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RICE–FISH CULTURE *in* CHINA

EDITED BY

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INTERNATIONAL DEVELOPMENT RESEARCH CENTRE

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Rice–Fish Culture and its Macrodevelopment in Ecological Agriculture

Yang Jintong[19]

Agricultural production is, in essence, a process of recycling materials and converting energy. Through this process, the natural functions of animals, plants, and microorganisms are applied to produce food and other basic necessities. There are two major trends in the development of contemporary science and technology: toward in-depth analysis and specialization, and toward integration, which is broader but less specialized. Integrated development of agriculture and food production is an important strategy that makes full use of agricultural resources and promotes the rational development of the agricultural ecosystem.

Experiments and experiences have repeatedly shown that adding fish to the ricefield ecology helps increase production and achieves social, economic, and ecological benefits. Rice–fish farming is, therefore, a primary option when trying to develop ecological agriculture.

Benefits of Rice–Fish Farming

Nonbiological factors (e.g., water, soil, light, heat, and air) and biological factors (e.g., animals, plants, and microorganisms) are interrelated and interdependent. They form an ecosystem with unilateral functions. When one factor changes, it triggers a chain of reactions. According to the principles of ecology, the structure of the food chain in a system has a direct impact on the net output of the ecosystem.

The farmland ecosystem is an anthropogenic system that is regulated to increase its output. In the biological community of the ricefield ecosystem, rice is predominant; weeds, plankton, humus, and photosynthesizing bacteria are the primary producers and the raw materials used by the secondary and tertiary producers. Rice and these primary producers undertake energy conversion and storage in a similar manner. They absorb a large amount of solar energy, carbon dioxide, and nutrients from water and soil to manufacture organic matter by photosynthesis, and they convert, transport, and store energy. When rice looses nutrients because of competition among the biological communities, this degrades the growing environment and increases factors that are unfavourable to growth. Weeds and large losses of bacteria and plankton through water movement waste nutrients and solar energy.

[19] Aquatic Production Technology Popularization Station, Changsha, Hunan Province.

However, if fish, especially herbivorous and omnivorous fish, are introduced into the ricefields, they add a new link to the food chain. They feed on the primary producers and therefore reduce energy losses and improve the use of photosynthetic products. Fish culture yields products, which can be consumed by humans, and promotes transformations in the ricefield ecosystem that increase the carrying capacity of the ricefield. Rice–fish mutualism is the best way to maximize the output of the ecological system, improve its functions, and reduce the loss of materials and energy. It is one of the most important natural ecosystems.

Mutualism of Rice and Fish

In the rice–fish ecosystem, rice and fish play the lead roles. Some of their ecological requirements are similar and this provides the basis for their synchronized growth. Fish are poikilothermic aquatic animals; rice plants are thermophilic and semiaquatic. Although each grows and multiplies in its own way, they have identical characteristics in relation to water. Water is a prerequisite for raising fish and is also important for the growth and development of rice. Water, as a component of plant cytoplasm, is indispensable for the synthesis of organic matter in plants and for the absorption and transfer of nutrients. Water is also a raw material in many metabolic processes. The amount and quality of water are also key factors in the survival and growth of fish. Both rice and fish need water. That is their common characteristic.

The relations between water, rice, and fish must be handled correctly by controlling water (through ditches or outlets), while satisfying the water needs of different growth stages of rice (proper irrigation and water discharge). Rice needs water about 2.5-cm deep during the nursing stage, about 5-cm deep in the booting and earing stages, and about 6-cm deep in the milk and dough stages. Fish, especially grass carp, which are adaptable to shallow waters, needs the same depth of water as rice. Therefore, it is possible to balance the water supply for both rice and fish by digging ditches or pits.

Because rice and fish also grow in the same temperature range, they can be grown in a synchronized manner. For example, temperatures above 10°C are suitable for the growing period of rice, temperatures above 15°C suit the active growing period, and 21–25°C is the optimum temperature for rice, especially during the ripening period. If the daily average temperature is lower than 11°C and lasts for three consecutive days in spring, early rice may rot. If the temperature in May is low, if there is a cold moist wind in autumn, or if the daily mean temperature is lower than 20°C, tillering of early rice and booting of late rice may be affected. If the daily mean temperature in summer exceeds 30°C and the highest temperature exceeds 35°C, the earing of middle rice may be harmed and ripening may be premature. Hybrid late rice is seedless if the temperature is above 38°C for five consecutive days. The optimum temperature range for common carp and crucian carp is 14–18°C; the range for grass carp, silver carp, and Beijing bream is 18–20°C. The temperature range 26–32°C is the peak feeding period. When the temperature goes over 38°C or drops to below 11°C, fish loose their appetite. When the temperature drops to about 4°C, fish go into a dormant state, although they can still survive. The optimum temperature for the tropical nile tilapia is 27–28°C and its critical temperature for survival is 10–38°C. Growth is inhibited when the temperature reaches 38°C, and temperatures below 10°C are lethal for tilapia.

