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Enhancing Aquaculture Productivity through Integrated Farming Systems: A Comparative Study of Fish-Pig and Fish-Duck Systems

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Integrated farming systems involving fish-animal are of high relevance in current scenario. Studies like this asses the suitability of such systems in improving the aquaculture productivity and overall benefits to the ecosystem. It plays a crucial role in optimizing the use of small water resources in rural areas to enhance animal production. Given the potential of pig and duck manure as nutrient inputs in fish culture, a grow-out trial was conducted in a 0.1 ha earthen pond located in Elangitampatty, Kezhisenkattupatti, and Asakkattuppatti villages of Kollihills Taluk in Namakkal

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district, Tamil Nadu. The pond was stocked with four carp species: Catla, Rohu, Mrigal, and Grass carp in a ratio of 40:20:30:10 at a density of 7500 fish per hectare. Three treatments were employed: (1) Control (T0), where fish were fed with commercial feed, (2) Integrated fish-duck farming (T1), and (3) Integrated pig-fish farming (T2). In the control group (T0), fish were fed commercial fish feed (24% crude protein, 4 mm pellet size) at 4% of body weight, while in T1 and T2, fish received 50% of the commercial feed and were supplemented with duck and pig excreta, respectively. After an 8-month grow-out period, fish weights and total production in each group were recorded. Water quality parameters, such as pH, dissolved oxygen, free carbon dioxide, alkalinity, and hardness, were measured using standard methods (APHA, 2019). Results showed that pond fertilization with pig and duck excreta promoted the growth of algae, phytoplankton, and zooplankton, providing a natural food source for the fish. Total fish production was highest in the fish-pig integration system (T2), with a recorded yield of 4960.09 kg. Catla (*Catla catla*) had the highest individual species yield, with a total harvested weight of 2225.98 kg, followed by Grass carp (*Ctenopharyngodon idella*) at 1490.37 kg. The final average weight of Grass carp in T0, T1, and T2 was 1047 ± 13.27 g, 1151.10 ± 12.85 g, and 1490.37 ± 13.52 g, respectively. For Catla, the final average weight in T0, T1, and T2 was 910 ± 9.45 g, 960 ± 10.26 g, and 980 ± 12.20 g, respectively. Similarly, Rohu in T0, T1, and T2 weighed 850 ± 7.98 g, 900 ± 11.23 g, and 910 ± 11.16 g, respectively, while Mrigal in T0, T1, and T2 weighed 600 ± 6.04 g, 720 ± 8.50 g, and 730 ± 10.56 g, respectively. The results highlight that the fish-pig system outperformed the fish-duck system in terms of fish productivity, which may be due to the better nutrient composition in pig manure and the genetic potential of the fish species. An economic analysis revealed that the fish-pig integration system generated the highest net income (Rs. 555,353.90) and benefit-cost ratio (2.12), indicating that integrated fish-pig farming is more profitable than both fish-duck farming and the control group without integration.

Keywords: Integrated farming; pig; fish; duck and commercial feed; costs; net return; BC ratio.

1. INTRODUCTION

The integrated farming system is one of the most effective methods for maximizing animal and plant protein production by optimizing the use of land, water, and waste resources in a sustainable manner. In this system, nothing is wasted, and the ecological balance is maintained. Recycling organic wastes for fish culture serves the dual purpose of environmental cleanup and economic gain (Shyam *et al.,* 2012). Recycling animal dung and other waste materials in aquaculture ponds is crucial for natural fish production, supporting sustainable aquaculture while reducing the need for supplementary feeds and fertilizers. Previous studies have highlighted the use of animal manures like cow dung, poultry droppings, and biogas slurry as cost-effective alternatives to expensive feeds and fertilizers (Schroeder, 1980). Such integration enhances overall production efficiency and reduces land, labor, and feed costs for both poultry and fish. In Kollihills, agriculture and livestock rearing form the primary livelihood for the local population. Approximately 85% of farmers belong to the Scheduled Tribes (ST) community, and small and marginal farmers account for 92% of the total operated area in the block(Bhagawati et al., 2020, Bibhudatta, et al., 2007). The rationale behind integrating fish farming with livestock is the significant nutrient content (N-P-K) found in animal feed, which is recovered in manure. Nutrient levels ranging from 72-79% nitrogen, 61-87% phosphorus, and 82-92% potassium act as fertilizers in fish ponds, promoting plankton growth, which serves as high-protein natural food for certain fish species. Recent experiments have demonstrated that considerable fish production can be achieved when animal manures are properly applied to polyculture systems (Shoko *et al*., 2011, Jhingran, 1986). Buck *et al.* (1978) reported a fish yield of 4 tons per hectare per year in a polyculture system of carps, channel catfish, and largemouth bass, where manure from 66 pigs per hectare served as the sole nutrient source.

