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Productivity, energy use efficiency, economics and CO_2 emission from integrated fish-duck farming in floodplain wetland ecosystems of eastern India

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Abstract

The study aims to assess productivity, economics, energy use efficiency and CO_2e emission from integrated fish-duck farming system (IFDF system) in floodplains of the eastern India. A total of six fish ponds were constructed and developed as IFDF system under floodplains in which fingerlings were stocked @4000 acre^{-1} and integrated with 150 numbers of Khaki Campbell ducks. Average growth rate of fishes ranged from 27 g month^{-1} of mrigal to 31.7 g month^{-1} of grass carp and average body weight ranged from 465.2 g of mrigal to 823.2 g of grass carp. The fish equivalent yield was obtained as 3.06 t acre^{-1} year^{-1}. The total energy input, output and energy use efficiency ratio estimated were 111.8 GJ and 21.2 GJ and 0.19, respectively. Net income earned was ₹234393 acre^{-1} year^{-1} and BC ratio estimated was 1.91. Further, 0.56 kg CO_2e was emitted to produce 1.0 kg of fish equivalent, which was much lower than that of the production of rice, mutton and milk.

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Introduction

India is the second largest fish-producing nation in the world after China with a production of 14.1 million t contributing 0.96% to the National Gross Value Added (GVA) and getting employed over 14 million people (Anon., 2020). About 10% of earth's surface is covered with wetlands, of which 15% is under floodplain wetlands (Tockner and Stanford, 2002). India occupies 0.35 million ha of floodplain wetlands mostly distributed in the eastern region of India and locally termed as chaur, maun, dhar, jheel, tal, pat, beel and boar (Ayyappan *et al.*, 2017; Sarkar and Borah, 2018). The floodplains are flat low-lying areas adjacent to rivers and streams which experience periodical or permanent flooding, particularly during rainy season and characterised by soil with higher silt content (Junk, 1997; Meitzen, 2018). Uncertain hydrology of floodplains such as sudden flash flood and draught is common phenomenon in the eastern region of India. Rice and fish farming are major farming practices in floodplains of eastern India and productivity of rice and fish varies between 1.0-1.5 and 0.05-1.1 t ha^{-1} year^{-1}, respectively. The productivity is much lesser than national average productivity of rice and fish, hence there is immense scope for improvement through the adoption of fish-based IFS (Singh and Khan, 2002; Das *et al.*, 2019).

Integrated fish farming (IFF) is defined as "concurrent or sequential linkage in terms of utilisation or recycling of wastes/ byproducts from one farming component to other (s) and *vice versa* of which fish remains major component" (Little and Edwards, 2003). The IFF enables efficient utilisation of resources, waste recycling, energy saving, diversification, extra income, diverse food and maintains ecological balance (Majumdar *et al.*, 2018). Integrated fish-duck farming (IFDF) has been practiced traditionally in India. Fish and duck get mutual benefits upon their co-existence, as the excreta of duck acts as fertiliser while duck feeds on snail, tadpole, insect and other benthic organisms available in the fish pond. Moreover, ducks help in the aeration of pond water which increases the dissolved oxygen level. Further, during the search for feed, duck excreta containing essential nutrients is distributed evenly over the pond bottom which helps in the escalation of plankton growth *i.e.* natural food of fishes. Therefore, duck is often termed as “bio-aerator” and “live manuring machine” for fish pond.

It is a well-known fact that energy being used in food production systems ought to be high in order to feed the ever-growing human population, therefore, adequate availability of green and renewable energy and its proficient use is necessary for improved productivity and to curtail environmental harms (Erdal *et al.,* 2007). It is evident that yield and economic return increase as the level of fertility increases, while a reverse trend has been observed with energy use efficiency in most of the agricultural production systems (Tuti *et al.,* 2012). The energy input in fish farming has been increased consistently in the form of fossil fuel, electricity, fertilizers, feed, chemicals and machinery causing environmental problems (Rahman and Barmon, 2012; Kumar *et al.,* 2019). Fish productivity evaluation based on the energy input-output relationship is essential to make efficient use of existing natural resources and to ensure economic and environmental sustainability of IFF system under floodplains.