Ecoagriculture

Ecoagriculture should not be assessed only in terms of grain output; quality, total biological output, and profits should also be considered. A highly efficient and rational agricultural ecosystem is ecologically balanced. There should be a balance between tilling and nursing and between input and output. There should also be unity in economic and ecological objectives.

In the artificial rice–fish mutualistic ecosystem, green plants are the primary producers that convert solar energy into the food energy the fish require for their survival. The sequential relationship in the distribution of rice and fish is apparent. A study of the ecology of fish in ricefields shows that fish feed on plankton (that compete with rice for fertilizer), insects and bacteria (that harm rice plants), and mosquito larvae (that are harmful to humans). Fish assimilate only 3% of these feeds and discharge the rest into the ricefield. When they swim in the water, fish release carbon dioxide and this increases the amount of carbon available to the plants. They also break the soil surface and oxidize layers of soil, which increases the supply of oxygen and promotes root growth.

Rice–fish culture increases the output of rice by more than 10% (range 8–47%). It is necessary to establish that rice is most important in rice–fish ecoagriculture to fully exploit its benefits, avoid harmful effects, and strive for maximum output using the least possible energy and materials. Recent improvements in rice strains and crop systems have produced great advances in rice–fish technology. For example, the raising of grass carp fry in late ricefields can yield 150 000 fry/ha in about 25 days, while improving the fertility of the field.

The new technique of combining ditches and small ponds in ricefields raises the temperature of the mud and water and aerates the soil. The technique may help improve cold water low-yielding fields shadowed by hills and prevent drought in fields on the sunny side of the hill. A rational layout of ditches and small pools also reduces the concentration of mosquitoes in the centre of the field, which reduces the number of mosquito larvae and improves health conditions in rural areas.

Grass carp raised in double-cropping fields not only eliminate some pests of rice, they also feed on and digest the nucleus of the bacteria that causes sheath and culm blight. Fish excrement does not inhibit the growth of the bacteria's nucleus, but it does retard the growth and activity of the cell walls of the bacteria. Grass carp may be an effective way to prevent sheath and culm blight from spreading in ricefields.

High ridges and low furrows turn horizontal production into vertical development. This helps improve the gley horizon of ricefield soil and expands the ploughed zone, which, in turn, promotes the growth of plants in the border rows and stimulates the development of individual rice plants. These developments lead to economic benefits. Yields of 15 000 kg of rice and 1 500 kg of fish per hectare can be attained. The latest scientific research should be applied to further improve rice-fish culture techniques and increase production.

New techniques maximize the use of ricefields by combining rice-fish culture with soil and farmland improvement and environmental protection and by adapting rice-fish culture to local conditions. The techniques include: planting rice on ridges and raising fish in furrows in low-lying land, in water-logged ricefields with a gley horizon, in cold-water fields, and in ricefields near mines; and digging ditches and small pools in dry, hilly ricefields. In fields where yields are stable despite drought and waterlogging, farmers should adopt methods such as intercropping, crop rotation, and the use of the free period during late rice, to increase biological control of rice pests and the yields of grass carp fry. Operations should be diversified by growing rice with azolla and fish or by growing rice with fish and frogs. These options will enhance the fertility of the fields, expand production, and improve economic results.

Forms of Rice-Fish Culture

Hunan Province is south of the middle reaches of the Yangtze River (24°30'-30°08' N). The influence of the monsoon is strong, and there are four distinct seasons. Hunan has a subtropical humid monsoon climate and an annual mean temperature of 16-19°C. The lowest temperature suitable for rice and fish growth spans more than 8 months. There are 270-310 frost-free days, 1 300-1 800 h of mean solar duration, about 3 months of rain, and 1 200-1 800 mm of annual precipitation. Light, heat, and water are concentrated in April-September each year.

