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Impact of Rice-Fish Integrated Farming Systems on Rice Yield: Ecological Benefits and Economic Returns

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Abstract The rice-fish integrated farming system is a composite agricultural model that integrates food production and aquaculture, and has the dual functions of food security and ecological environmental protection. Through case studies and data analysis, this study systematically evaluated the comprehensive impact of this model on rice yield, ecological benefits and economic returns. The study found that the rice-fish system effectively improved soil nutrients, suppressed pests and diseases, reduced pesticide and fertilizer inputs, and enhanced the stability of the field ecosystem without reducing rice yields. At the same time, farming aquatic animals such as fish, shrimp, and crabs can bring additional economic income to farmers and achieve a diversified output structure. Typical regional practices further verified the advantages of the rice-fish system in improving resource utilization efficiency and ecological cycle capacity. Rice-fish farming is an effective path to achieve green transformation of agriculture. This study hopes to make an important contribution to the construction of a high-yield, efficient, and eco-friendly modern agricultural system.

Keywords Rice-fish integrated farming; Rice yield; Ecological benefits; Economic returns; Sustainable agriculture

1 Introduction

Rice-fish integrated farming systems (RFS) have emerged as a promising approach to enhance agricultural sustainability by combining rice cultivation with aquaculture. This method leverages the symbiotic relationship between rice and fish, where fish contribute to pest control and nutrient cycling, thereby improving rice yield and reducing the need for chemical inputs (Hu et al., 2016; Wan et al., 2019; Zhang et al., 2023). The development of RFS has been driven by the need to address challenges in agroecology and food security, particularly in regions where traditional farming practices are no longer sustainable due to environmental degradation and resource scarcity (Liu et al., 2022; Fu et al., 2024; Ranjith et al., 2024).

The concept of rice-fish integrated farming involves the co-cultivation of rice and aquatic animals, such as fish, in the same paddy field. This system has been practiced traditionally in various parts of Asia and has gained renewed interest due to its ecological and economic benefits. The integration of fish into rice paddies can enhance biodiversity, improve soil fertility, and increase the overall productivity of the farming system (Yassi et al., 2023; Tokpanou et al., 2024; Wang et al., 2024). Recent studies have shown that rice-fish systems can lead to higher rice yields and better pest management compared to conventional rice monoculture systems (Wan et al., 2019; Jewel et al., 2023; Ranjith et al., 2024).

Despite the potential benefits, rice-fish integrated farming faces several challenges. These include the need for appropriate field configurations, management of water resources, and balancing the nutrient requirements of both rice and fish (Hu et al., 2016; Fu et al., 2024). Additionally, the variability in environmental conditions and the need for technical knowledge can pose barriers to the widespread adoption of this system (Liu et al., 2022; Jewel et al., 2023). Addressing these challenges is crucial for enhancing food security, particularly in regions where rice is a staple food and a primary source of livelihood (Zhang et al., 2023; Wang et al., 2024).

This study will evaluate the impacts of integrated rice-fish farming systems on rice yields, focusing on ecological benefits and economic returns. It will also explore best practices and strategies for optimizing the productivity and sustainability of these systems by studying various RFS models in different regions, including traditional rice-fish farming areas, as well as new areas where this approach is being introduced as a sustainable alternative to traditional agricultural methods, in order to promote a broader understanding of integrated farming systems and their role in achieving sustainable agricultural development.

2 Structure and Management Models of Rice-Fish Systems

2.1 Common integration models

Rice-fish integrated farming systems (RFS) are diverse and can include various aquatic animals such as fish, shrimp, and crabs. These systems are designed to enhance productivity and sustainability by utilizing the ecological interactions between rice and aquatic species. For instance, the rice-fish-duck (RFD) system has been shown to improve weed control efficiency and increase productivity by utilizing ducks and fish as biological control agents for weeds and pests (Nayak et al., 2018; Nayak et al., 2020). Similarly, the rice-crayfish system has been noted for its impact on soil nutrients and carbon pools, although it may slightly reduce rice yields compared to monoculture systems (Wang et al., 2024). The integration of fish, such as yellow finless eel and loach, with rice has also been demonstrated to reduce pest abundance and improve economic returns (Wan et al., 2019).

2.2 Field design and water level regulation

The design of rice fields in integrated systems is crucial for optimizing the interactions between rice and aquatic animals. Proper field configuration is necessary to ensure that both rice and fish can thrive without compromising each other's growth. This includes maintaining appropriate water levels that support fish survival while not adversely affecting rice growth. Studies have shown that maintaining water levels that support fish yields without reducing rice yields is essential for the success of intensive RFSs (Hu et al., 2016). Additionally, the presence of aquatic animals can enhance soil and water quality, contributing to the overall sustainability of the system (Nayak et al., 2018; Zhang et al., 2023).