The main greenhouse gases (GHGs) emitted from agricultural activities are water vapour, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), contributing to global warming (IPCC, 2007). Currently, India is the third-largest producer of GHGs after China and USA and agriculture sector being the second most GHG emitting sector, shared 18.3% of total emissions (Anon., 2015; WRICAIT, 2017; FAOSTAT, 2018). In the aquaculture sector, sources of CO_2 emission are fertilizers, chemicals, fossil fuel and lime, while CH_4 is mainly produced from combustion of fossil fuel and enteric fermentation. The N_2O is produced naturally from soils and water through nitrification and denitrification (Chavez-Crooker *et al.,* 2010). It is estimated that the annual global N_2O emitted from the aquaculture sector was 0.09 million t, which is about 0.5% of global N_2O emission (Williams and Cruzan, 2010). There is no information available on GHG emissions and energy use efficiency of IFF systems in India. Keeping this in view, the current study was planned with the objective of assessing the productivity, economics, energy use efficiency and CO_2e emission from integrated fish-duck farming under floodplains of eastern India.

Materials and methods

Experiment and site details

The study was carried out during September 2018 to August 2019, aiming to assess productivity, economics, energy use efficiency and greenhouse gas emission from integrated fish-duck farming under floodplains of eastern India. For this purpose, a total of six experimental integrated fish-duck farming (IFDF) models were developed at the farmers’ fields at different locations *i.e.* 260.29’33.75”N; 84052’56.48”E (Jasauli Patti); 260.28’06.04”N; 84053’05.44”E (Jasauli Patti), 260.35’19.44”N; 84054’16.04”E (Chandrahiya), 260.35’11.92”N, 84054’02.87”E (Chandrahiya), 260.30’35.98”N, 84058’31.88”E (Chintamanpur) and 260.33’21.71”N, 85000’15.26”E (KhairimalJamunia) in East Champaran District, Bihar, India (Fig. 1). The size of ponds varied from 0.25 to 0.5 acre with an average water depth of 1.5 m.

India

Bihar

East Champaran District,

Bihar Experimental sites

Fig. 1. Geographical locations of integrated fish-duck farming system

About a month prior to fish stocking in the newly constructed ponds, fertilisation and manuring of the ponds were done by applying dung manure, urea, DAP and MOP at the rate of 1000, 45, 15 and 10 kg acre^{-1}, respectively, for the development of planktonic food. All the inputs and outputs were estimated on per acre basis to bring uniformity in the dataset and further computations. In each experimental pond, fingerlings of six cultivable fish species namely, *Catla catla* (catla, 20%), *Labeo rohita* (rohu, 15%), *Cirrhinus mrigala* (mrigal, 15%), *Hypophthalmichthys molitrix* (silver carp, 20%), *Ctenopharyngodon idella* (grass carp, 15%) and *Cyprinus carpio* (common carp, 15%) were stocked together @ 4000 acre^{-1} with an average body weight of 28.4±2.5 g. Supplementary feed *i.e.* mixture of mustard oil cake and rice bran in 1:1 ratio was supplied to the fish pond @ 1.0% of the fish biomass on a daily basis. Khaki Campbell ducks (@ 150 nos. acre^{-1}) having an average body weight of 620±12.5 g were kept inside a low-cost shed constructed over pond dike and fed supplementary feed (mixture of wheat bran, paddy and maize) at the rate of 50-60 g day^{-1} duck^{-1} and rest of the feed they obtained from the pond.

Assessment of growth, survival and productivity

For the estimation of growth rate of the stocked fish species, fish samples were collected using dragnet, and average body weight of each species was recorded on a monthly basis and accordingly, the dose of feed was adjusted. Survival rate was estimated based on the number of fishes stocked and recovered after a year of culture period. After one year, complete harvesting of fish was done and biomass weighed directly on a digital weighing balance with an accuracy of ±0.1 kg. Additionally, growth rate and average body weight of ducks were also estimated.

Water analysis

Total water volume required for fish culture throughout the culture period was estimated based on water storage capacity while maintaining an average depth of 5.5±0.5 feet in each pond, and water loss through seepage and evaporation. During rainy season water filling was not required, however, rainwater volume which was received into the ponds could not be estimated and hence, was not considered in the analysis. Water parameters such as pH, temperature, dissolved oxygen and electrical conductivity were evaluated fortnightly throughout the culture period using digital multi-water parameter analyzer (Hanna, HI 98194).

