June 1995

# Rice–Fish Culture *in* China

Edited by
Kenneth T. MacKay

International Development Research Centre

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# Preface

A National Rice-Fish Farming Systems Symposium was held in China at the Freshwater Fisheries Research Centre of the Chinese Academy of Fisheries Sciences in Wuxi, Jiangsu Province, 4–8 October 1988. The symposium was cosponsored by the Chinese Academy of Agricultural Sciences (CAAS) and the Chinese Academy of Fisheries Sciences (CAFS). Funding was supplied by IDRC through its project Farming Systems (China) (3-P-87-0237).

Researchers from the major rice-producing areas of China presented papers at this interdisciplinary symposium. The proceedings of this symposium were originally published in Chinese by the Agriculture Publishing House (Beijing). To share this valuable information with researchers and development workers outside China, the proceedings were translated into English. The initial translation was done either by the researchers themselves or by translators with the Agricultural Publishing House. Initial English editing was carried out by Regina Morales, Manila, Philippines. Final technical editing and preparation of the camera-ready copy was undertaken by Michael Graham, MG Science Editing, Writing, and Publishing, Kemptville, Ontario, Canada. In some cases, two or more papers have been combined to remove redundancy.

Kenneth T MacKay

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# Introduction

This symposium on rice-fish farming in China brought together 55 experts and scholars from the Academia Sinica, the Departments of Agriculture and Hydraulics, the Institutes of Aquacultural Research and Education, and the Administration Bureaus. In addition, there were representatives from the International Development Research Centre, Canada, the Network for Aquaculture Centres in Asia (NACA), Thailand, the Freshwater Aquaculture Center, Central Luzon State University, Philippines, and the International Center for Living Aquatic Resources Management.

China has had a long history of rice-fish farming. As rural areas have been industrialized in recent years, rice-fish farming has gained attention because it is an organic method that combines rice and fish production while maximizing labour and ricefield resources. The Chinese Academy of Agricultural Sciences and the Chinese Aquacultural Research Institute organized this symposium, with financial assistance from the International Development Research Centre, to synthesize the rich experiences and skills of Chinese farmers and to improve rice-fish farming as a way to increase food production in Southeast Asia and in other parts of the world.

Rice has always been the number one grain crop in China in terms of both area and yield. During the 1950s, the tradition of rice-fish farming developed substantially but the benefits were not significant. Fish harvests were poor because the method was based only on traditional experiences and technical difficulties were encountered. However, rice-fish farming developed rapidly and by 1988, 800000 ha were being harvested with a average yield of 133 kg/ha. In some areas, yields exceeded 3750 kg/ha and many farmers harvested 15000 kg of rice and 1500 kg of fish per hectare. The incomes of these farmers increased considerably. The techniques of rice-fish farming improved markedly as additional skill and experience were acquired.

In 1972, Ni Dashu, of Academia Sinica's Institute of Hydrobiology, initiated experiments to increase fish production from rice-fish culture. These experiments established the theory for rice-fish integration, which guided the research work of Chinese scientists during the 1980s. Research was focused on the common needs of fish and rice for water, light, and nutrition under local conditions. Many new techniques were developed to suit various locations: ridge and ditch systems; semidry land; ditch manure pits; ditches with floating water; and rice-duckweed-fish systems. These new methods enriched and further developed the theory of rice-fish integration.

In 1984, the State Economic Commission arranged a project for the extension of these new techniques. The Fisheries Bureau, under the Ministry of Agriculture, Animal Husbandry and Fisheries, ordered a technical coordination group to carry out the work in Sichuan and 17 provinces, municipalities, and autonomous regions. After 3 years, the new techniques were widely adopted and produced economic, social, and ecological benefits that contributed to the large-scale adoption of rice–fish farming in China.

Rice–fish farming is no longer limited to the household economy and to production for personal or family consumption. It is now part of farmland improvement, soil improvement, and environmental protection. Rice–fish farming has increased the productivity of ricefields and is fast becoming an important part of the commodity economy. It has also played a significant role in reforming the structure of rural industries.

Wang Hongxi

*Deputy Director*
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# Part I:

# Review and Outlook

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# Rice–Fish Culture in China: The Past, Present, and Future[1]

*Cai Renkui,[2] Ni Dashu,[3] and Wang Jianguo[3]*

The combination of rice and fish has a long history in China. The practice of rice–fish farming may have evolved from pond culture. The canon for fish culture written by Fan Li about 400 BC states:

> *... dig six mu of land into a pond ... put 2 000 fry into the pond ... sell the rest in the market.*

In a good year with ample rainfall and moderate weather, 2 000 carp fry could produce numerous eggs. Some wise farmers may have placed excess fry in their ricefields. The fish in the ricefields may have grown better than those in the ponds, and the practice of raising fish in ricefields was born. There are no records of when the practice started, but this seems to be a logical explanation of how rice–fish farming began in China.

The archeological and written records do suggests the rice-fish culture is almost 2000 years old. In 1964-1965, tombs of the mid-Eastern Han Dynasty (25–220 AD) were excavated in the suburbs of Hanzhong County, Shanxi Province. Two clay models were unearthed: a model of a pond and a model of a ricefield. The pond model contained 15 miniature pieces (6 common carp, 1 soft-shell turtle, 3 frogs, and 5 water chestnuts). In 1977, a stone carving of a pond and ricefield model was discovered in the brick tomb of the Eastern Han Dynasty in Emei County, Sichuan Province. Half the stone was carved into a pond with frogs, fish, and ducks. The other half was carved into a ricefield with an inlet and outlet, two farmers toiling on one side, and two heaps of manure on the other. In 1978, four mid-Han Dynasty tombs with 200 relics were excavated in Mian County, Shanxi Province. One of the intact relics was a ricefield model containing 18 pottery miniatures of aquatic plants and animals. In it were sculptured frogs, eels, spiral shells, crucian carp, grass carp, common carp, and turtles. Another of a winter ricefield showed farmland with a reservoir that also contained these fish.

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[1] This paper is a combination of two papers: The History of Rice–Fish Culture in China by Cai Renkui and The Past, Present, and Future of Rice–Fish Farming in China by Ni Dashu and Wang Jianguo.

[2] Freshwater Fisheries Research Centre, Chinese Academy of Fisheries Science, Wuxi, Jiangsu Province.

[3] Institute of Hydrobiology, Academia Sinica, Wuhan, Hubei Province.

These relics suggest that at least 1 700 years ago, rice-fish culture was practiced in the vicinity of Hanzhong and Mian Counties in Shanxi Province, and in Emei County in Sichuan Province. The fish species stocked in the ricefields were common carp (*Cyprinus carpio)*, crucian carp (*Carassius auratus*), grass carp (*Ctenopharyngodon idellus*), and silver carp (*Hypophthalmichthys molitrix*). The bamboo fish trap and sluice gate that were installed at the inlet and outlet indicate that a primitive model of rice-fish culture existed at that time.

The earliest written record of rice-fish culture is from *Recipes for Four Seasons*, which was written in the Wei Dynasty (220-265 AD):

> *A small fish with yellow scales and a red tail, grown in the ricefields of Pi County northeast of Chendu, Sichuan Province can be used for making sauce.*

The small fish with yellow scales and a red tail could be common carp. This indicates that common carp may have been grown in ricefields in Pi County. This record coincides with excavated relics. An alternate view[4] is that the fish referred to is a type of small carp that "came from rice paddies" but was not necessarily raised in the ricefields. It is possible that, instead of being raised by rice growers, the fish was washed into ricefields during the rainy season through flooded waterways.

Rice-fish culture probably continued to develop. The next written record is found during the latter part of the Tang Dynasty. Liu Xun (about 889-904 AD), wrote in *Wonders in Southern China*:

> *In Xin, Long, and other prefectures, land on the hillside is wasted but the flat areas near the houses are hoed into fields. When spring rains come, water collects in the fields around the houses. Grass carp fingerlings are then released into the flooded fields. One or two years later, when the fish are grown, the grass roots in the plots are all eaten. This method not only fertilizes the fields, but produces fish as well. Then, rice can be planted without weeds. This is the best way to farm.*

The districts of Xin and Long are now in the vicinity of Xinxing and Luoding Counties in Guangdong Province. This means that rotational rice-fish farming was practiced there over 1 000 years ago. The chronicle of Shunde County, Guangdong, from the Ming Dynasty (about 1573) states that:

> *The periphery of a land was trenched as a plot, called the field base.... In the plot, a pond was dug to rear fish. During the dry season, rice seedlings were transplanted to the plot. The area might be several hectares.*

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[4] The first view was expressed in the paper by Cai Renkui; whereas, the alternate view was expressed by in the paper by Ni Dashu and Wang Jianguo.

According to this chronicle, the area for rice-fish culture was expanded in Guangdong 400 years ago.

Formal research appears to have started in the 20th century. In 1935, a rice-fish culture experiment was conducted in Songjian, Jiangsu Province. The species stocked were black carp (*Mylopharyngodon piceus*), grass carp, silver carp, bighead carp (*Aristichthys nobilis*), and common carp. During the rice-growing period, the weight of the silver carp increased 50-fold and the weight of common carp increased 20-fold. After 2 years, 20 000 fry hatched and were distributed to farmers for culture in rice paddies. Scientists provided technical assistance.

After the founding of the People's Republic of China in 1949, rice-fish culture developed quickly. In 1954, the fourth National Aquaculture Meeting proposed the development of rice-fish culture across the country. By 1959, the area of rice-fish culture had been expanded to 666 000 ha.

From early 1960s to the mid1970s, several factors, including the intensification of rice production and the large-scale application of chemical insecticides, impeded the development of rice-fish culture.[5] For example, in Guangdong Province the area of rice-fish culture dropped from 33 333 ha in the early 1950s to 320 ha in the mid1970s, and in Hunan Province the area dropped from 232 000 ha in 1958 to 5 333 ha in 1978.

## Rice-Fish Farming in China Today

During the late 1970s, there were changes in rice production. Improved modern varieties of rice and less toxic chemicals were used and there were changes in the units of production. The production-contract system was implemented in rural areas starting in 1978 and this allowed individual families to become the main units of production. In addition, there was a rapid development of aquaculture, which required the production of a large amount of fry and fingerlings. This demand was partly met by fingerling production in ricefields. Research and supporting policy and development activities have also encouraged the expansion of rice-fish production.

The research established an optimum ecological system to increase rice production, economize labour, and maximize economic returns. This lead to the evolution of a theory of rice-fish mutualism that has provided the theoretical basis for rice-fish culture. The practice has now spread to all rice-growing areas in China through the adaptation of rice-fish techniques that are suitable to local agroecological conditions.

[5] The years 1965-1975 also coincided with the cultural revolution. During this period, the raising of fish was considered a bourgeois way of making money and was officially discouraged. In addition, there were severe dislocations of research and extension during this period.

A number of regional and national meetings focused attention on rice-fish culture and advanced its development. In 1983, a workshop on Fish Farming for Eradicating Mosquitoes was held in Xinxiang, Henan Province, to exchange information on eradicating mosquitoes by rearing fish in ricefields. The First National Ricefield Fish Culture Seminar was held on 11-15 August 1983 at Wenjian County, Sichuan Province, under the auspices of the Ministry of Agriculture, Animal Husbandry and Fisheries (now the Ministry of Agriculture). The seminar established a large coordination group for Eastern China to popularize rice-fish farming techniques.

The potential and actual production in Eastern China is summarized in Table 1. There are 9 million ha of ricefields in Eastern China. This accounts for one-third of the country's total rice area, and 45% of it is suitable for raising fish. Before 1982, rice-fish farming was concentrated in the mountainous areas of Jiangxi, Fujian, and Anhui and covered only 26 000 ha. The area was expanded to include the plains and, by 1986, 138 000 ha were in production and yielded an average of 183 kg of fish per hectare.

In 1983, a key research project on the economics of aquatic resources in China included a subproject on economic problems related to rice-fish culture. The scientists, who thoroughly studied the economic benefits of rice-fish culture, received the Second Science and Technology Progress Award from the Agriculture Ministry in 1988.

In 1984, the Ministry of Agriculture, Animal Husbandry and Fisheries (MAAHF), organized a project to popularize the technique of raising fish in ricefields in Sichuan, Beijing, Hebei, Shanghai, Jiangsu, Anhui, Zhejiang, Jiangxi, Fujian, Henan, Hubei, Hunan, Guangdong, Guangxi, Shaanxi, Guizhou, and Yunnan. To promote the project, a technical group of six researchers was formed to provide guidance.[6] The members of the group were: Jiang Cimao of the Aquatic Products Bureau of Sichuan Province, Ni Dashu of the Institute of Hydrobiology of the China Academy of Sciences, Yin Pizhen of the Aquatic Products Institute of Jiangxi Province, Yang Yongshuan of the Aquatic Products Bureau of Hubei Province, Yang Jintong of the Aquatic Products Bureau of Hunan Province and Xu Xushi of the Bureau of Agriculture, Animal Husbandry and Fisheries of Zhongging City. The project sought to popularize the practice on a large scale. Initial achievements won the project a first-class award for technological progress from the MAAHF in 1986.

In 1985, 17 institutes were involved in another key research project called, "Ricefields as Fish Nurseries and Fish Grow-out Systems." This project, under the auspices of the National Aquatic Products Bureau, aimed to rear hybrids of common carp, tilapia, and crucian carp *(Carassius carassius)* in ricefields and to nurture grass carp fingerlings in ricefields. Each province was requested to extend rice-fish culture in a 200 ha demonstration area. The target yield was 225-625 kg

[6] A number of the researchers in this group were present at this workshop.

Table 1. Rice-fish culture in Eastern China in 1985 and 1986.

| Province or Municipality | Area of Ricefields ($10^3$ ha) | Suitable for Rice-Fish ($10^3$ ha) | Area Used for Rice-Fish ($10^3$ ha) | | Fish Production (tonnes) | | Production (kg/ha) | |
|---|---|---|---|---|---|---|---|---|
| | | | 1985 | 1986 | 1985 | 1986 | 1985 | 1986 |
| Jiangxi | 2 067 | 1 400 | 52 | 47 | 9 360 | 8 815 | 180 | 188 |
| Fujian | 1 040 | 400 | 22 | 28 | 2 915 | 4 265 | 131 | 150 |
| Anhui | 1 667 | 667 | 23 | 34 | 6 500 | 6 630 | 285 | 195 |
| Zhejiang | 1 333 | 667 | 21 | 19 | 3 050 | 2 810 | 149 | 150 |
| Jiangsu | 2 400 | 667 | 11 | 10 | 2 585 | 2 760 | 237 | 267 |
| Shanghai | 200 | 200 | 0.8 | 0.2 | 1 | 11 | 150 | 450 |
| Shandong | 66 | 13 | 0.7 | 0.4 | 3 | 0.5 | 153 | — |
| Total/ Average | 8 773 | 4 014 | 131 | 138 | 24 414 | 25 292 | 183.6 | 183 |

of fish per hectare. The total demonstration area of rice-fish culture in the eight provinces south of the Yangtze River was 1 600 ha. The project sought to promote the extension of rice-fish culture in the country to cover a total area of 800 000 ha.

There was also an increase in rice-fish culture in Northern China. In 1985, the Aquatic Products Section of the Water Resources Committee of the city of Urumqi in the Xinjiang Uygur Autonomous region in Northwest China, carried out an experiment on rearing fish varieties in ricefields in the northern suburbs of Urumqi. They put 1 977 fingerlings in two batches (10 and 2-3 cm in length) into a 0.4-ha experimental field. After 68 and 87 days, they harvested 174 kg of fish per hectare. The largest fish weighed 0.25 kg and the average weight was 0.11 kg. Rice output was 9 292.5 kg/ha, 18% more than in 1983. Net profit was CNY1916/ha.

From 1984 to 1985, the Rice Institute of the Agricultural Reclamation Academy in Heilongjiang Province, Northeast China, conducted experiments on rice-fish farming in high, cold areas. Rice yields increased by 7.2-12.1%, and the survival rate of fingerlings to harvest was 71.3-88.9%. The net value of the output increased by CNY656-950/ha. Grass carp averaged 0.2 kg in weight; common carp averaged 0.15 kg. Meanwhile, in Huanren County, Liaoning Province, another rice-fish culture experiment stocked grass carp and common carp as major species and tilapia as minor species in a 0.1-ha ricefield. They harvested 85.8 kg of fish and rice yields increased by 7.3-8.4%.

In 1985, Changchun City in Northeast China's Jilin Province raised common carp fry during the summer in 4.3 ha of ricefields. They harvested 35 000 fingerlings that measured 10–15 cm in length and weighed a total of 875.5 kg. The ricefields yielded 279 kg of fish per hectare. The current situation (1986) of rice-fish production in China is summarized in Table 2. There are almost 1 million ha of rice-fish culture in China in 15 provinces and three municipalities (Beijing, Shanghai, and Zhongging). In addition, experimental culture is being carried out in the northern provinces of Jilin, Liaoning, and Heilongjiang and in the Xinjiang Uygur Autonomous Region. Rice-fish culture is now practiced from southern Guangdong and Guangxi at 22°N to Beijing at 40°N, and experimental activities as far north as Heilongjiang Province (45°N).

## The Development of Rice-Fish Culture Techniques

### Concept and Significance of Rice-Fish Farming

The new concept of "mutualism" in raising fish in ricefields is entirely different from the traditional purpose and nature of rice-fish culture. The mutualism concept is to improve rice production by letting herbivorous fish eliminate weeds that compete with rice plants for sunshine, fertilizer, and space. At the same time, fish in ricefields feed on weeds, plankton, and benthos, and form an optimum ecological system that benefits both the fish and the rice. Traditionally, the idea was simply to raise fish with rice as an additional source of food. Now the concept includes the mutualism of both crops and has indeed become an effective way to boost rice yields. There are two basic forms of rice-fish farming: (1) rotating rice and fish, and (2) growing fish and rice together. Rice-fish rotation involves growing rice one season and raising fish the next. This method has been extensively adopted in winter ricefields, in fields that need to conserve water, and in low-lying areas in Sichuan Province. The fish raised in these fields are mainly adult or large fish.

The new concept of rice-fish farming combines the otherwise contradictory principles of growing rice and farming fish. By making full use of the mutual benefits of both rice and fish, the new concept provides a modern biological technique to invigorate agriculture in China. The emphasis is on growing rice and the role of the fish is to enhance the growth of the rice plants. But, the ultimate goal is to increase the production of both rice and fish in rice-growing areas. There are many advantages of growing fish with rice:

- The fish increase rice yields by more than 10%;
- A 0.07-ha ricefield can yield 300 fingerlings each measuring 10–16.5 cm. When table fish are reared, 150–450 kg/ha can be harvested. In rice-fish rotation, more than 50 kg of fish can be caught from 0.07 ha of surface water;
- The fish feed on weeds and worms, and loosening up the soil. This helps reduce labour requirements and is one of the outstanding benefits of raising fish in ricefields;

Table 2. The area (ha) of rice-fish culture in China (1981–1986).

| Province or Municipality | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|---|
| Beijing | — | — | 1 | 21 | 7 | 7 |
| Hebei | — | — | — | 15 | 15 | 100 |
| Shanghai | — | — | 1 | 23 | 83 | 23 |
| Jiangsu | — | — | 26 | 3 133 | 10 886 | 14 000 |
| Anhui | — | — | 2 666 | 10 000 | 22 666 | 34 000 |
| Zhejiang | — | — | 13 353 | 17 733 | 26 486 | 18 733 |
| Jiangxi | 3 333 | 16 666 | 18 666 | 37 800 | 52 000 | 47 000 |
| Fujian | — | — | 14 666 | 19 113 | 22 353 | 28 433 |
| Henan | — | — | — | 20 | 8 766 | 6 666 |
| Hubei | 1 000 | 2 333 | 3 333 | 13 333 | 28 133 | 21 653 |
| Hunan | — | 79 666 | 112 613 | 167 100 | 188 746 | 227 000 |
| Guangdong | — | 4 333 | 4 000 | 5 300 | 8 120 | 13 333 |
| Guangxi | 20 000 | 35 333 | 31 853 | 34 546 | 45 520 | 54 200 |
| Shanxi | — | — | 140 | 727 | 1 506 | 5 700 |
| Sichuan | — | 156 666 | 192 473 | 241 393 | 282 186 | 333 333 |
| Zhongging | — | — | 54 000 | 68 666 | 78 000 | 80 000 |
| Guizhou | 94 666 | 100 666 | 106 666 | 100 000 | 66 920 | 87 333 |
| Yunnan | — | — | 8 540 | 11 560 | 10 580 | 14 000 |
| Total | 120 980 | 397 645 | 564 980 | 732 467 | 854 958 | 987 500 |

- The fish (especially grass carp) conserve and enrich the fertility of the water and soil and therefore stimulate the growth of rice plants and increase grain yields;
- The fish eliminate some insect and disease pests of rice, and in addition eat mosquito larvae, which are pests to both animals and people, and thus help to reduce the incidence of meningitis, malaria, and filariasis.

Rice-fish farming is closely integrated with freshwater fish farming in China, especially in ponds, reservoirs, lakes, and family ponds. Freshwater aquaculture requires increased quantities of fry. The demand for fry cannot be met by relying on stock fish farms or by expanding stock fishponds.