2.3 Coordinated input, fertilization, and pest management

Integrated rice-fish systems require coordinated management of inputs such as fertilizers and pest control measures. The presence of fish and other aquatic animals can reduce the need for chemical fertilizers and pesticides, as they contribute to nutrient cycling and pest control. For example, fish and ducks in the RFD system help in nutrient recycling and pest management, reducing the reliance on chemical inputs (Nayak et al., 2018; Ranjith et al., 2024). The use of organic and inorganic fertilizers in combination has been found to significantly improve rice yield and quality in co-culture systems (Li et al., 2022). Moreover, integrated systems like rice-fish and rice-duck have been shown to lower greenhouse gas emissions and improve soil fertility, further enhancing the ecological benefits of these systems (Zhang et al., 2023; Fu et al., 2024).

3 Effects on Rice Yield

3.1 Yield trends under rice-fish systems

Rice-fish integrated farming systems have shown promising results in enhancing rice yield. Studies indicate that the co-culture of rice with aquatic species such as fish can significantly improve rice yield and quality. For instance, a meta-analysis revealed that rice yield increased by 7.77% in rice-animal co-culture systems compared to traditional monoculture systems (Liu et al., 2022). Similarly, the integration of fish and ducks in rice farming has been shown to enhance productivity and economic returns, with higher rice equivalent yields and improved agronomic characteristics (Nayak et al., 2020; Ranjith et al., 2024). These systems utilize the land and water resources more efficiently, leading to better growth and yield outcomes (Li et al., 2022).

3.2 Impact of aquatic species on weed and pest suppression

The integration of aquatic species like fish and ducks in rice fields plays a crucial role in suppressing weeds and pests, which are significant challenges in rice cultivation. Fish and ducks act as biological control agents, reducing the abundance of herbivore insects and weeds. For example, fish in rice-fish systems have been shown to decrease herbivore insect abundance by 24.07% and reduce weed abundance by up to 67.62% (Wan et al., 2019). The presence of ducks further enhances weed control efficiency, significantly reducing weed density and biomass, which in turn supports higher rice productivity (Nayak et al., 2020). This natural pest and weed management reduces the need for chemical pesticides, contributing to more sustainable farming practices. The picture shows a variety of rice field water structure designs, including outer ditches, inner ditches, central ponds, and staggered ditch systems. These designs not only help regulate water flow, but also provide ample space for fish and ducks to move around, allowing them to effectively distribute in various areas of the rice field (Figure 1) (Ibrahim et al., 2023).

3.3 Improvements in soil conditions and root zone environment

Rice-fish integrated systems also contribute to improved soil conditions and root zone environments, which are vital for healthy rice growth. The presence of aquatic species like fish and ducks enhances nutrient recycling and soil fertility. The continuous addition of organic matter from fish and duck activities improves soil nutrient levels, including nitrogen, phosphorus, and potassium, which are essential for rice growth (Nayak et al., 2018). Additionally, these systems promote better soil structure and organic matter distribution, leading to enhanced soil health and increased rice yields (Lv et al., 2023). The dynamic interactions in these integrated systems create a more favorable root zone environment, supporting sustainable rice production (Wang et al., 2024).

