

Feature Review

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Eco-environmental Benefits of Integrated Rice-Fish Farming: Reducing the Impact of Fertilizer and Pesticide Use

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Abstract Integrated rice-fish farming has emerged as a sustainable alternative to conventional rice cultivation, addressing environmental degradation caused by excessive chemical inputs. This study investigates the eco-environmental benefits of integrated rice-fish systems, with a focus on reducing fertilizer and pesticide use. By examining mechanisms such as nutrient recycling through fish activity, reduced reliance on synthetic fertilizers, and improved soil conditions, we demonstrate how these systems contribute to more efficient nutrient management. Additionally, the study explores the role of fish in natural pest and weed control, thereby lowering pesticide and herbicide dependence while enhancing overall agroecosystem biodiversity. Broader ecological benefits, including water quality improvement, carbon sequestration, and habitat conservation, are also evaluated. A case study from the Mekong Delta, Vietnam, illustrates the real-world impacts and adoption process of this farming practice. Despite notable environmental advantages, challenges such as technical barriers and limited policy support remain. This research underscores the potential of integrated rice-fish systems in advancing sustainable agriculture and recommends strategic interventions for wider implementation and policy integration.

Keywords Integrated rice-fish farming; Fertilizer reduction; Pesticide reduction; Eco-environmental benefits; Sustainable agriculture

1 Introduction

The practice of raising fish in rice fields has been increasingly seen as a promising sustainable agricultural method. It not only brings ecological benefits, but also economic gains. The basic idea of this practice is to combine rice cultivation and fish farming, and try to make good use of land and water resources, thereby improving the efficiency of agricultural production and protecting the environment. In this system, farmers grow rice and raise fish in the same rice field. When fish move in the rice field, they stir the soil, help decompose organic matter in the rice field, and eat some pests and weeds. These natural processes can reduce farmers' dependence on pesticides and fertilizers, make agriculture more environmentally friendly, and make farmland more "vital" (Nayak et al., 2018).

To put it simply, rice-fish symbiosis is to grow rice and raise aquatic animals, such as fish, in the same field. This method can make fuller use of nutrients in rice fields and improve the quality of soil and water. Because of the activities of fish, it can also promote the reproduction of microorganisms in the rice field ecosystem, which help maintain the ecological balance of farmland (Hou et al., 2024). Many studies have found that compared with rice farming alone, raising fish in rice fields can increase output and profits per unit area (Arunrat and Sreenonchai, 2022). More importantly, farmers can not only harvest rice, but also sell fish, which makes their income more stable and their food sources more abundant (Fu et al., 2024).

Traditional monoculture of rice usually requires a large amount of fertilizers and pesticides. Excessive use of these things will lead to many problems, such as the land becoming increasingly barren, water sources being polluted, and even more greenhouse gases being emitted (Ibrahim et al., 2023; Zhang et al., 2023). In the long run, this method not only damages the ecological environment, but also makes people worry about whether agriculture can continue. Moreover, pesticide residues may also affect human health and put pressure on rural life (Pearlin et al., 2024).

The focus of this study is to see whether the practice of "raising fish in rice fields" can reduce the use of fertilizers and pesticides and see if it has a positive impact on the ecological environment. We will combine some recent research results to analyze the differences between the rice-fish symbiotic system and traditional rice cultivation. For example, how do they differ in soil health, nutrient cycling, greenhouse gas emissions, and overall ecosystem services? We will also evaluate whether rice-fish integration can lead to more sustainable agricultural development, improve the rural living environment, and have a positive impact on farmers' economic income and quality of life.

