

Review

Analysis and Prospects of the Economic, Social and Environmental Sustainability Benefits of the Integrated Rice–Aquaculture Farming System in China

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Abstract

The integrated rice–aquaculture farming system (IRAFS), which combines rice cultivation with aquaculture, is a crucial strategy for improving economic efficiency, ecological sustainability, and social welfare. This model has been widely adopted across most regions of China, recognized for its sustainability and environmental benefits. The study analyzes the economic, social and environmental benefits of the current integrated rice–aquaculture integrated farming practices while assessing its market prospects. It identifies key limitations in existing models, particularly regarding water conservation, pollution reduction and system performance. Additionally, the study highlights future research directions and offers actionable recommendations to fully leverage the development potential of IRAFS. Through comparative analysis, this study identifies shortcomings in current water-saving and emission-reduction practices. It proposes an integrated model to balance grain production, environmental benefits, and economic returns. The aim is to provide theoretical support for enhancing agricultural quality and efficiency while promoting sustainable development.



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1. Introduction

China has the largest rice-planting area in the world, accounting for 27% of global rice production [1]. Rice cultivation encompasses both the traditional single rice variety model and the integrated rice–aquaculture farming system [2–5]. The single rice variety model, a more traditional planting method, has been widely practiced for many years. However, the long-term repetitive planting of a single variety has led to a range of issues, such as soil fertility depletion, increased dependence on chemical fertilizers and pesticides and heightened vulnerability to pests, diseases and weeds. These problems not only impact crop yields but also contribute to environmental degradation. Additionally, the economic benefits generated solely from rice cultivation are often limited, failing to meet the growing income needs of farmers [6–8]. This situation necessitates the exploration of more sustainable farming systems [9].

The IRAFS was initially introduced as a viable strategy to promote green and efficient agriculture. It leverages the complementary natural conditions shared by rice and aquatic species, such as shrimp, crayfish, and fish, which thrive in similar environments—land, water, and climate. These conditions support the simultaneous growth of both rice and aquatic organisms [10]. By employing specific agricultural techniques, this system allows for the simultaneous production of both rice and aquatic products without requiring additional land, labor or input costs. As a result, it enhances overall productivity and economic income, optimizes the industrial structure and improves the ecological environment. This integrated approach not only boosts agricultural output but also offers significant economic, ecological and social benefits, contributing to sustainable local development and improved livelihoods for farmers. Moreover, it promotes biodiversity, enhances resource efficiency and supports environmental conservation, making it a more resilient and sustainable alternative to traditional rice farming. In rice–aquaculture farming system, rice cultivation and aquaculture can be synchronized. Regarding the challenge of organizing rice harvesting in fields covered by water, careful management of water levels is critical. We acknowledge that aquaculture systems often have a longer-term planning horizon, particularly for species that require several months or years to mature. Therefore, it is important to design a system that takes into account both the time frames of rice cultivation and the aquaculture production cycle. This integrated approach can optimize land and water use, improve resource efficiency, and promote sustainability [11–15].

The research on the IRAFS in China has primarily focused on optimizing production efficiency, promoting industrial-scale operations and enhancing specialization levels [16–18]. Compared to the traditional single-rice cultivation model, most studies demonstrate that the IRAFS exhibits significant economic, social and environmental benefits. However, some studies indicate that certain benefits remain controversial and require further investigation and clarification [19–22]. For instance, introducing specific aquatic products, such as fish and shrimp, into rice fields can significantly enhance nutrient cycling and energy flow within the ecosystem. For example, fish and shrimp help control pest and weed populations, reducing the need for chemical pesticides. Additionally, they contribute to the recycling of organic matter by breaking down excess plant debris. The nutrient-rich waste they excrete, including nitrogen and phosphorus, is then absorbed by rice plants, promoting healthy growth and improving overall crop productivity [23,24]. The leftover feed and feces from the aquatic products also provide organic nutrients for rice growth, contributing to water resource conservation and the recycling of nitrogen and phosphorus. Despite these advantages, some studies have raised concerns about potential negative impacts. The combination of straw returning to the field and feed input in the IRAFS may result in higher concentrations of non-nutrient substances, such as organic matter, surplus feed particles and decomposing plant residues, in the water compared to the traditional single-rice cultivation model. This could increase the risk of water eutrophication due to the runoff from farmland, which may carry excess nutrients into nearby water bodies. Additionally, the IRAFS requires a certain level of technical expertise, and the income generated from this farming practice can be subject to significant fluctuations, introducing financial uncertainty into its implementation [25–27].

Therefore, while the IRAFS demonstrates significant potential for sustainable agriculture, continuous research and improvements are essential to overcome these challenges, optimize resource management and ensure stable economic returns for farmers. This study provides a comprehensive review of the existing research on the IRAFS, offering a detailed analysis of its economic, social and environmental benefits. It examines the current state of this farming model, highlights its limitations and offers targeted recommendations to address the identified challenges. The paper aims to provide valuable theoretical insights

for improving agricultural quality and efficiency while promoting green and sustainable development practices. By doing so, it seeks to achieve several objectives, including boosting agricultural output, reducing reliance on pesticides and chemical fertilizers, mitigating non-point source pollution, and enhancing the overall benefits of this farming approach. Ultimately, the paper aims to support the transition towards more sustainable and resilient agricultural systems.