The use of ricefields to grow fingerlings has allowed the demand to be met. If the area for rice-fish farming in China was expanded by 6.7 million ha, rice production would increase by more than 2 million tonnes and 30-50 billion fingerlings would be produced. This would also help increase the annual harvest of freshwater fish.

### Fish Species Stocked in Ricefields

In ancient times, the fish species stocked in ricefields were: common carp, crucian carp, grass carp, silver carp and bighead carp. In the 1950s, the species used were: black carp (*Mylopharyngodon piceus*), Chinese bream (*Megalobrama amblycephala*), tilapia (*Oreochromis mossambicus* and *O. niloticus)*, mud carp (*Cirrhina molitorella)* in the south, loach (*Misgurnus anguillicaudatus* and *Xenocypris argentea)* in Guangxi and Hunan, and snakehead *(Ophiocephalus argus)* in Guangdong.

In the 1960s and 1970s, rainbow trout (*Salmo gairdneri)* were introduced in the north, and catfish (*Clarius leather)* in the south. In the 1980s, the new species used were: carp (*Carassius auratus)*, aquatic crab (*Eriocheir sinensis)*; shrimp (*Macrobrachium nipponensis)*, American snail, pearly clam, and field snail.

### Increased Rice Yields After Fish Culture

There is considerable evidence that fish increase the yield of rice. Table 3 summarizes the information from a number of experiments throughout China. All experiments show an increase in rice yield of 2-34% (average of 11.8%).

### Chemical Insecticides Applied to Ricefields

There are over 50 pests and 10 diseases that attack rice. The major pests are: yellow stemborer (*Tryporyza incertulas* and *Chilo simplex*), green rice leafhopper (*Nephatettix apicalis)*, rice plant skipper (*Parana guttatus)*, and rice blast (*Piricularia oryzae)*, which is the most serious disease. Secondary pests and diseases are: snout beetle (*Echinocnemus squameus*), rice leafroller (*Cnapholocrosis medinalis*), yellow-legged lema (*Lama flavipes*), locust (*Oxya chinensis*), and brown spot (*Cochliobolus miyabeanus)*.

In the early 1970s, chemical insecticides toxic to fish gained widespread use. Some of these were 666, DDT, and limestone powder. Later, less toxic chemicals (Roxin, Dipterex, Kitazine, and Fenitrothion) were produced. Methods of application were improved to minimize damage to fish and to achieve the maximum effect of the chemicals. For example, the water level in the ricefields was increased before the chemicals were applied. Powdered chemicals were applied

Table 3. Increase in rice production in rice-fish culture.

| Experimental Unit | Increase (%) | Year |
|---|---|---|
| Guiping, Guangxi | 3.6–11 | 1957 |
| Gaoxi, Lingling, Hunan Institute of Hydrobiology | 4.8–13.4 | 1958 |
| Hubei Agriculture Research Institute and Wuhan Fisheries Research Institute | 9315 | 9051 |
| Guangxi Aquatic Products Experimental Station | 8614.5 | 8697 |
| Fujian Fisheries Research Institute Freshwater Branch | 4.6 | 1965 |
| Southwestern Normal College and Qingshen Hydroelectric Bureau, Sichuan Province | 13.6 | 1976 |
| Zhulou, Yuanyang Counties, Hunan | 15 | 1976 |
| Wenjia, Chendu, Sichuan | 4.1–8 | 1976–1977 |
| Shatou, Fanyu Counties, Guangdong | 6–8 | 1978 |
| Institute of Hydrobiology and Changsha Agriculture Modernization Research Institute, Academia Sinica | 19.7 | 1979 |
| Heyan, Taoyuan, Hunan | 34 | 1981 |
| Qing-guda Lake, Urumqi, Xinjiang | 18 | 1984 |
| Huanren County Broodstock Fish Farm, Liaoning | 7.3–8.4 | 1984 |
| Heilongjiang Academy of Agriculture Reclamation Science, Heilongjiang | 7.2–12.1 | 1984–1985 |

when the plants were covered in dew, and spray chemicals were applied when there was no dew. In some areas, fish were driven to trenches or sumps before the chemicals were applied. Insecticides were also applied in instalments or in patches. Table 4 shows the current dosages of chemicals that are used.

### Development of Rice-Fish Culture

Ricefields can be used as fish nurseries or to produce fish for food. In fingerling production, either 450 000–600 000 eggs/ha or 300 000 fry/ha of common carp are stocked early in the season. By the summer, the fingerlings are ready for harvest. To nurture large-sized fingerlings, the stocking density should be 15 000–22 500/ha. If grass carp is the dominant species, 12 000–15 000 grass carp should be stocked per hectare with 3 000–4 500 silver carp and bighead carp and 4 500–6 000 common carp and bream.

Table 4. Dosages of chemicals applied in ricefields.

| Chemicals | Common (g/ha) | Maximum (g/ha) |
|---|---|---|
| Dipterex | 1 500 | 2 250 |
| DDV | 750 | 1 500 |
| Fenitrothion | 1 125 | 1 500 |
| Calcium methyl arsenate | 3 000 | 3 750 |
| Kitazine | 1 500 | 2 250 |
| Methamidophos | 750 | 1 500 |
| Roxion | 50 | 100 |
| Chlordimeform | 3 000 | 3 750 |
| Jiangangmycin | 2 250 | — |
| Farmon condex | 15 000 | 18 750 |

In Shanxi Province, rainbow trout was cultured in winter fallows by using slightly running waters. Fish production was very high (30 t/ha). Rice-fish culture has been practiced, not only in shallow-water ricefields, but also in deepwater rice fields and in fields of wild rice (*Zizania* spp). In brackishwater along coastal reclamation areas, a rotational system is used. One crop of rice is grown one year, mullet *(Mugil so-iuy)* is cultured the next.

During the 1980s, several new developments occurred:

- Ridge rice planting - ditch fish farming system. This system is suitable for water-logged ricefields. The system involves a series of ridges and ditch in the ricefield. The rice is grown on top of the ridges and the fish in the ditch. The width of the ridge and the ditch is 40 cm, the height of the ridge is 80 cm, and water depth is 50 cm.[7]
- Rice-azolla-fish system. Rice is planted in the fields, azolla is cultured on the surface of the water, fish are cultured in the water, and squash or legumes are planted on the bunds. This is a multilevel comprehensive system of resource use.
- Running water system of trench fish farming. One or two broad trenches (1-1.5 m in width and 60-90 cm in depth) are dug in a ricefield. The trenches account for about 6% of the total area of the ricefield, and fish are cultured in the water running through the trenches.

[7] The dimensions of the ridge-ditch system appear to vary considerably. The ridge is often only 25 cm wide and 30 cm in height.

## Prospects for Rice-Fish Farming in China

China has 25 million ha of ricefields, and over 90% of this area is south of the Huai He River Basin. Although the practice has achieved excellent results in terms of scale and economic return, its potential to meet the needs of modern development remains untapped. If 10% of the ricefields south of the Huai He River were used (half for commercial fish and half for stocking fish), the commercial fish yields could be 346 000 tonnes (assuming 300 kg/ha) and the number of full-size fingerlings would be 5 billion (assuming 4 500/ha). The area north of the Huai He River is not as suitable for rice-fish culture, but if 5% of the rice fields become rice-fish systems, they would produce 8 000 tonnes of commercial fish and 243 million fingerlings. The total increase in rice output would be one million tonnes annually on the basis of the 1981 output (if annual increase is calculated at 10%) and commercial fish yields would reach 354 000 tonnes and 5.7 billion fingerlings. The number of fingerlings raised in ricefields would be sufficient to stock 0.75 million ha of water (e.g., ponds and reservoirs). The achievement of these goals would have very large ecological and economic benefits.

If fish farms were used to raise fry, ricefields were to be used to raise full-sized species, and ponds, reservoirs, and lakes were used to raise adult fish, fish farming would undergo considerable change. Fujian Province reported that, if ricefields are used to rear fingerlings, 200 ha of stock fishponds would be freed for intensive farming of commercial fish, and labour and feed, which would otherwise be used for breeding fingerlings, could be used for commercial fish farming. Jiangsu Province reported that, in 1986, Jianhu County used 4 700 ha of ricefields to raise fish. Three major stock fish farms supplied enough fry to meet the need for big-sized stock fish for 2 000 ha of intensive fish farming in the county. This indicates that the output of freshwater fish could be increased considerably.

Rice-fish farming has the potential to fully maximize the use of ricefields. Present trends for popularizing the practice are encouraging, and the area used to grow rice with fish is increasing yearly. In the past, the development of China's aquatic products has been slow, quality has been poor, and supply was often short. There have also been policy problems that remain unsolved. As the internal structures of agriculture are adjusted, various localities are becoming aware that rice-fish farming is an effective way to increase rice production and improve economic, social, and ecological conditions.

Since the national conference on rice-fish farming in 1983, various provinces, autonomous regions, and municipalities have undertaken measures to popularize the practice in line with local conditions. The Science Commission and Aquatic Products Department of Fujian Province organized several research projects. They achieved success by strengthening their leadership and by coordinating technical forces. East China's coordinating group met once a year to summarize work experiences and coordinate actions. Representatives from various provinces visited advanced units to draw on their experiences and to increase the awareness of leaders from different areas about the significance of rice-fish farming. They held meetings to discuss the practice and conducted training courses to expand the area of ricefields for fish farming.

Rice-fish farming should be combined with intensive fish farming in ponds, reservoirs, lakes, and cages to ensure that more fingerlings can be raised in ricefields. Recently, a national symposium called for the rapid development of ecological agriculture to improve productivity. Ecological agriculture has received increased attention in recent years, and the structure for agricultural production has been improved significantly. Undue emphasis used to be placed on plant culture; however, attention has now shifted to the comprehensive development of farming, forestry, animal husbandry, and fisheries. Instead of focusing only on economic results, both economic and ecological benefits are now considered. In the past, single items of technology were emphasized. Today, due attention is given to the comprehensive application of technical packages.

Rice-fish mutualism offers a model of ecological agriculture. However, fish farming has not yet been closely integrated with crop cultivation and the division of labour has not been clear; therefore, development and popularization have been slow. The production of both rice and fish can be maximized if agricultural researchers pay more attention to rice-fish farming and help hasten its development. It is imperative to integrate fish farming with crop cultivation. If the area for rice-fish farming was increased to 6.7 million ha as the area devoted to rice is increased, the supply of freshwater fish could be quadrupled.

Rice-fish farming can play an increasingly important role in freshwater fish farming if the nation's leaders give it due attention, if the technology is sound, and if the practice is carefully adapted to local conditions.

# Rice-Fish Culture in China: Present and Future

*Chen Defu and Shui Maoxing*[8]

In China, fish are raised in ricefields in the southeast and southwest mountainous areas where there are few bodies of water for growing fish and fishing regions and towns are far away. Rice-fish culture is a traditional and popular way for the people to grow their own supply of fresh fish in the mountainous areas of: Qingtian and Yongjia in Zhejiang Province; Jiening, Taining, Saxian, and Yongan Shaowu in Fujian Province; Yulin, Guilin, and Jinzhou in Guangxi Province; the southern part of Guizhou Province; and Pingxian, Jian, and Yichun in Jiangxi Province.

In these areas, the farmers practice rice-fish culture to raise fish for their own consumption, although it requires extensive management and fish harvests are poor. Before 1949, there was no organized extension of the technology; therefore, rice-fish culture did not improve.

## Present Situation

### Extension of Rice-Fish Culture

Since the founding of the People's Republic of China in 1949, the government has paid more attention to rice-fish culture. In 1954, the First National Conference on Aquatic Products formally called for the promotion of rice-fish culture. The area devoted to rice-fish culture increased rapidly and reached over 670 000 ha by the end of the 1950s. During the mid1950s to the early 1960s, rice-fish culture developed rapidly in the mountainous areas of south and north Zhejiang and in the plains and hilly areas of Shaoxin, Jin Hua, and Hangzhou. However, this development suffered a major setback during the 1960s to the mid1970s when planting systems were reformed and highly toxic pesticides were used. The area devoted to rice-fish culture decreased drastically, but began to increase slowly by the end of the 1970s as improved breeds of rice and less toxic, but effective, pesticides were introduced. In the 1980s, more farmers became interested in rice-fish culture as the government encouraged its adoption and introduced a family contract system in rural areas.

In 1983, the office of the Central Committee of Patriotic Hygiene in Xinxiang City, Henan Province, held a meeting about controlling mosquitoes in ricefields. They decided to promote and disseminate information about rice-fish culture and to advance its development.

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[8] Soil and Fertilizer Institute, Zhejiang Academy of Agricultural Sciences, Hangzhou, Zhejiang Province.

The first national meeting on rice-fish culture was held by the Ministry of Agriculture, Husbandry and Fishery in Wenjiang County, Sichuan Province, in August 1983. Similar meetings followed in provinces, cities, and autonomous regions. Rice-fish culture in China began a new period of rapid development. The total area of rice-fish culture increased 65% between 1983 and 1984. In Zhejiang Province, the total area[9] was 18 127 ha in 1984, a 36% increase from the 12 353 ha in 1983.

In 1984, the Bureau of Aquatic Products of the Ministry of Agriculture, Husbandry and Fishery organized and launched a project "Extending the Techniques for Fish-Raising in Ricefields" in 17 provinces, cities, and autonomous regions The total area for rice-fish culture in the country increased to 846 700 ha in 1985 and to 985 300 ha in 1986 and had a positive effects on the economy, society, and ecology. The project received the first grade award for advanced scientific technology from the Ministry of Agriculture, Husbandry and Fishery in 1986.

Rice-fish culture has now developed and been adopted in the southeast and southwest mountainous areas and the plains, and the northeast and northwest regions. It is practiced in the ricefields of Sichuan, Hunan, Guizhou, Chongqing, Guangxi, Jiangxi, Anhui, Fujian, Zhejiang, Jiangsu, Yunnan, Guangdong, Henang, Shaanxi, Hebei, Xingjiang, Liaoning, Helongjiang, Beijing, and Shanghai.

**Research on Rice-Fish Culture**

Since 1949, the main research areas in rice-fish culture have been:

- The relationship between rice and fish and ways to increase rice production using rice-fish culture;
- The different forms of the ricefield that can be used for rice-fish culture (plain, ditches, pits, wide ditches, and ridges);
- Suitable breeds of fish (i.e., grass carp, common carp, crucian carp, murrel, and mud loach). A few silver carp and bighead carp can be raised together with these fishes in ricefields with wide ditches. The raising of grass carp is the most effective way to clear up weeds and pests. Adult grass carp grow quickly in ricefields; therefore, fish yields and economic returns are increased. Techniques to prevent grass carps from injuring the rice plants must be used;
- Comprehensive techniques to improve harvests from rice-azolla-fish systems;
- Economic evaluations;

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[9] In some cases the areas differ from the summaries presented in Tables 1 and 2 of the previous paper by Cai et al. The editors have retained the figures presented by the individual authors.

- Suitable pesticides, their safe dosage, and methods of use, and the residual effects of methamidophos, carbofuran, and insect-paste in the rice-azolla-fish system;
- The control of mosquitoes in ricefields using fish-raising, and the development of the rural economy;
- Comprehensive techniques to efficiently manage agriculture, animal husbandry, and fisheries;
- The rates of absorption, transfer, and application of N and P, and the use of azolla by fish; and
- Feasibility studies.

**Types of Rice-Fish Culture**

There are two ways to combine rice and fish:

- Rice and fish together. Planting rice while raising fish is the main method used. The method makes full use of time, space, energy, and resources of the ricefield and provides economic benefits. Its shortcoming is the rather high requirement for labour and management.
- Rice and fish in rotation. Planting rice and raising fish are carried on alternately; therefore, the contradictions between growing rice and raising fish are avoided. After the rice is harvested, fish are raised in deepwater fields, which can improve fish yields. The disadvantages are that the growing period for the fish is shortened, and that the mutually beneficial and efficient relationship of rice-fish culture is lost. In regions with two rice harvests, the rotation of rice and fish will reduce rice yields.

The main methods of the rice and fish rotation are:

- early rice - late fish;
- early fish - late rice;
- after the harvest of one rice crop, fish are raised in deep water;
- fish are raised in clean summer fields for 1.5-2 months after the harvest of early rice and before the late rice is transplanted;
- fish are raised for 120-130 days in clean winter deepwater fields after the annual harvest of late rice (the fish are caught the following year before the early rice is transplanted); and
- in the same ricefield, two harvests of fish are raised and two crops of rice are planted during the same year (i.e., early rice - raising fish in summer, and late rice - raising fish in winter). In Guangdong Province, summer fish are raised for 40-50 days, winter fish for 80-100 days.

### Yields and Techniques

Fish yields in ricefields have been low. The average yield of fish per hectare from 1982 to 1987 was 70.5, 82.5, 100.5, 126, 141, and 133.5 kg, respectively. New techniques and high-yield demonstration plots all over the country have led to increased fish yields. However, average yields in large areas of the country are still low. Traditional techniques of rice-fish culture are still used in most parts of China.

The reasons for low yields of fish from ricefields are:

- Low water volume and little shelter. Traditionally, ricefields used to raise fish do not have ditches or pits. The low volume of water in these ricefields results in insufficient dissolved oxygen and few plankton, high water temperature in summer, and few places for the fish to hide from predators. The density of the fish, the rate of catching, and yields are limited.
- Inbreeding of fish and genetic degeneration. Carp are raised in most ricefields in China. For example, Tian carp are popular in south Zhejiang, West Hunan, and Sichuan, Gao Bei carp and Jin carp are popular in the mountainous area of Guizhou, "Hehua" carp are popular in northern Guangxi. These breeds of carp have mild characteristics and do not jump well; therefore, they cannot escape easily. They are suitable for raising in ricefields. However, because of prolonged inbreeding, the breed characters have degenerated and the fish grow slowly.
- Small fish breeds. The old regions of rice-fish culture use the traditional method in which small fish are raised and, in some regions, fingerlings are stocked directly into the field. This has led to slow growth of fish and low survival rates.
- Insufficient feed. Artificial feed is not used in the traditional method. However, there is insufficient natural feed in ricefields, especially in mountainous areas. The weeds decrease as the fish grow; therefore, the fish do not get a sufficient supply of weeds during the middle and late growing stages of the rice.
- Low density of fish. For breeding, 10 500–22 500 summer fingerlings are raised per hectare. For food, 1 500–7 500 summer fingerlings and 750–1 200 spring fingerlings are raised per hectare.
- Late stocking, early harvest, and short growing periods. Fingerlings are usually stocked a week after the rice seedlings are transplanted and the fish are caught during the rice harvest. The period for the rice and fish to grow together is short — about 90 days in regions with one rice crop and 160–180 days in regions with two rice crops. In southern China, 240 days (Jiangsu) and 330 days (Guadong) are considered suitable.
- Once raising and once catching. The fish carrying capacity in ricefields changes during the growing period. Early in the season, the field has many weeds and the fish are small; therefore, the

natural feed is sufficient. Later, when the fish are larger, there are fewer weeds. The resources in the field no longer match the density of the fish.

- Small-scale production. The farmers consider the fish a by-product; therefore, the area used to raise fish in ricefields is small and scattered.

### The Rise of Modern Rice–Fish Culture

Traditional rice–fish culture is no longer suited to the country's social development, and it hampers the extension of modern methods of rice–fish culture. In the 1980s, several reforms were made:

- The layout of the ricefields used to raise fish was improved. The traditional plan was changed to include ditches, wide ditches, pits, and ridges. The volume of water was increased to improve the environment for the fish.
- Several breeds of fish are now used instead of a single breed. Fish (e.g., grass carp, common carp, nile tilapia, silver carp, variegated carp, and crucian carp) were selected to suit local conditions.
- Fish size was increased. Fingerlings 10-cm or larger are now used instead of fingerlings 6-8 cm in length.
- Stocking density of the fish was increased. Depending on the fertility of the soil and feed supply, 4 500–6 000 adult fish from the previous year and 3 000–4 000 summer fingerlings are raised per hectare. The numbers can be increased if conditions are improved.
- Shifting from late stocking - early harvest to early stocking - late harvest. Because the ditch, pit (pool), and ridge systems have permanent fish pits, fish-raising can begin in the winter. Fish are now raised continuously after the harvest of late rice in deep-water ricefields. If crops are planted in winter for spring harvest, fish are caught 2 weeks before wheat or rapeseed are planted.
- Feed or the rice–azolla–fish method are used instead of not feeding the fish.
- One-time raising and one-time catching were changed to alternative catching and raising.

The new techniques have improved average yields to 750–3 000 kg of fish per hectare while increasing rice production. The highest fish yield reached 5 500 kg/ha in two-crop ricefields in Zhejiang. These new approaches have helped to modernize the traditional methods of rice–fish culture in China.

## Prospects for Rice–Fish Culture

### Potential

Because of the country's large population and limited agricultural land, agriculture in China is moving toward intensification. Rice–fish culture is part of this intensification. It is an effective way to increase the productivity of ricefields by harvesting both rice and fish. It is the quickest method to increase the economic efficiency of the ricefield and to help farmers increase their income.