Integrated animal-fish farming has been identified as an appropriate means of increasing returns from limited land areas while reducing the risks associated with crop diversification (Jhingran, 1986; Williams, 1997; Korikantimath & Manjunath, 2008, Samra et al., 2003). However, the success of such practices depends on their adaptability to the local climate, the availability of marketable fish seeds and feeds, and the economic viability of the system. Despite limited fishery resources, the district is known for its high fish consumption. With no marine coastlines or seas, the available fishery resources come solely from inland waters. Fish production can be significantly increased by using animal manures, particularly pig manure, which contains about 70% digestible food for fish, along with digestive enzymes. Pig manure also provides a nutrient base for plankton, which serves as natural food for fish. The growing trend of pig farming has increased the availability of pig manure, which can be effectively used in inland fisheries through integrated farming approaches. The addition of chicken droppings in intensive fish culture systems has also been shown to increase fish yield by 21% and reduce the feed conversion rate by 0.4 units (Rappaport, 1978). Against this backdrop, a study was conducted on integrated pig-fish farming in Kollihills. The study aimed to analyze two important fish-based integration systems: Fish-cum-Pig and Fish-Duck, in the Lower Kollihills block of Namakkal district.

2. MATERIALS AND METHODS

The study was conducted over a period of eight months, from June 2021 to December 2021, in three villages—Elangitampatty, Kezhi senkattupatti, and Asakkattuppatti—located in the Kollihills region of Namakkal district. Three sets of uniform ponds, each 0.1 ha in size, were selected in duplicate and marked as T0, T1, and T2. The pond soil was classified as clay loam, with a texture of 43% sand, 28% silt, and 29% clay.

Pond management: Lime was applied at a rate of 500 kg/ha/year. The first application consisted of one-third of the total annual requirement, spread evenly over the pond bottom, with the remainder applied in equal monthly installments. Prior to the experiment, the pond bottom was exposed to sunlight for at least 10 days. Excavation was carried out to ensure that the water depth was maintained between 1.5 m and 3.0 m during the monsoon months. The excavated soil was used for dyke repair.

Pigsty management and feeding: A pigsty was constructed on the pond bank, allowing waste to be directly channeled into the water. The spillover feed and pig manure served as a source of fish feed. Pig waste contains 1.36-2% nitrogen (N), 0.4% phosphorus (P), and 0.4% potash (K). The amount of pig waste recycled in the experimental ponds ranged between 35.50 and 38.75 kg of dung, which promoted the rapid growth of fingerlings. The pigsty was built using locally available materials, with a space allocation of 1-1.5 m² per pig, and a height limit of 1.5 m. Pigs were fed balanced rations at a rate of 1.4-1.5 kg per pig per day, with the cost of feed estimated at Rs. 30-35/kg. Supplements such as maize, wheat bran, rice polish, broken rice, fish meal, groundnut cake, minerals, and salts were added to the pig feed to enhance productivity and reproduction.

Stocking of fishes: After liming and manuring with pig dung, the ponds were stocked with fish. The stocking density was 7,500 fish per hectare, with an average body weight (ABW) of 50 g. The species composition was 40% surface feeders (Catla), 20% column feeders (Rohu), 30% bottom feeders (Mrigal), and 10% macro vegetation feeders (Grass carp). This combination was chosen to control aquatic weeds that compete for food, space, and dissolved oxygen. The fish derived their nutrition primarily from the natural food in the pond, which was enhanced by the regular application of pig waste. Pig manure acted as an organic fertilizer, promoting the growth of phytoplankton and zooplankton, which serve as natural fish food. The fish also fed on the uneaten pig feed, significantly reducing overall feed costs. Fish in the control group (T0) were provided with commercial fish feed containing 24% crude protein (4 mm pellet size) at 4% of their body weight. Fish in T1 and T2 were provided with commercial feed at 50% of the control group’s rate, supplemented with pig and duck excreta, respectively. After eight months, the final weights of the fish were recorded, and the total production of each group was noted.