A systematic and comprehensive literature search was conducted to explore the economic, social, and environmental sustainability benefits of IRAFS in China. The search was conducted across four databases, including CNKI (China National Knowledge Infrastructure), Web of Science, Elsevier ScienceDirect and Engineering Village databases, ensuring a broad and representative selection of studies. The search utilized a combination of keywords such as “Integrated farming”, “Rice-crayfish rotation system”, “Rice-Aquaculture Farming System”, “Rice-Fish co-culture”, “Pollution discharge coefficients of rice farming”, “Economic benefits of rice-aquaculture farming system”, “Environmental benefits of rice-aquaculture farming system”, “Social benefits of rice-aquaculture farming system”, and “non-point pollution in rice-aquaculture farming system”, using Boolean operators (AND, OR) to refine results.

The search period covered peer-reviewed articles, reviews, and reports published between 1 January 2010, and 1 June 2025. Initially, 1302 articles were identified. After careful screening of titles and abstracts based on relevance to the IRAFS and its impact on productivity, environmental sustainability, and socio-economic outcomes, a total of 175 articles were selected for further assessment. The criteria for inclusion were as follows:

- (1) Focus on the IRAFS, particularly related to the Chinese context.
- (2) Relevance to the sustainability benefits of IRAFS in terms of economic, environmental, and social impacts.
- (3) Peer-reviewed articles, reports, and reviews that provide scientific or empirical evidence on IRAFS.
- (4) Exclusion of studies that were unrelated to IRAFS or focused on non-sustainable farming practices.

Although the focus of this review was on the Chinese experience, a total of 14 references from other rice-growing countries were identified as relevant to IRAFS. Given the unique cultural, agricultural, and environmental context of China’s IRAFS, references that were less relevant to the specific rice–aquaculture integration model used in China were excluded from the final analysis. This systematic search ensures a comprehensive and up-to-date review of IRAFS developments and their sustainability benefits, with particular emphasis on the Chinese context.

2. Development and Current Status of Integrated Cultivation Model in Rice Fields

Rice farming and aquaculture have a long-standing tradition and are widely distributed across China. In recent years, integrated rice farming and aquaculture systems, which combine rice cultivation with the farming of economically valuable aquatic species, have gained prominence. These systems have attracted considerable social attention due to their multifaceted benefits, including economic gains, environmental sustainability and positive social impacts. The integrated approach not only enhances agricultural productivity but also supports biodiversity, improves water quality and promotes sustainable land use.

Since 2010, the IRAFS has received substantial support from national policies, technical promotion and scientific research. These efforts have been instrumental in encouraging the widespread adoption of this farming model, which is increasingly viewed as a solution

to the challenges posed by traditional farming practices. The strong backing from the government, along with technical promotion and research, has been pivotal in expanding the adoption of this model, helping to establish it as a key component in China’s agricultural development strategy.

For example, the Chinese central government’s No. 1 Central Document has consecutively emphasized the urgent need to promote the implementation of the rice–fish farming system. This document also underscores the important role that this model could play in stabilizing grain production, driving further development of the fishery industry and enhancing agricultural production quality and efficiency. The details of the support and its impact are further outlined in Table 1 [28–30]. This collaborative effort continues to drive the successful integration of rice farming and aquaculture, contributing to a more resilient and sustainable agricultural landscape in China.

Table 1. Relevant policies, promotion and research of the integrated rice–fish farming system in China [28–30].

Year	Policies, Promotion and Research Situations
2011	The Ministry of Agriculture and Rural Affairs of the People’s Republic of China (MARA) incorporated rice–fish integrated farming into the National Fisheries Development Twelfth Five-Year Plan (2011–2015)
2012	The initiative “Technology Integration and Demonstration Extension of Rice-Fish Integrated Farming” received special funding support from MARA to accelerate its nationwide application and standardization
2015	1. Rice–fish co-culture has been incorporated into the National Agricultural Sustainable Development Plan (2015–2030) as a critical strategy for promoting ecological conservation and the sustainable use of agricultural resources. 2. “In its Opinions on Accelerating the Transformation of Agricultural Development Models”, the State Council emphasized that rice–fish integrated farming should be prioritized as a core component of ecological circular agriculture. 3. MARA issued the “Guidance on Further Adjusting and Optimizing Agricultural Structure”, designating rice–fish integrated farming as a crucial approach to advancing green agricultural development and resource-efficient practices.
2016	China’s key policy plans, including the Chinese central government’s No. 1 Central Document, explicitly endorse the expansion of rice–fish farming as a means to enhance agricultural sustainability.
2017	MARA issued the “General Technical Requirements for Rice-Fish Integrated Farming” industry standard to standardize and promote sustainable practices in rice–fish co-culture systems.
2020	MARA issued the “Technical Guidelines for Rice-Fish Integrated Farming Production” to standardize practices and promote green, high-quality development in rice–fish co-culture systems.
2022	MARA issued the Guidelines on Promoting the High-Quality Development of the Rice–Fish Integrated Farming Industry, emphasizing a strategic shift from quantity-driven expansion to quality-oriented development in the integrated farming model. This transition focuses on ecological sustainability, technological innovation, and coordinated rural revitalization, aligning with national goals for food security and agricultural modernization.
2024	The National Standard “General technical requirements for integrated farming of rice and aquatic animals”, as the first of its kind in the field, has entered into force on 1 July 2024 [31]. It provides a critical framework for regulating production practices and promoting the high-quality development of the rice–fish integrated farming industry.

The IRAFS has proven to offer substantial overall benefits, prompting widespread exploration and implementation of related practices across various regions in China [32]. As a result, a diverse range of integrated farming systems has emerged, each characterized by unique features that cater to local conditions and needs. This model not only enhances agricultural productivity but also promotes ecological sustainability and economic resilience. In 2022, the total area dedicated to integrated rice farming and aquaculture in

China reached an impressive 2.86 million hectares, producing approximately 21.5 million tons of rice and 3.87 million tons of aquatic products, demonstrating the model's significant contribution to both the agricultural and aquaculture sectors (Figure 1) [29].