There are about 25 million ha of ricefields in China. If 30%[10] were to be used to raise fish, about 7.5 million ha would be available for rice-fish culture. If 600 kg of rice and 375 kg of fish were harvested per hectare, this would increase the country's production to 45 billion kg of rice and 28 billion kg of fish. Less than 1 million ha of land, or 3.9% of the total area of ricefields, are now devoted to rice-fish culture. Therefore, there is great potential to develop rice-fish culture.

The rapid development of township industries has improved the skills of farmers. The development of family farms has prepared favourable conditions for the large-scale management of rice-fish culture using advanced scientific techniques. A modern and effective rice-fish industry will alter traditional concepts about rice-fish culture and encourage more farmers to raise rice and fish together.

**Factors Limiting Development**

- Fish can only be raised in ricefields with sufficient water resources and good irrigation and drainage. Poor water resources, drought, serious leakage, and poor water-holding capacity of the soil make rice-fish culture difficult in north China; whereas, south China is rainy and flood-prone.
- Higher economic efficiency can be achieved in township industries and trade businesses than in areas that practice traditional methods of rice-fish culture.
- The family-contracted fields are scattered and on a small-scale. Advanced and scientific methods of rice-fish culture are difficult for farmers to adopt without further land consolidation.
- Support systems for rice-fish culture are inadequate. It is very difficult for farmers to obtain loans, new and improved fish breeds, feed, fertilizer, and pesticides. There are also few technicians available to instruct farmers. Therefore, the breed characters of some carps that are popular with farmers degenerate and as a result the fish grow slowly.
- For a long time, traditional techniques have hindered the development of rice-fish culture because they prevent farmers from accepting and grasping modern techniques. Farmers worry that fish pits and ditches will affect grain yield. These ideas hamper the extension of rice-fish culture.

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[10] Different authors suggest various levels for potential expansion of rice-fish culture in China. The estimates in this paper are probably overly optimistic because only about 25% of the rice area is suitable for rice-fish culture.

### Strategies for the Development of Rice–Fish Culture

Rice–fish culture must be given as much attention as the production of food grains, and should be seen as a way to develop grain production and to improve the economic conditions of farmers. Several tactics can be used to improve rice–fish culture:

- The efficiency of rice–fish culture, and the area devoted to rice–fish culture in traditional regions, should be increased through technical training and increased funding.
- Testing sites should be established in plain areas and modern techniques should be extended to farmers to increase yields of rice and fish, and to spark interest in rice–fish culture in these high-production rice areas.
- Rice–fish culture should be extended to large farm families who mainly grow rice. The technology could help improve their livelihood and become pioneers in the large-scale development and efficient management of rice–fish culture in the country.
- Agricultural and aquatic products units should be merged to coordinate research and improve extension of practical techniques for rice–fish culture. The basic theories of rice–fish culture and techniques for good harvests of both rice and fish must be studied.

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# Scientific and Technological Development of Rice–Fish Culture in China

*Zhang Rongquan*[11]

Rice–fish culture is an organic method that integrates rice production and aquaculture. It enhances the growth of both rice and fish, maximizes the use of field and water resources, and effectively increases harvests. Several scientific and technological developments have been made to rice–fish culture techniques in China.

## Development of Rice–Fish Culture Techniques

### Traditional Aquaculture Techniques in Ricefields

Historical records show that Chinese farmers started raising fish in ricefields more than 1 700 years ago. But despite its long history, rice–fish culture did not progress for many years and its development was hindered by feudal relationships. Farmers raised fish in ricefields as a sideline, usually only to augment their own meals. Rice–fish culture is described in the Tang Dynasty treatise (about 889–904 AD) *Wonders in Southern China* by Liu Xun:

> *... after the spring rains, water collects in the fields lots around the houses. Grass carp fingerlings are then released into the flooded fields. One or two years later, when the fish are grown, the grass roots in the plots are all eaten up. This method not only fertilizes the fields, but produces fish as well. Then, rice can be planted without weeds.*

During the Ming and Qing Dynasties, rice–fish culture gradually developed into an important sideline in the countryside. But, because of various restrictions, it did not grow into an organized technique. Operations were often scattered and little information was available; therefore, methods and yields varied considerably in different areas. Yields were low and the scale of production and the techniques did not progress.

Before the founding of the People's Republic of China, the Ministry of Agriculture and Forestry of the Kuoming-Dang Government promoted the development of rice–fish culture by stocking fingerlings in ricefields of Sichuan. They also published and distributed a brochure entitled *An Elementary Introduction to Rice-Fish Culture*. In Shong Jiang District, the Jiangsu Province Rice Experiment Station conducted experiments on rice–fish culture and provided technical guidance

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[11] Chinese Academy of Fisheries Science, Wuxi, Jiangsu Province.

to local farmers. These efforts promoted rice-fish culture locally, but restrictions limited its impact on the rest of the country.

During the early period of the People's Republic of China, rice-fish culture flourished as agricultural production was restored. Experiences in rice-fish culture were exchanged quickly and more districts began to adopt the technique. By 1959, the total area devoted to rice-fish culture had increased to about 670 000 ha. At this stage, fish were raised on a small-scale with traditional tall rice varieties grown without pesticides on level land. A few farmers dug fish ditches, which took up only 1% of the field area. The species raised were restricted to grass carp and common carp. Usually, the fish were not fed and only weeds were available. Production, efficiency, and benefits were low. Although there were new developments, rice-fish culture remained very traditional.

In later years, the system of rice cultivation was reformed and large quantities of fertilizer and toxic pesticides were used. Rice-fish culture decreased. Since 1978 new techniques have been developed.

## New Techniques

China is very large and the natural conditions vary substantially between different regions. Since the 1970s, the coexistence of rice and fish had been established based on the traditional system of rice-fish culture. However, reforms in the rice-growing system and progress in rice-fish culture techniques have intensified the conflicts between rice and fish culture. The traditional techniques did not suit the new situation and this hindered the development of rice-fish culture.

In 1972, Ni Dashu of the Institute of Hydrobiology, Academia Sinica, put forth the theory of feeding fish for rice culture. Later Ni Dashu and Wang Jianguo developed a theory of mutualism that stated that rice and fish could coexist. They conducted experiments on rice-fish culture. Ni Dashu studied the rational use of ricefield resources and deemed that although there were differences in growth and development of rice and fish, they shared common characteristics in terms of their need for water, light, and fertilizer.

Fish were fed in ricefields, and fish-raising was integrated with rice culture. Rice was regarded as the main product, and the biological productivity of ricefields was upgraded. Ricefields were used, not only to raise a single crop, but to grow several crops. Rice and fish could coexist in the same field. Bumper harvests of both rice and fish provided more protein, improved efficiency, and increased economic benefits.

In the 1980s, rice-fish culture made progress. Guided by the mutualism theory of rice and fish, scientific and technological workers developed many new techniques for shallow irrigation fields and adjusted the use of pesticides and fertilizer according to the new production structure and to changes in techniques of rice culture. Many new species of fish were used: grass carp, common carp, crucian carp, Beijing bream, silver carp, bighead carp, and tilapia. New techniques were developed that could produce yields of over 7500 kg of rice and 750 kg of fish per hectare.

Rice–fish culture techniques can be divided into three categories: growing rice and raising fish together in the same field, rotating rice and fish, and continuing fish culture in the ricefield after the rice is harvested. In some areas, all three forms are combined. According to engineering facilities, rice–fish culture can be further divided into: feeding fish in furrows and growing rice on ricefield ridges, using ditches, pits, or ditches with flowing water, and additional techniques, such as raising fish and azolla together in the ricefield and raising fish and ducks at the same time in the ricefield.

**Rice–fish culture, rotation of rice and fish, and continuous rice–fish culture.** In rice–fish culture, rice and fish live together in the same field. This technique can be used with early rice, midseason rice, and late rice. Some contradictions between growing rice and raising fish are unavoidable. Therefore, fertilizer and pesticides that can harm the fish are avoided. Generally, excessive engineering facilities are not necessary. Fish feed is not needed because the fish live on natural food in the ricefield. This is extensive culture. Average production is about 150 kg/ha and well-managed fields can produce over 750 kg/ha. The disadvantage of this technique is that the growth period of the fish is comparatively short and the harvested fish are small. Therefore, large fingerlings are usually used. The technique is occasionally used to stock adult fish for 1 year.

In a rotation of rice and fish, the fallow field left after the rice is harvested is used to raise fish. Generally, fish fry or fingerlings are stocked. After the rice harvest, the straw is left in the field. When the land is irrigated, the straw decays, which makes the water suitable for feeding adult fish. In this form of rice–fish culture, fish have more space to move about and it is convenient to spread feed, but the growth period is relatively long. Compared with raising rice with fish, production of fish is higher. Generally, fish yields are 300–450 kg/ha with maximum yields of over 1500 kg/ha. Because it provides remarkable economic benefits, rotation of rice and fish is widely used in fallow winter fields, during the summer with green manure crops, for stocking fingerlings to produce table fish, and in seedling beds to stock fish fry for fingerling culture.

In continuous rice–fish culture, rice and fish are raised together. Because the fish are raised after the ricefield is fallow, their growth period may be over 1 year, which produces better results. Generally, production reaches over 750 kg/ha. This form of culture is widely used in hilly and mountainous regions.

In practice, a combination of these techniques adapted to suit local conditions achieves the best results.

**Other techniques.** Fish can be raised quite successfully in furrows in ricefields. This method is based on a half-dry cultivation method developed by Hou Guang-jiong. It effectively transforms uncultivated ricefields and can increase rice production in low-yielding fields (e.g., fields in the foothills, cold fields, and water-logged fields). The ridges in the field can be thickened with layers of soil, and the water in the field can be made deeper. This raises the temperature of the soil, improves soil structure, promotes seedling growth, and improves water management. The fish help reduce diseases, pests, and wild grass and as a result, rice production is increased by 10–20%.

Fish can also be raised in ditches that contain water that is deeper than in the surrounding fields. Fish screens and ditches and pits in the centre of the field help improve the environment for the fish. Fish production in ditches is generally two to three times higher than in level fields.

In integrated fish culture in ditches and pits, pits are dug in the ricefields or along the side of the field and are connected with ditches. Fish are raised in the pits and ditches. This technique was developed after the contract-responsibility system was implemented for family operated rice-fish farms. The method offers several advantages. It improves water management, assures a good harvest, maximizes the use of pits in the field, and helps resolve conflicts between rice and fish caused by operations such as shallow irrigation, drainage of fields, and the use of chemical fertilizers and pesticides. The water in the pits helps the rice resist drought and provides a guarantee of steady rice production. The pits also provide more space for the fish, which enhances fish growth and improves yields.

If the pits are used as nursery ponds, the fry develop into fingerlings earlier, which reduces transportation costs for fingerlings. The pits also provide a capture area during harvest. Production is increased and farmers save work and time.

The technique of raising fish in ditches with flowing water is based on flowing-water aquaculture. It is a semi-intensive rice-fish culture technique that is used mainly in ricefields with good irrigation and sufficient water resources. Wide ditches are dug and a small flow of water is led into the ricefield. Because intensive aquaculture techniques and principles have been adopted, production is comparatively high. Farmers are adopting this technique rapidly in areas with the required water resources.

Rice-azolla-fish cultivation involves growing rice, fish, and azolla at the same time in the same field. This cultivation technique makes full use of space and water. The ricefield provides a good environment and rich food for the fish. Azolla, which grows on the water surface, provides feed for the fish and manure for the field. The fish eat pests and weeds and their excretions fertilize the field to improve the growth of rice.

Several other farming methods have also been developed to maximize the use of ricefield resources and involve rice-fish culture (e.g., growing various beans on the ridges of the field and herding ducks in the ricefield).

## Comparison of New and Traditional Techniques

Many developments have been made in the new technique for rice–fish culture. The traditional techniques are integrated into the rice-growing systems found throughout China. This ensures that rice–fish culture is practiced across China. However, the traditional technique does not suit all rice-growing systems. Because there is only one model, it is difficult to extend and develop this model of rice–fish culture throughout all regions of China.

The new techniques include advanced culture and engineering features adaptable to local conditions. Effective engineering facilities help avoid conflicts between rice and fish and improve the ability of the ricefield to resist drought and flood. Rice production is therefore guaranteed along with substantial increases in both rice and fish harvests. The traditional technique cannot resolve or avoid conflicts between rice and fish. Sometimes fish must be sacrificed to guarantee rice production. This reduces income and discourages initiatives in rice–fish culture.

The new techniques apply lessons learned from alternative aquaculture techniques and new developments with respect to stocking size, variety, management, multispecies culture, feeding, and maintenance of water quality using fertilizers. These developments, together with a certain degree of intensification, play a positive role in improving fish production. The traditional technique does not involve these new aquaculture techniques and harvests of both rice and fish are not as good.

The new techniques fully apply the principles of rice–fish mutualism and soil thermodynamics. Different disciplines and the technical systems of farming and aquaculture are organically integrated. The effects and benefits of economics, sociology, and ecology are unified to promote the development of the rice–fish culture system. The traditional technique does not organically combine agriculture with aquaculture. Because the technical system for rice–fish culture is not perfected steady development of rice–fish culture cannot be assured. Moreover, because the new technique has led to increased harvests of adult fish, it has established the technical foundation for rice–fish culture to move from a self-sufficient economy to a commodity economy.

In 1983, the area for rice–fish culture in China was 441 000 ha. In 1987, it increased to 796 667 ha with 106 000 tonnes of fish production.[12] At present, the area for rearing adult fish (excluding fingerling rearing) in ricefields is 708 027 ha with a total production of 124 900 tonnes and an average production of 180 kg/ha. This rapid rate of development is directly related to technical advances in rice–fish culture.

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[12] These figures differ from those presented in Table 2 of the paper by Cai et al.

### Constraints to Rice-Fish Culture

Despite great advances, several technical and production constraints must be resolved:

- The new technique has not been properly extended to farmers and there is a considerable yield gap between experimental models and the yields achieved by farmers. Some models yield over 3 750 kg/ha, but farmers obtain yields of 150-300 kg/ha.
- Fry and fingerling supply is insufficient.
- The composition of the species for stocking and stocking density must be more fully studied.
- Feed management must be improved to raise unit yields.
- Weaknesses in fisheries management discourage initiatives taken by farmers in rice-fish culture.

## Development of Rice-Fish Culture Techniques

Experience has proven that rice-fish culture is beneficial. Large amounts of fresh fish can be harvested, while the production of rice increases. In some cases, the production value of fish exceeds that of rice. Rice-fish culture therefore offers potential for China, a country with limited land and a large, growing population. The country must develop this potential for food production, while increasing the income of farmers. China's demand for grain and fish products will likely continue to increase.

There are no marketing problems for the products of rice-fish culture, and income is higher than from growing rice alone. Therefore, farmers are eager to develop rice-fish culture because of the demand for food and the increased economic benefits that can be realized.

Rice-fish culture in China combines the principles of water conservation, soil improvement, and biological control into an integrated technique for rice-fish production. The new technique will play a important role in land management and environmental protection. Rice-fish culture techniques are expected to develop rapidly in several areas.

### Basic Techniques of Rice-Fish Culture

The rice-fish mutualism theory advanced the development of rice-fish culture. When other disciplines were integrated into rice-fish culture, the theory was further developed and improved. It is important to study the mechanisms of rice-fish culture, the natural laws governing aquaculture and agriculture, and the interrelationships among rice and fish, and other factors such as soil, water, and fertilization in the ricefield.

### Rice Growing and Aquaculture

The study of the interrelationships between rice and fish will help understand the contradictions between the two production systems and find ways to enhance the harmony between agriculture and aquaculture and to improve yields for both rice and fish.

### Integrated Rice-Fish Culture Techniques

Rice-fish culture techniques must be integrated with alternative aquaculture (e.g., intensive pond aquaculture, lakes and reservoirs aquaculture, cage aquaculture, and other supporting techniques). This will help increase production per unit area and maximize the widespread practice of rearing fingerlings in ricefields.

### Engineering for Rice-Fish Culture

To strengthen the capacity of rice-fish production systems to withstand natural disasters, rice-fish engineering facilities should be integrated with techniques of water conservation. Engineering facilities should also be flexible and adaptable to local conditions.

### Management Model for Rice-Fish Culture Techniques

The economic benefits of the different rice-fish culture techniques that are practiced in different areas should be analyzed. Management methods for rice-fish culture must be studied to establish an economic model of rice-fish culture that is adaptable to local conditions, requires less input, but yields increased output.

There are 25 million ha of ricefields in China. Of these, about 10 million ha are suitable for rice-fish culture. If integrated rice-fish farming was further advanced by effective extension work, the area for rice-fish culture in China could be increased by several million hectares within this century. It would then be possible to produce the substantial quantities of fingerlings and adult fish needed to supply further development of freshwater aquaculture in ponds, lakes, and reservoirs. Rice-fish culture will play a vital role in freshwater aquaculture, in the commercial economy, and in agriculture. It will produce food for China and the world.

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# Development of Rice-Fish Farming in Guizhou Province

*Shi Songfa*[13]

Rice-fish farming has been practiced for over 1 000 years in Guizhou. It is most popular in eastern Guizhou (bordering the provinces of Hunan and Guangxi) in areas where communities of national minorities live. The most commonly cultivated species are "Gaopo" common carp and "river" common carp. Farmers gather fish eggs from ponds, ricefields, and rivers and hatch them to get fry. Because of climatic conditions, most areas have only two crops a year with a single crop of rice. Fish are cultivated at the same time as rice. Flat fields and extensive cultivation are the norm. Normally, fields are not drained and the farmers in southeast Guizhou even cultivate fish in the winter water fields.[14]

In 1984, the Departments of Aquatic Products, Soil and Fertilizer, and Agricultural Extension were organized to promote high-yielding techniques for rice-fish farming. A number of technical guidelines, such as the *Technical Rules for Rice-Fish Farming* and *Technical Standards for Cultivating Fish in Ridge Box-Ditch Ricefields* were published. Many demonstration plots were developed.

By 1987, there were over 3 000 ha of high-yield demonstration plots (a 13-fold increase from 1984). The average yield was almost 400 kg/ha (40% more than in 1984). With these encouraging results, rice-fish farming developed rapidly. In 1980, 42 700 ha of ricefields yielded 3 348 tonnes of fish, by 1983, this had increased to 60 000 ha and 4 611 tonnes of fish. In 1987, there was a 75% increase in area and a 210% increase in yield (74 700 ha and 10 400 tonnes of fish). This amounted to 57% of the total fish production of Guizhou in 1987. The unit yield also increased 78% from 1980 to 1987 and reached 139 kg/ha.

## Development Trends

With popularization and technical extension, rice-fish farming has improved the ecological environment of the ricefield and is making better use of the carrying capacity of the field and achieving additional benefits from low-level inputs.

[13] Aquatic Products Division, Guizhou Aquaculture Bureau, Guiyang, Guizhou Province.

[14] Winter water fields are ricefields that are left fallow and collect water during the winter. Rice is transplanted to these fields in the spring. This practice is prevalent in the cooler, mountainous areas of western China, particularly in the provinces of Sichuan and Guizhou.

**New Rice-Fish Farming Techniques**

Flat-field techniques of rice-fish farming have been replaced by ridge-ditch ricefields (in which the fish are grown in the ditches and the rice is grown on the ridges), box-ditch fish raising, and manure-pit fish raising in flat fields. Instead of farming fish only with rice, farmers now also grow wild rice or lotus.

Fish farming in the ridge-ditch fields does not require inundated irrigation, therefore, the conditions of water, fertilizer, oxygenation, and heat are improved in the soil. This has considerable impact on the rice. It stimulates the early growth of seedlings and early emergence of tillers. The grains of rice increase in number and size, which produces higher yields. This practice also increases field-water storage, improves drought-resistance capability, and provides sufficient deep water for fish. These factors all improve fish growth and lead to higher yields.

The Scientific Association of Southeast Guizhou Prefecture, the Information Institute of Scientific Committee, and the Prefecture Agricultural Institute conducted experiments in 1986 to observe the differences between ridge-field rice and flat-field rice. They found that there were considerable changes to the soil environment that affected the growth of the rice plants. Soil temperature in ridge fields was normally 0.2–0.4°C higher than in the flat fields. Results were particularly obvious in cold, muddy fields that had low soil temperatures. Growth was faster in ridge-rice cultivation. Seedlings recovered quickly after transplanting and tillers emerged 9 days earlier than in flat fields. The activity of soil microorganisms was also enhanced, which improves the breakdown of soil nutrients and helps provide adequate nutrition for root growth. With improved vitality, rice roots grew deep into the soil and the roots were stronger. During the tilling period, rice roots in the ridge fields were 8 cm longer than that in flat fields, and on average there were 20 more roots. During the full-ear period, the roots of plants on the ridges were 13 cm longer and there were 199 more roots. Ridge-rice cultivation can also enhance the resistance of the rice plant to drought and lodging. When fish and rice were grown together, topsoil fertility in ridge fields was significantly higher. There were increases of 0.55% in organic matter, 0.022% in whole nitrogen, 1.2 mg/100 gt in hydrolytic nitrogen, and 27.7 ppm in effective phosphorus.

Experiments carried out in 1986 by the Aquatic Products Station of Chishui County revealed that ridge-rice cultivation could improve rice tillering and increase average grain weight. In these experiments, the average number of grains per ear in the ridge fields was 140–155 compared with only 105–110 in flat fields. The average weight of 1 000 grains in the ridge fields was 27.5–28.4 g, compared with 26.5–27.0 g for flat fields. The empty grain rate was 26.5–28% in the ridge fields and 39–41% in the flat fields.