2 Mechanisms of Fertilizer Reduction in Rice-Fish Systems

2.1 Nutrient recycling by fish activity

In the rice-fish symbiotic fields, fish are not "supporting roles", they actually play a very important role in the nutrient cycle. Fish will eat organic matter in the rice fields, such as residual plants, plankton, etc. The feces they excrete contain a lot of nutrients such as nitrogen and phosphorus, which will be absorbed by the rice in the rice fields. Simply put, the fish help to circulate nutrients in the process of eating and defecating. In this way, farmers do not need to input so many external fertilizers. Especially nitrogen fertilizer, fish feed and fish feces can provide a lot of alternative nitrogen sources. Studies have found that using fish feed to replace 50% to 75% of the original nitrogen fertilizer input can still make rice grow well, and it can also reduce nutrient waste and reduce water pollution problems (Liu et al., 2024). The relationship between fish and rice is like mutual help, with higher nitrogen utilization and less damage to the environment (Xie et al., 2011).

2.2 Reduced need for synthetic inputs

In rice-fish symbiotic farmland, the use of fertilizer is generally much less than that of pure rice fields. Studies have shown that this system can reduce the use of fertilizer by up to 24% without affecting rice yields. In other words, rice still grows well even with almost a quarter of less fertilizer. This system can also use some alternatives, such as compost, organic fertilizer or wastewater from fish ponds, which are all good sources of nutrients, and there is no need to buy fertilizers specifically (Yassi et al., 2023). For example, experiments have found that using fish pond water to irrigate rice fields and reducing the amount of conventional fertilizer by 20% did not reduce rice yields, but improved water quality (Qi et al., 2020). This method is both economical and environmentally friendly. Using less fertilizer not only reduces the cost of farming, but also reduces the risk of pollution caused by excess nutrients in the water (Li et al., 2024).

2.3 Enhanced soil fertility and structure

In the rice-fish symbiotic system, the soil condition can also be improved. Because of the participation of fish, the organic matter content in the soil will increase, nitrogen and other nutrients will be richer, and the nutrient cycle efficiency will be improved (Xie et al., 2010). At the same time, the use of fish manure and some organic fertilizers can increase the carbon and nitrogen storage in the soil (Figure 1). The soil structure has also become softer, with more pores, better water and air circulation, and lower bulk density. This structure is more conducive to the growth of rice roots (the soil will not be hardened), making the soil healthier and more suitable for farming (Zhang et al., 2023). Long-term studies have also shown that this method of growing rice and raising fish can not only maintain soil fertility, but also maintain stable yields while reducing fertilizers compared to the method of growing rice alone. In other words, not only is the ecology better, but farmers can continue to make money. These changes make rice fields more sustainable and more resistant to risks, which is good for both the environment and farmers.

3 Reduction of Pesticide Dependence

3.1 Natural pest control by fish

Raising fish in rice fields can actually prevent insects. Because fish eat pests and their larvae in the water, there are naturally fewer insects. In this way, farmers do not need to rely on spraying pesticides to deal with pests as before. Studies have found that the use of pesticides can be reduced by up to 68% by using the practice of rice-fish symbiosis (Xie et al., 2011). Moreover, fish can control the number of insects before the pests break out, which is also a kind of protection for the growth of rice. Not only are there fewer insects, but this method can also make

rice and fish grow better together. Because if too much pesticide is used, it is easy to hurt rice and fish and affect their growth (Berg and Tam, 2018). Therefore, using fish to prevent insects not only saves pesticides, but also ensures yield, killing two birds with one stone.

