverse outputs including fish and other agricultural and livestock products, enhancing overall productivity and sustainability. This system generates additional employment opportunities and contributes significantly to improving the socio-economic status of farmers while supporting the development of the rural economy (Prein, 2002).

Pond-based IFS with minimum investment is economically better, environmentally sound and socially acceptable (Biswas *et al*., 2013). Ponds add value to farming activities by providing water for irrigation of crops and supporting other agricultural or integrated components. About 30-40% of the area is generally allocated to pond dykes, which are often left fallow or underutilised. These pond dykes can be effectively utilised for growing seasonal vegetables and fruits like guava, banana, papaya, lemon, pomegranate, custard apple and strawberry, among others. Fruit plants should be selected carefully to ensure they do not cast shade on the water body and they begin fruiting within 2-3 y, maximising the benefits from the dyke area. In the water body, mixed carp culture using rohu, catla, mrigal, silver carp, grass carp is more profitable compared to cultivating single fish species. In mix carp culture, the competition for feed and other required environmental resources is minimised due to the distinct feeding habits and habitats of the fish, categorised as surface feeders, column feeders and bottom feeders. This system can be effectively integrated with poultry, duckery or goat rearing, which enriches the pond ecosystem by providing feeding material to the fishes in the form of animal excreta and left-over feed. This integration helps to provide natural feed supplements for the fish and also significantly reduces the overall cost of fish rearing (Kumar *et al*, 2012a; Majumdar *et al.,* 2018). Furthermore, integrating fish farming with poultry, duck or crops holds significant potential for producing a diverse range of protein (both plant as well as animal based), minerals and vitamins, while also contributing to employment and livelihood security for small and marginal farmers. An integrated model requires more man-hours to manage various interconnected activities, either simultaneously or sequentially. This increased labour demand provides opportunities for enhanced engagement of man-power, thereby boosting employment generation in rural areas.

It can be hypothesised that by integrating suitable components with proportionate land areas and feasible numbers, can significantly benefit farmers by increasing farm productivity and income from the same piece of land. This is achieved through efficient utilisation of limited natural resources and recycling of farm waste. In light of these, the present investigation was undertaken in the middle Indo-Gangetic plains (MIGP) with the primary objective of intensification of pond-based systems to restore the natural productive capacity of the delicate land-water ecosystem through resource recycling. Further, the study aims to enhance the income and livelihoods of small and marginal farmers of the MIGP region as well as for the whole country.

Materials and methods

Fish based Integrated farming systems (IFS) model was experimented at the Research Farm of ICAR Research Complex for Eastern Region, Patna (25.59°N; 85.13°E) situated at an altitude of 53 m above mean sea level. Eastern region enjoys a tropical sub humid climate and more than 85% of total rainfall is received during June to September. November to April is dry period during which crops need ample irrigation. May-June is the hottest period with average maximum and minimum temperatures of 42.4 and 8.2ºC, respectively. The experimental site received an average rainfall of 1045 mm per annum during 2014-2020.