Additional evidence of the benefits come from farmer experiments. A farmer, Jiang Chengxu in Suiyang County, conducted a comparison trial in an area of 0.05 ha (0.025 ha for each of the two methods). In each area, he stocked 200 7-cm fingerlings. The flat field yielded 170 kg rice and 12.6 kg fish. The ridge field yielded 200 kg rice and 34 kg fish, or an increase of 18% for rice and 172% for fish. In the Southeast Guizhou Prefecture, ridge-field cultivation required 6-8 more farmer-days of labour, but the value of production increased by 50%.

Raising of fish in box ditches and manure pits in flat fields can also create a good ecological environment for fish because pesticides are not applied and exposure to sun and drought is reduced. This system increases the potential of the ricefield and produces higher fish and rice yields. Manure pits normally only occupy 10% (or less) of the ricefield and poses no threat to rice production. Chishui and Songtao Counties have carried out rice-wild rice-fish and rice-lotus-fish experiments. Production values were CNY3 809/ha in Chishui and CNY4 170/ha in Songtao.[15]

### New Species

Instead of raising only common carp, farmers now raise several fish species. The temperature of shallow water in ricefields changes with air temperature and is unstable. However, during the warm season, leaves of the rice plants shade the water surface and stabilize the water temperature. This creates a suitable environment for growing grass carp, common carp, silver carp, variegated carp, tilapia, and crucian carp.

The ricefield is an artificial ecosystem that abounds with various grasses, weeds, plankton, and other organisms. If only common carp are grown, these resources are not fully utilized and yields are not very high. In recent years, several species have been raised together and the results have been encouraging. This demonstrates that the ricefield ecosystem is suited for polyculture of fish. Normally, common carp are raised with grass carp or silver carp, grass carp with tilapia, or common carp with crucian carp and catfish. Either fry or adult grass carp can be raised.

With the appropriate number of fish, rice seedlings are not eaten by the grass carp. The fish consume grass and weeds to the benefit of rice growth. For example, 2 250–3 000 grass carp and common carp (in the ratio of 4:6 of 10-cm fish) can be raised in 1 ha without damage to seedlings. When the fish have grown to 17 cm in length and are able to eat seedlings, the rice plants are tall enough to avoid damage. If the grass carp are over 20 cm in length, 450–750 fingerlings can be put into a 1-ha ricefield. In this case, additional feed (grass) must be provided during the early stage to keep the grass carp from eating the rice seedlings. If silver carp and variegated carp are raised, their number should be limited to 5–10% of the total number of fish raised.

In Huangping County, farmer Yang Zaigui raised fish in a 0.08-ha ricefield. On 12 June 1988, he stocked 49 grass carp fingerlings (8.9 kg), 372 common carp fingerlings (18.4 kg), and two silver carp fingerlings (0.6 kg). After 105 days, he harvested 34 grass carp (31.15 kg), 356 common carp (66.9 kg), and two silver

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[15] In October 1988, USD1 = CNY3.7221 and CAD1 = CNY3.1889.

carp (1.81 kg). Total net production was 73.05 kg. Yield per hectare was 906.8 kg fish and 7 875 kg rice.

### Species Improvement

Local common carp have been replaced with hybrid common carp. The trend is toward improved species. Local Gaopo carp has long been raised in Southeast Guizhou. It is docile, quiet, and usually does not jump. During floods, it does not panic and swim away. It hides in muddy rice water when disturbed. However, its quality is deteriorating because of poor selection of brood stock. Parent fish are so small that their offspring do not develop properly.

In 1985, the Aquatic Products Bureau of Leishan County sampled 50 Gaopo carp. The heaviest one was 350 g and the smallest 25 g. Five of the fish that weighed 25-95 g were mature. Work by the Aquatic Products Bureau of Luping County revealed that this fish is sexually mature at approximately 100 g. Results from the Aquatic Products Bureau of Guiyang City showed that 35% of the fish with an average weight of 185 g were sexually mature. This suggests that Gaopo carp have seriously deteriorated and are maturing at a small size. Since 1980, many localities like Zunyi, Chishui, Wuchuan, Zheng'an, Jinping, and Tianzhu have worked to improve carp varieties. While paying attention to the selection and improvement of local varieties, they have also introduced improved brood fish.

In 1983, the Aquatic Products Bureau of Zunyi Prefecture introduced parent fish of two common carp varieties, Yuanjiang carp and Wuyuanhese red carp. They achieved good results when they released the hybrid Heyuan carp from these two varieties. In 1988, the Aquatic Products Bureau of Luping County compared improved common carp and local common carp. Growth characteristics were evaluated by taking five samples at monthly intervals after release. Improved common carp gained 1.95 g more each day and relative growth was 1.5% higher. When the improved common carp weighed 520 g each, the local common carp weighed only 200 g (40% less).

In 1987, the entire province began the systematic improvement of common carp. In 44 variety improvement sites, 31.4 million fry and 9.8 million fingerlings of improved common carp were produced. A total of 967 ha of ricefields received this variety and results were good.

### Intensive Cultivation

Intensive cultivation of fish is now replacing extensive cultivation. Extensive cultivation only uses natural feed; therefore, yields are low. In 1980, the provincial average yield of fish was 78.3 kg/ha. To achieve high yields, traditional culture systems must be replaced with intensive culture systems that make full use of the carrying capacity of the ricefield ecosystem. Farmer Lu Binlun in Danzai County conducted a comparison trial in 1985. Intensive culture yielded 1 242 kg of fish per hectare or 4.6 times more than extensive cultivation (220.5 kg/ha). In 1983, farmer Liu Dingzhong of Longquan Township raised fish in a 0.32-ha ricefield using earthworms and maggots as additional feed. He harvested 580 kg fish or 1 812 kg/ha. In 1984, farmer Li Xingji in Suiyang County harvested 325.4 kg from a 0.21-ha field by using wastewater from factories.

**Prospects**

Guizhou Province is a subtropical area with a humid monsoon climate. It has low latitudes and high elevation. The temperature is relatively high in winter but low in summer. The yearly average temperature is between 14°C and 16°C in most areas. The temperature is above 10°C for 220–240 days a year, and 270 days are frost-free. Annually, there are about 180 rainy days, 1 100 mm of rainfall, and 1 200 hours of sunlight. There are many cloudy and rainy days and yearly changes in light, heat, and water are synchronized. All these conditions are conducive to growing rice and fish. The longer growth period for fish and the good overwintering conditions allow a sound farmland ecosystem can be established to increase the production of rice and fish.

Ricefields in the province cover a total area of 791 000 ha, over half (about 400 000 ha) of which are low-yielding fields. There are 122 000 ha of winter water fields. These areas are, to various degrees, poor, barren, highly acidic, sticky, sandy, muddy, and cool and therefore do not produce high yields of rice. Fish farming improves the soil and rationally uses the land to produce more rice. Fish farming is profitable and has the potential to improve the economic situation of farmers, particularly in mountainous areas.

In 1984, a survey was conducted of 20 farming households in Danzai County that covered about 1.32 ha of rice–fish farms. The output of fish and rice was valued at CNY4 374/ha, 90% more than rice cultivation alone. Surveys in Danzai and other counties showed that rice–fish farming increased the output value of ricefields by CNY817.5/ha.

In the future, rice–fish farming will undoubtedly supply a large portion of the fisheries production in Guizhou, especially in mountainous areas where there are large ricefields but few ponds or reservoirs. It is important to develop rice–fish farming and to establish systems for technology extension and for the production and supply of improved varieties. Ridge-ditches, box-ditches, manure pits in flat fields, and other forms of rice–fish farming should be adopted to suit local conditions. Improvement of the common carp variety must continue. Mixed culture of species (mainly common carp and grass carp) should be practiced. Intensive cultivation should replace traditional extensive cultivation, which usually has low yields with low input. Improved fish-farming techniques should be adopted in a systematic way to make the best use of ricefield resources and to improve fish yields.

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# Reforming Rice–Fish Culture Technology in the Wuling Mountains of Eastern Guizhou Province

*Chen Guangcheng*[16]

In the past, traditional methods of rice–fish culture were used in the Wuling Mountains. Because output was very low, several reforms were undertaken to improve rice–fish culture.

**Improving the Environment for Fish**

Depending on the type of soil, furrows, wide ditches, or pits were dug to culture fish in flat ricefields. In cold, muddy, fertile fields, rice–fish culture can be carried out in furrows and wing ditches. The ridge of the furrow is normally about 26-cm wide and the ditch about 39-cm wide and 26–33 cm deep. In muddy fields, where it is difficult to make ridges, wing ditches were introduced. The wing is 2-m wide and the ditch about 0.8-m wide and 0.5-m deep. This innovation improves soil structure, light, and temperature and increases rice production.

In 1985, these innovations were tested at 54 sites (13.7 ha). The dry rice yield averaged 6712 kg/ha (18.% more than in flat fields). Ditches help solve problems created by shallow water and variations in water temperature in flat fields because they increase the volume of water by about 100%. In summer, changes in water temperature are 2–3°C lower than in flat fields. This improves the environment for the fish. In these tests, average fish yield was 507 kg/ha. In high-yielding fields that can produce 7 500 kg of rice per hectare, fish production is often 750 kg/ha. In 1987, a 1.5-ha field averaged 7 605 kg of rice and 825 kg of fish (average weight per fish 0.85 kg).

The farmers are given these instructions to implement the new technology:

> *To culture fish in a field, dig a pit big enough to make up 5–10% of the field. The pit should be 1.5-m deep and it should link to the fish ditch. There is four times more water in this field than in flat fields. This not only benefits fish growth, but increases the quantity of fish and provides the convenience of dry fields, where farmers can apply additional fertilizer and agricultural pesticides.*
>
> *In terraced fields, a big side ditch is dug in the back ridge. The side ditch should be 1-m wide and 1-m deep and should be linked to the fish ditch. This enhances the growth of rice, which benefits from warmth, and the fish,*

[16] Bureau of Aquatic Products, Tongren Prefecture, Guizhou Province.

*which like the water. These changes provide conditions for high yields in rice-fish culture.*

### Stocking Large Fingerlings and Late Harvesting

In the past, the fish species were usually breed and cultured by the farmers. Most of the strains have degenerated. A system of elite breeding has now been established based on the district and township fish hatcheries (e.g., there are 104 sites in Yinjiang County).

Instead of small fingerlings, 250–300 large (about 10 cm) fingerlings are stocked in the fields. Fingerlings should be stocked before the seedlings are planted (from February to April). This allows the fish to obtain food when plankton is abundant. Experience has shown that the same-size fingerlings stocked before planting rice seedlings weigh 100 g more than fingerlings stocked after planting.

Keeping water in the fields when the rice is harvested allows the fish to grow for an additional 60 days and to increase their weight (to about 150 g). During this period, the rice that falls into the field and the young rice seedlings that grow from the roots of the rice are good food for fish.

In February 1987, Li Demin, a farmer in Yundu Township, Jiangkou County, put 200 grass carp and 200 common carp, each about 15-cm long, into a 0.2-ha field. In May, he put 1 800 small fingerlings into the same field. On 19 October, he harvested 162 kg of adult fish and 31 kg of fingerlings. The adult fish averaged 0.52 kg and some were as large as 1.6 kg. The average yield was 986 kg of fish and 6 358 kg of dry rice per hectare.

### Polyculture and Intensive Culture

In mountainous areas, the fields are poor and weedy; therefore, a polyculture of grass carp, common carp, and silver carp is used in the ratio of 3:6:1. From May to July each year, 15 000 small fingerlings of grass carp and common carp are stocked per hectare of field. By November, the fingerlings reach a length of 12–18 cm and the survival rate is 20–30%. Weeding is not necessary in fields devoted to polyculture.

In intensive culture, a base fertilizer is applied before the fish are stocked into the fields. From April to May, it is not necessary to feed the fish because they are small, water temperature is low, and benthos and weeds are plentiful. From June to September, feed should be applied once a day. After the rice is harvested, the quantity of feed should be reduced.

### Scientific Water Management, Proper Irrigation, and Drainage

The basic principal is to consider the needs of both the rice and the fish. When fingerlings are stocked before the rice seedlings are planted, the water level should be maintained to minimize fish deaths. Five to seven days after the rice is planted,

Table 1. Output and value of rice and fish harvests before and after technical reforms.

| | | | Rice (1986) | | Rice (1987) | | Fish (1987) | |
|---|---|---|---|---|---|---|---|---|
| Farmers | Location | Area (ha) | Output (kg) | Value (CNY) | Output (kg) | Value (CNY) | Output (kg) | Value (CNY) |
| Liu Shu-chen | Tongren | 4.4 | 27 056 | 16 234 | 27 571 | 16 543 | 3 286 | 19 717 |
| Yian Zhu-shen | Yuping | 1.5 | 10 545 | 6 327 | 10 605 | 6 363 | 1 175 | 7 050 |
| Wu Xiu-shu | Songtao | 1.3 | 8 360 | 5 016 | 8 740 | 5 244 | 726 | 4 354 |
| Long Tian-ci | Songtao | 0.8 | 5 350 | 3 210 | 5 670 | 3 420 | 481 | 2 886 |
| Li De-ming | Jiangkou | 0.2 | 1 200 | 720 | 1 238 | 743 | 192 | 1 155 |
| Huang Xin-tuan | Tongren | 0.2 | 1 260 | 756 | 1 462 | 878 | 160 | 959 |
| Total | | 8.4 | 53 771 | 32 263 | 55 286 | 33 191 | 6 020 | 36 121 |

the water level should be reduced to promote tillering. In a furrow or ridge system, the water should flood the roots of the rice seedlings. When the rice seedlings begin to turn green, the water level can be reduced. This will not affect the fish because they are still small.

A month after rice seedlings are planted, the flat fields should be drained for weed control. Later, the rice water level should be raised to about 12 cm to control ineffective tillering of rice and to benefit fish growth. After the rice is harvested, the water should be raised to over 50 cm for continuous fish culture.

## Economic Benefits

These technical reforms have produced economic benefits (Tables 1-3).

### Value of Output

In 1986, 8.6 ha of ricefields produced 53 771 kg of dry rice, valued at CNY32 262 (Table 1), or an average of CNY3 840/ha. In 1987, with rice-fish culture, these fields produced 6 020 kg of fish valued at CNY36 121 and 55 286 kg of rice valued at CNY33 171. The total value of production was CNY69 292, or an average of CNY8 249/ha, which was 2.1 times more than in 1986 without fish culture.

### Ratio of Investment to Income

In 1987, CNY7 567 was invested in rice-fish culture, an increase of CNY5 252 from 1986. But in 1987, net income was CNY61 725, which was CNY31 778 more

Table 2. Investments (Invest.) and income before and after rice-fish culture (CNY).

| | Area (ha) | 1986 Net Income | 1986 Invest. | 1986 Income | 1987 Net Income | 1987 Invest. | 1987 Income |
|---|---|---|---|---|---|---|---|
| | 4.4 | 15 130 | 1 104 | 16 234 | 31 796 | 4 464 | 36 260 |
| | 1.5 | 5 869 | 458 | 6 327 | 12 259 | 1 154 | 13 413 |
| | 1.3 | 4 610 | 406 | 5 016 | 8 657 | 941 | 9 598 |
| | 0.8 | 2 986 | 224 | 3 210 | 5 768 | 520 | 6 288 |
| | 0.2 | 650 | 70 | 720 | 1 628 | 270 | 1 898 |
| | 0.2 | 703 | 53 | 756 | 1 619 | 218 | 1 837 |
| Total | 8.4 | 29 948 | 2 315 | 32 263 | 61 727 | 7 567 | 69 293 |

Table 3. Achieved value by labour force before and after rice-fish culture (CNY).

| | Area (ha) | 1986 Net Income | 1986 Investment | 1986 Income | 1987 Net Income | 1987 Investment | 1987 Income |
|---|---|---|---|---|---|---|---|
| | 4.4 | 15 130 | 706 | 21 | 31 796 | 1 170 | 27.18 |
| | 1.5 | 5 869 | 275 | 21 | 12 259 | 440 | 27.86 |
| | 1.3 | 4 610 | 228 | 20 | 8 657 | 349 | 24.8 |
| | 0.8 | 2 986 | 137 | 22 | 5 768 | 227 | 25.41 |
| | 0.2 | 650 | 27 | 24 | 1 628 | 53 | 30.71 |
| | 0.2 | 703 | 30 | 23 | 1 619 | 51 | 31.74 |
| Total | 8.4 | 29 948 | 1 403 | 21 | 61 726 | 2 290 | 26.95 |

than in 1986 (Table 2). The ratio of investment to income from rice-fish culture was 1:6.

### Rate of Return

In 1986, net income was CNY29 947. In total, 1 403 workers were employed and each produced an output value of CNY21.34. In 1987, net income was CNY61 725, which was achieved with 2 290 workers; therefore, each produced an output value of CNY26.95 or CNY5.61 (26%) more (Table 3).

### Value of Fish

Before the reforms in rice-fish culture, fish from the fields weighed about 100 g each. Because the species had degenerated, they could only be sold for food for about CNY2/kg. After the technical reforms, 11780 fish were caught from 8.4 ha of ricefields. Total weight was 6020 kg, or an average of 0.51 kg/fish. These fish fetched a price of CNY6/kg; therefore, the commodity value of the fish increased three times after the technical innovations.

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# The Development of Rice-Fish Farming in Chongqing City

*Xu Shunzhi*[17]

Rice-fish farming has been conducted for over 1 000 years in the city of Chongqing. For a long time, however, fish yields were poor and unstable because of extensive cultivation, traditional methods, and a variety of limiting factors. Advances in science and technology, the development of the fish industry, changes in the structure of rural industries, and an increase in the commodity market led people to seek new ways to maximize water resources. They pursued new productive technologies that changed the traditional system of rice-fish culture and produced economic, social, and ecological benefits.

The productivity of rice-fish farming in Chongqing has been improved by engineering installations, new technologies for rice-fish farming, and improved circulation of nutrients and energy in the water. The contribution of rice-fish farming to total fish production in the city increased from 2-4% in the 1970s to 29% in 1987. In 1987, rice-fish farming ranked second as a method of fish production and was conducted on 73 300 ha of ricefields that produced 10 200 tonnes of fish. New cultivation technologies were practiced on 22 250 ha of the total area and produced 6 680 tonnes of fish. Some demonstration fields produced 3 000-4 500 kg/ha. Total production from rice-fish farming was valued at more than CNY50 million.

## Rice-Fish Farming in Chongqing

Chongqing, in eastern Sichuan Province, has a subtropical monsoon climate with adequate heat and rainfall during the warm season. The average temperature is 17.5°-18.5°C, and there are 1 000-1 100 mm of rainfall, 320-340 frost-free days, and 1 200-1 300 h of sunshine. These conditions are suitable for the cultivation of fish.

For many years, production from rice-fish farming remained poor and unstable. Improvements were not made because of political changes, faulty economic policies, changes in farming systems, primitive cultivation technologies, traditions that were difficult to change, and damage from natural disasters. The area devoted to rice-fish farming eventually decreased to less than 4 000 ha with a total production of only 300 tonnes. New cultivation methods that used trenches and sumps were introduced before the 1980s, but results were limited because the

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trenches were small and the pits were shallow. During the hot, dry season, conflicts between the water requirements for rice and fish could not be solved.

However, recent improvements in the rural-responsibility system, the extension of rice-fish culture technology and the commodity market, and new economic benefits have encouraged farmers to develop rice-fish farming. The units responsible for developing aquatic products advocated, demonstrated, and extended advanced fish-culture technology. These efforts contributed to the rapid development and increased productivity of rice-fish farming in Chongqing (Table 1).

To increase production, a variety of methods were studied and adapted to local conditions of topography, terrain, water quality and temperature, soil, and vegetation. The goal was to enhance the growth of both rice and fish and to achieve bumper harvests of both crops. Gradually, fish culture in ricefields was developed and promoted through demonstrations and extension, and an increased number of farmers adopted the new technology. Farmers started to stock fish rather than depend on natural populations. Ricefields produced multiple, instead of single, crops. The management and administration systems for fisheries were also improved.

## Cultivation Models of Rice-Fish Farming

In rice-fish farming, both rice and fish live in the same body of water and help each other by creating a favourable living environment that meets their physiological needs. Optimum conditions include the correct temperature, proper quality and depth of water, and appropriate nutrients and feed. The methods of cultivation must promote stress resistance.

Chongqing is located in the hills and low mountain areas of Sichun Basin where ricefields are widely distributed and natural conditions vary. Several methods of rice-fish farming have been established to suit local conditions.

**Flat fields (or fish sumps and trenches).** Ricefields with good water resources, irrigation, drainage, and stable water (despite drought or excessive rain) can be used for fish culture. The height of the ricefield dikes is raised to above 0.5 m and reinforced to prevent collapse and leakage. Bamboo screens are installed to prevent the fish from escaping through irrigation and drainage holes, which must be higher than the level of the field. Sumps and trenches are dug before seedlings are transplanted. Usually, ditches are dug around the edge of the field. If the ricefield is larger than 0.07 ha, a cross-shaped ditch should be dug in the middle; if the field is more than 0.3 ha, a ditch in the shape of a double-cross (#) should be dug. In the lower part of the field where the surface is not smooth, 1-m deep trenches are scooped out along the water inlet or the cross. The number of trenches varies according to the size of field. Fish varieties are 70–80% common carp and crucian carp and 20–30% grass carp. The total stocking rate is 3 000–4 500 fry per hectare (using the previous years stock). Production is 150-600 kg of fish per hectare.