The principal crop in the province is rice, which is grown on 2.8 million ha. High- and intermediate-yielding fields make up 64.7% of the total area. Single-crop rice (one middle rice or a late rice) is grown on 0.5 million ha, mostly in the western and southern parts of the province. Based on the distribution of ricefields in the area, the available resources of light, water, and heat, the current production of rice and fish, and technical conditions, rice-fish culture can be developed in four different areas in Hunan.

Western Hunan

The area covers the Western Hunan Autonomous Prefecture, the Huaihua Prefecture, Cili, Taoyuan, and other hilly counties with high altitudes and terraced and sloping land that lacks the ability to conserve water and fertility and to resist drought. The southwestern part of the area is warm; the north is cool, humid, and foggy. Annual mean temperature is 15.8-16.8°C, 1-3 degrees lower than in other areas of the province. Annual solar duration is 1 300-1 500 h, which is less than in northern Hunan. Annual precipitation is 1 300-1 500 mm, one of the lowest in the province, but with 330-550 mm of rain in July-September, it has the wettest summers.

Ricefields take up a large portion of the arable land; most ricefields are hill-shadow fields, cold-water fields, and winter-ponding fields. The time for raising fish is long. Because there are few ponds and reservoirs, the area depends mainly on rice-fish culture for its supply of fish. The area has a long history of rice-fish farming. In the past, people raised mainly common carp by collecting locally available fish eggs and hatching them. These operations were extensive and the variety of fish was limited; therefore, catch per unit was low.

Fish production in ricefields could be increased by improving production conditions in middle ricefields, adding irrigation facilities and fertilizer, improving fish-raising techniques, and developing more varieties of fish. Fry should be hatched outside the fields, seeded in summer, and raised in small ponds in or outside the ricefields. Farmers should also be encouraged to seed bigger fry, mostly common carp mixed with some grass carp, crucian carp, and tilapia.

Southern Hunan

The area covers Hengyang City and Chengzhou and Lingling Prefectures. It has an abundant supply of heat and leads the province in degree days, with 5 300–5 600°C and an average daily mean temperature of 10°C. The annual mean temperature is 17.5–18°C, the lowest average temperature is 14°C in March, and the mean temperature in mid-October is 16.5–19°C. Annual precipitation is 1 300–1 500 mm, with about 200 mm falling in July–September. The rainy season ends in July, 10–15 days earlier than other areas of the province.

Conditions are favourable for rice-fish farming, especially in spring. The area has abundant sunlight, an annual solar duration of 1 600 h, and 193–195 days with temperatures above 15°C. This provides ample time for fish growth and encouraging results have been obtained with fish raised in winter-ponding fields.

The soil in the ricefields is mostly fertile tidal sand mud and black river mud. Historically, the area practices double-cropping. (The double-cropping system of planting soybean with hybrid rice in spring was recently introduced and proved to be a great success.) However, low-yielding fields account for a third of the total ricefields, and there are also some gley horizon ricefields in valleys and lowlands where the soil particles are dispersed and marshy. A soil-amelioration plan should be developed to transform the soil by opening up drainage ditches and flood diversion channels and canals to direct mountain floods and toxic wastewaters from mines away from the fields and underground water. Cold run-off water and water high in iron content should also be drained from the fields. Low-yielding ricefields could be improved if fish were raised in combination with the rice.

In the Hengyang Basin, fish culture in ponds and pools is flourishing and is well-known throughout the province. There are ample sources of fish fry and many fish varieties. Local people collect fish fry along the Xiangjiang River and raise the fry themselves. To take advantage of favourable conditions, the culture of diverse varieties of fish in ricefields should be encouraged. At the same time, fish culture in ponds should be continued. The terrain and weather conditions are variable, which is favourable for raising fish. A variety of rice-fish culture techniques, including fish-seedling-rice, rice-seedling-fish, seedling-rice-fish, fish-rice-seedling, and fish-rice-fish should be adopted.

In the immediate future, more grass carp varieties should be cultivated in the wheat-rice fields to ensure the supply of fry for intensive pond culture. Fish production, from egg collection to the culture of adult fish, should be streamlined by combining the practice of fish-raising in small pools with rice-fish culture, and by combining rice-fish farming with pond culture. To expand the area of surface water and to produce fry on a commercial scale, it will be important to cultivate fry in ricefields.

In areas where farmers grow early ripening varieties of late rice and plant grass to raise common carp, the area for rice-fish culture should be expanded by raising mainly common carp and some other varieties. In winter-ponding fields where fish are raised, more feed and fertilizer should be applied and a mixture of species should be used to develop intensive fish culture within one season. In Ningyuan, Jiangyong, Daoxian, and Lanshan where tilapia can over-winter, fish varieties should be improved and more nile tilapia should be raised.