Economic analysis

The total cost of all the inputs and outputs in IFDF model was analysed based on the current price in the local market. The net profit was calculated by subtracting the total input cost from the total output cost. Benefit-cost ratio (BCR) was computed by dividing the gross income to the total expenditure (Devi *et al.,* 2014). The depreciation cost of capital expenditure (non-recurring input cost, like pond construction, bore-well and 5HP diesel/motor pump set) was calculated using the formula described by Kahlon and Singh (1980): DC = TC−SL /T, where, DC is annual depreciation cost; TC=Total cost; SL= Salvage value and T= Economic life in years.

The fish equivalent yield was calculated by dividing farm gate price of fish to the gross economic return. The farm gate price of fish, duck and egg were taken as ₹160 kg^{-1}, ₹150 kg^{-1} and ₹5 unit^{-1}, respectively.

Energy analysis

Average data of all inputs such as labour, fossil fuel, electricity, fertilizers, manure, lime, feed, fingerlings, ducklings, water, machinery and output as fish, eggs and ducks produced were recorded to analyse energy input-output relationship. Farm machineries like diesel pump set or electric motor were employed for water filling, hence, their energy input was estimated based on their distributed weight. The distributed weight was calculated using the following formula as described by Soni *et al*. (2013):

$$\text{Distributed weight} = \frac{\text{Machinery unit weight}}{\text{Economic life}\times 365\ (366\text{ for leap year})\times 8)}$$

Resource inputs and outputs were converted from physical unit to energy (MJ), using conversion coefficients (Table 1) and energy indices were calculated using the following formulae (Rahman and Barmon 2012; Soni *et al.,* 2013; Kumar *et al.,* 2019) :

$$\text{Energy use efficiency (EUE)} = \frac{\text{Total energy output}}{\text{Total energy input}}$$

$$\text{Human energy profitability (HEP)} = \frac{\text{Total energy output}}{\text{Labor energy input}}$$

$$\text{Water energy profitability (WEP)} = \frac{\text{Total energy output}}{\text{Water energy input}}$$

Renewable energy (RE) = (Labour + Manure + Feed + Seed)
Nonrenewable energy (NRE)=(Fuel + Electricity + Fertilizer + Chemical + Machinery)

Calculation of greenhouse gas (GHG) emission

In the current IFDF, fertilizers, manure, lime, fossil fuel and electricity were the major sources of CO_2, CH_4 and N_2O emission. Therefore, GHG emission was calculated and expressed as carbon dioxide equivalent (CO_2e) using emission factor of each input (Table 2). The computation of direct N_2O emission was done based on the fact that about 1% (0.71 - 1.80%) of total nitrogen added to the food production system is converted to N_2O (Hu *et al.,* 2012; IPCC, 2014). In the IFDF system, nitrogen was added to the fish ponds through urea, manure and ducks excreta. For the quantification of nitrogen added to the system was done considering N content in manure and duck excreta as 0.6 and 1.12%, respectively (Hargreaves, 1998; Naylor *et al.,* 2000; Robb *et al.,* 2017). The eco-efficiency (EE), the ratio of economic creation to ecological destruction was estimated following Soni *et al.* (2018).

$$\text{Eco-efficiency (EE)} = \frac{\text{Net economic return (₹)}}{\text{Environmental impact (kg } CO_2e \text{ emitted)}}$$

Data analysis

For the estimation of growth, productivity, economics, energy efficiency and GHG emission, analysis was performed after taking the average of inputs and outputs of all the IFDF systems. Data analysis was done using MS Excel.

Table 1. Resource input, output and their energy coefficient

Sl. No.	Resource input	Unit	Energy eq. (MJ Unit^{-1})	Reference
1	Labour	man-hr	1.96	Singh and Mittal (1992)
2	Diesel	lit	47.87	Singh and Mittal (1992)
3	Electricity	kWh	3.6	Ozkan *et al.* (2004)
4	Fingerlings	kg	4.52	Rahman and Barmon (2012)
5	Ducks	kg	5.44	Gopalan *et al.* (1971)
6	Mustard oil cake	kg	14.4	Rahman and Barmon (2012)
7	Rice bran	kg	18.9	Soni *et al.* (2013)
8	Wheat bran	kg	9.02	Rahman and Barmon (2012)
9	Paddy, maize	kg	14.7	Singh and Mittal (1992)
10	Minerals	kg	2.00	Wells (2001)
11	N	kg	60.6	Singh and Mittal (1992)
12	P_2O_5	kg	11.1	Singh and Mittal (1992)
13	K_2O	kg	6.7	Singh and Mittal (1992)
14	Dung manure	kg	0.3	Taki *et al.* (2012)
15	Lime	kg	1.32	Soni *et al.* (2013)
16	Water	m^3	1.02	Tuti *et al.* (2012)
17	Machinery (all)	kg	68.4	Singh and Mittal (1992)
Resource output				
1	Fish	kg	4.61	Rahman and Barmon (2012)
2	Eggs	Kg	7.57	Gopalan *et al.* (1971)
3	Duck	kg	5.44	Gopalan *et al.* (1971)