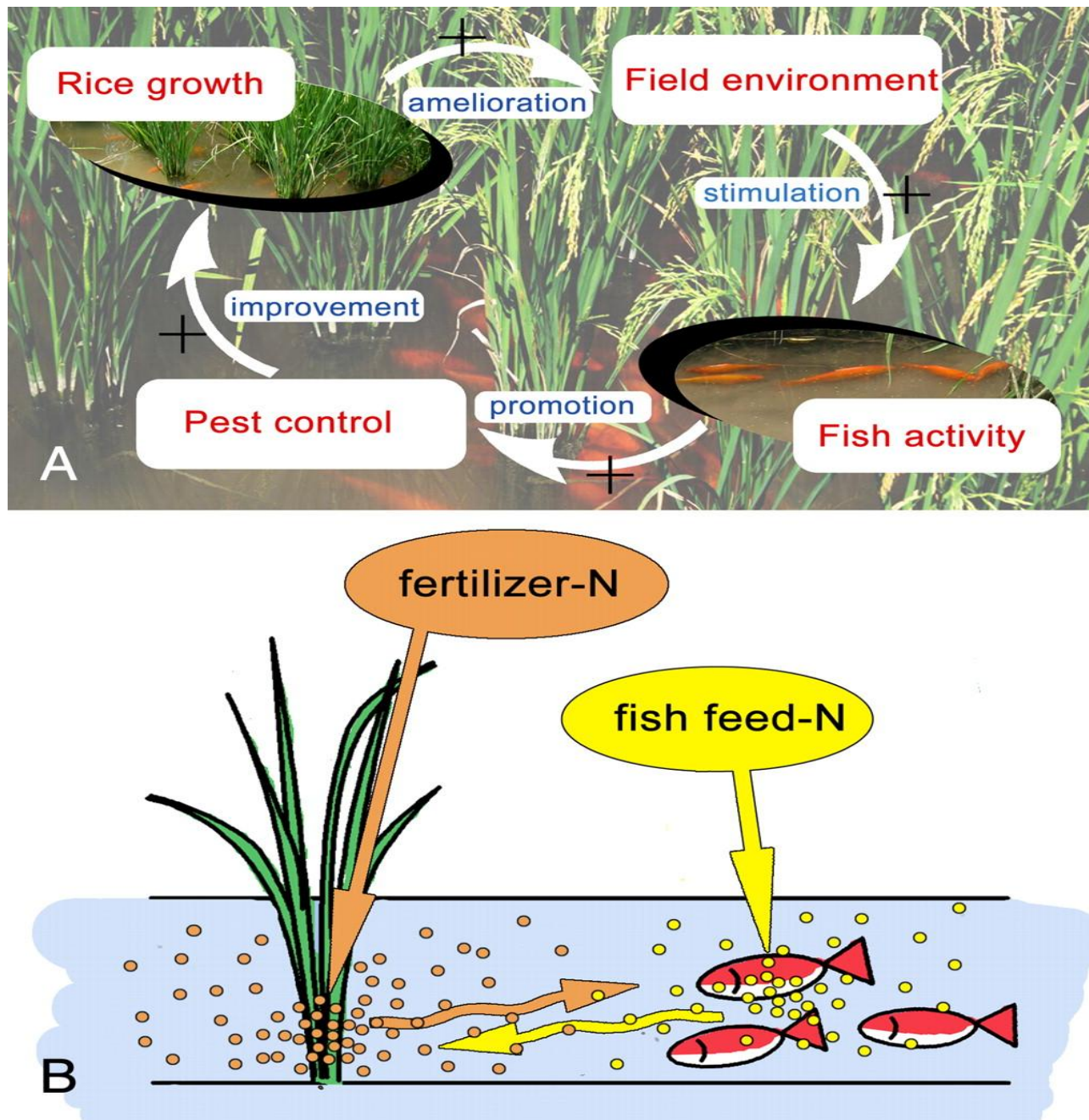


Figure 1 Positive interactions and complementary use of nitrogen (N) between rice and fish explain why the rice-fish coculture system maintains productivity for long time periods with low input of chemicals. (A) Positive interactions between rice and fish: Fish remove pests from rice through feeding activity, while rice plants moderate the field environment for fish, which in turn promotes fish activity and pest removal. (B) Complementary use of N by rice and fish: Unused fertilizer N promotes plankton in paddy fields that is consumed by fish. The unconsumed fish feed acts as an organic fertilizer, with the N in the unconsumed feed being gradually used by the rice. Thus, rice and fish use different forms of N, resulting in a high efficiency of N utilization in RF (Adopted from Xie et al., 2011)

