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Seasonal Dynamics of Phytoplankton in Integrated Paddy-cum-Fish Culture

M.S. Dorothy[1], N. Felix[2], B.K. Bhattacharjya[3], B. Ahilan[1], A. Uma[1], P. Chidambaram[1]

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ABSTRACT

Background: An experimental study was conducted during June-November 2020 at Tungjoy village of Manipur, India, to assess the assemblage pattern, abundance and seasonal dynamics of phytoplankton in simultaneously integrated paddy-cum-fish culture (IPFC).

Methods: The experimental IPFC fields were prepared by enhancing width and height of dykes and constructing central refuge pond. Rice saplings were manually transplanted into the prepared fields in June 2020 while the common carp fingerlings were introduced 30 days after rice-transplantation. Both rice and fish were harvested in November 2020. Assemblage pattern, abundance and dynamics of phytoplankton, soil nutrients and water quality were analysed for three seasons (monsoon, post-monsoon and winter) in paddy fields without fish (PF) compared with IPFC fields. Relevant fish growth parameters were analysed on monthly basis.

Result: The study recorded 37 genera of phytoplankton belonging to 25 families and 18 orders falling under class Bacillariophyceae, Chlorophyceae and Cyanophyceae. Bacillariophyceae was the most diverse class. Phytoplankton density ranges from 14.00±1.57 × 10^3 to 33.25±3.60 × 10^3 μL^{-1} and 9.05±2.27 × 10^3 to 33.06±3.45 × 10^3 μL^{-1} in PF and IPFC, respectively, wherein Chlorophyceae dominated during monsoon and post-monsoon. Phytoplankton in IPFC was lower than PF, indicating effective utilisation by the reared fish. Fish production from IPFC fields was 326 kg ha^{-1} with 83% survival rate while rice production was enhanced by 7.4% as compared to rice monoculture.

Key words: Phytoplankton, Plankton dynamics, Rice-fish culture, Terrace farming.

INTRODUCTION

Rice cultivation in wet fields involves various agronomical processes that undergoes a series of growth stages of paddy within a short span of time (Halwart and Gupta, 2004). These wet fields are rich in nutrients and harbors vast assemblages of aquatic flora and fauna, including fish (Coche, 1967; Edirisinghe and Bambaradeniya, 2006). Realising the potential of rearing fish by integrating with rice cultivation, the initial form of harvesting wild entry fishes advanced further in to stocking selected fish species and rearing to desirable size. Rice remained the chief crop while fish is an additional food crop and often reared with no external feed. In such system, the reared fish depends on the naturally available food sources in the field such as planktons, soft aquatic plants and other small organisms (Das *et al*., 2007). Phytoplankton, which is the major primary producer of an aquatic food web, thus, plays a vital role in productivity of the rice-fish ecosystem. Planktons are dynamic and their assemblages pattern, diversity and density are influenced by various biotic and abiotic factors, particularly nutrient availability, temperature, altitude, rainfall, sunlight exposure, depth of water body, *etc* (Saikia *et al*., 2015). Omnivore fishes such as common carp effectively utilise planktons as fish food (Das, 2018). Thus, to understand the biological productivity of rice-fish ecosystem, it is pertinent to understand the compositions of phytoplankton, their nature of assemblage and dynamism. Earlier studies on plankton community diversities in rice fields were restricted to waterlogged lowland and flood-plain fields (Das *et al*., 2007; Kumar and Sahu, 2012; Shivakumara and Pattar, 2015; Awasthi, 2021). Thus, this study could form a baseline document for phytoplankton in IPFC, especially for terraced rice fields at high altitude regions with temperate climate. Besides, common carp is one of the most commonly reared fish in high altitude regions as well as in integrated farming systems due to its hardy nature, especially, the ability to tolerate fluctuating temperature and water turbidity (Wahab *et al*.,1995; Bera *et al*., 2016).

[1]Dr. M.G.R. Fisheries College and Research Institute, Ponneri-601 204, Tamil Nadu, India.
[2]Directorate of Incubation and Vocational Training in Aquaculture, Muttukadu-603 112, Tamil Nadu, India.
[3]ICAR-Central Inland Fisheries Research Institute, Regional Centre, Guwahati-781 006, Assam, India.