Table 2. Emission factor for CO_2e emission from various inputs

Sl. No.	Source	Gas	Emission factor	Unit	Reference
A	GHGs emission from production, transportation and storage of agricultural chemicals				
1	Fertilizer				
	N	CO_2	1.3	kg CO_2e kg^{-1} N	Lal (2004)
	P_2O_5	CO_2	0.2	kg CO_2e kg^{-1} P_2O_5	Lal (2004)
	K_2O	CO_2	0.15	kg CO_2e kg^{-1} K_2O	Lal (2004)
2	Lime ($CaCO_3$)	CO_2	0.16	kg CO_2e kg^{-1}	Lal (2004)
B	Utilisation for cultivation				
1	Fossil fuel	CO_2	0.0741	kg CO_2e MJ^{-1}	IPCC (2006)
		CH_4	0.0025	kg CO_2e MJ^{-1}	IPCC (2006)
		N_2O	0.00018	kg CO_2e MJ^{-1}	IPCC (2006)
2	Electricity	CO_2	0.74	kg CO_2e kWh^{-1}	IPCC (2006)
3	Lime ($CaCO_3$)	CO_2	0.396	kg CO_2e kg^{-1} lime	IPCC (2006)
4	Urea	CO_2	0.733	kg CO_2e kg^{-1} urea	IPCC (2006)
5	Direct N_2O from N inputs (fertilizer + manure)	N_2O	3.1	kg CO_2e kg^{-1} N	Hu *et al.* (2012) IPCC (2014)

Results and discussion

After a culture period of one year, the survival rate of fishes was estimated to be 87.5±2.5%. The average growth rate was estimated to be minimum and maximum as 27.4 g month^{-1} and 31.7 g month^{-1} of mrigal and grass carp, respectively (Fig. 2). The studies have reported monthly average weight gain for IMCs reared in integration with Indian Runner duck while maintaining fish stocking density as 6000 fingerlings ha^{-1} reported to be 70-80, 60-68 and 57 g for catla, rohu and mrigal, respectively (Chand *et al.,* 2006; Kumar *et al.,* 2012). These variations can be due to differences in the species stocked, stocking density, ratio and size at the time of stocking, feed, duck variety and local environmental factors. The maximum and minimum average body weight after harvesting was estimated to be 823.2 and 465.2 g of grass carp and mrigal, respectively, whereas, Kumar *et al.* (2012) reported average body weight of IMCs about 550 g with a survival rate of 63%. Moreover, the fish yield from current IFDF was estimated to be 2.25 t acre^{-1} year^{-1}, whereas Kumar *et al.* (2012) reported productivity of 0.84 t acre^{-1} year^{-1} under duck-fish integrated farming in Chhattisgarh State in the eastern India. Various other studies have reported fish productivity under IFDF from 0.8 to 2.8 t acre^{-1} year^{-1} (Cruz and Shehadeh, 1980; FAO, 2001; Biswas *et al.,* 2013). The analysis revealed that to produce 1.0 kg of fish, 8.15 m^3 water (excluding rain/runoff water) was required for the culture period of one year under floodplains of eastern India.