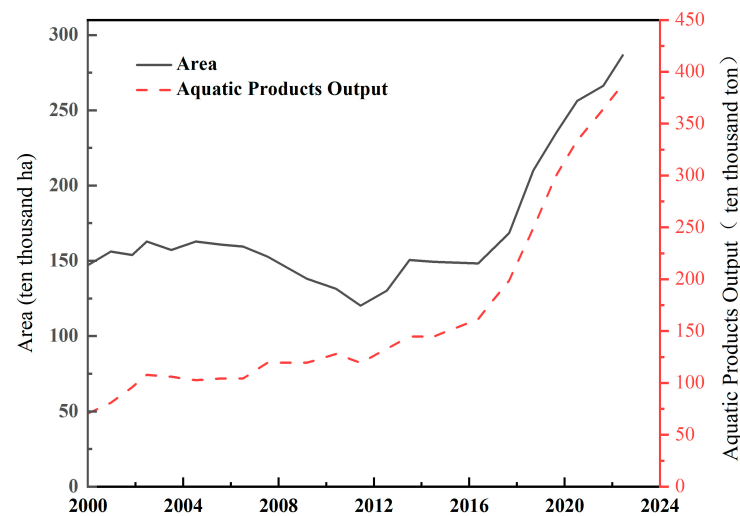


Figure 1. The integrated cultivation area and aquatic product output in China from 2000 to 2022 [29].

3. Benefit Analysis of the IRAFS

The development of rice farming and aquaculture is influenced by three key factors: economic, social and environmental aspects. The future advancement of rice farming models aims to strike a balance that maximizes economic returns, promotes positive social outcomes and minimizes environmental impact. By optimizing resource utilization, boosting productivity and ensuring sustainability, the goal is to create a farming system that is both profitable and eco-friendly. This comprehensive approach is essential for achieving long-term, sustainable growth in both agriculture and aquaculture [33].

3.1. Economic Benefits

Economic benefits at the farm level play a crucial role in determining the feasibility and potential of promoting integrated farming models. At this level, farmers face the challenge of covering the gap between the costs of production and the benefits they receive. The term “costs” refer to farming-related expenses, such as purchasing of seeds, fertilizers, labor, equipment, and maintaining irrigation systems. On the other hand, “benefits” refer to the financial returns from the sale of crops or products after deducting these costs. Economic benefits are categorized into direct and indirect benefits. Direct economic benefits focus on the financial outcomes for farmers, including production costs (such as seeds, fertilizers, labor, etc.) and revenues from selling both crops and aquatic products. Indirect economic benefits, however, encompass the economic advantages arising from environmental and social improvements, such as reduced pesticide use, enhanced soil health, and increased biodiversity in integrated farming systems. These externalities contribute to long-term sustainability and resilience, thus generating broader economic benefits. In traditional rice farming, income is primarily derived from the sale of rice, while costs are mainly allocated to pesticides, fertilizers, and labor. In contrast, integrated farming allows for the simultaneous cultivation of rice and the harvesting of aquatic products, thus diversifying the range of products. Furthermore, integrated farming can effectively improve environmental and social benefits, including reduced pesticide use, improved soil health, and greater biodiversity in integrated farming systems. These externalities contribute to sustainability and long-term viability, ultimately generating economic benefits. This diversification not only enhances income but also reduces reliance

on chemical fertilizers and pesticides, leading to better economic outcomes and more sustainable practices. However, the financial success of integrated farming is influenced by various factors, including technological maturity, geographic and climatic conditions, as well as the level of regional economic development. These factors contribute to differences in economic returns across various regions and farming systems [34,35]. There is still some debate about whether a stable and mutually beneficial symbiotic relationship can fully develop between rice and aquatic products. Nevertheless, integrated farming models generally yield higher profits compared to traditional monoculture rice farming, offering a more profitable and sustainable alternative for farmers.

3.1.1. Increased Product Yields

Rice–crayfish farming is the predominant integrated farming system in the Jiangnan Plain and has gained widespread adoption in recent years. This system has demonstrated significant economic advantages, with its average profit being 6.6 times higher than that of traditional monoculture rice farming, reaching an impressive 7516 USD/ha. However, the economic benefits of integrated farming are not uniform across all regions due to factors such as technological maturity, local geographic and climatic conditions, and variations in farming practices. Consequently, the financial outcomes of integrated farming systems exhibit considerable variation across different areas, shown in Figure 2. In the rice–crayfish system, the highest yields of rice, market crayfish and crayfish fry are 13,493.3, 4497.85 and 4293.3 kg/ha, respectively, representing the upper limits of potential production. In contrast, the lowest yields are significantly lower, with 449.8 kg of rice, 75 kg of market crayfish and 78.7 kg of crayfish fry per hectare. These significant fluctuations in product yields result in considerable variations in output value, directly influencing income [36,37]. The rice–crayfish co-culture system can increase yields compared to the traditional monoculture rice farming system, while also improving the quality of rice [38]. A study on the economic outcomes of integrated rice farming in Jiangxi Province found that 68.29% of farmers saw an increase in income after adopting the integrated farming approach, while 21.95% reported no change. On average, total income from integrated farming increased by 7431 USD/ha. This highlights the considerable potential of integrated farming systems to enhance agricultural profitability, although regional disparities and environmental challenges must be taken into account [39].