Measurement of physicochemical characteristics: Water quality parameters such as pH, dissolved oxygen, free carbon dioxide, alkalinity, and hardness were measured using standard methods (APHA, 2019). Dissolved oxygen was measured twice daily, at 6:00 am and 4:00 pm. Plankton samples were collected in duplicate by filtering 100-200 liters of pond water through a 28 mm mesh nylobolt plankton net, following the method described by Santhanam et al. (1987). The samples were preserved in 3-4% formalin in separate plankton tubes.

Plankton identification was carried out at the genus level using the identification keys of Edmondson (1959), Needham & Needham (1966), and the ICAR monograph series on algae (Ramanathan, 1964; Philipose, 1967). The collected data were analyzed using SPSS version 17.0 following standard statistical methods (Snedecor and Cochran, 1994) and expressed as mean ± SE. The Duncan Multiple Range test was performed to identify statistically significant differences between means.

3. RESULTS

Growth performance: The total fish production (Table 2) was highest in treatment TP2, with a recorded value of 4960.09 kg. Among all the treatment ponds, the total harvested weight of Catla (*Catla catla*) was the highest at 2225.98 kg, followed by Grass carp (*Ctenopharyngodon idella*) with a total harvested weight of 1490.37 kg. The final average weight of Grass carp in the T0, T1, and T2 ponds was 1047 ± 13.27 g, 1151.10 ± 12.85 g, and 1490.37 ± 13.52 g, respectively. Similarly, the final average weight of Catla in T0, T1, and T2 ponds was 910 ± 9.45 g, 960 ± 10.26 g, and 980 ± 12.20 g, respectively. For Rohu, the final average weight in T0, T1, and T2 ponds was 850 ± 7.98 g, 900 ± 11.23 g, and 910 ± 11.16 g, respectively. Mrigala showed final average weights of 600 ± 6.04 g, 720 ± 8.50 g, and 730 ± 10.56 g in T0, T1, and T2 ponds, respectively.

Significant differences in the productivity of the four fish species were observed between T0 and T1, and between T0 and T2, as shown in Table 2. However, only numerical differences were noted between T1 and T2. Among the species, Grass carp exhibited the highest growth, followed by Catla, Rohu, and Mrigala. Growth percentages of Grass carp in T0, T1, and T2 were 743.80%, 805.78%, and 847.10%, respectively, which may be attributed to its feeding potential and genetic characteristics. Overall, fish productivity was greater in the fish-pig system compared to the fish-duck system.

This result indicates the superior ability of pig excreta, compared to duck droppings, in fertilizing ponds and promoting the production of phytoplankton and zooplankton (Sahoo and Singh, 2015). The growth percentages of Catla in T0, T1, and T2 were 395.65%, 417.39%, and 426.08%, respectively. Rohu exhibited growth percentages of 531.25%, 562.50%, and 568.75% in T0, T1, and T2, respectively. Mrigala showed growth percentages of 348.83%, 418.60%, and 424.41% in the same treatments. The study revealed that pig excreta serve as excellent manure for fish, followed by duck manure.

The total fish production in this study aligns with earlier research conducted in the Indian plains, where fish production in integrated farming systems ranged from 5.0 to 7.5 metric tons per hectare per year (Samra *et al.,* 2003). In terms of fish growth, Grass carp showed the highest production in the fish-pig integration system, followed by Catla (*Catla catla*), which contradicts the findings of Bhat *et al*. (2011). This variation could be attributed to the differing agro-climatic conditions under which the experiments were conducted, where factors like temperature and dissolved oxygen play a crucial role in fish growth.

Physico-chemical parameters: The physico-chemical parameters of the pond water in this study were found to be conducive to the growth of both plankton and fish. The productivity of freshwater bodies can often be gauged by the water's pH. The optimal pH range for inland water bodies is between 6.00 and 9.00 (Bhatnagar *et al.,* 2013), and our findings are consistent with this range. Other parameters such as dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, total dissolved solids, and electrical conductivity also fell within the ideal range for fish culture (Table 3).