A crop area of 2610 m^2 and a pond area of 1390 m^2 was established under the All India Coordinated Research Project (AICRP) on Integrated farming systems (IFS) at the project site during the period 2010-2020. A duckery (comprising 35 females and 5 males) and a poultry farm (with 100 birds per batch) were established over the water area. Out of the total 1390 m^2 pond area, water area covers 1000 m^2 having an average depth of 1.6 m. In the IFS pond, 1000 fingerlings (Catla 130.9±17.8 mm, 24.8±11.85 g; Rohu: 122.4±28.9 mm, 19.80±9.37 g and Mrigal: 120±4.08 mm, 14.08±3.96 g) of three different carp species *viz.* grass carp, rohu and common carp obtained from the hatchery of ICAR Research complex for Eastern Region were released at a stocking ratio of 3:2:1. The three different species of fishes were carefully selected to minimise competition for feed as they have different feeding habits and feeding zones. No supplementary feed was provided; and the fishes thrived on poultry and duck droppings. Liming was carried out to maintain optimal water pH and farm yard manure (FYM) was applied to promote growth of phytoplankton in the pond. Tender vegetable leaves, azolla and banana leaves were also added for better growth of fishes, especially to meet the feed requirements of grass carp. A 3 m wide pond dyke was made all-round the water body which was utilised for cultivating fruits (banana 20 no., lemon 20 no., mango 12 no. and guava 12 no.). In the interspace, seasonal vegetables *viz*. bitter gourd, sponge gourd, broccoli, tomato, cauliflower, cowpea and lady's finger (okra) were grown throughout the year. On the slope of the pond (upper 0.75 m), mentha was planted. Elephant foot yam was also planted in two rows at a spacing of one meter in pits on each side of the dyke to provide additional income. This resulted in a 3-tyre production system on the pond dyke; with a mix of deep rooted fruit trees, shallow rooted vegetables and intermediate rooted yams. As field crop, rice was grown during kharif season (starting 2nd July), maize and wheat during rabi season (starting 20th November) and moong during summer season (starting 3rd April) in each year of the experiment. All recommended agronomic practices were followed for each crop, with no major insect or pest infestations was observed in the crops grown on the dykes except for shoot borer in tomatoes which was controlled by spraying Spinosad 45% at 15 days interval. The pond dyke was manually tilled for sowing of vegetables ensuring enough space left on the sides to prevent soil erosion due to run off water. Tomato, cauliflower and broccoli were planted on 20th November and cucurbits were planted on 2nd July each year. Elephant foot yam was planted biannually (alternate year) in the month of February. The crops were irrigated with pond water using a 0.5 HP water pump in summer and occasionally during the rabi season. Mentha was planted on the slopes of the pond in the month of February each year to prevent soil erosion by binding the soil, while also contributing additional income to the system. The yield of fruit crops was calculated based on fruit weight/plant, vegetable yield on basis of 10 m^2 area and yield of rice/maize/moong on a 20 m^2 area.

Poultry (150 sq ft.) and duckery (120 sq. ft.) units were constructed over the water area in such a way that the droppings would go directly to the pond enriching pond soil and providing feed for the fish. Twenty-five percent of the poultry droppings and all the duck droppings were allowed to go into the pond, while the remaining droppings were used for vermicompost production, along with other farm wastes such as straw, weeds, vegetables leaves and stems as well as fruit tree trimmings, to use for crop cultivation. Poultry and duckery units placed over the water area facilitated effective use of space, saved labour costs and reduced time spent in transporting feed and manure. Construction of sheds above the water bodies also provided additional security to birds from predators like dogs, mongoose, jackals and cats. The roofs of the poultry and duck sheds were made sloppy to prevent stagnation of rain water on the roof top and to facilitate protection from strong winds. Proper ventilation was provided for adequate air circulation in both the sheds. The floor of both sheds was made with bamboo sticks with 0.5 cm gap to allow droppings to be easily washed into the pond every morning. The chicks (100 per batch) were sourced from external suppliers and reared for 35-40 days, with 7 batches of 100 birds raised annually. To maintain the required temperature (22-25°C) in poultry shed, three 200 W bulbs were lighted throughout the day during cold season and only in night hours during summer season. In the duck shed, only one 200 W bulb was lighted during night hours. The poultry birds were fed a mixture prepared from the produces obtained from the 2610 m^2 area (paddy, maize and moong) adjacent to the pond which included bran/husk (rice, maize, moong); broken grains (moong, maize) and a supplement of Agrimin (2.5 kg per100 kg of concentrate mixture). In order to protect the poultry birds from diseases, proper care and hygiene conditions were maintained in the shed. One-day-old chicks were vaccinated against New Castle disease and given 2000 IU of vitamin D.daily for the first 3 weeks. Broilers attained an average weight of 1.8 kg n 35 days with a mortality of 2-3%. A brief description of low-cost broiler production is presented in Table 1. The required data on different parameters for vegetable crops and fruit crops were recorded every 15 days, for field crops every 30 days, and daily for broilers and ducks. Pond silt, vermicompost and poultry/duck droppings were tested in the lab for estimation of nitrogen (N), phosphorus (P) and potassium (K) content. The collected data was pooled and analysed for calculation of different returns, benefit:cost ratio (B:C ratio), system productivity (kg per unit area) and system production efficiency using standard methods and formulae (Babu *et al.*, 2019) as described below:

System productivity: FEY/Area

System production efficiency (SPE): FEY (kg)/Area)/365

$$\text{Relative production efficiency (RPE) in (\%):} \quad \frac{(\text{EYD- EYE})}{\text{EYE}} \times 100$$

$$\text{Relative employment generation (REG) efficiency:} \quad \frac{\text{MDD- MDE}}{\text{MDE}} \times 100$$

where, FEY = Fish equivalent yield (FEY= Yield of non-fish component x Price of non-fish component/Price of fish)

EYD = Equivalent yield from diversified system

EYE = Equivalent yield from existing system

MDD = Man-days requirement in diversified system

MDE = Man-days requirement in existing system

Benefit:Cost ratio (B:C ratio) : Gross return / Cost of cultivation

Net return (₹) : Gross return-Cost of cultivation

Total net return (₹) : Sum of net return obtained from all components of IFS

Table 1. Summary of poultry (broiler) and duck production technology

Particulars	Poultry	Duck
System of rearing	Ventilated shed above water body	Ventilated shed above water body
Materials used in sheds	Locally available materials	Locally available materials
Batch size	100±5 Nos.	35 female + 5 male
Bath interval	35±3 days +10 days for cleaning and drying	Regular
Batch per year	7 Nos.	Annually
Cost of one day old chick/60 days old duckling (₹)	30	60
Cost of feed per kg (Recycled from system) (₹)	20	10
Cost of equipment per bird (feed and water tray) (₹)	10	4
Vaccination cost per bird (₹)	02	---
Purpose of rearing	For meat	For egg
Av. age of selling (live)/Av. age for laying	35 days	180 days
Av. weight at selling time/Bird or av. egg production/Duck	1.8	170 per annum
Av. feed requirement per day	3.0 kg per 100 birds	3.2 kg per 40 ducks
Av. productive age	35±3 days	3.0 years

Results and discussion

Economics of intensive fish-based IFS *vs* rice-wheat+sole fish system

In the intensive fish-based IFS**,** integration of rice-wheat cropping system with poultry, duckery and the utilisation of pond dykes for 3-tier vegetable and fruit production system resulted in a fish equivalent yield (FEY) of 2261.8 kg per acre. This system achieved a net return of `1,61,717 per acre, with a production efficiency of 0.0017%.It demonstrated a relative production efficiency increase of 332.14%, profitability of ` 443 per day and a 300% improvement in relative employment generation efficiency compared to conventional r rice-wheat + sole fish production system (Table 2). Further, the intensive fish based IFS recorded a 7% higher B: C ratio (1.91) compared to rice-wheat + sole fish system (1.79). Similar findings on enhanced income through the integration of crop, fish and poultry under IFS than rice-wheat + sole fish system have been reported by Babu *et al*. (2019) and Kumar *et al.* (2017). Intensification of pond dykes with vegetable and fruit crops combined with poultry and duck production, demonstrated potential for enhancing the income per unit area. This approach ultimately provides more savings for farmers and also enhance the living standards of the farm family in addition to ensuring enriched balanced diet (Vincke, 1988). This increased profitability, enhanced relative production efficiency and reduced cost of production observed in the system are attributed to its multiactivity and multicommodity production approach on a single piece of land. Recycling of farm wastes from various components within the system reduced production costs substantially by minimizing the reliance on chemical fertilizers. Gabriel *et al*. (2007) also highlighted the benefits of integrated fish farming, noting its ability to recycle resources efficiently within the system without generating wastes thereby contributing to sustainable and cost-effective farming.

Economics of composite fish culture

The inclusion of fishes having different feeding habits and feeding zones helped to minimise competition for feed and enhanced the pond productivity, yielding an appreciable 342 kg of fish per 1000 m^2 a time span of 10 months The selling price of the fish (at the institute level) was ₹150 per kg. The study revealed that cost of composite fish production under IFS was ₹53.22 per kg and gross and net returns per sq. m. were ₹51.3 and 33.1, respectively with B:C ratio of 2.82. The net return was found to be 2.8 times higher than the rice-wheat + sole fish production system (Table 3). Rautaray (2013) also reported similar results, highlighting enhanced productivity and profitability with high returns from composite fish culture.