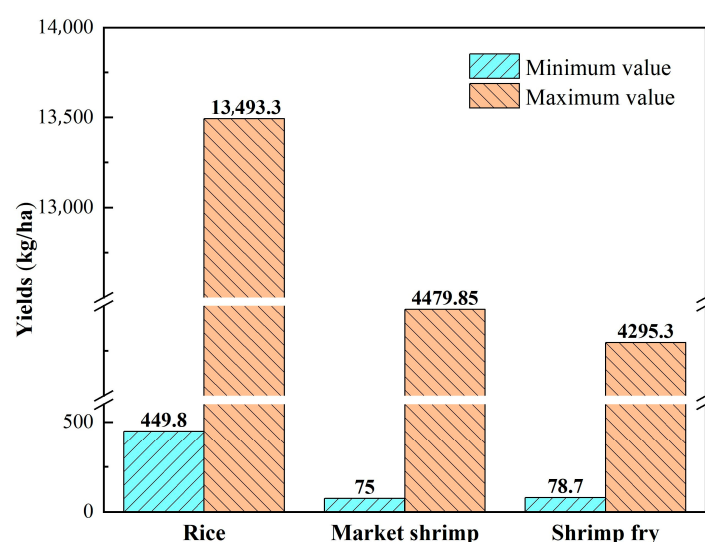


Figure 2. Output of rice, market crayfish and crayfish fry under the rice–crayfish integrated farming system [36,37].

3.1.2. Enhanced Overall Profit

The costs associated with IRAFS primarily include expenses related to both rice cultivation and the farming of aquatic products. Compared to traditional monoculture rice farming, the inclusion of aquatic animals in integrated farming systems reduces the need for chemical inputs such as weed control, fertilization and pest management. These additional ecological benefits not only enhance the sustainability of the farming system but also improve resource efficiency, leading to an increase in overall net revenue.

Chen conducted a statistical analysis of costs and net revenue across various integrated farming models implemented in demonstration projects, as shown in Figure 3. The results revealed that the cost of monoculture rice farming was 2944 USD/ha, yielding a net revenue of 925 USD/ha. In contrast, the rice–crayfish integrated model incurred a total cost of 6730 USD/ha, with a total net revenue of 4290 USD/ha. The rice–turtle model had a total cost of 9149 USD/ha, with a net revenue of 7803 USD/ha. The rice–goose model had the highest cost at 12,093 USD/ha, but also produced the highest net revenue at 9170 USD/ha. Across all these models, integrated farming significantly increased the overall profit of the rice fields, while also improving the profit margin per unit cost [40]. A study further analyzed the income differences between integrated rice farming and traditional monoculture rice farming under various conditions. The results indicated that integrated rice farming, due to the additional income generated from aquatic products, can significantly increase net revenue by 306 to 4187 USD/ha compared to monoculture systems. This highlighted the considerable financial benefits of integrated farming systems, particularly when the synergy between rice cultivation and aquaculture is fully optimized [41].

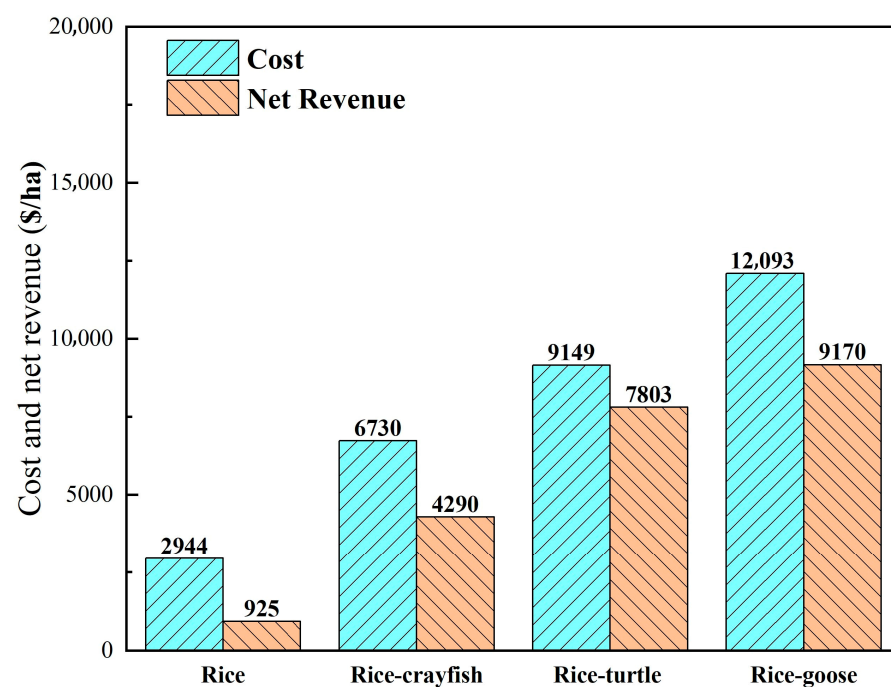


Figure 3. Cost and net revenue of various planting models, including rice farming, rice–crayfish, rice–turtle and rice–goose systems [40].

3.2. Environmental Benefits

Compared to traditional monoculture rice farming, the IRAFS significantly reduces the use of pesticides and fertilizers. It takes advantage of the symbiotic relationship between rice plants and aquatic organisms to create a more sustainable agricultural environment. The presence of aquatic species helps naturally control pests and weeds, thereby reducing

the need for harmful chemical treatments. Moreover, the aquatic organisms contribute to nutrient cycling within the ecosystem, ensuring that nutrients are more effectively utilized by the rice plants and minimizing the loss of fertilizers to the environment. This process not only mitigates the environmental impact of excessive chemical use but also enhances the overall health and biodiversity of the agricultural ecosystems. As a result, the IRAFS contributes to the long-term sustainability of farming by promoting environmental conservation and enhancing the ecological health of farmland [42–44].