Water quality management is crucial for carp culture, especially given the heavy manure load, which can cause dissolved oxygen (DO) levels to drop below critical thresholds, particularly at dawn during the summer when water temperatures are high and water depth is low. As shown in Table 3, DO levels fluctuated throughout the day, peaking at 4:00 pm across all culture ponds. The lowest DO value, 6.35 ppm, was recorded in T1, followed by a gradual increase to 6.87 ppm in the same treatment pond. These findings suggest that DO levels experience significant diurnal fluctuations, which corroborates the findings of Bhatt *et al.* (2006).

Plankton diversity: Plankton diversity in each treatment pond was observed every 45 days. Plankton density (Table 4) was significantly higher in T2 (109 ± 2.58–132 ± 1.47 Units/L) than in T0 and T1, likely due to the high nitrogen and phosphorus content in pig manure. The phytoplankton composition primarily consisted of species such as *Closterium, Chlorella, Chlamydomonas, Oedogonium, Spirogyra, Staurastrum, Ulothrix, Volvox, Diatoma, Fragilaria, Melosira, Navicula, Nitzschia, Pinnularia, Spirulina,* and *Chroococcus*. The zooplankton density included species like *Moina, Daphnia, Cyclops, Brachionus, Bosmina,* and *Copepoda*. These findings are in full agreement with those of Tripathi and Sharma (2005).

Table 1. Experimental setup and stocking ratio in four species

Species	Control(T0)	Fish-Duck Integration(T1)	Fish-Pig Integration(T2)
Catla	40	40	40
Rohu	20	20	20
Mrigal	30	30	30
Grass Carp	10	10	10

Table 2. Details of stocking, survival (%) and fish production in treated ponds

Species	Species Ratio	Initial Av.Wt. (kg)	T0 (Control Pond)			T1(Duck cum Fish)			T2(pig Cum fish)		
			Final Av. Wt. (kg)	Survival (%)	Total Wt. Harvested (kg.)	Final Av. Wt. (kg)	Survival (%)	Total Wt. Harvested (kg.)	Final Av. Wt. (kg)	Survival (%)	Total Wt. Harvested (kg.)
Catla	40	0.05	0.910	61.15	1712.2	0.960	66.29	2094.76	0.980	65.47	2225.98
Rohu	20	0.03	0.850	60.95	585.12	0.900	68.59	617.31	0.910	60.13	553.19
Marigal	30	0.03	0.600	62.00	744.00	0.720	66.94	763.11	0.750	63.94	690.55
Grass Carp	10	0.04	1.50	69.80	1047.00	1.800	63.95	1151.10	2.100	70.97	1490.37
Average of %Survival rate			63.47			66.44			65.12		
ABW(kg)			0.77			0.85			0.94		
Total Production(Kg)			4088.32			4626.29			4960.09		

**Means bearing similar superscripts in a row do not differ significantly.(Pond 1 (T0) = Fish only, Pond 2 (T1) = Fish-Duck Integration and Pond 3 T2=Fish-Pig Integration*

Table 3. Mean value of physiochemical characteristics of the three ponds before and after treatment

Parameters	Pre-treated pond			Treated pond		
	T0	T1	T2	T0	T1	T2
Temperature (^{0}C)	25.5±2.0	29.67±2.7	26.9±2.6	26.58±0.44	26.94±0.43	26.46±0.58
pH	7.84±0.50	7.61±0.38	7.62±0.25	7.9±0.06	8.2±0.06	8.1±0.07
Dissolved oxygen (mg/lit)	4.88±0.05	4.98±0.12	4.81±0.08	6.05±0.18	6.85±0.01	6.57±0.22
TDS(mg/lit)	0.63±0.01	0.51±0.01	0.9±0.2	38.72±2.50	39.44±2.54	45.15±2.72
Hardness(mg/lit)	74.07±0.49	71.08±0.12	79.08±0.02	91.09±0.19	93.08±0.23	95.08±0.01
Total Alkalinity (mg/l)	86 ± 0.33	104 ± 0.32	101 ± 0.01	107 ± 0.12	98 ± 0.17	96 ± 0.07

Table 4. Plankton density

Treatment	45th day		90th day		180th day	
	No/liter	Total Plankton	No/liter	Total Plankton	No/liter	Total Plankton
T0	28±1.25	27,000	39 ±0.29	42,200	43±0.08	59,000
T1	93±0.79	1,08,050	101±0.86	103,600	83±1.02	1,65,000
T2	109±2.58	1,65,110	133±2.98	1,96,000	162±1.47	2,73,00