Economics of crops grown on pond dyke

The cultivation of vegetables and fruits in a 3-tier system (1390 m^2) and on bamboo trellises on pond dyke slopes added an additional advantage to the integrated farming system enhancing the overall profitability. This approach proved highly beneficial for resource poor small and marginal farmers, who often lack access to adequate vegetables and fruits for household nutrition. Year-round vegetable and fruit production on pond dykes ensured steady supply for household consumption along with generation of additional income through market sales. The earnings from these crops, in addition to income from fish and other enterprises, substantially increased the total income of the system. The economics of year-round production of vegetables and fruits on pond dykes is illustrated in Table 4, where a total net return of ₹65,660 was recorded. These findings align with the studies of Alam *et al*. (2009); Babu *et al.* (2019) and Shukla *et al*. (2020). This income from pond dyke based vegetable and fruit cultivation has a remarkable potential to improve the livelihoods of resource poor farmer, offering both income generation and enhanced nutritional security for their families.

Economics of poultry and duck rearing within the system

The integration of livestock/birds with crops or fish has proven its effectiveness in enhancing system productivity and economic viability. Among these, rearing poultry and ducks rearing above fish ponds in an integrated mode has emerged as one of the most remunerative and promising approaches. Net returns from poultry

Table 2. Economics of intensive fish-based IFS system and rice-wheat + sole fish production system (av. of 10 years)

Particulars	Field crops +Sole fish production system	Intensive fish-based IFS
Rice-wheat system (FEY) (kg)	26.2	-
FEY for whole system (kg)	523.4	2261.8
Gross returns (System) (₹)	78,510	3,39,294
Net returns (System) (₹)	34,710	1,61,717
Production cost (System) (₹)	43,800	1,77,577
B: C ratio	1.79	1.91
Production efficiency	1.43	6.19
Relative production efficiency (%)	-	333.14
System profitability (₹)	95.1	443.0
Man-days requirement	61	244
Relative employment generation efficiency (%)	-	300

Table 3. Economics of composite fish culture (av. of 10 years)

Total no. of fingerlings	Total production (kg)	Production cost (₹)	Gross returns (₹)	Net returns (₹)	B: C ratio
1000	342	18200	51300	33100	2.82

Note: Selling price of fish @ (₹) 150 per kg and duckery production over IFS pond (1390 m^2a) with 100 broilers per batch and 40 ducks (35 female + 5 male) in a year are presented in Table 4. Broilers attained an average weight of 1.80 kg reached at their marketable age of 35±5 days. Seven batches of broilers were reared annually during the whole period of experimentation, with averages computed over 10 years. The B:C ratio of poultry and duckery operations, highlighting their economic feasibility within the IFS, is detailed in Table 5.

Forty ducklings of 2 months of age were reared above the pond for dual purposes, *i.e.* meat and egg production. Ducks for meat purpose were sold every four years. The female ducks started laying egg at the age of 180-185 days with an average egg production of 170 per duck annually. Their productive life span was about 3.5 y, after which spent ducks were sold in the market @ ₹100 per duck. Detailed information on duck rearing and its economics is presented in Table 5. The poultry unit achieved gross returns of ₹1,19,700, net returns of ₹40,120 and a B:C ratio of 1.50, while the duck unit recorded gross returns of ₹35,700, net returns of ₹11,287 and a B:C ratio of 1.46. In addition to the enhanced income, poultry unit generated 2.1 t of droppings, with 75% recycled into vermicompost for application to vegetable and fruit crops on pond dyke and 25% were fed directly to the fishes. The duck unit provided 1.3 t of droppings all of which were fed to the fishes in the pond. The integration of these units significantly enhanced the income of the system and ensured nutritional security for the farm family. Similar findings on integration of poultry and duck were also reported by Kumar *et al*. (2012b); Babu *et al*. (2014) and Ehsanul (2016).