Corresponding Author: N. Felix, Directorate of Incubation and Vocational Training in Aquaculture, Muttukadu-603 112, Tamil Nadu, India. Email: n.felix@tnfu.ac.in

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MATERIALS AND METHODS

The study was carried out under Dr. M.G.R. Fisheries College and Research Institute, Ponneri, Tamil Nadu at Tungjoy village (25°48′N latitude and 94°23′E longitude) at an elevation of 4350-4398 ft under Senapati district of Manipur State in the north eastern region (NER) of India during June 2020 to November 2020. Six uniform flow through terraced rice fields (50 m^2 each) were prepared with enhanced dykes (0.7 m height and 0.5 m width), central refuge pond (2.5 m dia × 1.0 m depth) and netted gauge inlets and outlets, following Bera *et al.* (2016). The wet fields were composted and puddled prior to transplantation of rice seedlings. Rice fields without fish (PF) were compared with IPFC having common carp (*Cyprinus carpio*) stocked at advanced fingerling stage (6.95±0.67 g mean weight and 5.98±0.47 cm mean total length), obtained from ICAR-Research Complex for NEH-Imphal, Manipur, @ 0.6 nos. m^{-2} following (Das, 2018). Fishes were released to the fields 30 days after rice transplantation to ensure proper rooting of rice plants. A short-stalked, long duration local variety rice (*Anga dodzii*) was used for the study. No chemical input like manures/ fertilisers, pesticides or fish feed were used in the fields during the study. Manual harvest of both rice and fish were done in mid-November 2020.

Phytoplankton samples were collected for three different season as; before stocking fish in July 2020 (Southwest monsoon), during the mid period of paddy growing season in September (Post monsoon) and at end of the experimental period in November (winter) using plankton net (25 µm mesh size) and fixed in 5% formalin on-site. Identification of phytoplankton was done using a trinocular research Microscope (Dewinter) with digital camera (DIGI 510 CCD) fitted with an image analyser software at 16×40 and 16×10 magnification with bright field and phase contrast illumination. Quantitative analysis of phytoplankton was carried out using Sedgewick-R after counting chamber (S-R cell) with 1 ml subsample in the counter and counting of plankton units present within 10 random squares of the cells and computed the density with Stirling (1985) as follow:

$$\text{Number of cell unit in a litre of water} = \frac{A \times 1000 \times C}{V \times F \times L}$$

Where,
A= Total no. of plankton counted.
C= Volume of final concentrate of the sample in ml.
V= Volume of a field in cubic mm.
F= No. of fields counted.
L= Volume of original water in litre.

The phytoplankton were then identified up to genus level and enumerated using standard identification manual (*e.g.* Bellinger, 1992; Guiry and Guiry, 2018). The mean number of phytoplankton was recorded and expressed as unit per litre (μL^{-1}) of water.

Growth performance of fish was assessed at 30 days intervals by random sampling from IPFC field for total length (cm) and weight (g), percentage weight gain (WG%) and daily weight gain (DWG) by following the formulae:

$$WG\ (\%) = \frac{FW - IW}{IW} \times 100$$

$$DWG\ (g) = \frac{FW - IW}{\text{No. of culture days}}$$

Where,
IW= Initial weight (g).
FW= Final weight (g).

Survival rate was recorded after final harvest using the formula:

$$\text{Survival rate (\%)} = \frac{\text{Nos. of fish harvested}}{\text{Nos. stocked}} \times 100$$

Rice was manually harvested at 180 days using sickle, threshed, sundried and winnowed before milling and dehulled for final rice yield.

Salient physico-chemical parameters of water in the experimental fields were recorded fortnightly which includes water depth, pH, dissolved oxygen (DO), temperature and total dissolved solids (TDS) estimated using standard measuring scale, digital pH meter (pHep, HANNA, Italy), DO meter (Euktec DO, India) and TDS reader (Aquafine, India) respectively. Total alkalinity and total hardness were analysed titrimetrically following (Baird *et al*., 2012). Rainfall report was obtained from Anonymous (2021) and analysed to arrive at the maximum, minimum and average precipitation levels. For nutrient profiling of soil, the soil samples were collected for three seasons following Dhaliwal *et al.* (2011) wherein hydrogen ion concentration was obtained using a soil pH meter. Iron, manganese, zinc and copper content in soil samples were analysed following (APHA, 2005). Available nitrogen in soil was anaylised following Subbiah (1956), available P_2O_5 (Bray and Kurtz, 1945) and neutral ammonium acetate extractable K_2O (Jackson, 1973). SPSS statistical software package was used to analyse the experimental data which were subjected to one-way ANOVA.