3.2 Lower weed infestation and herbicide use

Fish swimming around in rice fields stir up the water, making it difficult for weeds to grow. When the water and soil are stirred up by fish, weed seeds are less likely to germinate and grow more slowly. This reduces the number

of weeds and reduces the number of times farmers use herbicides. Studies have shown that compared with traditional rice fields, rice-fish symbiotic fields have fewer weeds and the need for herbicides is reduced. This not only protects the environment, but also helps farmers save money on weeding. Using less chemical pesticides also reduces residual pollution in fields and water, making the ecosystem cleaner.

3.3 Enhanced biodiversity for pest regulation

In addition to fish, other aquatic animals can be raised in rice fields, such as snails, shrimps, and small insects. These animals can increase the number of species in the field and form a more balanced ecosystem. In this ecosystem, some animals will eat pests, while others will compete with pests for living space, thereby suppressing the development of pests. Studies have also found that rice-fish symbiotic fields have richer species, the ecosystem has a stronger "self-repair" ability, and has a better control effect on pests (Ibrahim et al., 2023). Because there are so many "helpers", farmers can use less pesticides, while maintaining a good level of yield and ecology. This system that relies on nature to help is more environmentally friendly and easier to sustain in the long run. It not only protects the environment, but also allows farmers to earn more.

4 Eco-environmental Benefits Beyond Chemical Reduction

4.1 Improved water quality and aquatic health

Rice-fish symbiosis not only reduces pesticides and fertilizers, but also significantly improves water quality. The water in rice fields often comes from wastewater from aquaculture, such as water from fish farming. There are a lot of nutrients such as nitrogen and phosphorus in the water. Rice in the field will absorb these excess nutrients, so that the water becomes clean. In addition, microorganisms in the field will also help to transform these nutrients. Studies have shown that this can greatly reduce the total nitrogen, total phosphorus and chemical oxygen demand in the water (Liu et al., 2023). Clearer water is also good for fish and other aquatic animals. Harmful blue algae are less likely to break out, and the entire water ecology will be more balanced and healthier. Moreover, fish swimming in the water can make the water flow better, which helps to increase the oxygen in the water. In this way, fish and other aquatic organisms can live better, and farmland can continue to produce (Ahmed et al., 2020).

4.2 Biodiversity conservation in agroecosystems

The rice-fish system can also increase the number of species in the field. The addition of fish will affect many animals and plants in the rice field, such as snails, insects, and microorganisms. These animals and microorganisms live at different "trophic levels", forming a more complex ecosystem. Studies have found that rice-fish co-culture can increase the number of predators of invertebrates, but reduce weeds and pests (Wan et al., 2019). Because there are more species, the entire ecosystem is more "resistance". If one link fails, other parts can also take over. More importantly, the addition of fish can help attract and protect some natural enemies that threaten pests. There are also many small aquatic and terrestrial animals that find their "home" in this environment, which is equivalent to helping them preserve their habitat (Berg et al., 2016; Hou et al., 2024). Therefore, this system is not only good for farmers, but also for the environment. It can provide more ecosystem benefits, such as natural insect control, water purification, and preservation of biodiversity.

4.3 Climate regulation and carbon sequestration

Another great benefit of the rice-fish system is that it also helps mitigate climate change. Why? Because it helps the soil store more carbon. The increase in organic matter in the soil is like "saving money" for the land, storing carbon underground. This reduces the amount of carbon dioxide and other greenhouse gases entering the air. For example, in rice fields where fish or shrimp are raised, as long as fertilizer use is properly arranged, direct and indirect greenhouse gas emissions can be reduced, and rice yields will not decrease (Cui et al., 2023). These systems can also help regulate the temperature and humidity in the fields, making the agricultural landscape more comfortable and more suitable for plant and animal growth (Arunrat and Sereenonchai, 2022). Rice-fish farming is contributing to climate regulation and sustainable agricultural development by reducing emissions and increasing carbon storage in many ways (Zhang et al., 2024).