Central and Eastern Hunan

The area covers Pingjiang, Liuyang, Changsha, Wangcheng, Ningxiang, Chaling, Youxian, Liling, Junxian, Xiangtan, Shuangfeng, Lianyuan, Xinhua, Xinshao, Shaodong, Shaoyang, Longhui, Dongkou, Wugang, Suining, Chengbu, and Anhua. Water and heat are abundant and increase gradually from the northwest to the southeast. Annual solar duration is 1 500–1 740 h. Precipitation in the Dongting Lake area alone is 1 300–1 500 mm annually, and 170–190 mm fall in August-September. The lowest rainfall is in autumn. Most of the ricefields are distributed between hills and the soil is a red clay. The main cropping system is double rice plus green manure. Most of the counties in the area raise fish in ponds and reservoirs.

The area should raise more fish, both fry and adult fish, in ricefields and continue pond and reservoir culture. Grass carp should be raised in late ricefields and tilapia should be grown where there are geothermal resources. In areas where rice-fish farming is practiced, farmers should be encouraged to seed bigger fry, raise adult fish, and expand the area devoted to rice-fish cultivation. At the same time, efforts should be made to popularize and improve fish-raising techniques.

Lakeside Rice-Fish Culture Area

The area covers Huarong, Nanxian, Anxiang, Lixian, Changde, Hanshou, Yuanjiang, Yiyang, Xiangyin, Miluo, Linxiang, Yueyang City (county), Jinshi, and provincial farms and fish farms. With its alluvial plains, abundant water resources, and fertile soil, this area is the centre for commodity grain production. Double rice crops are grown on 92% of the land and green manure on 80%. There is plenty of gley horizon soil. In some open expanses or plains, surface water often accumulates and a layer of green mud appears near the plow base. In some places, the soil is submerged in water all year round, and the soil particles are dispersed, muddy, and marshy.

There are vast expanses of water that are often interconnected. The area is one of the most important ten freshwater fish areas in China. There are about 170 000 ha of exploitable water surface in the area (50% of the provincial total), but fry are in short supply.

Weather conditions are good, with abundant sunshine and heat, but less rainfall. Spring comes late and autumn sets in early. Solar duration is 1 700–1 800 h annually, the longest in the province. Annual mean temperature is 16.3–17°C and annual precipitation is 1 200–1 500 mm. Precipitation is concentrated in April–September, which account for about 800–1 000 mm (67% of the annual total). Because summer is late, early rice often ceases to sprout because of low temperatures in May. The first day when the daily mean temperature is 12°C about 5 April, and the last day when the mean temperature is 20°C is about 25 September.

To match the mode of production to the lakeside ecology and economic conditions, the area should concentrate on improving the soil, transforming low-yielding land, and raising fish in ricefields by introducing the method of growing rice on ridges and raising fish in furrows. At the same time, efforts are needed to develop sources of grass carp fry. Technically, several points require attention:

- Breeding and selection should be intensified to advance the artificial breeding of grass carp to the end of April to match the seasons for rice and fish production. This would overcome the need to keep rice in the field to let the fish grow and would improve land use.
- Methods of raising fish in both ponds and ricefields and of hatching fry outside the fields should be introduced. This would mean that fry could be seeded before the early rice seedlings begin to turn green, and the fish would have enough time to grow and eat weeds.
- It is advisable to raise fish in ricefields with plain open areas and good drainage and irrigation systems. Flood-diversion ditches, water-directing canals, and round-the-field drainage ditches are needed to prevent floods and waterlogging and to prevent fish from escaping with the irrigation water.
- To stimulate rice production by raising fish, fertilizer should be properly applied in gley horizon ricefields. More phosphate and potash fertilizer should be applied according to the characteristics of the soil to improve the quality of crop cultivation. Muddy fields should be plowed less and extensively worked. Ridge culture should be adopted in marshy fields to breed strong, sturdy seedlings. Resistant rice varieties should be planted to increase output.
- In water-logged areas in which rice output is low, the soil should be dug deeply, ridges should be built, and fish should be raised in ditches and pools. Mulberry trees and hemp can be planted on the

banks. Sericulture can be undertaken, silkworm excrement fed to the fish, and fish dung used to fertilize the soil. The mud from the pools or ditches can be used to fertilize the soil in which the mulberry and hemp are grown, and the hemp leaves can help preserve water. The cycle provides economic and ecological benefits.