Table 1. Area and production of rice-fish farming in Chongqing (1980–1987).

| | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 |
|---|---|---|---|---|---|---|---|---|
| Total fish production (t) | 9 730 | 10 845 | 14 275 | 18 845 | 23 540 | 26 560 | 32 745 | 35 321 |
| Fish production in rice fields (t) | 1 390 | 1 165 | 3 270 | 5 090 | 6 690 | 6 669 | 8 341 | 10 202 |
| Area of rice-fish culture (ha) | 23 200 | 18 470 | 43 600 | 54 600 | 68 730 | 78 200 | 70 530 | 72 800 |
| Average production (kg/ha) | 60 | 63 | 75 | 93 | 97.5 | 85.5 | 118.5 | 139.5 |
| Proportion of the total production of freshwater fish (%) | 13.3 | 10.7 | 22.9 | 27.6 | 28.4 | 25.1 | 25.5 | 29.0 |

**Fish ponds.** Fishponds are dug in the back edge or a secluded spot in the ricefield. The size and number of ponds depend on the size of the field. The bottom of the pond should be at least 1 m lower than the level of the ricefield. A stone wall is built around the pond to prevent it from collapsing. In ricefields of more than 0.1 ha, ditches (70-cm wide and 50-cm deep), should be dug to connect the ponds. Stone breaches between the ponds and ditches hold fish screens and prevent collapse. A 10-cm pipe is sometimes installed in the pond bottom to improve drainage and management. The fish varieties stocked include common carp, crucian carp, and grass carp, in equal proportions. Some silver carp and tilapia are also stocked. From 1982 to 1985, there were 5 880 ha of fishponds in Dazu County, Chongqing, with an average production of 547.5 kg/ha.

Fishponds are used mainly in winter water fields and in deep-mud fields and water-logged fields where rice production is low. The specifications for ditches and banks should be based on the fertility of the field, the farming system, and the rice varieties. The ditch is usually about 80 cm wide. The field is normally not ploughed and the bank is built 7 days before transplanting to a height of 20–25 cm or 30–40 cm. The field should not be drained dry, the banks should be even, and the ditches straight and connected. A small bank is built, and a row of seedlings is transplanted onto this bank. The ridge should be reinforced before the bank is built to prevent fish from escaping. There should be a fish screen in the irrigation and drainage holes and the width of the breach should be according to the size and drainage volume of the field. The time, varieties, and size of the fingerlings should suit local conditions. Common carp or grass carp are the main species, but some tilapia are cultivated later in the year. Production is about 600–750 kg/ha.

**Semiarid plus pond.** This method is suitable for use with semi-late rice. The height of the dike is increased to 0.6–1 m and the dike is strengthened. A ditch for flood drainage and an opening are dug and fish screens are installed. About 5%

of the field is used as a fishpond (1–1.5 m deep). Before the seedlings are transplanted, a ditch (35-cm wide, 25-cm deep) and a bank (25-cm wide) are constructed. When the seedlings have turned green, the natural feed is supplemented with prepared feed and 80 common carp, 80 grass carp, 40 silver carp (6.6-cm fingerlings), crucian carp, and tilapia are stocked. Production can reach 750–2 250 kg/ha.

**Ridge-ditch system.** Ridges and ditches are dug, based on the size of the field, available water resources, sunlight, and wind direction, to bring the edge effect into full play to increase the rice production. Ridges are 1.1-m wide (transplanting five rows of seedlings) or 0.8-m wide (transplanting four rows of seedlings); and ditches are 35 cm wide and 25–35 cm deep. Depending on the size of the field, one or two horizontal ditches are dug to connect all the ditches and improve the flow of water. This increases the volume of water for the fish and improves the capacity of the field to store water. Fish are stocked at 4 500–7 500/ha as 3-cm fingerlings that include 30–40% grass carp, 50–60% common carp, and 10% silver carp. Production is 750–1 500 kg/ha.

**Wide ditch around the field.** A 1-m wide ditch in the shape of a cross is dug around and through the field. Both ridged and flat fields are used. Methods are similar to other systems. Production is 450–750 kg/ha.

**Farming with fish cultivation.** This method is also called the *seven layers production of rice-fish cultivation.* Sugarcane is grown in the ridges of the field and rice is transplanted into the field. Wild rice is planted between the rows of rice, and water chestnuts or water hyacinth are cultivated on the water surface. In the water, fish are cultured in three layers: silver carp in the upper layer, grass carp in the middle layer, and common carp or crucian carp in the bottom. Fisheries engineering is the same as for other methods. This method is based on ecological principles and achieves a balance between plant growth and fish culture and better economic benefits (Table 2).

### Cost-Benefit Analysis of Rice-Fish Farming

Rice-fish farming is an effective way to make full use of ricefield resources and to cultivate freshwater fish. It offers remarkable advantages: it does not require the use of other land and water bodies, it has a short cycle, requires small capitalization, gives fast results and benefits, is easy to manage and uses simple technology. It also fully uses the productive potential of water in the ricefields. A 1984 study of rice-fish farming in Chongqing by the Bureau of Agriculture, Animal Husbandry and Fishery, provided data from 153.4 ha of winter ricefields in four counties near Chongqing (Table 3).

In 1984, the production of fish was 701 kg/ha and rice 7 640 kg/ha. The net income of rice-fish was better than other cultivation industries. Through demonstrations and extension, small areas of rice-fish culture were enlarged into commercial rice-fish farming that incorporated pond cultivation and reservoir fishery. Rice-fish culture has become an important part of the Chongqing fishery.

Table 2. Cost-benefit analysis of combination-growing with fish culture in Yangmingqin, Rong Chang County. Total area 0.12 ha (1985-1987).

| | Rice | | Fish | | Sugarcane | | Wild Rice | | Total Output | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Prod (kg) | Output Value (CNY) | Prod (kg) | Output Value (CNY) | Prod (kg) | Output Value (CNY) | Prod (kg) | Output Value (CNY) | Total Value (CNY) | Output Value (CNY/ha) |
| 1985[a] | 745 | 335 | 290 | 812 | — | — | — | — | 1 147 | 9 558 |
| 1986 | 764 | 382 | 370 | 1 665 | 500 | 100 | — | — | 2 147 | 17 892 |
| 1987 | 870 | 478 | 450 | 2 700 | 600 | 120 | 500 | 200 | 3 498 | 29 125 |

[a]Production prices (Prod) were calculated on the basis of average prices in Chongqing each year.

Table 3. Economic benefits of rice-fish in 153.4 ha of winter ricefields in the Chongqing area (1984).

| Counties | Farms | Area (ha) | Fish Prod (kg/ha) | Rice Prod (kg/ha) | Gross Income (rice+fish) (CNY)[a] | Net Income (rice+fish) (CNY) |
|---|---|---|---|---|---|---|
| Jiangbei | 319 | 38.3 | 691.7 | 7950 | 2675.0 | 1245.0 |
| Jiangjin | 409 | 47.6 | 761.3 | 7869 | 2284.9 | 1370.9 |
| Dazu | 243 | 33.8 | 661.1 | 7875 | 1983.3 | 1190.0 |
| Bishan | 233 | 33.7 | 665.9 | 6855 | 1819.6 | 1091.8 |
| Total | 1 204 | 153.4 | 701.0 | 7637.3 | 2063.9 | 1238.3 |

[a]Prices were calculated on the basis of constant prices of CNY3/kg, CNY0.234/kg for rice, and 60% of output value for net income per hectare.

## Advantages and Limiting Factors

In agriculture, ecological and multiple uses of land should not be overlooked. Rice-fish cultivation can improve the ecological environment of the field, while providing economic benefits. It makes good use of water resources in the ricefield, decreases competitors in the waters, makes reasonable use of fertilizer and sunlight, and improves the fertility and permeability of soil. It can also inhibit or eliminate weeds in the field. Rice diseases and insect pests are reduced and fish wastes are a good manure. Extensive rice-fish cultivation helps prevent floods, increases the resistance of the rice plant to drought and strengthens the regenerative ability of the ecological system.

In over a decade, the rapid development and multiple cultivation models of rice-fish farming have also provided direct benefits to Chongqing:

- A suitable natural environment — There are 460,000 ha of ricefields in Chongqing and about 40% of these can be used for fish culture. Because Chongqing is the main city on the upper Yangtze River, there is a growing demand for aquatic products.
- Productive technology — Chongqing now has several production units in aquatic science and technology and in fisheries who are working to develop rice-fish farming.
- Enthusiasm of leaders and farmers — Rice-fish farming is an aquacultural development project of national importance. Because bumper harvests in both rice and fish have increased the income of farmers and stimulated the rural economy, rice-fish farming now appeals to farmers.

Several factors limit rice-fish culture: naturally occurring floods and droughts and environmental conditions such as terrain and water temperature and quality. Anthropogenic factors also limit rice-fish farming: lack of fry and fingerlings, the need to popularize science and technology through extension, and the difficulty of changing traditional production methods.

# Development of Rice–Fish Farming in Jiangsu Province

*Xu Guozhen*[18]

Jiangsu Province is located along the coast of the Yellow Sea and is situated in the lower reaches of the Yangtze and Huai He rivers. Its mild climate and abundant rainfall make this region ideal for growing rice and fish. Jiangsu Province has 2.4 million ha of land for rice cultivation and about 670 000 ha of water surface for fish production, which makes it one of the important rice and fish producers in China. There have been substantial developments in rice–fish farming in Jiangsu Province and farmers are becoming more familiar with the new practices.

## Current Situation

Since 1982, rural economic reforms have spread and the industrial structure has been readjusted. Rice–fish farming in Jiangsu Province grew rapidly during this period. In 1983, the area for rice–fish culture was 1 000 ha; by 1987, 13 000 ha of ricefields were devoted to fish farming. The practice was adopted mostly in the Lixiahe region in North Jiangsu and in the hilly country in the centre of South Jiangsu.

Most farmers incorporated fish farming with midseason or hybrid rice; a few rotated rice and fish or cultivated them in succession. Farmers also developed their own ways of raising fish to suit the local conditions, topography, traditions, and fish species. These included digging fixed fish pits, connecting ricefields to outfield ditches and ponds, polyculturing different species, breeding summer fry in ricefields, and cultivating rice with fish and freshwater mussel.

The extension of new farming techniques brought vitality to the development of rice–fish farming in the whole province and upgraded the level of intensive farming. The average yield of fresh fish increased from 150 kg/ha in 1984 to 300 kg/ha in 1987. Yields were even higher in some areas. In 1985, 190 ha of ricefields produced 750 kg of fish per hectare; whereas, in 1986, a similar demonstration area of 270 ha produced the same yield of fish.

In 1987, high production demonstration farms were established in Funin, Jianhu, and Hai'an counties. Each farm was 670 ha and produced an average fish yield of 705 kg/ha. From 1984 to 1987, the area for rice–fish culture in the province rose to 40 000 ha with a total commercial fish yield of 1 630 tonnes, plus a fry yield of 6 140 tonnes that could be used to produce 2 400 tonnes of commercial fish. The total value of fish production was over CNY100 million.

[18] Bureau of Aquatic Products, Nanjing, Jiangsu Province.

However, in comparison with other provinces, rice-fish farming in Jiangsu has developed slowly. The area for rice-fish culture decreased from about 13 000 ha in 1987 to 6 000 ha in 1988. The main reasons for this decrease were:

- The high-yielding techniques for rice-fish farming were not adequately extended or widely adopted, which resulted in poor management. In rice-fish farming, extra care is needed in pesticide application and drying of the ricefield because these can adversely affect fish growth. Other factors that can affect rice growth must also be considered carefully: fish species, fish size, size of water body, and the type of ditches and pits. However, in practice, some farmers found it hard to change their cultivation traditions, found themselves short of labour at the time of planting and harvesting, or did not take sufficient care. Because of poor management, high-yielding techniques could not be fully applied and this reduced unit yield.
- The actual recovery rate was low. At present, the mechanization level in grain production is low and irrigation facilities in many areas are poor. In addition, under the current household-management system, management of a piece of land often involves several households. This creates difficulties and weakens the ability of the farmers to deal with natural disasters such as drought or flood. From 1984 to 1987 only 67–70% of the rice-fish farming areas were harvested.
- Production and extension services were not well organized and there was a lack of channels to provide farmers with inputs such as fry and chemical fertilizers. Some farmers could not sell their fry, which were produced too early to be used to stock ponds and reservoirs. Furthermore, because reproduction quantity and output value were low, benefits from fish farming were not significant. At the current yield level of 300-375 kg/ha, unit income is CNY1 200-1 500/ha. A farmer household normally only has up to 0.7 ha for fish farming, which would yield only a few hundred yuan. This is not attractive, particularly in regions where there are many other economic options.

## Ways to Further Develop Rice-Fish Farming

### Introduce Appropriate-Scale Management

Economic benefits from rice-fish farming should be improved. Because the rural economy is developing rapidly, employment opportunities are increasing and some farmers opt to leave their land for other undertakings. Improved productivity allows other farmers to farm larger areas and to produce much more grain. This new kind of farmer provides the basis for larger-scale management and makes it possible for farmers to make long-term plans. This, in, turn enhances their ability to cope with nature-induced difficulties and to mass-produce products, which improves the supply to city markets. Appropriate-scale management is conducive to specialization and commercialization in the rural economy, brings economic benefits to farmers, can lead to ecological benefits by improving soil fertility, and can help reduce pesticide application and pollution.

There are two types of management in fish farming. In one type, specialized households or individuals raise fish, while individual households plant rice. In this case, specialized fish-raisers take care of water management and fish farming, while other farmers plant and manage rice. The fish pits and ditches are dug by the rice-planters. A village committee takes charge of the general production arrangement. The income from fish farming is distributed among the fish-raisers, the rice-planters, and the committee in the proportion of 7:2:1. This system makes management easy, allows for a large area (10–30 ha) for raising fish, and provides satisfactory benefits to those concerned. A specialized fish-raiser can earn several thousand yuan each year.

The second type of management concentrates fish farming and rice growing in a single household and depends on available labour, mechanization level, and the farmland arrangement of the household. Generally, the farms cannot be too big (about 2 ha per household). About 10 tonnes of grain and CNY2 000 from fish farming can be produced each year.

### Improve Production Conditions and Facilities

Adequate construction work and facilities are essential not only for fish survival in ricefields but for bumper harvests of fish and rice. Given the precondition of not affecting rice yields, the better the construction work, the higher the fish production. With good construction, conditions it is also easier to resolve the contradictions between rice growing and fish farming and to tackle natural difficulties.

Various types of constructions are made for fish farming in different rice-farming systems. In high-yielding areas of Jiangsu Province, several practices are adopted:

- Farmland is rearranged to expand the fish-farming water surface and increase fish-carrying capacity while trying to reduce the area for fish ditches and pits. This can be done by combining in-field with out-field construction. For example, in-field fish ditches can be connected to out-field water inlet–outlet ditches, natural pits, and ditches beside roads and tractor paths. To better use in-field ditches, multiple uses can be made of ditches and pits in rice and wheat fields.
- Appropriate pits and ditches are made in ricefields. These pits and ditches should be simple in form and relatively close to each other. The surface proportions of the pits and ditches are 7:3 or 6:4 and the pits are 1.2–1.5 m deep; the ditches 0.45–0.06 m deep. This increases the size of the water body and its fish-carrying capacity. Normally, pit and ditch surfaces occupy 10% of the ricefield.

- Fish pits and major ditches are dug in a single operation before rice is planted. The advantages are: much of the work can be done during slack seasons in connection with other projects such as irrigation system construction, road construction, and house building. This not only saves labour, but also reduces labour shortages during the busy season. Furthermore, these larger pits can be used for early season fry and late season fish.

**Adopt Comprehensive Measures to Prevent Escape of Fish**

The key to better economic benefits from rice-fish farming is to increase the actual catching rate. Fish escape in several ways: because of floods and overflow of water, through damaged or poorly placed fish screens, and through holes dug by rats and eels.

To prevent fish from escaping: dikes should be high enough to keep fish-farming fields from flooding, ricefields should be well equipped with irrigation and drainage facilities, fish screens should be firm and durable and be placed appropriately in water exits and entrances, field ridges should be 0.4–0.6 m high and not leak, and strict management should be practiced to ensure that prompt action can be taken when problems arise.

**Adopt Intensive Farming Measures**

Technical guidelines for high-yielding rice-fish farming need to be developed and promoted using some of the experiences gained from pond-fish rearing:

- Fish species adapted to the specific needs of different areas must be selected and used. In Jiangsu, several options could be considered. Farmers with large areas of water and large numbers of fingerlings can: mainly breed fingerlings of grass carp and common carp, and aim for a fingerling yield of 600 kg/ha; or mainly breed fingerlings of grass carp and common carp, plus 1-year-old fingerlings of a fast-growing species (e.g., tilapia or hybrid common carp). The target yield for fingerling and commercial fish is 750 kg/ha. When the area for fish breeding is small, when breeding is for producing commercial fish, or when there is no temporary pond for fingerlings, farmers can: mainly breed *Megalobrama amblycephala*, plus a small number of fingerlings (yield could reach 750 kg/ha); or mainly breed mature carp with a target yield of 750 kg/ha. Fish growth should be enhanced with supplemental feeding. To gain better results, additional weeds, duckweed, and commercial feed are needed to improve fish growth. Frequent water renewal is also needed to improve water quality, particularly after land baking and pesticide application, when the water body for fish is small, and when organic matter content is high. The added water increases oxygen, improves feed consumption, and reduces the concentration of pesticides. Daily field monitoring is also needed to raise the survival rate by preventing problems such as pollution, and loss of fish by escape, theft, of attacks by natural enemies.

- Increase the number of species that are raised. Currently, only commonly bred fish species are raised in ricefields, although some farmers are exploring ways of breeding specialty aquacultural products such as clams, shrimp, and mandarin fish. These measures may help improve economic results; however, the farming techniques must still be developed and are experimental.

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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.

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[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.

# Value of the Rice–Fish Production in High-Yielding Areas of Yuyao City, Zhejiang Province

*Cao Zenghao*[20]

In Yuyao City, Zhejiang Province, rice–fish farming was developed in the 1950s at scientific institutions, state farms, and some fishery villages. However, because of changes in production relations and farming systems, rice–fish farming soon stagnated. In 1978, it was revived.

Experience has shown that integrated rice–fish production offers economic, social, and ecological benefits. It has become an important way to increase the income of grain-producing households, diversify single-product economies in rural areas, and supply animal protein to improve the nutrition of the people. There are new problems. Rice–fish farming is limited in high-yielding ricefields where labour is limited, where arable land is limited and highly productive, where there are a large number of households that work the land part-time, and where township enterprises are well-developed. However, these contradictions can be mitigated by research and field trials to develop rice–fish farming techniques to produce high yields of rice and fish.

## Benefits of Rice–Fish Culture

Recent multilocation trials, demonstrations, and extension efforts in Yuyao City have shown that major benefits can be derived from integrated rice–fish production systems.

### Efficient Use of Natural Resources

Yuyao City in the southeast coast (29.39°N, 120°E) has an accumulated temperature of 5073°C, 210 frost-free days, and abundant precipitation and sunlight. It is a high-yielding area that produces a double crop of rice (10–11 tonnes/ha of early and late rice). These temperature, sunlight, and meteorological conditions are also suited to fish culture. In a 1986 study of 107 lowland rice-farming households in Changlou township, fish were cultured in 21.1 ha of ricefields. The output was 6 400 kg/ha of early rice and 5 260 kg/ha of late rice, which was the same output produced in ricefields without fish culture. Adult fish were cultured in 6 ha with an output of 926 kg/ha. Production reached 11 250 kg of rice and 750 kg of fish per hectare, and the value of the output was doubled. Another 15.1 ha were used to produce 499 kg of fingerlings per hectare.

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[20] Yuyao Aquatic Product Bureau, Yuyao City, Zhejiang Province.

Farmer Yang Tiexian dug ditches in 11% of his 0.18-ha ricefield to breed 120 grass carp, 1 000 bream, 750 crucian carp, and 5 000 adult carp in early spring. By 10-15 October, he harvested 703 kg (3 905 kg/ha) of rice and 100 kg (558 kg/ha) of fish. His experiments were verified by researchers from both Ningbo and Yuyao.

This example illustrates that pits and ditches for fish culture can enhance the growing environment for both rice and fish and can increase economic efficiency. Organic matter in the water (e.g., plankton, benthos, insects, weeds, and organisms harmful to rice) serve as fish food. The movements of the fish stir the water and loosen the soil to improve oxygenation and soil fertility. Fish feces are quality organic manure for rice.

### Intensification of Agriculture

Farmers in Yuyao City only have about 0.05 ha of ricefields each. The multiple-cropping index has reached 240% and the population continues to grow rapidly. The amount of arable land limits agricultural production. For this reason, agricultural production must be diversified and farming must be intensified to obtain maximum economic, social, and ecological benefits. Rice-fish farming is an effective way to increase productivity when farmland is limited.