3.2.1. Reduction in Pesticide and Fertilizer Use

In traditional rice farming, the extensive use of herbicides and insecticides is a standard practice for controlling weeds and pests. However, the reliance on these chemicals has raised significant environmental concerns, including soil degradation, water pollution and negative impact on non-target organisms. In contrast, the IRAFS leverages the natural ecological interactions between rice plants and aquatic species to control weeds and pests, thereby reducing the need for chemical inputs. In this system, aquatic species play a crucial role in maintaining ecological balance. Aquatic organisms consume weeds and insects, significantly reducing the weed population and controlling pest infestations. Research has shown that in rice–fish co-culture models, fish can effectively remove between 74% and 87% of weeds and have strong predatory capability over insects, thus effectively controlling pests that might otherwise damage the rice crop. As a result, the incidence of rice pests, such as the rice water weevil, brown planthopper and white-backed planthopper, is notably reduced compared to monoculture rice fields [45].

Furthermore, the IRAFS leads to a substantial reduction in the use of fertilizers, which are commonly applied in the traditional rice farming to promote crop growth [36]. Significant differences exist in the application rates of nitrogen and phosphate fertilizers between the two models, but not in potassium and compound fertilizers. When implementing the rice–crayfish integrated farming system, aquaculture-crop integrated units appropriately reduce the application of nitrogen and phosphate fertilizer due to their impacts on aquatic product growth and water eutrophication. However, they continue the fertilization management practices used in single-crop rice cultivation during rice planting and other stages, which may explain the observed phenomenon. The results are shown in Figure 4. In traditional monoculture rice farming, the average application rates of nitrogen, phosphorus, potassium and compound fertilizers which combine multiple macro-nutrients, typically nitrogen, phosphorus and potassium are 116.66, 178.33, 43.33 and 313.31 kg/ha, respectively. However, the application rates of nitrogen and phosphorus fertilizers are significantly reduced, with nitrogen decreasing to 64.36 kg/ha and phosphorus decreasing to 38.12 kg/ha. The application rates of potassium and compound fertilizers show no significant change, remaining at 44.96 and 339 kg/ha, respectively. This change is primarily driven by the natural nutrient cycling that occurs in the rice–fish system. The presence of aquatic organisms helps absorb excess nutrients, particularly nitrogen and phosphorus, which would otherwise contribute to water eutrophication and disrupt the aquatic ecosystem. Consequently, the integrated system not only reduces the need for synthetic fertilizers but also helps prevent the environmental consequences associated with nutrient overloading, such as algal blooms and deteriorating water quality [45].

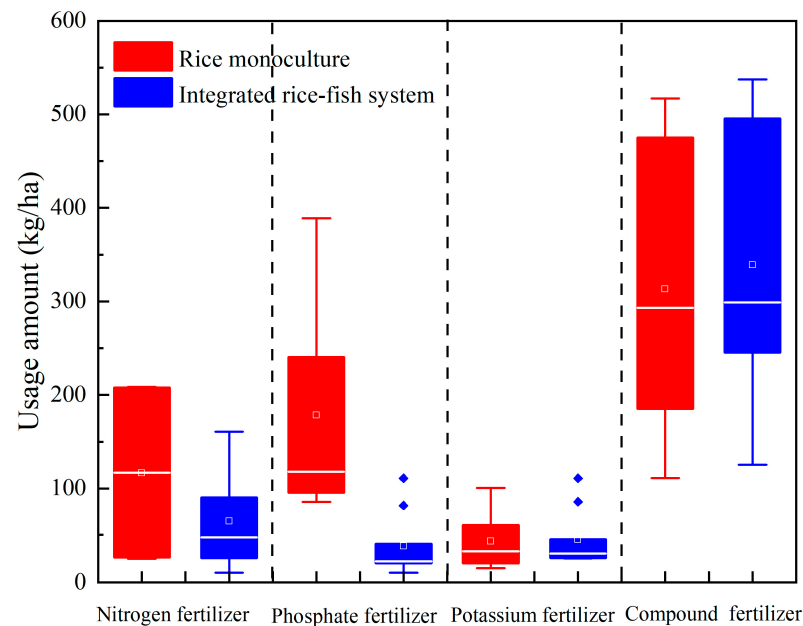


Figure 4. The fertilizer usage under different farming systems [45].

3.2.2. Reduction in Pollutant Emissions

Traditional rice farming significantly contributes to greenhouse gas emissions, and aquaculture wastewater is a major source of nitrogen and phosphorus pollution. Research has shown that integrating aquaculture with rice farming can enhance wetland ecosystem management and improve the overall agricultural environment. The IRAFS has proven effective in reducing emissions of nitrogen, phosphorus and carbon, with carbon emission reduction now being a key policy focus in the global effort to green agricultural development [46–49].

Nitrogen and phosphorus loss fluxes in paddy fields of different planting systems in different regions of China was shown in Table 2. In China's six major rice-growing regions, the average nitrogen and phosphorus losses in single-cropping and double-cropping rice areas in the central region are 16.59 kg/ha and 0.89 kg/ha, respectively [50]. Monitoring results from Chaohu Lake in Anhui indicate that the average nitrogen and phosphorus losses in single-cropping rice areas are 14.58 kg/ha and 1.41 kg/ha, respectively. In rice–crayfish co-culture models, the average nitrogen and phosphorus output from field drainage is 31.72 and 1.43 kg/ha, respectively [51].

Table 2. Nitrogen and phosphorus loss fluxes in paddy fields of different planting systems in different regions of China [52–54].