5 Case Study: Implementation in the Mekong Delta, Vietnam

5.1 Background and adoption process

In Vietnam's Mekong Delta, many farmers have begun to abandon their original rice-only farming methods and adopt a "rice-fish combination" farming method. This change is mainly because farmers want to make agriculture more sustainable and their family income more stable. Although the original intensive single rice farming has high yields, it also has many problems, such as high fertilizer and pesticide use and high environmental pressure. The promotion of rice-fish symbiosis is not achieved overnight. It is affected by many factors, such as the size of farmers' land, water conditions, whether they have received training, and how much they know about this combination of farming and farming. Generally speaking, farmers with larger fields, more abundant water sources, and who have participated in training are more likely to accept this new method. Participatory promotion and research are also crucial. For example, the promotion of methods such as "integrated pest management" (IPM) allows farmers to not only learn farming techniques, but also know how to use less pesticides (Figure 2). This method is particularly helpful in promoting the popularization of the rice-fish model and can better ensure that this model can develop in the long run (Bosma et al., 2012).

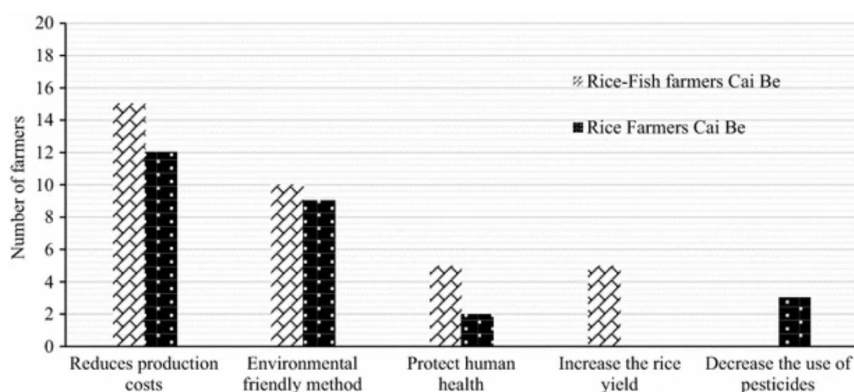


Figure 2 Main reasons for applying IPM among 20 rice-fish farmers (RF) and 14 rice farmers (R) in Cai Be (Adopted from Berg et al., 2016)

5.2 Outcomes on fertilizer and pesticide reduction

In the Mekong Delta, farmers who use rice-fish farming use less fertilizer and pesticides than traditional rice farmers. Many surveys have found that rice-fish farmers, especially those who use IPM pest management methods, have reduced their pesticide use by almost 65% over three years. On the contrary, those who do not use IPM use more and more pesticides, even up by 40%. Why is this so? Because after raising fish, farmers will pay more attention to the impact of pesticides on fish. If too much pesticide is used, the fish may die, so they will be more cautious. This makes the use of chemical pesticides more reasonable. The amount of fertilizer used is also much less than that of single rice cultivation, but the rice yield has not decreased significantly. This shows that using less fertilizer can still maintain yield, and there is no need to rely on heavy investment to get a good harvest (Rothuis et al., 1998; Berg, 2001; Berg et al., 2016; Berg and Tam, 2018).

5.3 Broader environmental and socioeconomic impacts

In addition to reducing the use of chemical fertilizers and pesticides, rice-fish symbiosis has also brought many benefits to the environment and society. For example, the water has become cleaner and there are more organisms in the rice fields. The functions of the ecosystem have become stronger, such as the natural reduction of pests, and the living environment of fish and other aquatic organisms has also become better. Many farmers have reported that they can now see more organisms that are beneficial to the ecology, such as more small animals that can eat pests, and the water quality is clearer. They are not only producing food, but also working with nature. In terms of income, this model of combining farming and breeding is also very cost-effective. Because less fertilizer and pesticides are used, the input cost is naturally lower. Moreover, they can sell not only rice, but also fish, which has a richer source of income. Even if the rice yield is slightly lower, farmers still think it is worthwhile because the overall benefits are better, it can also protect the environment, and it will be more sustainable in the future (Berg, 2002; Bosma et al., 2012; Berg et al., 2023).