Farmer Jin Wanshun and his family contracted 1 ha of ricefields. Since 1984, he has managed this farm using an integrated method that includes growing rice, fish, fruit, and vegetables. In 1987, he implemented the rice-fish system and planting grapes and vegetables on the ridges of 0.7 ha of ricefields. He harvested 12 335 kg/ha of rice and 1 061 kg/ha of fish. His family sold 5 200 kg of commodity grains, 440 kg of live fish, and 150 kg of fingerlings. Calculated on the basis of local prices, his family earned CNY2 514 from rice, CNY3 305 from fish, CNY1 000 from melons and vegetables, and CNY4 000 from household sideline products. Of the total income of CNY10 500, rice-fish farming contributed 30% to total income and 46% of agricultural income.

Integrated rice-fish production plays an important role in the development of a diversified economy. Its economic benefits are double those obtained in monoculture under the same conditions.

### Creation of a Favourable Ecological Environment

At present, increased crop yields depend on the application of a large amount of fertilizer. These fertilizers have increased energy consumption and production costs and polluted the environment. In the rice-azolla-fish ecosystem, azolla is a fertilizer and food for the fish. Fish eat insects and weeds, and their feces fertilize the rice plants. This reduces the need to apply chemicals because pests and diseases are minimized and soil fertility is improved.

In Chang Feng Township in 1985, farmer Chen Bingcan and his family contracted 2.3 ha of farmland. They used the rice-fish system and grew rice with azolla in the spring and fish in the summer and autumn. After 3 years, soil fertility had greatly improved. The Institute of Soil and Fertilizer, Zhejiang Academy of Agricultural Sciences, determined that the organic matter content of the soil had increased from 2.9% to 3.3% and that the nitrogen content had risen from 0.2% to 0.3%. Pest damage was also reduced, and weeds had been reduced by 56 times. There were only 27 weeds/m$^2$ in the ricefield with fish and 1 521 weeds/m$^2$ in the field without fish. Sheath blight had declined from 47% to 33%. Rice seedlings were transplanted into untilled ricefields, which meant that plowing and weeding were not necessary. The application of fertilizer and agricultural chemicals was reduced by 40%, which lowered production costs and increased income.

A 1987 survey showed that a 1.7-ha ricefield that used the rice–fish integrated production system yielded 2 860 kg of hybrid rice seed, 1 560 kg of rice grain, and 2 860 kg of live fish. The income was CNY6 240/ha, or CNY3 820/ha more than the CNY2 420/ha that was obtained from planting rice alone in a 0.4-ha ricefield.

## Limiting Factors

Although Yuyao City has favourable temperature, sufficient sunlight, and 2 915 ha of ricefields for rice–fish farming, there are also limiting factors.

### Scattered Plots and Extensive Cultivation

Since the implementation of the production responsibility system, most farmers have only have about 0.2–0.3 ha of arable land. Many have left their farms to work in township enterprises. The resulting labour shortage has limited the development of rice–fish production systems.

### Limitation of Traditional Cropping Systems

There are contradictions between the management techniques for the traditional rice-cropping pattern and the rice–fish pattern. For example, when the close planting pattern (12.5 cm x 12.5 cm x 12.5 cm x 10 cm) is adopted for transplanted rice, toxic chemicals are applied to prevent pests and diseases and the field is frequently idle. These chemicals limit rice–fish farming.

### Lack of Knowledge of Fish-Culture Techniques

Farmers are experienced in rice farming but lack knowledge about fish culture. Techniques for breeding fish in ricefields have been developed in recent years, but farmers need more technical guidance as well as an effective service system and administration. The supply of fish fry and fingerlings are insufficient. These factors have constrained the development of the rice–fish production system.

## Future Needs

### Identification of Development Priorities

To boost the commodity economy in the countryside and to improve its efficiency and benefits, arable land must be gradually centralized by big rice-grain producers in rural areas. This centralization should be followed by extension information about rice-fish production systems.

### Strengthen Research

The rice-fish production system lacks a model and must be standardized to be easily adopted by farmers in rice-growing areas. Rice-fish farming techniques should be disseminated through technical training, demonstrations, and on-farm visits.

### Improve Engineering Facilities

Rice-fish farming facilities must be altered to enhance the symbiotic environment. Scattered and shallow trenches should be converted to centralized and deep trenches that make up 6-8% of the total area of the ricefield. The growth of both rice and fish should be promoted by providing a habitat for fish migration and by changing from square close planting to wide-row close planting. These changes will alleviate the contradictions between fertilizer application, water irrigation, plowing, transplanting, and pest control.

### Enhance Cooperation and Service

The rice-fish integrated production system is multidisciplinary and combines agronomy with the aquatic products industry. To develop fish farming in ricefields, farmers must be provided with an adequate supply of fish fry and fingerlings, marketing information, and an effective fishery administration to ensure production safety.

# Developing Rice–Fish Culture in Shallow Waters of Lakes

*Wan Qianlin, Li Kangmin, Li Peizhen, Gu Huiying, and Zhou Xin*[21]

Per-unit fish output from lakes, especially large ones, is low in China. Rice–fish culture increases the yields of both fish and rice; therefore, the potential exists to invigorate inland fisheries and to increase rice production. Deepwater rice is adaptable to different water depths and is a stable and natural adjusting and controlling factor that could help solve the difficult problems involved in the establishment of large-scale ecological agriculture. Deepwater rice might also prevent the proliferation of blue algae in East Taihu Lake and lessen the impact of water pollution and eutrophication caused by population growth and urban and rural development. Deepwater rice is usually grown in areas that hold water during floods. Deepwater rice is a major crop in Southeast Asia, but few data are available on deepwater rice–fish culture in lakes. The feasibility of deepwater rice–fish culture was studied to observe the growth of deepwater rice in deep ponds and in shallow lakes and to determine which species of fish might be suitable.

## Experiments with Deepwater Rice

### Deepwater Rice

Twenty-three varieties of deepwater rice (including two varieties of floating rice) developed by the International Rice Research Institute (IRRI) and quarantined in the Philippines were studied. Seeds were dried in the sun, soaked, and germinated on 18 May 1987. Seedlings were transplanted on 18 June, three to a hill, 25 cm apart and in rows that were 25 cm apart (variety no. 1 was planted two to a hill). Some of the seedlings were transplanted to a 60-m$^2$ area in Huayuan Lake that was 10–40 m in depth. On 12 July, the water in the lake rose sharply by 1 m in 12 h, which submerged the rice plants. The water remained at that level for so long that all the rice plants drowned.

### Fish

Five days after the seedlings were transplanted, 3 200 crossbred fingerlings were released into a 0.07-ha experimental plot. The fingerlings were bred by the Freshwater Fisheries Research Centre of the Chinese Academy of Aquatic Products. There were 1 000 crosses between *Cyprinus carpio* Wuyuanensis and *C. carpio* Yuankiang (averaging 2 cm in length) and between *Oreochromis aurea* and *O. niloticus* (averaging 1–2 cm in length). As well, crucian carp (crosses

[21] Freshwater Fisheries Research Centre, Chinese Academy of Fisheries Science, Wuxi, Jiangsu Province.

between *Carassius auratus* Gibelio (Bloch) and *Carassius curierit*, (averaging 4 cm in length) came from the Wuxi Aquatic Products Breeding Farm in Jiangsu Province. The fish were caught on 6–7 November. The length and weight of some of the fish were recorded. Others were released into an aluminum tub (without feed or changes in water) to test their physical ability to withstand adversity.

**Experimental Sites**

Experiments were conducted simultaneously in Wuxi and in Anhui Province. In Wuxi, deep open pits were rebuilt with clay into two experimental plots (pH 8). An adjacent stream served as the water source. One plot was 0.07 ha; the other 0.03 ha. Each could hold water more than 1-m deep. Before the rice seedlings were transplanted, one pit was pumped dry, and 1 000 kg of mud were removed and spread on the bottom of the experimental plot to increase fertility and stabilize the plants. Then 735 kg of barnyard manure (496 kg pig dung and 240 kg poultry dung) were added as base manure. After the seedlings were transplanted, 5 kg of urea were applied as manure to stimulate the rice seedlings to turn green and another 5 kg of urea, 3 kg of calcium superphosphate, and 5 kg of plant ashes were added as manure to stimulate booting. Before the autumn equinox, 50 kg of lime were spread to prevent and control fish diseases. Later, 60 ml of 25% sumithion dissolved in 60 L of water were sprayed to control stem borer, and 25 g of 50% thiophnate were applied to control green smut.

It was difficult to raise the water level steadily, but water depth and temperature were recorded daily, and the heights of 10 rice plants for each rice variety were measured at random every 10 days. The degree days during the initial booting stage for 10 varieties and the degree days during the earing stage for two mature varieties were determined from the mean daily temperature readings issued by the Wuxi City Weather Station.

On 5 November, before the harvest, varieties 1 and 2 ripened and birds began to eat the ears of rice. Twelve sample plants were collected at random to record effective tillering. The 1 000-kernel weight and the length of each ear were recorded for every 20 ears. The earing of each variety was closely scrutinized to avoid underreporting. Plants were sampled randomly to measure the distribution of the degree of earing. The Huayuan Lake experimental zone in Anhui is situated where Fengyang, Jiashan, and Wuhe counties cross on the southern bank of the lower reaches of the Huai He River. The surface of the lake is 4 000–8 000 ha, the area where water rises and falls covers more then 1 000 ha, and the depth of water is 1.6–4.9 m. Mean annual water temperature is 17.2°C; during May–September the water temperature is 18–30°C. Mean air temperature is 14.9°C and there are 212 frost-free days. The shallow areas of the lake are broad, with a slope of about 1:20, and the lake is rich in humic substances.

## Results

### Growth of Fish

A total of 1 264 fish were caught (average 300 kg/ha), and the overall survival rate was 39%.

**Common carp** ***(Cyprinus carpio).*** The first catch netted 246 fish weighing a total of 2.89 kg, with a survival rate of 24.6%. Body length ranged from 6.9 to 23 cm (a difference of more than three times) and weight ranged from 6.5 to 264 g (a difference of 40.6 times). The fish seemed physically strong; 30–40 days into the experiment, and they were still active.

**Crucian carp** ***(Carassius carassius).*** The first catch netted 682 fish weighing a total of 9.23 kg. Survival rate was 56%. Body length was 9.5–12.4 cm, and weight 10–24 g. The average weight ranged from 12 g to 15.3 g. Growth was uniform, and the fish were strong and healthy, except those grown without rice in the 0.03-ha pond. The smallest and the largest fish withstood adversity-resistance tests for 43 days and still swam actively (water temperature was 7.3°C).

**Tilapia (*****Oreochromis*** **spp.).** The first catch netted 336 fish weighing a total of 7.85 kg. Survival rate was 33.6%. Body length was 9.8–12 cm and weight 14–28 g (70% were 10–11 cm in body length and 19.5–23.5 g in weight). Length growth was uniform, but because of infertility of the water, body weights were not uniform. The weight difference among those with 9-cm bodies was as much as 6 g; among those with 11.4–11.5-cm bodies, the difference was as much as 4.5 g. Some fish measured 9.5 cm in body length, but weighed only 23.5 g; others measured 9 cm in body length, but weighed 28 g.

### Ripening of the Deepwater Rice

Two varieties ripened and bore fruit: IR40992-1-3-2-1-1-2 865020 (no. 1) and IR40992-1-3-2-1-3-3 865022 (no. 2). Their productive properties are shown in Table 1. Part of the grains of variety IR41125-7-3-2-2-3-3 865026 (no. 3) were at the milk stage and one-third of the plants showed a 100% heading rate. The varieties that approached the milk stage were IR23426-RR (no. 22) and IR41132-R-27-1-1 (no. 4). No. 22 was 50% better than no. 4 in terms of heading, and one-third reached the late heading period (>80%). No. 4 only approached the middle and late heading period. Eleven other varieties showed heads, but not on all plants. The other varieties either just entered the heading stage (e.g., no. 13, 7, and 9) or showed heads, which disappeared before the harvest (e.g., no. 14 and 20).

The height of 23 varieties (1.4–2.1 m) exceeded previous records. Water depth in the experimental ponds was usually 40–60 cm, but exceeded 60 cm for one-fourth to one-third of the days. Booting and earing occurred when the water was 65–80 cm deep. Seven varieties grew in water more than 2-m deep and only no. 15 did not show heads. Two varieties grew in water less than 1.5 m and all showed heads.

Table 1. Productive properties of two varieties of mature deepwater rice.[a]

| Productive Property | Variety No. 1 | Variety No. 2 |
|---|---|---|
| Effective tillering (no./plant) | 4.9 | 3.9 |
| Number of plants/ha | 288 720 | 432 720 |
| Plant height (cm) | 180 | 185 |
| Number of ears/ha | 1 423 380 | 1 674 630 |
| Length of ears (cm) | 24.7 | 28.7 |
| Number of grains/ear | 154.4 | 196.8 |
| Fertility (%) | 65 | 65 |
| 1 000-kernel weight (g) | 26.0 | 26.3 |
| Estimated output (kg/ha) | 3 689 | 5 625 |

[a] Plant and row spacing = 25 cm. For variety no. 1, two plants were planted per hill; for variety no. 2, three plants were planted per hill. Fishways occupied 10% of the surface area of the water.

In either case, the highest and the lowest, there were varieties that showed heads in large tracts: no. 4 plant was 2.0-m high, and no. 22 was 1.4-m high. The stage of heading in the 1.8-m high mature varieties varied: some of the plants of variety no. 3 were in the milk stage, no. 9 and 7 showed heads to varying degrees, and two varieties did not show heads. Ears in floating varieties (no. 8 and 17), which were 1.9-m and 1.7-m high, respectively, were rare.

## Prevention and Control of Pests

Fish, rice, frogs, and spiders lived together in the ponds. The experiment explored ways of combining the use of pesticides with biological methods of pest control.

**Pests.** Rice plants infested by stem borer had the symptom of white ears. Although road lamps on the side of the ponds attracted some borers, it was difficult to kill all of them. Where the stem borer invaded, the ear stem was higher than the water surface. The depth of water (≥50–60 cm during the earing stage) was far from being completely used by the fish. Furthermore, pesticides were not very effective. It is advisable to apply pesticides before stem borers invade the ear stem.

**Plant disease.** Green smut infested the rice in spots, often on ripened rice, but the spread was limited.

**Birds.** There were no ricefields around the experimental plots and flocks of birds were spotted only in nearby woods. No birds were seen feeding on the rice during the ripening stage until three short-grained rice plants on the edge of the plot were eaten off.

### Growth of Deepwater Rice

Growth and survival rates of rice in Huayan Lake in water 10-cm deep were better than in water over 25-cm deep. Seedling growth was not apparent during the first few days after transplanting. New shoots were not visible until a week later; then growth was 1.0–1.5 cm/day and, after the tenth day, about 2 cm/day. When the rice plants had grown to 45 cm, they were already submerged in water. Seedlings 3 cm above the water survived and grew well if the water did not submerge a third or half of the plant. Twelve hours after transplanting, one or two new roots were visible; these proliferated after a week. Although the seedlings were placed in a dry place for more than 30 h before transplanting, survival rate was 85%.

## Discussion

Of the 23 varieties improved by IRRI, only seven (30.4%) showed unripened ears and 16 (69.6%) showed apparent heading. Except for a few which showed booting, most had more than 50% of heads showing. The booting stage of 10 varieties lasted 39 days (21 August - 29 September). During the 32 days starting from 28 August, full heading was seen in some plants and large tracts of heads were seen in some varieties. But from 29 August to 3 September, only varieties no. 1 and 2 showed mature heads (hard doughed ears). The booting stage for no. 22, 3, and 4, which showed no milking or did not fully mature (hollow or immature ears), started in mid- and late-September. This was related to the low temperature (<20°C) at the time. Varieties no. 7 and 14 entered the booting stage a week earlier than no. 1 and 2, but mature ears were rare and heads were found on less than 80% of the plants. This may have been caused by high temperatures (>35°C) for 3 days in mid-August, which affected follow-up growth.

In other immature varieties, analysis of the distribution of the number of heads showing revealed that some were affected by degree days. For example, varieties no. 9, 7, 13, and 3 showed a large difference in degree days, with the range of difference decreasing from large to small (81%, 76%, and 39%). The plants needed more degree days. Some had immature ears. Variety no. 6 had a head showing of 65–97%; whereas, no. 22 had 53–86%. Variety no. 22 entered the booting stage 10 days later than no. 6, but it was able to reach the earing stage in large expanses and mature more quickly than no. 6. The booting period does not necessarily determine the maturity of ears. Varieties 6 and 13 entered the booting stage on the same day, but the head showing of no. 13 was no more than 39%, which was lower than the lowest (65%) of no. 6. If no. 6 had been transplanted earlier, it might have shown the same general maturity as no. 2.

### Pool Experiment

On 1 July, 12 days after transplanting, and when the plants were less than 50-cm high, the water rose nearly 30 cm in one week. After that, the water level rose and fell alternately until 1 August when it was nearly 60-cm deep on two occasions. It dropped to about 40 cm 43 days after transplanting, and most plants were more than 100-cm high. Therefore, the plants could withstand the water when it rose later to more than 60 cm. During this period of nearly one month, plant growth experienced two cycles, one from fast to slow (50–60 days after transplanting and at 70–80 days), the other from slow to fast (60–70 days after transplanting and at 80–90 days), that corresponded to the rise and fall of the water level. This shows that the water level had some impact on the growth of the rice plants. When a plant is about 50-cm high, it can resist submergence; as the water rises, the plant is able to continue to grow. Before Huayuan Lake was flooded, the plants were 45-cm tall and had already acquired the ability to survive submergence. However, if the water had risen too fast and too high, the plants would have died. They would not have been able to grow quickly enough to rise with the water level.

The deepwater-rice seedlings showed new roots less than 12 h after transplanting. It may be possible to replace transplanting with a new planting method that exploits the rapid root development of seedlings. When the seedlings turned green, the root system began to proliferate. After 10 days, plant growth doubled. The fertile soil in the lake, the density of transplanted seedlings and their accelerated growth during the later stages, built up their capacity to resist flooding. Because the water was shallow, the plants could have drooped as they grew taller, but they withstood the sharp rise in flood water without damage. However, it is important to prevent the plants from being submerged until they have grown tall. A certain time is needed between the growth of the rice plants and flooding.

Although the common carp grew unevenly, those in the experimental plots had reached a fairly high level of growth. In the comparative ponds where fish grew in a natural environment, maximum weight was 169 g, with 19 cm body length and 23 cm total length. The corresponding common carp (18.5 cm, 22.6 cm) grown in experimental plots with deepwater rice, weighed 191 g. The largest was 264 g, with 23-cm body length and 27 cm head-to-tail length. There were apparent differences between the least-developed common carp in the two ponds (5.7-cm in body length and 6.8–8.0 cm in head-to-tail length). Before the fish were caught, living organisms (144/$m^2$) at the bottom of the lake were collected (weight 96.2 g). These included annelids, mosquito larvae and silk earthworms, and tulip shells (data collected by Mr Chen Wenhai). Because rice was planted, the bottom organisms had a rich supply of food. But because the pond leaked, water had to be constantly replenished, which reduced the level of fertilization. This change corresponded to good growth of bottom-living common carp and crucian cap, and poor growth of tilapia.

Rice planted in a shallow lake increases the productive surface area, oxygen, and food. These factors promote the growth of common carp. Because the volume of water is greater than in rice paddies, it is suitable for raising marketable common carp. Crossbred crucian carp, like the silver crucian carp in Northeast China, are large (up to 3 kg each), and when combined with the planting of deepwater rice, will help raise the harvest. The planting of deepwater rice will help create conditions that will turn lakes into highly efficient fishery bases for a variety of fish species. The shallow waters of lakes provided good fertility, temperature, and sunshine. The open expanses of water are deep and can hold large numbers of fish. The development of such resources will help increase fish harvests from lakes.

It is not possible to establish truly comparative conditions in the experimental ponds; therefore, data are lacking to substantiate the benefits of growing rice and fish together. The experimental ponds contained more water and received 2–3.4 times more fingerlings than flooded ricefields. The depth of water could not be kept at 60 cm, and therefore the volume of water per fish was lower than in the flooded ricefields. Per-unit output remained at about 20 kg, the same level of production as fish culture in flooded ricefields. Furthermore, the fingerlings were released late, they were small in size (the survival rate of winter fish may be higher), and water quality was poor. The fish were not fed in July–August, their peak growing season. The water levels changed quickly and there were potential natural enemies. All these factors limited the fish catch and the benefits from rice–fish cultivation.

## Conclusion

Two of the deepwater rice varieties developed by IRRI grew to maturity in the catchment area of the Yangtze River in the Taihu Lake area. Rice–fish culture in this area produced 3 750 kg/ha of rice and 350 kg/ha of fish, which indicates there are prospects for developing rice–fish culture in the shallow waters of lakes. Although per-unit fish catch in the laboratory was the same as in ricefields, the fish were strong, and the crucian carp were uniform in size. Common carp were not uniform in size, but improved fertility at the lake bottom might produce common carp of a higher quality. The short-term trial production of rice–fish culture in the shallow waters of Huayuan Lake shows that the growth of rice plants and the proliferation of new roots is as good as in flooded ricefields. Despite incomplete results, the comparison of rice and fish production in both enclosed ponds and lake shallows suggests that rice–fish culture is feasible in shallow areas of lakes.