Cropping System	Nitrogen Loss Amount/(kg/ha)	Phosphorus Loss Amount/(kg/ha)
single-cropping (China's six major rice-growing regions)	16.59	0.89
single-cropping (Chaohu Lake)	14.58	1.41
Rice–shrimp co-culture models	31.72	1.43
Chinese freshwater prawn	37.20	7.78
<i>Litopenaeus vannamei</i>	181.00	46.80
<i>Macrobrachium rosenbergii</i>	148.00	34.50

For aquaculture systems, the average nitrogen emission intensities for Chinese freshwater prawn, *Litopenaeus vannamei* and *Macrobrachium rosenbergii* are 37.20, 181.00 and 148.00 kg/ha, respectively, while the average phosphorus emission intensities are 7.78, 46.80 and 34.50 kg/ha, respectively. Although pollutant emissions in integrated rice–fish farming systems are higher than those in monoculture rice farming, they remain significantly lower than those from high-density pond aquaculture systems [52–54].

Tao et al. used the equivalent pollution load method to estimate pollutant emissions under the rice–crayfish rotation model and compared them to those from monoculture rice farming. The average emission coefficients for total nitrogen, total phosphorus, chemical oxygen demand and ammonia nitrogen in the aquaculture tailwater of the rice–crayfish model are 2.994, 0.458, 35.1232 and 1.504 kg/t, respectively. The non-point source pollution emission coefficient is lower, resulting in reduced environmental pollution. Compared to monoculture rice farming, the resource renewal input ratio, energy output rate and sustainability index are all higher, while the environmental load rate is lower, making the integrated system more favorable for sustainable development [55]. Dong et al. conducted a life cycle assessment to analyze the environmental impacts of pond aquaculture versus integrated rice–fish farming systems. The results indicated that the integrated rice–fish farming system enhanced the utilization of land and water resources, offering significant ecological benefits. This system was found to be more environmentally friendly and holds greater development potential compared to pond aquaculture [56].

3.2.3. Improvement of the Agricultural Ecosystem

In monoculture rice farming, rice is the dominant component of the agricultural ecosystem, often resulting in a simple and less diverse ecological structure. In contrast, the IRAFS fosters a more diverse and resilient ecosystem. This system not only involves rice cultivation but also integrates algae, weeds, insects and other natural components, which are effectively utilized and contribute to the cyclical nature of the entire system. The interactions among diverse organisms enhance the overall ecological balance, leading to a more sustainable agricultural environment [57]. Tang et al. investigated the changes occurring in agricultural ecosystems under various integrated rice–fish farming models. The research revealed that the activity of farmed animals plays a key role in controlling weed growth in rice fields [58]. Additionally, the presence of these animals significantly boosts the microbial activity in the soil, leading to a notable increase in the population of bacteria, actinomycetes, fungi and other microorganisms. This surge in microbial diversity improves overall soil health and fosters a more balanced and dynamic community structure [59–61].

Similarly, a research focused on the abundance and community structure of soil microorganisms in the co-culture model. The results showed that soil composition played a critical role in determining the quantity, variety and structure of microorganisms. In the co-culture model, the population of ammonia-oxidizing bacteria and archaea was significantly higher compared to the traditional monoculture rice farming system. The shift in microbial population not only enhanced soil fertility but also improved the overall ecological balance, contributing to the long-term sustainability of the farming system. The improved soil community structure in the co-culture system suggested that integrating multiple components within the farming system leads to a more robust and efficient ecosystem [62].

Some studies have investigated the incidence of pests and diseases in rice under single-cropping and rice–crayfish integrated farming systems. The results showed that compared to single-cropping rice, the incidence of insect pests was significantly lower in the rice–crayfish integrated farming system, shown in Figure 5. In the rice–crayfish integrated system, except for a slight increase in the incidence of sheath blight, the incidence

of other rice pests and diseases decreased. Specifically, the incidence of brown planthopper, second-generation rice borer and third-generation rice borer decreased by 51.48% and 30.38%, respectively. The increase in sheath blight incidence may be related to the long-term flooding of rice fields and insufficient drying time [25,45]. Therefore, the rice–crayfish integrated farming system has been effective in reducing the incidence of various rice pests and diseases.

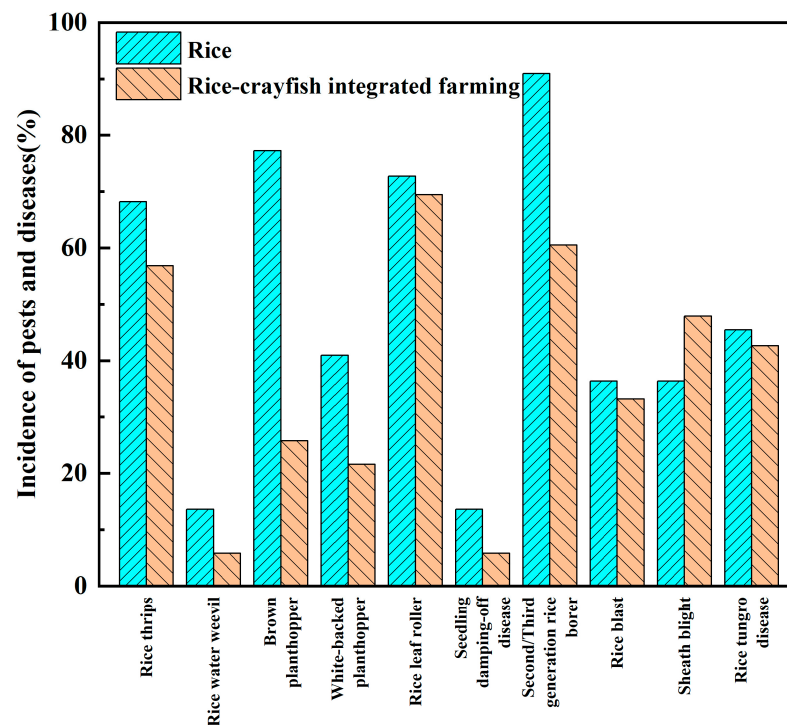


Figure 5. Incidence of pests and diseases in rice under two different models [25,45].