The survival rate of ducks was estimated to be 90%. Growth analysis of ducks showed that they reached an average body weight of 1630 g at the end of a year from an average body weight of 620 g at the time of stocking with an average growth rate of 28 g month^{-1} (Fig. 3). Furthermore, they produced a total of 19620 nos. of eggs during the culture period of one year. Fish equivalent yield of the present IFDF

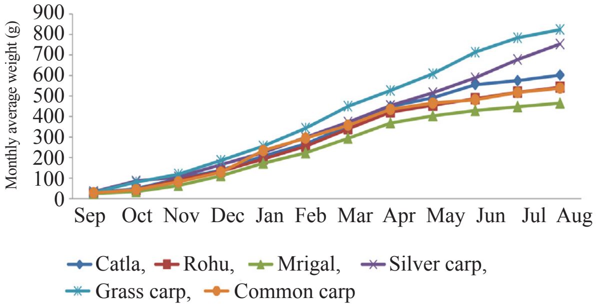

Fig. 2. Growth of fishes

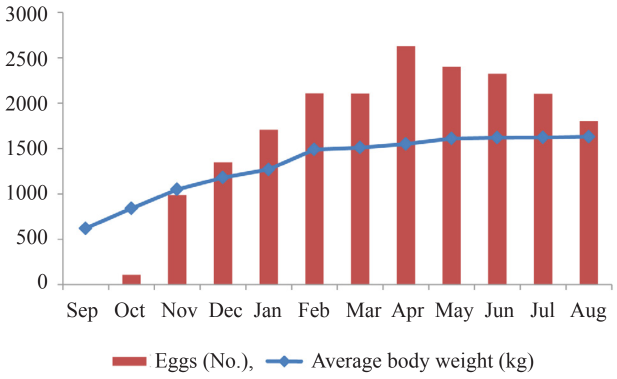

Fig. 3. Monthly average body weight (g) of ducks and number of eggs produced

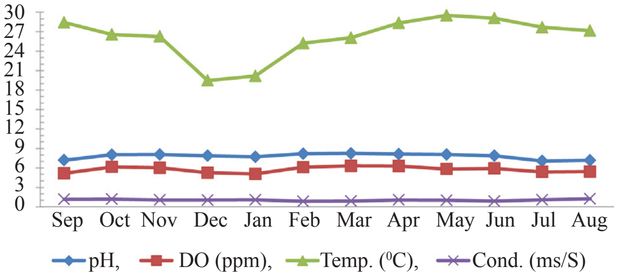

Fig. 4. Average pH, DO (ppm) and temperature (^{0}C) and EC of pond water

model was 3.06 t acre^{-1} year^{-1}, which is two and a half times higher than national average aquaculture productivity *i.e.* 1.2 t acre^{-1} year^{-1} (Anon., 2018). The documented fish productivity under floodplains in the eastern India is 0.02 to 0.45 t acre^{-1} year^{-1} only (Anon., 2018; Das *et al.*, 2019), which can be enhanced several folds if IFDF system is scientifically adopted and managed.

Water analysis

Water parameters like pH, dissolved oxygen (DO), temperature and electrical conductivity (EC) were analysed throughout the culture period and annual average pH, DO, temperature and EC were estimated to be 7.8±0.42, 5.74±0.5 ppm, 26.16±3.20C and 1.04±0.12 mS cm^{-1}, respectively (Fig. 4). The minimum pH, DO and temperature were recorded as 7.07 (July), 5.06 ppm (January) and 19.48^{0}C (December), respectively. The maximum pH, dissolved oxygen and temperature were recorded as 8.25 (March), 6.31 ppm (March) and 29.52^{0}C (May), respectively. The EC levels ranged between 0.84 mS cm^{-1} and 1.25 mS cm^{-1}. It was noticed that DO, pH and temperature remained within the optimum level of tolerance throughout the culture period. However, temperature in the months of December and January was recorded to be as low as 6 to 8^{0}C on some days; therefore growth rate of fishes particularly of IMCs was observed to be lowest during this period.

Energy analysis

Energy analysis of the current IFDF revealed total energy input as 111.8 and total energy output as 21.2 GJ. The renewable and non-renewable energy inputs were estimated to be 79.7 and 32.1 GJ, respectively (Table 3). Moreover, HEP and WEP were found to be 12.9 and 1.1, respectively. Major source of energy inputs like seed (fingerlings and ducks), feed (fish feed and duck feed) and water together contributed about 86% of total energy input, whereas fossil fuel and electrical energy together shared 8.9%. Other energy sources like labour, fertilisers, manure, lime and machinery collectively contributed 5.1%. Further, energy analysis revealed that on an average 36 MJ energy was spent to produce 1.0 kg fish equivalent. The EUE ratio was found to be 0.19, indicated that current IFDF in floodplain ecosystems is energy inefficient. Though, EUE of different IFS varied from 3.39-8.16 in rice-based IFS in the middle Indo-Gangetic plains of India and 0.45 in fish production under rain-fed ecologies of Thailand (Soni *et al.*, 2013), 2.27 in crop-dairy-fish-poultry IFS under coastal lowlands of India (Parmesh *et al.*, 2019), 0.11 in fish-prawn farming systems in Bangladesh (Rahman and Barmon, 2012) and 2.63 in crop-livestock-poultry IFS under irrigated ecologies of eastern India (Kumar *et al.*, 2019). The net economic return per gigajoule of energy input was estimated to be ₹2096.5 acre^{-1} year^{-1}.