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# Part II:

# Patterns and Technology

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# Different Methods of Rice–Fish Farming

*Nie Dashu and Wang Jianguo*[22]

Many methods of rice–fish farming have been developed in China. Although they involve various production systems, these different methods are inseparable and interlinked. The common aim is to boost rice production by eliminating weeds and pests. Many different types of rotation are practiced.

## Rice–Fish Mutualism

Early, middle, and late rice are planted continuously without interruption. Two kinds of fry (fingerlings and summer fry) are released directly into the flooded ricefields. Specific practices include raising fingerlings in flooded ricefields, raising fish in ricefields and in nearby ponds, planting rice on the ridges while raising fish in the furrows, and raising fish in ricefields in which channels have been dug.

### Breeding Fry in Ricefields

To reduce the cost of summer fry, a model has been devised that involves releasing fry directly into early flooded ricefields. Grass carp (*Ctenopharyngodon idella*) fry are generally used, and because feed is not needed, the method is economical.

After middle rice is planted, 1 000 fry, 3.3–5 cm in length, can be harvested from the early ricefields. Because costs are kept to a minimum, it is easy to popularize the method in areas with large expanses of water. The early rice planting season (late April) in Hunan, Jiangxi, Anhui, Jiangsu, and Zhejiang coincides with the production of common carp (*Cyprinus carpio*) fry. Therefore, after the rice seedlings have been transplanted, the ditches dug, and the screens installed, *C. carpio* fry can be released into the ricefield. The fry are too small to uproot the seedlings and because this is the peak period for plankton, fry growth is enhanced. It is best to release the fry as early as possible to take full advantage of this peak in plankton growth. If the artificial hatching of fry is delayed, the application of base manure and the transplanting of early rice should also be delayed to maximize the mutual benefits that can be achieved.

At present, large fish-fry breeding farms have advanced the season of fry hatching to late April and the rice growers on these farms delay the transplanting of rice seedlings. But the practice has not gained much popularity. Additional effort is needed to disseminate the idea and launch demonstration projects. For every

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hectare of ricefield, 45 000 artificially hatched fry are needed. Along the Yangtze and Zhujiang Rivers, where people catch river fry, it is better to put these fry into early ricefields because it makes it easier to regenerate fish of the same family. Stocking fry, which have just begun to eat, into early ricefields 3–4 days after the rice is transplanted offers many advantages. It eliminates the need to buy summer fry, means that ponds are not needed for summer fry, and maximizes the mutual benefits of growing rice and fish together. It is an economical, practical method that yields better and faster results.

*Ctenopharyngodon idella*, with its ability to eliminate weeds and worms, can help increase rice output and reduce the need for labour. However, in areas with few ponds or banks, other fish species *(e.g., C. carpio*, crucian carp, and tilapia) can be raised. Even in ricefields overgrown with weeds, it is feasible to grow *C. idella* along with some *C. carpio* and *C. auratus*.

When this method is adopted, the banks of the fields must be raised 50–70 cm and strengthened before the fry are released into the field. Lime is applied (375–750 kg/ha) to kill leeches, eels, and other natural enemies of the fish. Six to eight days later, water is channelled into the field and base manure is applied. The field is raked level, and the rice seedlings are transplanted. Fish canals and ditches (30 cm wide and 30 cm deep). Where the canals cross, a fish ditch 100 cm long, 70 cm wide, and 80–100 cm deep is dug. Rice seedlings in the canals should be transplanted to the edges of the field to from a fence. Screens, each 100 cm wide and 80–90 cm tall, should be installed in the water inlet and outlet. Each screen should be arch-shaped with thin bamboo strips placed 0.2 cm apart. Fry may then be released into the field. Field management should be strengthened. Before the rice ripens and all the weeds are eaten by the fish, the canals and ditches are opened and the water is drained slowly to force the fish to gather in the canals. The fish are then driven into the ditch where they are netted.

This is the best method for raising fingerlings. In Sanming City, Fujian Province, the area of ricefields for raising fingerlings increased in 1982–1984, from 270 ha to more than 670 ha, and the number of fingerlings raised increased from 2 to 8 million (62% of the fingerlings raised in the entire city). In addition, rice output increased by 6–17 %.

The catch of adult *C. idella* from fishponds has remained low. Because they are unable to adapt to the environment in fishponds, the fish easily become ill. Usually only 20–30% survive. In ricefields, on the other hand, the ecological environment is suitable for *C. idella*, and few, if any, become ill. This is why the output of freshwater fish can be doubled.

**Rice, Fish, and Azolla**

In this method, the raising *of C. idella* or tilapia in ricefields is organically combined with the growing of azolla. Rice is grown in the field, azolla on the surface of the water, and fish in the water. Fish feed on the azolla, and the field is fertilized by fish excrement. Melons and beans can also be planted on the banks of the field to form a vertical cultivation system. Instead of the conventional equal-distance planting method, rice growers use wide and narrow rows. They raise azolla and fish in the wide rows and plant rice in the narrow rows. This keeps the field well ventilated and maximizes the use of sunshine and the effects of edge rows. As a result, it ensures stable and high yields of rice and fish, good economic returns, social benefits, and ecological efficiency.

This research was sponsored in recent years by Liu Zhongzhu, President of the Fujian Academy of Agricultural Sciences. After 3 years of experimentation, the method is now widely applied in Jianning County, Fujian Province. In 1986, the county devoted 6 670 ha or 46% of its ricefields to this method of farming. The method generates additional income of CNY2 250-2 700/ha of rice planted, and rice output can be increased by about 7%. Because there are fewer weeds and pests in the fields, there is less need to apply chemical fertilizers and pesticides, which helps reduce costs by about CNY150/ha. The county reported a total fish catch of 1.15 million kg from ricefields in 1985 and 1.5 million kg in 1986. Most of the fish were sold in the market, which added, on average, CNY20 of income per household.

**Raising Fish in Ricefields with Wide Ditches**

This method is used to raise winter fingerlings. Ditches, about 1-m wide and 1-m deep, are dug on the water inlet side and inside of the field bank. The total area of the ditches is about 5–10% of the area of the ricefield. The ditch ridge is raised 25 cm above field level. A 24-cm opening every 3–5 m links the ditches with the field and allows the fish to move freely from the ditches to the field. Long before the rice-transplanting season, winter fingerlings are put in the ditches so that they can enter the ricefield for food as soon as the early rice seedlings turn green. Jiangxi Province devoted 6 670–9 330 ha of ricefields to this method in 1985–1986 and reported a 20–50% increase in rice output.

**Ricefield Plus Fish Farming in a Pond**

In rice–fish farming, there is a time difference of about 1 month between the early rice and the hatching of summer fingerlings. The rice plants need sunlight, fertilizer, and pesticides. These conditions are not favourable for fish farming. In areas where a double rice crop is planted, the fingerlings and early rice must be harvested between the two rice crops, the field must be worked, and the late rice must be transplanted. At the same time, the ditches must be redug and fry released. Therefore, there is a need for more labour than is available. If rice–fish culture is combined with pond culture these contradictions can be eased. The method is easy to popularize.

One basic condition is that there be ditches or ponds around the ricefield. The pond should be 10–30 $m^2$ and about 1.5 m deep. The pond can be dug in advance and should be linked by a bank to the ricefield. It can also be used to hatch the fry. After the early rice is transplanted and the fish canal dug, the pond and ricefield are linked to let the fish in the pond swim across into the ricefield. Just before the early rice is harvested, the fish are driven back into the pond. After the field is reworked, the second rice crop is transplanted, a ditch is dug, and the fish in the pond are allowed back into the ricefield.

In 1983 at Lingshan Village in Meichuan District, Guangji County, Hubei Province, a rice farmer named Hu Maoyu used this method on a 0.17-ha ricefield linked to a 0.02-ha natural pond. He raised fish in the ricefield for 348 days, including 117 days when rice and fish lived together (61 days for early rice and 56 days for late rice). He put in 2 143 fry and netted 1 770 fish that had a net weight increase of 216.2 kg and a harvest rate of 82.6% (Table 1). The output was 5 431 kg/ha for early rice and 4073 kg/ha for late rice, or 5.81% more than the output from fields in which fish were not raised. Average net income was CNY2 156/ha. This method is gradually gaining popularity.

**Rice-on-Ridges and Fish-in-Furrows**

Ridges are built in the ricefield for the rice and fish are raised in the furrows. This method was developed on the basis of a semidry cultivation method advocated by Hou Guangjun. This method improves low-yielding ricefields because it makes multiple uses of available resources. It helps increase the contact of soil and air; balances water, air, and heat to raise soil temperature; and reduces the formation of toxic matter. Soil, water, microclimate, and heat are therefore stabilized at an appropriate level. This stimulates rice to grow roots, which absorb water and nutrients and changes gravitational water in the ricefield into lateral water that rises through capillaries to moisten the rice roots. Movement of fish in the furrows moves the water in the lower strata, stimulates the solution of nutrients, and increases soil fertility. The deep furrows increase the volume of water stored in the ricefield and create more room for fish activity. Fertilizers applied in the furrows make the water fertile and increase natural feed for fish.

In 1986, 16 counties of the Southeast Miao and Tong Autonomous Prefecture of Guizhou Province popularized this farming method over 688 ha. To ensure its success, the prefecture and the country earmarked CNY100 000 for the project. Thirty six persons went on a study tour to Sichuan Province and 83 persons from the Departments of Aquatic Products and of Soil and Agricultural Technique Popularization were sent to the fields. Various districts, townships, and villages ran 21 training courses for 1 000 people. In 1985, a 4.5-ha experiment area yielded more than 10 350 kg/ha of rice and 472 kg/ha of fish.

Specifically, the method involves digging a ditch, 50-cm wide and 67-cm deep, and building ridges 70-cm wide (enough to plant 4–6 rows of rice). Mud from the ditch is spread onto the ridge and rice is transplanted without working the soil. In a 0.07-ha field, 300 5-cm fingerlings [100 *C. idella*, 75 silver carp *(Hypophthalmichthys molitirix)*, 50 bighead carp *(Aristichthys nobilis)*, and 75 *C. carpio* and *C. auratus*] are released. During the growing season, green grass is put into the ditch to feed the *C. idella*, but no other feed is provided for the other species.

Table 1. Results of rice–fish farming in ricefields and adjacent ponds in Lingshan Village, Guangji County, Hubei Province (1983).

| | Number of Fish | Size (g) | Weight (kg) | Average Weight (kg) | Recovery Rate (%) |
|---|---|---|---|---|---|
| **Fry released 10 January** | | | | | |
| *Ctenopharyngodon idella* | 161 | 50–150 | 11 | — | — |
| *Cyprinus carpio* | 300 | 50–150 | 32.5 | — | — |
| *Hypophthalmichthys molitrix* | 369 | 20–50 | 6.5 | — | — |
| *Aristichthys nobilis* | 13 | 100–350 | 3 | — | — |
| **Fry released 16 January** | | | | | |
| *Ctenopharyngodon idella* | 1 300 | 5.0–6.7 cm | 4.8 | — | — |
| Total | 2 143 | | 57.8 | | |
| **Fish harvested 23 December** | | | | | |
| *Cyprinus carpio* | 271 | 200–500 | 70.5 | 260 | 90 |
| *Hypophthalmichthys molitrix* | 357 | 100–400 | 82.8 | 235 | 97 |
| *Aristichthys nobilis* | 13 | 300–900 | 7.8 | 600 | 100 |
| *Ctenopharyngodon idella* | 1 129 | 20–650 | 112.9 | — | 77 |
| Total | 1 770 | — | 274 | — | 83 |

Research using this high-yielding, high-efficiency semidry cultivation method in Chongqing City showed that yields of 6 750–7 450 kg/ha of rice and 705–765 kg/ha of fish could be achieved. This method has been popularized in the Mianyang and Huangbo Counties of Hubei Province, and in Hunan and Jiangxi Provinces where conditions are suitable. Good economic returns have been reported.

## Rotating Rice and Fish

In this method, rice and fish are alternatively raised in one ricefield. In 1 year, only one rice crop is planted, the rest of the time is devoted to fish farming. First, rice and fish are farmed in one field. When the rice is ripe, the rice and fish are harvested and the straw is left in the field to rot. Adult fish are then released into the harvested ricefield. The method can also be applied in double-cropping areas, but the fish are only raised in winter.

**Rotating Rice and Fish in Low-Lying Land**

In 1982, this method was adopted on 1.3 ha of low-lying land farmed by the Luopitang Production Brigade of the Huaqiao People's Commune in Guangji County, Hubei Province. This piece of low-lying land previously grew only one late rice crop a year and remained fallow for the rest of the year. On 2 July 1982, fish ditches (50 cm wide and 27 cm deep) were dug, and the next day, rice seedlings (Gu-154) were transplanted at a distance of 11.5 x 17 cm. The field was not weeded during the entire rice-growing season and no pesticides were applied. Only 300 kg of sodium bicarbonate (232.5 g/ha) and 140 kg of urea as a top dressing (109 kg/ha) were used. The rice output was 5 530 kg, 10% more than the expected 5 000 kg, with a per-unit output of 4 298 kg/ha. On 23 July, 19 690 fingerlings [84% *C. idella*, 5% black carp *(Mylopharyngodon piceus)*, 10% *H. molitirix*, and 1% *A. nobilis*] were introduced at a rate of 115 300/ha. The fish were grown for 64 days without feed and on 24-25 September, 10 094 fish, weighing a total of 229.5 kg (176.5 kg/ha) were collected. Ten percent of the fish were 10 cm in length, 70% were 10.1-20 cm, and 20% were over 20.1 cm.

During the second rotation season, 10 787 fingerlings (vaccinated for *C. idella* bleeding) were introduced (8 385/ha). The total weight was 279 kg and the average size of the fingerlings was 15.6 cm. A small amount of fertilizer was applied after January 1983 and the rate was increased after April. During the entire rotation season, 40 kg of urea, 1 450 kg of night soil, 600 kg of vegetable cake, 3 508 kg of azolla, and 1 830 kg of green grass were applied. Because 5 500 kg of rice straw were left in the field, the total amount of fertilizer and feed was 12 928 kg.

On 26-27 June 1983, 1 689 kg of fish (average 1 300 kg/ha) were harvested. Excluding the fingerlings, the net catch was 1 095 kg/ha. The net income from fish alone was CNY2 519, or an additional CNY1 957/ha.

**Raising Fish in Winter Ricefields**

This rotation method makes full use of the ricefields after the late rice harvest until the middle rice is planted the following summer or the next late rice crop is planted. In some areas, fingerlings are released right after late rice is transplanted, and the fish are harvested either before the spring festival in January or February or before the next early rice crop is transplanted. This method yields a high output of fish, mostly as food. During the winter season, most ricefields store water that is overgrown with plankton and bottom organisms, especially in East Sichuan Province. This water is very suitable for fish.

In the winter of 1983, Cheng Jinghong of the Freshwater Products Institute of Fujian Province reared fish in three pieces of land covering 0.25 ha at the Andou Fry Farm, Jinjiang County, Fujian Province. On 20 November 1983, he released 57.5 kg of fingerlings (*C. idella*, *C. carpio*, *H. molitrix*, and *A. nobilis)*. On 28 March 1984, 128 days later, he collected 85 kg of fish, a net increase of 27.5 kg. The weight of *C. carpio* increased 5-8 fold (average 0.2 g/day), and the survival rate was 89.3%. After the costs for fingerlings and feed were deducted, the net profit was CNY92 (CNY5 520/ha).

Cheng Jinghong raised the field bank by 50 cm and packed it firm after harvesting the late rice. He dug a ditch 30-cm wide and 30-cm deep along the field banks (1 m from the banks) and dug two fish ditches or pits (each covering 1 $m^2$) near the water inlet. He installed screens at the inlet and outlet of the field, stored water in the field, and released the fingerlings. Fish feed consisted of peanut cake, rice husk, wheat bran, and fish powder mixed in a ratio of 8:6:5:1 with water. The mixture was spread in the ditches or put on a food platform at 14:00–15:00 each day. The total amount of feed used was 2–3% of the total weight of the fingerlings, depending on the weather and how well the fish fed.

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# New Techniques for Raising Fish in Flooded Ricefields

*Wan Banghuai*[23] *and Zhang Qianlong*[24]

The traditional model of raising fish in ricefields has been practiced for a long time. It does not include digging ditches or pits; therefore, the field remains flat. With this model, fish raising and rice growing do not interfere with each other. This method proved that fish and rice could coexist and elucidated the relationship between fish and rice. It inspired the theory of rice–fish mutualism in ricefields. This traditional model suited cultivation systems in which high-stalk strains of rice were planted in ricefields with relatively high water levels. The fields were not directly exposed to the sun, weeding was not performed, and chemical fertilizers and pesticides were not applied. The model helped improve skills in fish raising in ricefields and promoted reforms in the cultivation system. The fact that fish raising in flat ricefields has been in practice for over 2 000 years clearly demonstrates the viability of this technology.

However, the traditional model had disadvantages. The technology was not fully developed, management was poor, production was on a small-scale and done spontaneously by farmers, and the method was limited to hilly, mountainous areas and areas with sufficient water. The fish that were raised were usually a single species, small in size and in quantity. Yield was low (75–150 kg/ha) because of extensive raising and poor management. Moreover, production was subject to the constraints of the cultivation system and natural disasters. Therefore, development was slow and unstable. The history of fish-raising in flat ricefields in Jiangxi Province illustrates this slow development. The amount of land devoted to rice–fish culture was 3 300 ha in 1956, 2 800 ha in 1957, 3 470 ha in 1958, 14 620 ha in 1959, 20 640 ha in 1960, 10 570 ha in 1961, and 12 520 ha in 1962. There was a steady decline until 1976, when fish raising in ricefields became virtually extinct. The area gradually increased again and by 1983 reached 18 700 ha.

## Emergence of the New Technology

Fish culture in flat ricefields developed to its height in the 1950s and 1960s in China when it covered a total area of 0.7 million ha. By 1986, the area had grown to 1 million ha; however, the following year it declined to 0.73 million ha. Fish yield was less than 150 kg/ha. The cultivation system has changed, but fish raising

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in ricefields has not completely returned to its peak level, and even in areas where rice-fish production has been restored or developed it is still normally based on flat ricefields.

However, in some areas, fish raising in ricefields has been more highly developed. For example, in 1984-1986 demonstration areas (66 000 ha of ricefields) were cooperatively developed in 18 provinces, municipalities and autonomous regions all over the country. Fish yields reached 300-750 kg/ha (maximum 1 500 kg/ha), and rice output increased by about 10%.

New models were developed in the 1960s. These reforms in the cultivation system led to increased rice output, but also sharpened the conflicts in fish raising in ricefields. Because the old model was no longer suitable, efforts were made to find solutions to these conflicts. During 1959-1960, people in Jihe Village, Yaoxia Township, Suichuan County, Jiangxi Province, raised fish in double-cropping ricefields by digging ditches and pits (more or less like the current ditch-pit models). Fish yields reached 375 kg/ha. However, this technique remained on a small scale of only 0.67 ha and yields remained constant for over 20 years. It was not until the beginning of the 1980s that progress was made.

In 1982, scientists in Jiangxi Province began to systematically spread the new technology over the entire province and to promote the theory of the supportive coexistence of rice and fish. Extensive research was conducted on several rice-fish cultivation models: flat ricefield, ditch-pit, wide-ditch, zigzag ditch, small pit, field pond, semidry ridge and ditch, and ridge-ditch.

In 1984 and 1986, cooperative extension efforts were undertaken in 18 provinces, municipalities, and autonomous regions. In Jiangxi Province, the Provincial Aquatic Products Department sponsored and entrusted the cities and prefectures of Yichun, Wanzhai, Shangyou, Suichuan, Puyang, Fengxin, Shanggao, and Anyi to conduct technical extension and demonstrations of ditch-pit, ditch-pond, and ridge-ditch models. In Jiangxi Province, this marked the beginning of the expansion of the new technology.

### Advantages and Disadvantages

The new technology is based on the theory that raising fish in ricefields and growing rice with fish improves the harvest of both crops. Rice-fish culture improves the ecological cycling of material and energy in the ricefields and therefore enhances the growth of rice and fish.

Fish raising in ricefields can be classified into various categories based on cultivation system: simultaneous cropping of rice and fish, rotation cropping of rice and fish, and intercropping of rice and fish. It can also be classified according to crop system and raising method into fish raising in double-cropped ricefields, fallow winter fields, lotus fields, and wild-rice fields. From the point of view of engineering, technology, and technique, rice-fish culture can be divided into flat-field, ditch-pit, and ditch-pond (inclusive of small pond, wide and semidry ridge, and ditch-in-the-middle sided by rice). All these models are now in use.

**Ditch-pit model.** In Jiangxi Province, this is the primary model for the new technology. Fish are raised in ricefields in open ditches and pits. Each ditch is as wide as two rows of rice and is 24 cm deep (or as deep as the hard layer of soil). The pits are 50–70 cm deep and 1 $m^2$ in area. One or two pits are placed at each inlet and outlet for water at the corner(s) of the field. Rice seedlings are planted along the sides of each ditch and along three sides of each pit to serve as a fence.