RESULTS AND DISCUSSION

Qualitative and quantitative analysis of phytoplankton

The present study identified 37 genera belonging to 25 families, 18 orders under 3 major classes *viz*., Bacillariophyceae, Chlorophyceae and Cyanophyceae (Table 1), most of which were also reported by Gupta *et al.* (2013) and Awasthi (2021) from water-logged rice fields of Arunachal Pradesh and Das *et al.* (2014) from floodplains of Assam. Bacillariophyceae was the most diverse class with 19 genera, 14 families and 9 orders as Achnanthales, Bacillariales, Cymbellales, Fragilariales, Melosirales, Naviculales, Rhopalodiales, Surirellales and Tabellariales. The high diversities of diatoms in rice fields irrespective of the seasons agrees with the report of (Gupta *et al.,* 2013). Among diatoms, Naviculales was most the dominant order with 4 families and 7 genera. This study recorded 7 orders, 8 families and 14 genera of Chlorophyceae with dominance of *Spirogyra, Chlorella, Ulothrix, Zygnema* and *Desmidium.* Khalil *et al.* (2021) also reported abundance of these green algae in less polluted water with slightly acidic pH condition. Cyanophyceae was represented by only 2 orders, 3 families and 4 genera comprising *Microcystis, Lyngbya, Oscillatoria* and *Phormidium,* all of which are found in both PF and IPFC. These blue green algae play essential role in rice-field ecosystem as they have the capability to perform mutually compatible functions like photosynthesis and nitrogen fixation, thereby supporting the growth and productivity of rice plants (Shivakumara and Pattar, 2015).

The study recorded the highest numerical abundance of phytoplankton during initial study period, before introduction of fish (33.25×10^3 to 33.06×10^3 μL^{-1}) during southwest monsoon season with almost equal densities in both PF and IPFC fields (Table 2) which apparently were due to composting and puddling of the fields that enhances nutrients availability in the fields. Besides, the temperature were warmer and received high rainfall that periodically replenishes nutrients into the fields with the run-off from the upper stretches. During monsoon, Chlorophyceae dominated the fields contributing upto 58.0% to 59.6% of total phytoplanktons, followed by Bacillariophyceae (35.4% to 38.5%) and Cyanophyceae contributing a meagre 3.6% to 5.0% (Fig 1). The dominance of Chlorophyceae may be attributed to warmer temperature and high nutrient availability. Other apparent reason is due to sufficient direct sunlight exposure of the fields as the rice plants were short and less dense.

In post-monsoon months, the density in PF was 31.63×10^3 μL^{-1} which showed slight reduction (5%)

Table 1: Phytoplankton taxa recorded in the experimental fields.

Group	Order	Family	Genus	PF	IPFC
Bacillariophyceae	Achnanthales	Achnanthaceae	*Achnanthidium*	+	+
	Bacillariales	Bacillariaceae	*Nitzschia*	++	++
		Catenulaceae	*Amphora*	++	+
	Cymbellales	Cymbellaceae	*Cymbella*	++	++
		Gomphonemataceae	*Gomphonema*	+	+
	Fragilariales	Fragilariaceae	*Diatoma,*	+	+
			Fragilaria	+	+
			Synedra	+	+
	Melosirales	Melosiraceae	*Melosira*	+	+
	Naviculales	Amphipleuraceae	*Amphipleura*	+	+
			Frustulia	+	+
		Naviculaceae	*Navicula*	++	++
			Gyrosigma	+	+
		Pinnulariaceae	*Pinnularia*	++	++
			Pleurosigma	+	+
		Stauroneidaceae	*Craticula*	+	+
	Rhopalodiales	Rhopalodiaceae	*Rhopalodia*	+	+
	Surirellales	Surirellaceae	*Surirella*	+	+
	Tabellariales	Tabellariaceae	*Tabellaria*	+	+
Chlorophyceae	Chlorellales	Chlorellaceae	*Chlorella*	++	+
	Desmidiales	Closteriaceae	*Closterium*	+	+
		Desmidiaceae	*Bambusina*	+	+
			Cosmarium	+	+
			Desmidium	++	++
			Hyalotheca	+	+
			Pleurotaenium	+	+
	Oedogoniales	Oedogoniaceae	*Oedegonium*	+	+
	Oscillatoriales	Microcoleaceae	*Arthrospira*	+	+
	Sphaeropleales	Microsporaceae	*Microspora*	+	+
	Ulotrichales	Ulotrichaceae	*Ulothrix*	++	++
	Zygnematales	Zygnemataceae	*Mougeotia*	+	+
			Spirogyra	+	++
			Zygnema	+	++
Cyanophyceae	Chroococcales	Microcystaceae	*Microcystis*	+	+
	Oscillatoriales	Oscillatoriaceae	*Lyngbya*	+	+
			Oscillatoria	+	+
		Phormidiceae	*Phormidium*	+	+