Table 5. Gross income earned in fish cum pig and fish cum duck farming (per ha)

Integrated farming system	Item	Production/ha	Price (Rs.)	Gross income/ha/Rs
Control(T0)	Fish	4088.32kg	150/kg	490598.40
	Total(Rs)			490598.40
Fish cum Duck(T1)	Fish	4626.29kg	150/kg	693943.50
	Egg	564Nos	10	5640.00
	Meat	157kg	350	54950.00
	Total(Rs)			754533.5
Fish cum pig(T2)	Fish	4960kg	150/kg	744000.00
	Piglet	68nos	3000.00/no	204000.00
	Pig meat	510.93kg	200.00/kg	102186.00
	Total(Rs)			1050186.00

Table 6. Comparative benefit-cost ratio analysis of the integrated farming systems (per ha)

Integrated farming systems	Total operational cost (Rs.)	Gross return (Rs.)	B:C Ratio
Control(T0)	2,92,267.66	4,90,598.40	1.67
Fish cum Duck(T1)	3,82,267.66	7,54,533.50	1.97
Fish cum pig(T2)	4,94,832.18	10,50,186	2.12

Comparative Benefit-cost ratio analysis: The economic analysis and benefit-cost ratio (BCR) for the fish-pig and fish-duck farming systems are presented in Table 6. The total operational costs for the fish-pig, fish-duck, and control farming systems were ₹4,94,832.18, ₹3,82,267.66, and ₹2,92,267.66, respectively. The total gross returns for the treatment and control systems were ₹10,50,186, ₹7,54,533.50, and ₹4,90,598.40, respectively. The benefit-cost ratio was highest in the fish-pig farming system (2.12), compared to the fish-duck farming system (1.97), indicating that fish-pig integration is more profitable than fish-duck integration. Haobijan and Ghosh (2018) also reported that integrated pig-fish farming is a high-income practice, highlighting that fish-pig integration results in better fish growth, optimal resource utilization, and higher net income. Parag Saikia.,*et.al*(2020) reported that The economics of the integrated farming system as well as farmer's practice has been worked out and it has been found that gross profit to the tune of Rs. 5.69 lakh/ha and Rs. 2.39 lakh/ha were recorded from integrated fish cum duck farming and traditional fish farming practice with a net profit of Rs. 3.1 lakh/ha and Rs. 1.54 lakh/ha respectively. This gave an average benefit-cost ratio of 2.19 in integrated fish-cum-duck farming and 1.83 in traditional fish culture practice.

4. DISCUSSION

Growth performance: The present study reveals notable differences in the growth performance of fish varieties in the integrated systems of fish-pig and fish-duck farming, as compared to the control. The fingerlings in all systems exhibited significant weight gain, primarily due to the enhanced availability of natural food resources such as algae, phytoplankton, and zooplankton, which are stimulated by the pond fertilization processes. The role of pig excreta and duck droppings as organic fertilizers cannot be understated, as their nutrient content, specifically nitrogen and phosphorus, plays a pivotal role in fostering the growth of these tiny plants and animals, which form the base of the aquatic food chain. The initial weight of 50 g for all fingerlings was followed by substantial weight gain across the various fish species tested. For Grass Carp, the final average weights were 1047 ± 13.270 g, 1151.10 ± 12.850 g, and 1490.37 ± 13.520 g in the T0, T1, and T2 ponds, respectively. Similarly, Catla reached final average weights of 910 ± 9.450 g, 960 ± 10.260 g, and 980 ± 12.20 g in the same treatments. Rohu, on the other hand, exhibited average final weights of 850 ± 7.980 g, 900 ± 11.230 g, and 910 ± 11.160 g, while Mrigala showed weights of 600 ± 6.040 g, 720 ± 8.500 g, and 730 ± 10.560 g in the respective ponds. These significant weight gains underline the effectiveness of the integration between livestock and fish farming.