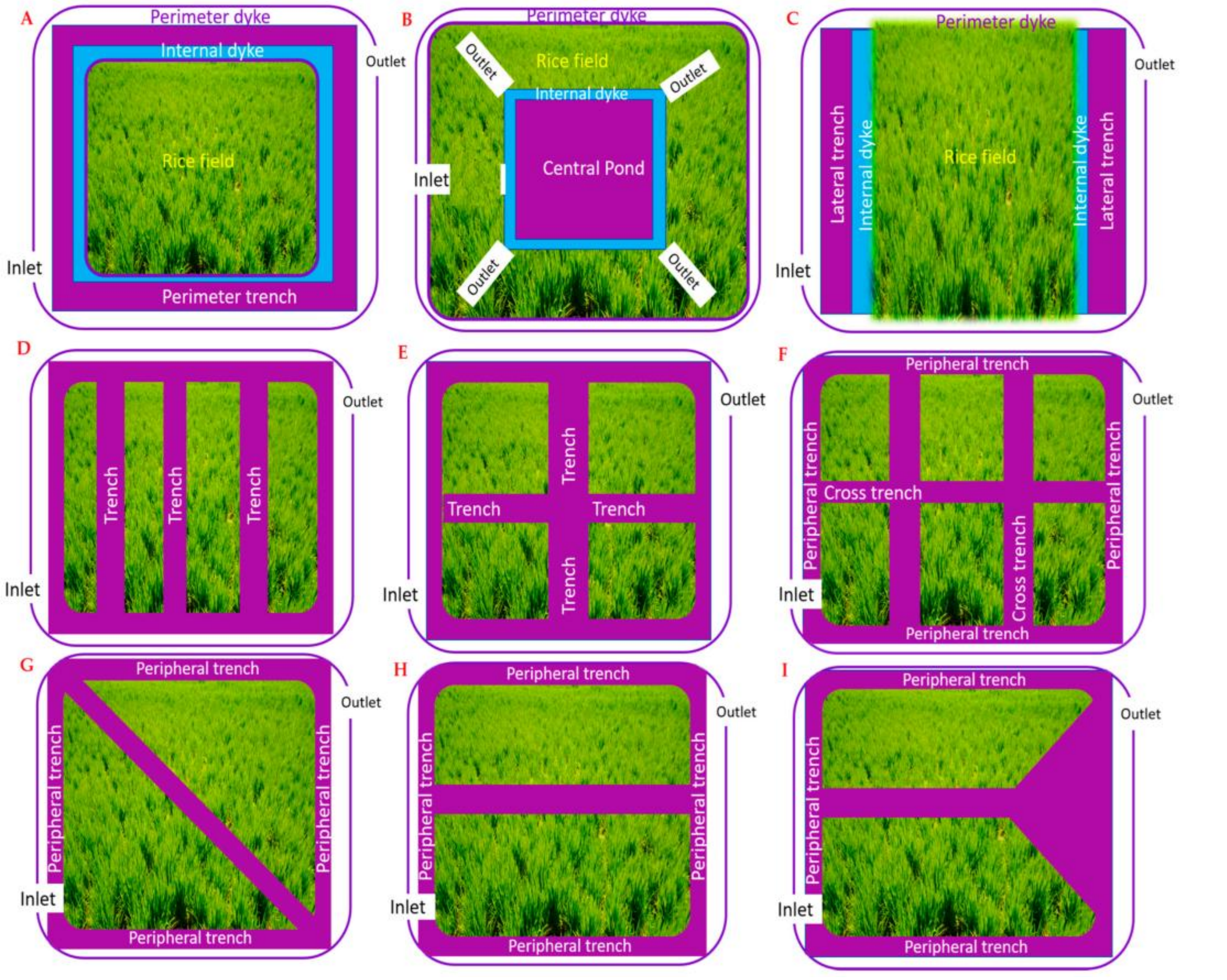

Figure 1 Different types of trenches that are utilized in the integration of rice and aquatic species include: (A) Perimeter, (B) Central Pond, (C) Lateral trench, (D) line-shaped (two equidistant transverses with a peripheral), (E) cross-shaped (crossed) (F) circular-shaped ones made up of cross (latticed trenches), (G) diagonal, (H) peripheral, and (I) Y-shaped (Adopted from Ibrahim et al., 2023)

4 Ecological Benefits Analysis

4.1 Enhanced biodiversity and system stability

Rice-fish integrated farming systems significantly enhance biodiversity and system stability by creating a more diverse ecosystem. The presence of fish in rice paddies contributes to increased invertebrate predator abundance, which helps control pest populations and reduces the need for chemical pesticides (Wan et al., 2019). Additionally, the integration of fish and ducks in rice farming systems has been shown to increase the diversity and evenness of weed species, thereby promoting a more balanced ecosystem (Nayak et al., 2020). This biodiversity not only supports ecological stability but also contributes to higher rice yields and improved soil health (Nayak et al., 2018; Li et al., 2022).

4.2 Reduction in chemical fertilizer and pesticide use

The integration of fish into rice farming systems reduces the reliance on chemical fertilizers and pesticides. Fish contribute to nutrient recycling by feeding on plankton and other organic matter, which enhances soil fertility and reduces the need for synthetic fertilizers (Nayak et al., 2018). Studies have shown that rice-fish systems can decrease the use of nitrogen fertilizers by over 30% compared to conventional rice farming, while also reducing pesticide use by approximately 23% (Wan et al., 2019; Fu et al., 2024). This reduction in chemical inputs not only lowers production costs but also minimizes environmental pollution and promotes sustainable agricultural practices (Ranjith et al., 2024; Tokpanou et al., 2024).