Economics

The economic analysis of the current IFDF showed that the recurring cost of cultivation was ₹181082 and non-recurring cost ₹76000 acre^{-1} year^{-1}. The gross and net income were analysed and found to be ₹491475 and ₹234393 acre^{-1} year^{-1}, respectively (Table 4). Moreover, Majhi (2018) reported the average net income from IFDF system as ₹88900 acre^{-1} year^{-1} from Purulia District of West Bengal, India. The benefit-cost ratio was found to be 1.91, whereas Katiha *et al.* (2005) reported the BC ratio of different aquaculture systems ranged from 1.22 to 1.86. The current IFDF system provided employment to as many as 105 man-days in a year. It was also noted that about ₹84/- only was invested to produce 1.0 kg fish equivalent biomass. The percentage share of the recurring (operational) and non-recurring (fixed) cost was estimated to be 70.4 and 29.6%, respectively. The analysis showed that feed, seed (fingerlings and ducks) and labour expenditure contributed 50.7, 19.8 and 14.5%, respectively to the total recurring expenditure cost, whereas diesel and electricity collectively shared 8.3% and fertilizers/manure shared 6.6% only. Usually, the cost of feed in freshwater aquaculture production systems has been accounted to be 60-70% of the total operational expenditure (Rana *et al.*, 2009; Ayyappan *et al.*, 2017), however, in the current IFDF system, feed was prepared from locally available ingredients priced at ₹17 kg^{-1}, which was almost 40-50% lesser than the commercial feed available in the local market. It is important to mention that total operational expenditure in the current IFDF required about 20% lesser than most of the aquaculture systems adopting commercial diets, while getting no lesser productivity. The IFDF has immense potential to provide improved food and nutritional security, employment and to uplift livelihood status of the fish farmers in the eastern India (Majhi, 2018; Prasad *et al.*, 2020).

Table 3. Energy input-output relationship results

Sl. No.	Resource	Unit	Resource input	Energy eq. (MJ)
1.	Labour	man-hr	840	1646.4
2.	Diesel	lit	160	7659.2
3.	Electricity	kWh	637	2293.2
4.	Fish fingerling	kg	80	361.6
5.	Ducks	kg	60	326.4
6.	Fish/ duck feed			
	Mustard oil cake	kg	1200	17280
	Rice bran	kg	1100	20790
	Minerals	kg	150	300
	Wheat bran	kg	1000	9020.0
	Paddy	kg	1000	14700.0
	Maize	kg	1000	14700.0
7.	Fertilizer/Manure			
	N	kg	23.4	1418.0
	P_2O_5	kg	6.9	76.6
	K_2O	kg	6	40.2
	Manure	kg	2000	600.0
8.	Lime	kg	500	660.0
9.	Water	m^3	18350	18717.0
10.	Machinery (all)	kg	19.12	1307.8
Total energy input (GJ)				111.8
Output				
1.	Fish	kg	2250.0	10372.5
2.	Eggs	kg	1275.3	9654.0
3.	Duck	kg	222.5	1210.4
Total energy output (GJ)				21.2

One gigajoule (GJ)=1000 megajoule (MJ)

Table 4. Economics of integrated fish-duck farming system in floodplain ecosystems