+ Indicate the presence of the identified plankton; ++ indicates dominance; PF= Paddy field without fish; IPFC= Integrated paddy-cum-fish culture.

compared to that during monsoon season while in contrast, a drastic reduction of phytoplankton abundance (64%) was recorded in IPFC fields 60 days after fish stocking (Table 2). The reduction of plankton densities in IPFC fields as compared to PF suggested effective harvesting of phytoplankton by the reared fish, as no external feed and manure/fertilizers were used. Besides, common carps are hardy in nature and have potential to feed on a wide range of planktons, soft aquatic plants and small organisms (Ghost *et al*., 1985; Halwart and Gupta, 2004; Das *et al*., 2007; Rahman *et al*., 2008). With the onset of winter season, phyotoplankton density drastically declined in all the experimental fields which may attribute to reduced temperature, less rainfall and poor nutrient availability as evident from the soil nutrient profile (Table 3). Besides, with increased in density of rice plants and fish biomass, there were higher competition for food and space among the reared fish which was clearly reflected in drastic reduction of phytoplankton densities in IPFC fields (Fig 1).

Biogrowth of fish and survival rate

The reared fish gained an average of 58.38±1.41 gm during the 120 days experimental period from initial 6.89±0.11 gm to final weight of 65.27±1.32 gm with percentage weight gain of 850.71±24.55 % and daily weight gain of 0.49±0.01 gm day^{-1}. Common carp is omnivorous with bottom-feeding nature, burrowing into soft sediments and detritus (Rahman *et al*., 2006). This species also tolerates wide water temperature and turbidity and therefore, thrives well in shallow water, such as rice fields (Wahab *et al*.,1995; Bera *et al*., 2016). Besides, water bodies with earthen bottom harbors a large consortium of aquatic flora and fauna thereby offered a favorable growing environment for detritus borrowing fishes such as common carps (Rahman *et al*., 2008). The monthly growth pattern showed highest growth rate during the initial 30 days of introduction which gradually reduced as the study period progress and found lowest in November month. This might have been due to the fact that the rice fields were initially prepared by decomposing aquatic plants and are rich in aquatic flora and fauna, which the fish might have effectively devoured when introduced. Moreover, during that phase, the paddy plants were short and had a lesser number of tillers wherein sunlight penetration was better, that might have contributed to the higher productivity of planktons and aquatic flora in the field. Besides, due to small rice plants and lesser tillers, the fish gets more space of movement for hunting food (Islam *et al*., 1998). The good growth rate of fish was maintained up to the second-month sampling, which might probably be due to the weeding wherein the small aquatic plants were uprooted, which later decomposed under the sunlight exposure leading to enriched natural food sources for the fishes to consume. The growth in the last two months was gradually reduced, which could be because of the growth of rice plants and thick tillers that blocked

Table 2: Numerical abundance of phytoplankton recorded in the experimental fields.

Parameters	July		September		November	
	Monsoon		Post-monsoon		Winter	
	PF	IPFC	PF	IPFC	PF	IPFC
Bacillariophyceae	11.00±1.11	11.50±1.02	12.17±1.15	7.14±1.77	6.60±1.15	4.40±1.00
Chlorophyceae	20.50±2.15	19.67±1.87	18.33±1.08	12.03±1.04	6.15±0.42	4.00±1.02
Cyanophyceae	1.75±0.34	1.89±0.56	1.13±0.51	1.00±0.38	1.25±0	0.65±0.25
Total	33.25±3.60	33.06±3.45	31.63±2.74	20.17±3.19	14.00±1.57	9.05±2.27

Values expressed as $\times 10^3$ μl^{-1} (Mean±SE, n=3); PF= Paddy field without fish; IPFC= Integrated paddy-cum-fish culture.