Statistically significant differences in productivity were observed between the control pond (T0) and the treatment ponds (T1 and T2) across all fish species. However, differences between T1 and T2 were found to be numerical rather than statistically significant, suggesting that both pig and duck manure are effective in promoting fish growth, although pig manure exhibits slightly better results. Grass Carp demonstrated the highest growth rate among all species, with growth percentages of 743.80%, 805.78%, and 847.10% in T0, T1, and T2, respectively. This could be attributed to the species' high feeding potential and inherent genetic characteristics, which allow them to thrive under favorable environmental conditions. This finding aligns with the well-established notion that Grass Carp is one of the most efficient filter feeders among freshwater species, consuming large quantities of phytoplankton and macrophytes. In contrast, Catla showed growth rates of 395.65%, 417.39%, and 426.08% across the same treatments, while Rohu exhibited growth percentages of 531.25%, 562.50%, and 568.75%. Mrigala had the lowest growth rates at 348.83%, 418.60%, and 424.41%. Although these growth figures suggest that all species responded positively to the integrated farming systems, the differences in growth rates may be related to species-specific dietary preferences and environmental tolerance levels. Notably, the study highlights the superior growth performance of fish in the fish-pig integration system compared to the fish-duck system, which is consistent with previous studies. Pig manure appears to be more effective than duck manure in fertilizing ponds, as it enhances the production of phytoplankton and zooplankton more efficiently. This is likely due to the higher nitrogen and phosphorus content in pig excreta, which serves as a rich nutrient source for primary producers. Research by Sahoo and Singh (2015) supports this finding, stating that pig manure significantly increases plankton productivity in aquaculture ponds. The daily application of pig and duck manure not only provides soluble nitrogen and phosphorus for algal growth but also creates substrates for zooplankton, which are crucial for the diet of many freshwater fish species (Milstein *et al.,* 1995). The findings of the present study echo the observations of Wohlfarth and Schroeder (1979), who emphasized that wet manure from livestock increases nutrient availability in pond ecosystems, thereby enhancing fish growth and overall productivity.

Physico-chemical parameters: The physico-chemical parameters of the pond water were also conducive to fish and plankton density growth. Water quality plays an integral role in determining the success of aquaculture systems. Freshwater productivity, in particular, can be strongly influenced by the pH of the water, which affects nutrient availability and overall water chemistry. The pH levels in the current study fell within the optimal range of 6.00 to 9.00, as recommended by Bhatnagar *et al.* (2013). This range is ideal for maintaining the health of aquatic organisms and ensuring the efficient functioning of metabolic processes in fish. Additionally, parameters such as dissolved oxygen, free carbon dioxide, total alkalinity, total hardness, total dissolved solids, and electrical conductivity were all within acceptable limits for fish culture, further validating the suitability of the integrated systems used in this experiment.

The role of pond sediments in nutrient cycling also deserves attention. As Boyd and Bowman (1997) pointed out, pond sediments are an integral part of the pond ecosystem, influencing the availability of nutrients for plankton and plant growth. The soil analysis in the current study revealed neutral to slightly alkaline conditions (pH 6.92–7.86), with increasing levels of organic carbon, available nitrogen, and phosphorus. These findings indicate that the pond sediments played an active role in nutrient recycling, which ultimately benefited fish growth. Similar observations have been made by Avnimelech and Lacher (1979) and Boyd (1995), who stressed the importance of pond sediments in maintaining nutrient balance in fertilized aquaculture ponds.

Plankton density and diversity: The diversity and abundance of plankton were monitored every 45 days in each treatment pond. Plankton density was found to be significantly higher in T2 (102 ± 2.58 to 132 ± 1.47 Units/L) compared to T0 and T1. This can be attributed to the nutrient-rich pig manure, which provided an optimal environment for plankton growth. The phytoplankton community was dominated by species such as Closterium, Chlorella, Chlamydomonas, Oedogonium, Spirogyra, and Volvox, among others, while the zooplankton population consisted of Moina, Daphnia, Cyclops, Branchionus, Bosmina, and Copepoda. These results align with the findings of Tripathi and Sharma (2005), further emphasizing the role of livestock manure in enhancing plankton biodiversity and supporting sustainable fish production in integrated farming systems.

5. CONCLUSION

The study demonstrates that fish-pig integration is more effective than fish-duck integration in promoting fish growth and pond productivity. The high nutrient content of pig manure, combined with its ability to enhance plankton density and diversity production, results in higher fish yields and improved water quality. These findings have important implications for the future of sustainable aquaculture practices, particularly in regions where integrated farming systems are viable. By optimizing the use of organic fertilizers such as livestock manure, aquaculture farmers can achieve higher production levels while maintaining environmental sustainability

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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