6 Challenges and Limitations

6.1 Technical and knowledge barriers

It is not easy to promote rice-fish symbiosis. Many farmers do not know much about this method of combining farming and breeding, and do not have relevant technical experience. For example, they are not good at managing water resources in rice fields, and do not know how to stock fish, let alone how to prevent and control pests and diseases without harming fish (Ahmed and Garnett, 2011). Sometimes, a flood or drought can cause them great losses. But the problem is that there are few training opportunities and insufficient extension services in many areas. Farmers do not know where to learn these new knowledge, and no one teaches them step by step. This makes it more difficult for them to try new methods. Many experts and researchers believe that more research should be carried out and more "farmer-participatory" training activities should be organized. Only in this way can farmers gradually learn these technologies and be willing to try rice-fish symbiosis (Hu et al., 2016).

6.2 Economic and market constraints

In addition to technical difficulties, money is also a big problem. Converting rice fields into fish farming requires a lot of initial investment, such as digging ditches, repairing dams, and buying fish fry and fish feed. These expenses are a huge burden for some small farmers (Li et al., 2023). What's more troublesome is that the sales of fish and other products are not very good. In some places, the market is not sound, and the things grown and raised by farmers are difficult to sell, and the prices are not stable. As a result, everyone is less motivated to try this model. In addition, social and economic issues such as the land not belonging to oneself and the large fluctuations in prices also make the rice-fish model difficult to promote. Farmers will back off if they raise good fish but cannot sell them, or if the investment is too high and they cannot make a profit (Pearlin et al., 2024).

6.3 Institutional and policy gaps

In many places, policies are still not keeping up with the development needs of rice-fish symbiosis. The government has not yet formulated policies specifically to support this model, and there is not enough funding for promotion projects and research (Subedi and Paudel, 2020). What farmers are most worried about is that the use rights of land and water are unclear. Sometimes they don't even know whether the land is theirs. In addition, it is difficult to get loans, the loan amount is small, and there is no one to manage infrastructure construction, which has become a big problem. If you want to make rice-fish symbiosis really take off, you need a stronger policy system to support it. For example, clarify land and water rights, provide training and financial support, help open up sales channels, etc. Only in this way can rice-fish symbiosis truly play a role in food security, ecological protection and farmers' income increase (Sathoria and Roy, 2022).

7 Future Directions and Recommendations

7.1 Research needs and data gaps

Now, many people are beginning to pay attention to the practice of rice-fish symbiosis, but more research is needed to make it work. In particular, we need to figure out how to best combine organic fertilizers and biofertilizers to make both rice and fish grow well (Yassi et al., 2023). Too much of these fertilizers is not good, and too little is not good either, so finding the right amount is crucial. In addition, we also need some actual experimental data. For example, what impact does this combination of crop-livestock farming have on the environment? Will it reduce greenhouse gas emissions? Can it save water? What is the benefit to biodiversity? These questions need to be studied in different weather conditions and different regions, and we cannot just look at one situation. We still lack long-term data, especially on sustainability performance in different agricultural ecological zones, and whether its economic returns are good. In order to make farmers feel more confident to use it and policymakers more willing to support it, we need to evaluate these systems in a variety of ways, such as setting multiple indicators and conducting detailed statistical analysis. This will help us find the best practices and provide a more realistic reference for policy making (Zhang et al., 2024).