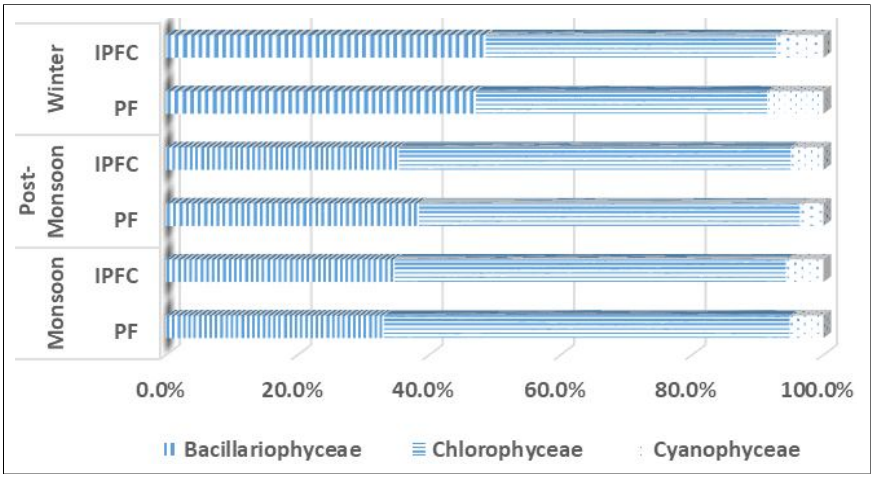

Fig 1: Percentage compositions of phytoplankton in three different seasons.

sunlight penetration almost completely and the natural organisms in the system might have reduced due to excessive browsing and feeding by the fish as the biomass increased. Moreover, from September month onwards, the water temperature began to reduce, which might have contributed to slower metabolism and, thereby, reduction in the growth rate of the fish (Chatterjee *et al*., 2004). The growth pattern also correlates with the plankton density which was highest in the initial month and least in winter, suggesting that the reared fish effectively consumes the planktons. Das *et al.* (2007) also reported a wide range of phytoplankton in the gut of common carp reared in natural water bodies. Survival rate of the fish recorded was 83%. The high survival rate may be due to the presence of paddy that act as shelter and apparently the good water quality aided by the mild flow of water through the terraces.

Fish and rice production

The current study recorded 326 kg ha^{-1} of fish in 4 months crop duration, which was higher than 186 kg ha^{-1} reported by Das (2018) from paddy fields stocked with common carp at a density of 6,000 Nos. ha^{-1} and fed with domestic kitchen waste or mustard oil cakes and rice bran. These might be due to the rich soil nutrients resulting from field composting and consequent plankton density. Ghost *et al.* (1985), in their reports, projected that one hectare of freshwater paddy field could produce up to 1,000 kg of fish. However, the actual production may vary based on species, input source, region and culture methods. Rice production in IPFC was 2379.5 kg ha^{-1} which was 164.5 kg ha^{-1} or 7.4% higher than PF (2215 kg ha^{-1}). The increased yield enhancement in the current study is in agreement with Saikia *et al.* (2015) who reported 7-30% increase even when some rice-growing areas are converted into fish refuge trends. This might be due to the nutrient enrichment in the soil contributed by fish through faecal matters, soil loosening due to the burrowing nature of the reared fish and various other direct or indirect roles played by fish in a rice-field system.

Meteorology, water quality and soil nutrient dynamics

Salient physico-chemical water quality parameters observed in experimental fields during the study period (Table 4) were conducive for rearing fish (Boyd, 1982). Good water quality with high dissolved oxygen level in the rice fields were attributed by cascading flow of water through the field's terraces. It is evident from the dynamic changes of phytoplankton that community assemblages pattern and densities changes with environmental conditions including nutrient availability, water quality, temperature, rainfall, water depth, sunlight exposure, size of plants, *etc*. Loss of soil nutrient in rice fields at the end of the study period were lower in IPFC when compared to PF which suggest that presence

Table 3: Seasonal dynamics of soil nutrient quality in the experimental fields.