4.3 Water quality improvement and ecological cycling

Rice-fish integrated systems improve water quality and promote ecological cycling within the paddy fields. The presence of fish enhances the cycling of nutrients and organic matter, leading to improved water quality parameters such as dissolved oxygen and reduced ammonia levels (Nayak et al., 2018; Tokpanou et al., 2024). These systems also contribute to the reduction of greenhouse gas emissions, such as methane and nitrous oxide, by improving soil structure and increasing soil carbon and nitrogen sequestration (Zhang et al., 2023). The improved water quality and nutrient cycling support healthier rice plants and contribute to higher yields and better-quality rice (Li et al., 2022; Liu et al., 2022).

5 Economic Returns Assessment

5.1 Income diversification and increase for farmers

Integrated rice-fish farming systems have been shown to significantly enhance income diversification and increase for farmers. By incorporating fish and other livestock into rice farming, farmers can generate additional revenue streams beyond traditional rice cultivation. For instance, the integration of fish and ducks in rice farming not only improves rice yield but also provides additional income from fish and duck sales, thereby diversifying income sources and increasing overall farm profitability (Nayak et al., 2020; Fu et al., 2024; Arumugam et al., 2025). The rice-fish-duck system, in particular, has been noted for its ability to enhance total farm production and income through effective nutrient recycling and improved soil health (Nayak et al., 2018).

5.2 Cost-benefit analysis of integrated systems

The cost-benefit analysis of integrated rice-fish systems reveals that these systems can be economically advantageous despite higher initial costs. Studies have shown that while integrated systems like rice-fish symbiosis (RFS) and rice-duck symbiosis (RDS) incur higher costs compared to single cropping rice (SCR), they also produce significantly higher net benefits. For example, RFS and RDS have been reported to yield 1.30 to 1.48 times higher net benefits than SCR, with a benefit-cost ratio comparable to or higher than SCR (Fu et al., 2024). Additionally, the use of organic manures and reduced reliance on chemical fertilizers in integrated systems further enhances economic efficiency by lowering input costs (Pearlin et al., 2024).

5.3 Marketability and branding potential

Integrated rice-fish farming systems offer unique marketability and branding opportunities. The production of high-quality proteins and organic produce from these systems can be leveraged to create niche markets and premium pricing strategies. The ecological and sustainable nature of integrated farming can be a strong selling point, appealing to environmentally conscious consumers. Moreover, the potential for agrotourism in rice-fish co-culture systems can generate additional revenue and increase the economic value of these farming practices (Arunrat and Sereenonchai, 2022). The branding potential of integrated systems is further enhanced by their ability to meet food demands sustainably while ensuring ecological balance (Pearlin et al., 2024).

6 Case Study: Application of Rice-Fish Systems in Key Regions

6.1 Rice-duck co-culture model in Deqing, Zhejiang

Rice-duck co-culture technology is a kind of Ecological Symbiosis mode of breeding ducks simultaneously when planting rice. This technology is based on the principle of mutual benefit between rice and duck. Ducks prey on pests to suppress pests and diseases, replace the use of chemical pesticides, and duck field activities promote the ventilation and light transmission of rice fields and the development of roots, and their excretions are converted into organic fertilizer, while reducing the amount of herbicides, improving rice quality and breeding income, and realizing green production of rice (Figure 2).Generally, more than 60% of chemical fertilizers and more than 50% of pesticides are saved, with significant cost savings and income increase.

Figure 2 Rice-duck co-culture base of Changlin family farm, Xinshi Town, Deqing County (Photographed by Xiaoying Zhu)

6.2 Rice-turtle integration in Guigang, Guangxi

Rice-turtle integration in Guigang, Guangxi, represents a unique adaptation of rice-fish systems, where turtles are co-cultured with rice. This system leverages the natural behaviors of turtles to control pests and weeds, thereby reducing the need for chemical inputs. The integration enhances biodiversity and contributes to ecological balance within the paddy fields. Although specific data on rice-turtle systems in Guigang is limited, similar integrated systems have shown increased economic returns and improved soil quality, as seen in other rice-animal co-culture models (Wan et al., 2019; Liu et al., 2022; Li et al., 2023).

6.3 Rice-shrimp co-culture in Fuzhou, Jiangxi

In Fuzhou, Jiangxi, rice-shrimp co-culture has been implemented to optimize the use of paddy fields. This system has demonstrated significant economic benefits, with increased yields and reduced input costs compared to traditional rice monoculture. The rice-shrimp system enhances nutrient cycling and reduces pest populations, contributing to sustainable agricultural practices. Studies have shown that such systems can increase rice yield by 5%~7% and improve nutrient use efficiency, making them economically viable and environmentally sustainable (Hou et al., 2021; Yuan et al., 2022; Li et al., 2023).