3.3. Social Benefits

The IRAFS offers a range of social benefits that extend beyond economic advantages. These benefits are evident in its ability to effectively address the issue of idle or underutilized farmland, create employment opportunities, improve living standards, promote the development of local rice–fish industries, optimize the industrial structure, foster agricultural innovation, and contribute to environmental sustainability. The social benefits of this model have been largely assessed through theoretical frameworks and empirical analysis, often supported by various models to provide a more comprehensive understanding [63].

Peng et al. utilized the Analytic Hierarchy Process (AHP) and indicator weighting methods to conduct a quantitative and comprehensive evaluation of the social benefits of the integrated farming model in Chenzhou, Hunan Province. By selecting various social and economic indicators and constructing an indicator system, they calculated a social benefit index of 0.45 for the integrated farming model. The index showed a slight improvement in social benefits compared to the traditional monoculture rice farming model. The result demonstrated that integrating fish farming into rice production can yield tangible social benefits, particularly in rural areas where farming efficiency and productivity are crucial for community development [64].

Based on survey data from the Jiangnan Plain region, Wang et al. employed methods such as BP neural networks and treatment effect models to examine the benefits of the integrated rice–fish farming model. The results indicated that the system brings considerable social improvements to farmers, particularly in terms of enhanced living conditions, improved agricultural labor quality, and the promotion of agricultural product brand-

ing. For instance, farmers involved in integrated farming systems often have access to higher-quality inputs, can adopt better farming techniques, and receive premium prices for products marketed under local or organic labels. Branding not only increases the economic value of their products but also helps create a sense of local pride and recognition. Importantly, the research revealed that the social benefits of the integrated farming model were largely unaffected by the scale of farming operations or the age of the farmers. This suggests that even small-scale or elderly farmers can benefit from the model, highlighting its accessibility and potential for widespread adoption. The system's impact on social welfare extends beyond the economic realm, promoting a more inclusive and sustainable approach to rural development. The improved labor quality and skill improvement resulting from the adoption of the integrated model also foster social mobility for farmers and their families [65,66].

Furthermore, the integrated rice–fish farming system plays a pivotal role in promoting regional economic development. By creating new value chains and local industries focused on rice and fish production, this system supports regional economies, enhances income distribution and reduces rural poverty. As these industries expand, there is also a multiplier effect, with other sectors such as transportation, food processing, and marketing benefiting from the growth of the rice–fish value chain. This expansion leads to improved infrastructure and services within rural communities.

In addition to its economic and labor-related advantages, the integrated rice–fish farming system contributes to environmental sustainability. By maintaining a healthy ecological balance in agricultural production, it helps improve local water quality, reduces the need for chemical fertilizers and pesticides, and enhances biodiversity. These environmental benefits are indirectly linked to social well-being, as healthier ecosystems often lead to better health outcomes for local populations.

In conclusion, the integrated rice–fish farming system offers significant social benefits that extend beyond economic growth. These benefits include improved living conditions for farmers, enhanced labor quality, and the development of new industries that support local communities. Moreover, the system positively impacts regional economic development, environmental sustainability and social inclusivity, making it a promising system for rural development.

4. Existing Issues and Shortcomings

The IRAFS partly fulfills the principles of “dual uses of one water, double harvests in one field”. It has the potential to fully leverage the resources of the rice field ecosystem, offering significant economic, environmental and social benefits through a green farming approach. However, several issues and shortcomings must be addressed in its practical implementation [28].

4.1. Impact on Total Rice Yield

Although the IRAFS theoretically enhances both the yield and quality of rice, several factors can cause a decrease in total rice production. The density of aquaculture and the proportion of ditches and ponds in the rice field can negatively impact the overall rice yield. While the model is expected to boost unit yield and enhance rice quality, factors such as aquaculture density and the space occupied by ditches and ponds can reduce the available area for rice cultivation, leading to a decline in total rice yield. A research analyzes rice samples from 309 integrated farming and aquaculture models across 13 provinces in China and finds that systems such as rice–carp, rice–crab, rice–crayfish and rice–turtle result in lower rice yields compared to traditional monoculture rice farming [20]. This is primarily

due to the impact of aquaculture density and the space consumed by water bodies, which reduce the area available for rice cultivation [67,68].

4.2. Highest Income but Lowest Profit

Some studies have shown that small-scale farmers often generate the highest revenue but the lowest profit, primarily due to higher production costs and undesirable outputs compared to their large-scale counterparts. Limited access to modern technologies and efficient farming practices forces many small-scale farmers to depend heavily on fertilizers to sustain crop yields, which intensifies their financial strain. Furthermore, the lack of economies of scale reduces the cost-effectiveness of fertilizer use in small-scale operations, making it far less efficient than in larger farming systems, where such resources can be utilized more effectively. This combination of high input costs and restricted access to advanced farming techniques places small-scale farmers at a significant disadvantage, both in terms of profitability and long-term sustainability [34,69]. For instance, it has been observed that fertilizer usage per hectare increases as farm size decreases. To maintain profitability, small-scale farmers are forced to adopt intensive farming methods, which are more costly and generate higher carbon emissions due to the increased input requirements. Another challenge is that small-scale farms struggle to implement innovative, eco-friendly techniques, such as new rice–crayfish fertilizers and chemical-saving technologies. Although these techniques may not provide significant short-term benefits and often come with high fixed costs, they have the potential to reduce carbon emissions and improve soil health over time. However, the difficulty of promoting these techniques on small farms negatively impacts their profitability. According to technical guidelines, the ideal unit area for rice–crayfish co-culture is between 1.33 and 3.33 hectares. However, most farms in China operate below this optimal size. To ensure the rational and sustainable adoption of rice–fish co-culture systems by small farmers, it is crucial to implement a comprehensive approach that includes effective supervision, incentives, and penalties. This strategy will not only encourage farmers to adopt best practices and improve their production methods, but also help them optimize resource usage, enhance profitability, and minimize environmental impact. Through targeted guidance and the establishment of clear incentives and penalties, smallholder farmers can be motivated to embrace sustainable farming practices that balance both economic and ecological considerations, leading to long-term benefits for both their livelihoods and the broader agricultural ecosystem [70,71].