Parameters	July		September		November	
	Monsoon		Post-monsoon		Winter	
	PF	IPFC	PF	IPFC	PF	IPFC
pH	6.23±0.38	6.41±0.42	6.57±0.12	6.83±0.06	6.82±0.33	6.78±0.11
Available N (kg ha^{-1})	232.04±6.91	233.35±6.19	210.35±3.15	220.84±1.98	203.76±2.16	210.96±1.56
Available P (P_2O_5 kg ha^{-1})	29.02±1.05	28.87±1.11	24.01±0.68	26.41±1.00	22.17±1.13	25.03±0.96
Available K (K_2O kg ha^{-1})	38.15±1.14	38.12±1.20	31.43±1.11	32.14±1.31	21.01±1.13	21.85±1.18
Fe (mg ha^{-1})	27.54±2.11	27.65±1.43	25.96±1.29	25.52±2.01	23.79±1.36	24.55±1.06
Mn (mg ha^{-1})	49.52±1.23	50.13±2.00	45.53±3.21	46.79±2.94	43.18±2.71	44.89±3.12
Zn (mg ha^{-1})	1.36±0.22	1.33±0.12	1.12±0.50	1.20±0.61	1.01±0.12	1.11±0.09
Cu (mg ha^{-1})	1.79±0.20	1.79±0.10	1.31±0.11	1.48±0.11	1.07±0.05	1.09±0.05

Values expressed as Mean±SE; n=3; PF= Paddy field without fish; IPFC= Integrated paddy-cum-fish culture.

Table 4: Seasonal variations of water quality in the experimental fields.

Parameters	July		September		November	
	Monsoon		Post-monsoon		Winter	
	PF	IPFC	PF	IPFC	PF	IPFC
Temperature (°C)	23.50±1.00	23.50±0.50	22.50±1.00	22.50±1.00	17.0±0.50	17.0±0.50
Depth (cm)	14.50±0.87	16.50±1.13	20.00±1.58	24.5±1.92	21.5±1.33	27.00±1.81
Dissolved oxygen (mg l^{-1})	5.46±0.91	5.52±0.41	6.82±0.18	6.11±0.42	7.90±0.91	7.55±0.18
pH	6.46±0.24	6.58±0.18	6.68±0.11	7.01±0.20	6.94±0.15	7.31±0.17
Total Alkalinity (mg l^{-1})	49.52±1.13	49.12±0.94	52.28±1.02	52.84±1.14	55.34±0.92	56.50±0.74
Total Hardness (mg l^{-1})	34.91±0.73	34.71±1.22	34.48±1.08	36.65±1.50	34.42±0.78	35.06±1.02
Nitrate-N (mg l^{-1})	2.58±0.09	2.46±0.12	2.32±0.15	2.06±0.10	1.84±0.59	1.48±0.88
TDS (mg l^{-1})	59.45±1.34	59.62±2.81	59.12±1.86	58.06±1.43	59.24±1.82	57.32±1.03

Values expressed as Mean±SE; n=3; PF= Paddy field without fish; IPFC= Integrated paddy-cum-fish culture.

of fish contributed to nutrient enrichment in rice fields through fecal matters, soil sediments loosening and increasing soil porosity while feeding and movement, *etc* thereby lowering the total soil nutrient loss during the culture period (Halwart and Gupta, 2004). Even though phytoplankton density in IPFC groups was recorded lower than that of PF, the actual phytoplankton production in IPFC groups might be higher due to enriched soil nutrients caused by the presence of fish but effectively grazed by the reared fish.

CONCLUSION

The present study showed that rice fields support rich phytoplankton assemblages with diverse communities in all the seasons. Green algae dominated the fields during monsoon and post-monsoon seasons whereas diatoms dominated during the winter. Diatoms flourished well in rice fields at low temperature and low nutrient availability. Common carp effectively harvested these naturally available phytoplankton as nutrient rich fish food for their growth, in absence of external supply of fish feed. The presence of fish in rice field contributed to enhanced soil nutrients and reduced the overall soil nutrient loss due to rice cultivation. About 326 kg ha^{-1} of fish and an enhanced rice production of 7.4% was observed in IPFC as compared to rice monoculture. IPFC emerges as a cost effective agricultural technology that can significantly enhance the nutritional well-being of rural farmers by optimising the utilisation of existing available land and water resources, concurrently fostering financial and environmental advantages.

Authors' contributions

The first author carried out the research work at field. All authors have made substantial contributions to planning and carrying out the research, analysis and interpretations of data and in preparation of the article.

Conflict of Interest

The authors declare no conflict of interest.

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