7.2 Policy and institutional support

If we want to make rice-fish symbiosis develop faster and on a larger scale, policy support is indispensable. The national level, local governments, and even international organizations can come forward to formulate some

special policies, give farmers clear guidance, and provide subsidies, training and related services (Ibrahim et al., 2023). For example, the government can help farmers get loans more easily and help build necessary infrastructure, such as ditches, dams, water source systems, etc. At the same time, scientific research institutions should be encouraged to increase their research efforts and spread successful experiences and knowledge, especially countries like China that have mature experience. Institutions must also have corresponding supporting support, such as clarifying the right to use land and water to ensure that farmers have guaranteed land use. In addition, the promotion of the concept of green agriculture, such as less pesticides and more ecological methods to prevent insects, should also be promoted simultaneously. In this way, rice and fish can grow healthily together (Berg, 2002).

7.3 Promoting broader adoption and awareness

To make rice-fish symbiosis really enter more fields, it depends not only on policies and research, but also on "letting people know about it". It can be promoted through some targeted educational activities, demonstration farmland projects, or ecological education courses, not only in rural areas, but also in small-scale models in cities and suburbs (Son et al., 2022). Farmers, government officials and consumers should know the benefits of this method. For example, how it saves money, how it protects the environment, how it helps food safety, and what good effects it has on the ecosystem. Only when people understand it will they be more willing to support it. We can also build some knowledge sharing platforms so that farmers can learn from each other's experiences and promote some successful cases. Participatory training is also important, and it is best to let farmers participate in person rather than just listen. Putting these contents into school courses or community projects can also let young people and children understand the importance of biodiversity and sustainable agriculture from an early age (Halwart and Gupta, 2004).

8 Concluding Remarks

Rice-fish farming is a very useful agricultural method that has many benefits for the ecological environment. For example, it allows farmers to use less pesticides and fertilizers, and it can also make the water cleaner and the soil healthier. Because fish eat the larvae of pests, there are fewer insects and weeds in the rice fields. And the presence of fish can also increase the number of animals that feed on pests, so there are fewer pests. Farmers no longer have to rely on too many chemicals, but the rice yield in the fields can still be maintained, and sometimes even increased. At the same time, the fish yield can also bring in extra income. Rice-fish farming can also increase the variety of organisms in the rice fields, such as small fish, shrimp, and aquatic plants. This biodiversity makes the entire ecosystem more stable and the field environment more vibrant. More importantly, this practice can make agricultural production more profitable and easier to stick to in the long run, which is a win-win choice for farmers.

It can be said that rice-fish farming is a "less for more" agricultural method. It embodies the concept of ecological intensiveness, that is, to maximize the output of agricultural products without damaging the environment. This system makes the use of resources more efficient, such as fertilizers, water and land can be used more reasonably. It can also increase carbon storage in the soil, reduce greenhouse gas emissions, and is also beneficial to the control of climate change. The agricultural system has also become stronger and is more likely to recover when encountering disasters or pests and diseases. Through this combination of farming and breeding, farmers can not only grow rice, but also raise fish, and one field can bring two harvests. This diversified production method reduces farmers' dependence on pesticides and fertilizers, and also increases their living income, which is helpful for food security and ecological protection. Rice-fish farming can also make agricultural landscapes more beautiful and more environmentally friendly.

There is now a lot of evidence that rice-fish farming is a good way to achieve sustainable agriculture. It is not only good for the ecology, but also has real help for the economy. To make this practice more widely promoted, we need to do more research and formulate more specific and powerful policies. At the same time, we must strengthen education and training so that more people know and learn how to do it. Farmers, researchers, policy

departments and local communities should all work together and cooperate with each other to promote rice-fish farming. In practice, we should constantly adjust and improve this method to make it more suitable for the actual conditions in various places. In this way, we can truly improve agricultural development, environmental protection and farmers' welfare and embark on the path of long-term sustainable agricultural development.

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Conflict of Interest Disclosure

The authors affirm 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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