Nutrient recycling within the system

One of the key features of integrated farming system is the recycling of nutrients within the system, which enhances resource use efficiency. In this model, various farm wastes including . plant residues (leaves, stems and other parts including weeds), poultry and duck droppings (both raw and in the form of vermicompost) and pond silt were effectively recycled within the system. A total of 2880 kg of plant wastes was converted into 1728 kg of vermicompost, which in turn provided N:P:K: 17.6:19.6:18.5 kg, respectively to the system. Likewise recycling of poultry and duck droppings also provided 93.6 and 48.7 kg of nitrogen (N), 56.5 and 15.4 kg of phosphorus (P_2O_5) and 39.5 and 23.9 kg of potassium (K_2O), respectively to the system. Overall, 159.9 kg of N, 91.5 kg of P_2O_5 and 81.9 kg of K_2O were added to the system upon recycling which is equivalent to 347.6 kg of urea, 571.8 kg of single super phosphate (SSP) and 136.5 kg of muriate of potash (MOP) (Table 6). The resource recycling within the system resulted in significant savings of `8197.6 by reducing the dependence on chemical fertilisers. These findings align with studies conducted by Jayanti *et al*. (2004), Zira *et al.* (2015) and Kumar *et al*. (2018), which also demonstrated nutrient addition to soils through resource recycling in integrated farming systems

Economics of field crops

Under the pond-based IFS system, a crop area of 2610 m^2 was allocated for field crops, adopting a rice-wheat-moong cropping system to meet the feed requirements of farm family and other system components. An average rice equivalent yield (AREY) of 3093 kg was achieved generating a net annual return of `24,994 with a B:C ratio of 1.81 (Table 4). This production was sufficient to sustain a seven-member farm family (4 adults and 3 children). By-products like paddy and wheat straw ((21.3 quintals) were sold in the market @ ₹40 per quintal. while moong crop was ploughed back into the soil after the first picking to serve as green manure, enriching soil fertility. Moong husk, broken grains and rice bran were

Table 4. Economic of crops cultivated in field (rice-wheat-moong) and on pond dyke (av. of 10 years)

Crops	Area (m^2)/no.	Production (kg)	FEY (kg)	Production cost (₹)	Gross returns (₹)	Net returns (₹)	B:C ratio
Cropping system (field crops) (Gross area for all the seasons)							
Rice-maize-moong	2610 (each crop)	3093 (REY)	371.16	30680	55,674	24,994	1.81
Crops on pond dyke							
Kharif season							
Bitter gourd	210	262	17.4	1240	2620	1380	2.11
Sponge gourd	210	315	21.0	1390	3150	1760	2.27
Rabi season							
Broccoli	120	215	28.7	2150	4300	2150	2.0
Tomato	120	480	32.0	1850	4800	2950	2.59
Cauliflower	120	300	20.0	1520	3000	1480	1.97
Summer Season							
Cowpea	190	190	12.67	844	1900	1056	2.25
Okra	190	285	19.0	1200	2850	1570	2.37
Annual crop							
Yam	130no.	195	26.0	1180	3900	2720	3.30
Mentha	130	205	41.0	1880	6150	4270	3.27
Fruit crops (in number)							
Lemon	20	425	85.0	3080	12750	9670	4.14
Banana	20	410	54.6	2300	8200	5900	3.56
Mango	12	440	88.0	3420	13200	9780	3.85
Guava	12	505	67.3	2650	10100	7450	3.81
Average	--	7320	883.83	55384	132594	77210	2.39

Selling price of the produce (₹ per kg): Cucurbits - 10; Broccoli - 20; Tomato/Cauliflower - 10; Cowpea/Okra -10; Yam - 20; Mentha leaves - 30; Lemon - 30; Banana - 20; Mango - 30; Guava - 20; Paddy - 18; Maize - 18; Moong - 40; FEY - Fish equivalent yield

Table 5. Economics of duck and poultry rearing over the water surface in integrated mode (av. of 10 years)