6.4 Rice-fish eco-farming and agritourism in Yunnan

Yunnan has embraced rice-fish eco-farming, integrating agritourism to boost local economies. This approach not only enhances rice yield and quality but also attracts tourists, providing additional income streams for farmers. The rice-fish system in Yunnan is part of a broader trend of ecological intensification, which has been shown to increase economic values by over 10% compared to mono-rice farming. The system also improves soil health and reduces the need for chemical fertilizers and pesticides, aligning with sustainable agricultural goals (Wan et al., 2019; Hou et al., 2020; Ye et al., 2024).

7 Technological Innovations and System Optimization

7.1 Digital tools and smart monitoring

While the provided papers focus primarily on the ecological and economic benefits of integrated rice farming systems, they do not specifically address the use of digital tools and smart monitoring technologies. The studies concentrate on comparing different integrated systems and their impact on soil health, nutrient recycling, and overall productivity (Nayak et al., 2018; Fu et al., 2024; Ranjith et al., 2024). The evaluation of water and soil quality indices is mentioned as a helpful tool for farm management decisions, but not in the context of digital or smart technology (Nayak et al., 2018).

7.2 Enhanced cultivation and integration strategies

Integrated rice farming systems, such as rice-fish, rice-duck, and rice-fish-duck, enhance overall productivity through effective nutrient recycling (Nayak et al., 2018). Integrating goats into rice-fish systems can significantly increase rice yield, the number of filled spikelets per panicle, and the number of panicles per land area (Tokpanou et al., 2024). Furthermore, incorporating farming system components like Azolla, fish, and duck as nutrient sources can positively impact rice growth and productivity (Ranjith et al., 2024). Optimal combinations of compost and local liquid organic fertilizers can further enhance the yield of both rice and fish in integrated systems (Yassi et al., 2023). Meta-analysis shows that rice-animal co-culture systems can optimize the paddy ecosystem and increase rice yield (Liu et al., 2022).

7.3 Integrated solutions for ecological optimization

Integrated rice farming systems offer integrated solutions for ecological optimization by improving soil health, reducing greenhouse gas emissions, and promoting biodiversity (Nayak et al., 2018; Zhang et al., 2023; Ye et al., 2024). These systems enhance soil fertility through nutrient recycling and increased soil organic carbon and nitrogen storage (Nayak et al., 2018; Zhang et al., 2023). The integration of rice with aquatic animals can lead to reduced methane and nitrous oxide emissions, contributing to climate change mitigation (Zhang et al., 2023). Different co-culture modes, such as rice-duck and rice-crayfish, have varying effects on greenhouse gas emissions and soil fertility, highlighting the importance of selecting appropriate integration strategies (Zhang et al., 2023). The co-culture of rice with fish or waterfowl had the greatest benefits for both rice yield and quality (Li et al., 2022).

8 Concluding Remarks

The integration of rice-fish farming systems has demonstrated significant positive impacts on both rice yield and ecological health. Studies have shown that rice-fish co-culture can enhance rice yield by improving soil fertility and reducing pest incidences, which in turn decreases the need for chemical inputs like pesticides and fertilizers. This system also supports biodiversity, as the presence of fish and other aquatic animals contributes to nutrient recycling and pest control, leading to a more balanced ecosystem. Additionally, integrated systems have been found to improve soil structure and increase soil organic carbon and nitrogen storage, further supporting sustainable agricultural practices.

The findings suggest that adopting rice-fish integrated farming systems can lead to higher economic returns and improved ecological outcomes compared to traditional rice monoculture. Practitioners are encouraged to consider these systems as a viable option for sustainable agriculture, particularly in regions where environmental degradation and resource scarcity are concerns. Future research should focus on optimizing these systems by exploring different combinations of aquatic species and management practices to maximize both economic and ecological benefits. Additionally, studies should investigate the long-term impacts of these systems on greenhouse gas emissions and climate change mitigation.

Rice-fish integrated farming systems offer strategic value in building sustainable agriculture by enhancing productivity while maintaining ecological balance. These systems provide a model for sustainable intensification, where increased production does not come at the expense of environmental health. By reducing reliance on chemical inputs and promoting biodiversity, integrated systems can contribute to food security and economic stability, particularly in developing regions facing the dual challenges of population growth and environmental stress. As such, they represent a critical component in the transition towards more sustainable agricultural practices globally.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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