4.3. Lack of Standardized Guidelines

While the government has introduced relevant policies and conducted research to promote integrated rice farming and aquaculture, the existing technical guidelines and regulations remain insufficient [72]. There are no unified standards for key aspects of the farming process, such as irrigation practices and water management, which are critical for the success of aquaculture within rice fields. Furthermore, factors like temperature, soil quality, and water conditions significantly affect the effectiveness of the farming system. Therefore, further research is essential to establish clear and standardized guidelines to ensure the sustainable and efficient operation of integrated farming and aquaculture systems. Given the high investment costs associated with the integrated rice farming and aquaculture model, producers must allocate resources carefully and adopt scientific management practices. Failing to do so will expose them to considerable risks. In practice, some farmers have invested heavily in materials with the expectation of economic gains, only to face significant resource waste and environmental pollution. Similar research abroad has shown that by implementing relevant policy frameworks, integrated rice–fish farming could provide a long-sought solution for sustainable agriculture by optimizing the

use of land and resources. This approach could greatly enhance the prosperity and health of marginalized and poor farmers in developing countries [72,73].

4.4. *Insufficient Promotion and Application*

The IRAFS which combines rice cultivation with aquaculture, requires specialized knowledge and significant labor. This complexity makes it essential to have skilled expertise to effectively manage both agricultural and aquaculture practices. However, the widespread adoption of this model has been limited due to factors such as insufficient guidance, inadequate technological advancements and a lack of comprehensive support. As a result, the model has only been implemented in a limited number of regions, particularly in Hubei, Hunan, and Jiangxi provinces, which has led to yields lower than expected. To fully realize its potential, it is essential to enhance support systems, provide more comprehensive technical training, and invest in further research and development to improve efficiency and productivity.

5. Prospect and Suggestion

The IRAFS as an environmentally friendly and sustainable agricultural system, significantly improves both yield and income efficiency compared to traditional monoculture rice farming. This model offers substantial economic benefits while promoting ecological balance. Although it is being scaled up, it is crucial to maintain a focus on the overall health of the ecosystem. The benefit indicators, including crop yield, aquaculture productivity, harvested fish biomass, economic benefits, environmental sustainability, labor productivity, farmer adoption rates, and social impact, must be quantified and scientifically analyzed in order to comprehensively assess and maximize the potential of the integrated rice farming model. This analysis will not only provide valuable insights into the overall effectiveness of the system but also enable data-driven decision-making, fostering continuous improvement and ensuring the long-term sustainability of the model. By thoroughly examining these indicators, we can identify areas for optimization, quantify the economic and ecological gains, and ensure that the model delivers both short-term and lasting benefits for all stakeholders involved.

Firstly, it is crucial to significantly intensify research and development efforts aimed at advancing rice–fish integrated farming technologies. The focus should be on fostering innovation to improve both the efficiency and long-term sustainability of the farming model. Specifically, comprehensive investigations should be conducted into key areas such as ecological aquaculture practices, the development of intelligent management systems, and the implementation of resource recycling techniques. This will enable substantial improvements in resource utilization, waste reduction, and environmental impact minimization, ensuring the farming model remains both environmentally responsible and economically viable.

Secondly, establishing a robust and well-integrated industrial chain for rice–fish farming is vital for the model's scalability and long-term success. Creating seamless connections across all stages, including rice cultivation, aquaculture, processing, and sales, is essential. This interconnected chain will streamline operations and foster the formation of industrial clusters, which can serve as hubs for innovation and collaboration. Additionally, promoting regional cooperation will optimize resource allocation, enhance knowledge sharing, and improve overall productivity. Strengthening this industrial ecosystem will increase the added value of the entire rice–fish farming industry, boosting its competitiveness in both domestic and international markets.

Thirdly, accelerating the adoption and diffusion of advanced rice–aquaculture farming technologies is key to the model's widespread implementation and success. This can

be achieved by implementing comprehensive training and skill development programs tailored to farmers. These programs should focus on enhancing farmers' managerial and operational skills, equipping them with the necessary knowledge to manage integrated farming operations efficiently. By empowering farmers with the tools and expertise to make informed decisions, we can strengthen their capacity to sustain and grow their operations. This, in turn, will foster greater confidence in the long-term viability of rice–fish integrated farming, encouraging wider adoption and enabling farmers to thrive in a competitive agricultural landscape.

Lastly, the government should introduce and implement supportive policies aimed at advancing rice–fish integrated farming, including financial subsidies, tax incentives, and land transfer support. These policies will encourage greater participation from both farmers and enterprises. Additionally, targeted public awareness campaigns should be carried out to raise farmers' awareness and understanding of the model, thereby increasing their acceptance and adoption of this sustainable farming method.

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