Particulars	Poultry	Duck
Expenditure Statement (Capital cost)		
Purpose of rearing	Broiler (meat)	Dual purpose (egg + meat)
Construction of sheds over the water body (poultry 150 ft.^{2}Duck 120 ft.^{2}) with average life of 10 y	20,800	20,000
Total capital cost	20,800	20,000
Splitted expenditure for one year	2,080	2,000
Recurring cost		
Feed and water trays @ ₹8 per bird	5,600	320
Cost of chicks (@ ₹30 per chick- one day old)/ducklings (@₹100 per duckling of 30 days old- 40 nos.) - 7 batches of 100 birds per annum for poultry	21,000	4,000
Productive age of birds	35-38/batch	3years
Cost of feed @ 2.5 kg per bird @ ₹18 per kg (poultry) and 80 g per bird per day for ducks @ ` 10 per kg as recycled within the system	31,500	11,680
Miscellaneous expenditures (vaccination, medicines, saw dust etc.) @ ₹2 per bird	1,400	80
Labour cost @ ₹300 per day	18,000 (60 man-days/year)	9,000 (30 man-days/year)
Grand total of rearing cost (Capital + recurring) per annum	79,580	24,413
Income statement		
Mortality (±5%)	35 birds/year	No mortality
Average weight at selling time (poultry) and no. of eggs per year	1197 kg	5950 eggs
Fish equivalent yield (FEY) in kg	798	238.0
Gross income (₹)	1,19,700 @ Rs. 100/kg	35,700 @ Rs. 6/egg
Net income (₹)	40,120	11,287
B:C ratio	1.91	1.46
Additional benefits to the system		
Poultry/duck droppings	2250 kg	1460 kg
Nutrient addition in terms of N: P: K (kg)	56:45:34	37:29:22

Table 6. Average nutrient recycling within the pond-based IFS system (Average. of 10 years)

Nutrient	Raw poultry dropping	Poultry manure (75 % of raw droppings)			Pond recycled manure (25 % of raw droppings)		Additional nutrient gain by recycling
	%	kg per 2250 kg	%	kg per 1688 kg	%	kg pr5000kg	kg
N	2.50	56.2	3.22	54.0	1.92	95.8	93.6
P_2O_5	1.82	40.9	2.50	42.2	0.99	49.8	56.5
K_2O	0.86	19.3	1.20	20.2	0.74	36.8	39.5
Raw duck dropping							
	%	kg per 1460 kg		%		Kg per 5000 kg	Additional nutrient gain by recycling
N	1.8	26.3		1.5		75.0	48.7
P_2O_5	1.0	14.6		0.6		30.0	15.4
K_2O	1.1	16.1		0.8		40.0	23.9
Farm waste				Vermicompost			
	%	kg per 2880 kg		%		Kg/1728kg	Additional nutrient gain by recycling
N	0.62	17.4		2.0		35.0	17.6
P_2O_5	0.40	11.5		1.8		31.1	19.6
K_2O	0.50	14.4		1.9		32.8	18.5
Additional nutrient gains due to recycling							
N							159.9
P_2O_5							91.5
K_2O							81.9

utilised as feed for poultry and ducks, supplemented by maize grain flour as feed (Table 5), reducing feed costs by half compared to market rates. These results align with the findings of Kumar *et al*. (2017) and Haque *et al*. (2011) who reported similar benefits from integrated farming approaches.

The findings of the study on integrated farming system, demonstrate that intensive fish-based IFS is a sustainable and profitable production model and has potential to enhance the income and livelihood of small and marginal farmers of eastern region. This system optimally utilises limited available resources by integrating diverse components and efficiently recycling farm wastes. The recycling of waste materials reduces production costs, enhances net returns, and offers multiple benefits for soil health and environmental sustainability. By incorporating diversified production systems, the developed IFS model reduces dependency on external inputs compared to traditional farming practices such as rice-wheat cropping systems or rice-wheat + sole fish production systems.The rearing of ducks or poultry above the water surface mimimizes the feed cost for fishe and also enriches the pond soil and enhances the production of phytoplankton and zooplankton, which are vital for aquatic productivity. Further, the silt deposited in the pond can be effectively used as a nutrient-rich resource for crop cultivation by scrapping the top 4-6 inches of the pond bottom soil layer. This integrated approach offers multiple advantages, including increased income, improved livelihood opportunities, enhanced soil fertility, better nutritional security and a safer environment.

Acknowledgements

The authors extend their sincere thanks to the Director, ICAR Research Complex for Eastern Region, Patna and ICAR-IIFSR, Modipuram for providing all the research support and financial support for carrying out this research work.

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