SN.	Resource	Unit	Resource input	Price (₹ per unit)	Expenditure (₹)
A	Recurring input				
	i. Labour	Man-days	105	250	26250
	ii. Diesel	Liter	160	70	11200
	iii. Electricity	kWh	637	6	3822
	iv. Fish fingerlings	kg	80	300	24000
	v. Duck	kg	60	200	12000
	vi. Feed				
	Mustard oil cake	kg	1200	18	21600
	Rice bran	kg	1100	13	14300
	Wheat bran	kg	1000	16	16000
	Paddy	kg	1000	15	15000
	Maize	kg	1000	16	16000
	Minerals	kg	150	60	9000
	vii. Fertilizer and Manure				
	Urea	kg	45	8	360
	DAP	kg	15	30	450
	MOP	kg	10	10	100
	Manure	kg	2000	2.5	5000
	viii. Lime	kg	500	12	6000
B	Non-recurring input (Annual depreciation value)				
	i. Pond construction	1 acre			48000
	ii. Duck shed (low cost)	1			15000
	iii. Bore-well and pipes	150' deep			5000
	iv. 5 hp electric motor or diesel pump set	1			8000
C	Total expenditure (A+B)				257082
D	Resource output				
	i. Fish	kg	2250	160	360000
	ii. Eggs	Number	19620	5	98100
	iii. Duck	kg	222.5	150	33375
E	Gross income (Total of D) (₹)				491475
F	Net income (E-C) (₹)				234393

GHG emission

The total CO_2 e emission was estimated to be 1.75 t acre^{-1} year^{-1} from the current IFDF models. Further, analysis revealed that 0.56 kg CO_2 e was emitted to produce 1.0 kg fish equivalent from current IFDF, while Robb *et al.* (2017) reported 1.84 kg CO_2e emission to produce one kilogram of fish fed concentrated diets. Moreover, GHGs emission from rice, mutton and milk production is reported to be 5.65 kg CO_2e kg^{-1} rice, 45.54 kg CO_2e kg^{-1} mutton and 2.4 kg CO_2e kg^{-1} milk (Vetter *et al.*, 2017). Therefore, it is evident that current IFDF created much lesser environmental harm than crops and livestock-based farming systems. The GHG emission from current IFDF system was contributed maximum (63%) by fossil fuel and electricity which can be minimised to some extent if solar energy is used. Solar energy can play a vital role in making IFDF system more energy efficient and environmentally friendly as it will not only minimise the use of non-renewable energy inputs but also GHG emission, which has been realised to be extremely essential nowadays. The prevailing solar radiation in the eastern India is reported to be 4.95 kWh m^{-2} day^{-1} for about 300 days in a year (Mishra *et al.,* 2019) which can be utilised using solar operated machinery (solar pumping system, solar aerator and solar lighting), in order to bring sustainability in the fish-based IFS models. Further, analysis revealed that fossil fuel and electricity contributed 34 and 29%, respectively to the total emission. Moreover, CO_2e emission from nitrogen application was estimated to be 20% and rest of the emission was contributed by the production, storage and transportation of fertilizers, urea and lime application (Fig. 5). The eco-efficiency of the current IFDF resulted in net economic return of ₹160.0 kg^{-1} of CO_2e emission.

The study attempted to evaluate productivity, economic viability, energy use efficiency and environmental impact of integrated fish-duck farming under floodplains in eastern India. Fish productivity of current IFDF system was estimated to be higher than that of national average. Therefore, IFDF farming can be adopted in unutilised/underutilised floodplain resources to enhance the productivity and profitability. The IFDF system has synergistic and symbiotic effects rather than additive and self-contained and also, it is easier to manage without any reduction in economic return. The IFDF system is economically and environmentally viable and can provide on-farm employment to many. The GHG emission was found to be comparatively much lower than fish farming without integration and fed concentrated diets, and rice, mutton and milk. Adoption of IFDF under floodplains of the eastern India can improve productivity, socio-economic sustainability while causing lesser environmental harms.

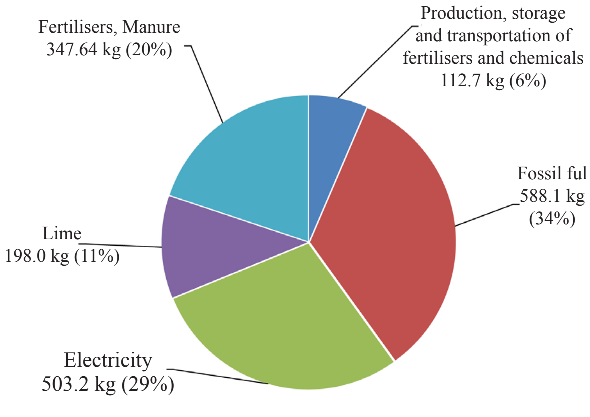

Fig. 5. Contribution of CO_2e emission from different inputs used in IFDF system

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