This model does not require much work or a large investment, it is easy to operate, and can be used in most fields. The conflicts between rice and fish are mitigated, rice output can be increased by 10%, and fish yields can be doubled or tripled compared with flat ricefields. Farmers readily adopt this model; however, because the ditches are shallow and the pits small, the fish are grown for a limited time and are small. These fish can be used as fish fry or as food by the farmers, but cannot be sold in the market. The yield is low.

**Ditch-ridge model.** A semidry rice planted on raised ridges is combined with fish culture in the ditches. At the same time, lotus, wild rice, and azolla are grown in the ditches. One advantage of this model is that there are many ditches filled with water where azolla can be grown as fish feed. This solves the conflict between rice and fish. The fish can be raised for a longer time and be given supplemental feed. Fish yields easily reach 750 kg/ha. This method improves the yield from ricefields and creates economic benefits.

The disadvantage of this model is its limited adaptability, particularly in Jiangxi Province, which is dominated by double-cropped rice. As well, the method requires a lot more work that must be repeated each year. Therefore, this model is not well accepted by farmers, and extension efforts have only been successful in establishing this model in 0.5% of the areas involved in rice–fish farming in the province.

**Ditch and pond model.** This is the most widely used model in the province because it can be practiced in different ways to suit local field conditions. A small pond is dug at one end of the field, or shallow pond(s) between the ricefields can be used. The ponds are 1-m deep and occupy only 6–8% of the total field area. The ditches are 30–50 cm deep and cover about one-third of the total pond area.

This model provides an optimized environment by using improved engineering and by extending and controlling the time available to raise the fish. Different varieties of commercial-size fish can be grown yields are 750–1 500 kg/ha. Rice production is also increased by over 5%. This is an ideal model for raising fish in double-cropped ricefields. The disadvantages of this model are that a lot of labour is involved, the engineering work must be done each year, and the fish cannot be grown during the winter.

## Principles and Economic Benefits

The new technology can create an artificial ecosystem that is similar to the natural ecosystem. The new models attempt to develop cash crops and livestock that are suitable for socioeconomic development. These models incorporate the advantages of pond raising. They produce high yields and fully use the ecological conditions of the ricefield. The fish have sufficient natural feed and this can be supplemented with artificial food. Therefore, conflicts between rice and fish are resolved and a balanced ecosystem is developed in which it is possible to increase the output of both rice and fish.

Empty spaces and small patches of land can be used by putting up shelters that not only provide refuge, but also provide suitable conditions for crops such as melons. Vegetables and beans can be planted on the ridges, and lotus, wild rice, taro, and azolla can be raised in the water. This comprehensive use of the land makes it possible to obtain good harvests of rice, fish, and vegetables. Because the model makes good use of land, water, biological, and nonbiological resources in the ricefields, it is an ideal model of production for fish-rice culture. Substantial ecological, economic, and social benefits are produced.

### Biological Benefits

**Weeding and fertilizer.** Grasses that grow with rice absorb available fertilizer and compete for nitrogen. When 500-600 fish that feed on grass are raised, the grass is kept under control and the fertilizer is reserved for the exclusive use of the rice. Experiments have shown that every 1 000 g of grass-eating fish fry can eat as much as 40-60 g of weeds/day. Experiments in 1988 in the Shang-gao area showed that a 500-g grass carp *(Ctenopharyngodon idella)* can eat 3.5 g/day of weeds in a ricefield and therefore turn weeds into fish protein. Fish excrement, in turn, fertilizes the rice, increases organic matter in the soil, and improves the fertility of the ricefield.

**Pests and plant diseases.** The insects (and their eggs) that harm rice are good food for the fish. When insects move about in the water, or when their eggs fall into the water, they are eaten by the fish. In this way, fish raising benefits the rice because it reduces plant diseases and eliminates pests. In experiments in the Shang-Gao area, a 150-g common carp *(Cyprinus carpio)* was found to eat 1.3 g of insect pests each day. One study compared the index of harm caused by pests (e.g., leaf folders and stem borers) and found that the leaf folding rate of every 100 clusters of rice was 90 cases in ricefields with fish and 210 in ricefields without fish. The rate of blight was zero in ricefields with fish and 0.014% in ricefields without fish. Fish also help rid rice plants of surplus tillers and disease-ridden leaves. This increases the penetration of light and reduces the occurrence of plant diseases and pests.

In addition, the movements of fish stir the water and soil, which increases oxygen in the water, speeds the release of fertilizer in the soil, and improves the development of the root system of the rice. Loosening the soil, eliminating weeds,

Table 1. Results of demonstration work using the new technology to raise fish in ricefields (organized by the Jiangxi Provincial Aquatic Products Department, Jiangxi Province).

| Year | Area (ha) | Fish Catch (kg/ha) | Increase in Rice (kg/ha) | Average Added Value of Rice and Fish (CNY) | Investment (CNY/ha) | Ratio of Investment to Added Value |
|---|---|---|---|---|---|---|
| 1984 | 247 | 605.7 | 1651.8 | 214 | 271 | 1:11.8 |
| 1985 | 278 | 593.1 | 823.5 | 215 | 593 | 1:5.5 |
| 1986 | 445 | 690 | 408 | 175[a] | 546 | 1:4.8 |

[a] Includes income from 4 kg of lotus seed (an increase of 8.7%).

and adding fertilizer raises rice production in many ways. The need to weed by hand is eliminated and reduced amounts of chemical fertilizer and insecticide are needed. These benefits produce savings in labour and investments and help improve the rural environment and the health of the people.

### Economic Benefits

Rice–fish culture using the new technology makes multiple uses of available land. It is an intensive farming model that requires a small investment, is highly efficient, and produces quick benefits. The results of the new technology are illustrated by demonstration work organized by the Jiangxi Provincial Aquatic Products Department from 1984 to 1986. The lowest ratio of investment to added value was 1:4.8; the highest was 1:11.8 (Table 1). An investment of CNY36 produced an increased value of CNY175. At the high end, an investment of CNY18 produced an increased value of CNY214. These figures do not include the extra income generated from melons, vegetables, and beans.

### Social Benefits

**Increased employment.** Surplus labour is employed. This is particularly true in poor mountainous areas where only a limited amount of arable land is available and there are few opportunities for sideline occupations. In Suixiang Township, Yichun Prefecture, for example, although many people were engaged in sideline occupations in the past, many others often visited relatives or friends because they had a lot of leisure time. Now, in over 95% of the nearly 46.7 ha of ricefields, fish are raised. The people are happy: *fish raising in the ricefields gives people things to do and that they live contentedly.*

**More fish to market.** Fish are a well-liked source of high-quality animal protein. The average per capita consumption of fish in China is 10 kg/year; in Jiangxi, it is only 6–7 kg/year. It is difficult to supply fish to hilly and mountainous areas. However, the extensive development of rice-fish cultivation and efforts to increase fish catch will help activate the urban and rural markets and supply more fish for the table.

**Increase of income.** Fish raising and the associated intensive farming are attractive to farmers because of the increased yields of rice and fish and the income derived from other cash crops. The extension of the new technology will promote reforms in the cultivation system, further enrich rice-fish farming, and further develop agriculture and increase national income.

## Conclusion

Research and extension using the new technology are similar in Jiangxi Province to other places in China. These models can be further improved if they are adapted to local conditions and if rice output is increased. The new technology will be extended through the process of application, and perfected through extension.

For thousands of years, fish raising in ricefields in China has been more advanced than in other countries. However, considering China's favourable natural conditions, the wisdom of the people, and the fact that China is basically an agricultural nation, development has been slow and unbalanced, and the amount of land devoted to rice-fish farming is limited. Moreover, the catch is still low (about 150 kg/ha on a national scale over a million ha). The new technology and its different models are still in the primary stages of development.

Administrative and professional leadership is needed. An agricultural extension program must be established to encourage fish raising in ricefields. This is the only way that the technology can be introduced to transform flat-type agriculture into three-dimensional agriculture and to produce increased yields and generate more income.

# Methods of Rice–Fish Culture and their Ecological Efficiency

*Wu Langhu*[25]

Rice–fish culture is the best model of an artificial ecological system. Rice is predominant, but weeds, plankton, and saprophytic and photosynthetic bacteria compete with the rice plants for nutrients and diminish the environment. The introduction of fish into the ricefield creates a new link in the food chain that uses energy that would otherwise be lost and improves the function of the system and its economic efficiency. Appropriate techniques make bumper harvests of rice and fish possible.

## Models of Rice–Fish Culture

### Intercropping of Rice and Fish

This model is suitable for most types of ricefields. It requires ample water resources. Before the fish are introduced, ridges (50–70 cm high) and fish ditches are constructed. The number of ditches is determined by the size of the field. Each ditch is 33-50 cm wide and 25–30 cm deep. A pit (100 cm long, 50–70 cm wide, and 80–100 cm deep) is dug where the ditches cross. The distance between the ridges and the ditches is 40–60 cm. Rice plants on the ditches and the pit are transplanted near the ridge to form a fence or marginal row. All water inlets and outlets are fitted with screens to prevent the fish from escaping. About 19 500–225 000 summer fingerlings of summer grass carp (*Ctenopharyngodon idella*) are introduced per hectare.

### Rotation of Rice and Fish

This model is suitable for cold-water fields. Its pattern is one season rice, one season fish. Ridges (100 cm high and 50 cm wide) are built and then 1 000–1 500 summer fingerlings of *C. idella* are introduced per hectare. When the rice matures, the grain is harvested but the straw is left in the water. Another 5 000–7 000 fingerlings of silver carp (*Hypophthalmichthys molitrix*) and variegated carp (*C. carpio*) are then introduced per hectare.

### Rice–Fish with Ridge

This model is suitable for marshy lowlands or deep, cold, water-logged land. Rice is planted on ridges and fish are reared in ditches. The ricefield is reconstructed in

[25] Hubei Aquatic Science Research Institute, Wuhan, Hubei Province.

two steps. First, ditches (50 cm deep and 20 cm wide) are constructed to cover 45-50% of the field, and ridges (20-130 cm wide) are built with soil from the ditches. Second, the ridges are levelled with mud from the ditches. Rice seedlings are transplanted close together on the ridge surface. Close planting compensates for the space taken up by the ditches. About 1500-3000 winter fish fingerlings and 12 000-18 000 variegated carp fingerlings are introduced per hectare.

### Rice-Fish with Fish Pit

The fish-pit model is devised according to the principles of fish-pond culture. The technique provides *7500 kg of rice and 750 kg of fish*[26] and solves the problems of drying and of applying fertilizer and insecticide. A pit is dug on one side of the field and covers about 8-10% of the area of the field. The pit should be 2-3 m wide and 1.5-2 m deep. Its length depends on the length of the field. The pit can be used to hatch carp fingerlings, breed summer or winter fingerlings, and raise adult fish. About 3 000-5 000 summer or 300-500 winter fingerlings are introduced per hectare.

### Rice-Fish with Wide Ditches

In addition to the ridges and the ditches used in the mutualism model, this model requires that a wide ditch (1-2 m deep and 1-2 m wide) be dug along the side of the water entrance of the field. The wide ditch usually takes 7-10% of the area of the ricefield and has an inner ridge (26 cm high and 23 cm wide). Between the wide ditches, at intervals of 3-5 m, are passageways. About 4 500-7 500 winter fingerlings are introduced per hectare. The wide ditches can also be used to hatch fingerlings.

## Economic and Ecological Efficiency of Rice-Fish Culture

### Economic Indicators

An experiment was conducted between 12 May and 15 July 1983 in three neighbouring ricefields (0.15 ha, 0.07 ha, and 0.01 ha). The ricefields produced good harvests of early maturing rice under both drought and water-logged conditions. The 0.01-ha field was used as the control. By the end of the experimental period, fingerlings in the control ricefield reached an average length of 8 cm, and 936 *C. idella* were harvested. The rate of recovery was 50%. Rice yields in the two experimental fields were 7 584 and 7 992 kg, an increase of 1 209 kg/ha (19%) and 1 617 kg/ha (25%) over the control (Table 1).

In October 1984, similar results were obtained in another experiment with late maturing rice. Four plots (each 141 m$^{2)}$ were established in a 0.08-ha field. Three

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[26] The popularization slogan for increasing rice-fish production was *thousand jin rice grains, hundred jin fish* based on the Chinese units per mu (1 mu=0.07 ha; 1 jin=0.5 kg).

Table 1. Yields of early maturing rice in a rice-fish field and a control field.

| | Yield (kg/ha) | Panicle No. (10 000/ha) | Panicle Length (cm) | Total No. of Grains per Panicle | Fertility Rate (%) | 1 000-Grain Weight (g) |
|---|---|---|---|---|---|---|
| Treatment 1 | 7 585 | 367.5 | 18.7 | 94 | 91.1 | 24.8 |
| Treatment 2 | 7 962 | 367.5 | 18.6 | 107 | 92.2 | 24.8 |
| Control | 6 375 | 366 | 17 | 87 | 87 | 24.8 |

Table 2. Yields of late-maturing rice in a rice-fish field and a control field.

| | Yield (kg/ha) | Panicle No. (10 000/ha) | Total No. of Grains per Panicle | Fertility Rate (%) | 1 000-Grain Weight (g) |
|---|---|---|---|---|---|
| Treatment 1 | 7 439 | 312 | 104 | 80.3 | 28.5 |
| Treatment 2 | 7 700 | 285 | 116.8 | 81 | 28.7 |
| Control | 6 573 | 259.5 | 111.6 | 78.6 | 28.6 |

plots were used as replicates, one as the control. The rate of increase in rice yields was 10.2–20% (Table 2). Tables 1 and 2 show that rice-fish culture can increase effective tillering, improve the grain fertility rate of the rice, and increase (or at least maintain) the fertility of the field.

### Effect on Weeds

On 29 July 1982, the amount of weeds in two fields were measured. In the field with 100.8 kg of weeds, fish were introduced. In the field with 44.2 kg of weeds, no fish were introduced. On 13 October, there were 20.2 kg of weeds with the fish and 273.0 kg without the fish. Similar results were obtained in 1984–1985. In experimental plots in October 1984, there were 2.0 kg (148.5 kg/ha) of weeds in the field with fish, and 29.8 kg (2 100 kg/ha) in the field without fish. The field with fish had 1 951.5 kg/ha less weeds. On 2 May 1985, before fingerlings were introduced, the amount of weeds averaged 1 504 kg/ha. On 27 July, after fish had been raised for 2 months, there were 17.1 kg of weeds in the treatment fields and 263.1 kg in the control fields. About 246 kg of weeds had been eaten by the fish.

### Increase in Soil Porosity

Porosity directly influences the ability of the soil to retain water, the aeration of the soil, and the movement of water. It also indirectly affects the activity of aerobic and anaerobic bacteria and therefore influences the decomposition rate of organic substances and the capacity of the soil to provide nutrients. The activity of the fish

Table 3. Influence of rice-fish culture on the physical properties of soil in late maturing ricefields.

| | | | Porosity | |
|---|---|---|---|---|
| Sampling Date | Unit Weight | Treatment | (g/m³) | (%) |
| 27 August | Fish raising | -1 | 1.37 | 48.3 |
| | | -2 | 1.36 | 48.7 |
| | | -3 | 1.39 | 47.6 |
| | Control | | 1.38 | 48 |
| 27 October | Fish raising | -1 | 1.24 | 59 |
| | | -2 | 1.25 | 52.8 |
| | | -3 | 1.25 | 52.8 |
| | Control | | 1.47 | 44.7 |

can lessen the unit weight of the soil, increase its porosity, and therefore improve ventilation.

This increase in soil porosity has been experimentally verified. Experiments in October 1982 showed that soil porosity of a field with fish was 59%; whereas, porosity in a field without fish was 53%. In other experiments in 1984, soil samples were taken twice. The first samples showed no difference in soil porosity. The second samples, taken after 2 months of rice-fish culture, showed that soil porosity in the field with fish was 8.1-14.3% higher than that in the field without fish (Table 3).

### Fertilization of Fields

Rice plants obtain two thirds of their nutrients from the soil and one third from fertilizer applied during growth. However, weeds, plankton, and saprophytic and photosynthetic bacteria compete with rice for nutrients. Weeds can reduce rice yields by 10-30%.

Rice-fish culture can eliminate or inhibit weeds and help retain soil fertility. Only about 30% of the weeds and plankton eaten by fish are digested and absorbed, about 70% are excreted, which increases the organic matter content and fertility of the soil. This was verified by testing the organic and alkaline-nitrogen content of the soil in ricefields with and without fish (Table 4). The ricefield with fish showed increases of 0.114% in organic nitrogen, 6.95 ppm in alkaline nitrogen, and 0.0044% in total nitrogen, compared with ricefields without fish.

Table 4. Influence of rice-fish culture on the organic and nitrogen content of soil in ricefields.

| Sampling Date | Treatment | Organic Matter (%) | Alkaline Nitrogen (%) | Total Nitrogen (g/m$^3$) |
|---|---|---|---|---|
| 19 October 1982 | Fish raising | 2.19 | 100.6 | 0.1288 |
| | Control | 2.09 | 93.6 | 0.1244 |
| 8 August 1984 | Fish raising | 3.05 | 137.0 | 0.0763 |
| | Control | 3.26 | 142.0 | 0.0733 |
| 27 August 1984 | Fish raising | 3.25 | 151.1 | 0.0712 |
| | Control | 3.13 | 140.0 | 0.0588 |
| 12 October 1984 | Fish raising | 4.44 | 134.8 | 0.0811 |
| | Control | 3.36 | 128.5 | 0.0623 |
| 25 July 1985 | Fish raising | 4.67 | 147.0 | — |
| | Control | 4.60 | 140.0 | — |
| Mean | Fish raising | 3.52 | 134.1 | 0.089 |
| | Control | 3.29 | 128.8 | 0.08 |

Table 5. Numbers of planthoppers in ricefields with and without fish (1984).

| Generation | Clumps | Imago | Larva | Insects per 100 Clumps | Clumps | Imago | Larva | Insects per 100 Clumps |
|---|---|---|---|---|---|---|---|---|
| **Fish Raising** | | | | | | | | |
| I | 10 | 5 | 58 | 630 | 20 | 4 | 31 | 175 |
| II | 10 | 4 | 40 | 440 | 20 | 3 | 27 | 150 |
| III | 10 | 2 | 68 | 700 | 20 | 14 | 37 | 255 |
| Mean | 10 | 3.7 | 55.3 | 590 | 20 | 7 | 31.7 | 193 |
| **Control** | | | | | | | | |
| I | 10 | 6 | 69 | 750 | 20 | 7 | 52 | 295 |
| II | 10 | 2 | 57 | 590 | 20 | 7 | 28 | 175 |
| III | 10 | 6 | 106 | 1 120 | 20 | 9 | 42 | 225 |
| Mean | 10 | 4.7 | 77.3 | 820 | 20 | 7.7 | 40.7 | 232 |

### Insect Control

Fish eat harmful insects and their larva, especially planthoppers. In an experiment in September 1982, three fish from a ricefield were dissected. Leafhoppers and planthoppers were found in the bellies of common carp and silver carp. In 1984, the population density of snout-moth larva and leafhopper were investigated. Fish were dissected to determine their capacity to eat insects. In the ricefield without fish, there were 820 snout moths and 11 275 leafhoppers; in the ricefield with fish, there were only 692 snout moths and 10 127 leafhoppers. When the fish were dissected 3 of the 10 *C. idella* had snout moths in their digestive organs, and all 10 contained 2–3 leafhoppers. More leafhoppers were found in *C. idella* that were more than 7 cm long.

In 1985, a detailed investigation was done on planthoppers (Table 5). The number of planthoppers per 100 clumps of rice in ricefields with fish was 17–28% less than that in fields without fish. By the fourth generation of planthoppers, there were 820 per 100 clumps of rice in the ricefield without fish, which was enough to warrant the use of an insecticide. The ricefield with fish had only 590 planthoppers per 100 clumps of rice and no insecticide was needed. Rice–fish culture can also help control mosquitoes, which significantly improves the health of people in rural areas.

# Ridge-Cultured Rice Integrated with Fish Farming in Trenches, Anhui Province

*Yan Dejuan,*[27] *Jiang Ping,*[27] *Zhu Wenliang,*[28] *Zhang Chuanlu,*[29] *and Wang Yingduo*[29]

The earliest record of rice–fish farming in Anhui is from the Ming Dynasty. Traditional techniques produce low yields; however, improved methods have been introduced in recent years in many parts of the country. Changes include mixed culture of fish instead of monoculture; release of adult fish instead of fry; provision of feed for the fish; and disease prevention and control. Research on biology and ecology have attempted to find ways to increase the yields of rice and fish. Engineering facilities for rice–fish farming have been continuously modified. Some new ecological techniques include digging trenches that surround the field, horizontal trenches, and ditches, semidry cultivation, and ridge-cultured rice integrated with fish farming in trenches (high ridge and deep trench).

## Advanced Cultivation Techniques

In 1987, the Provincial Aquatic Product Technique Extension Station in Fengtai County, Anhui Province, conducted experiments and established a project to demonstrate advanced techniques of ridge-cultured rice integrated with fish farming in trenches that obtained bumper harvests of rice and fish.

### Selection of Experimental Plot

A 7.1-ha ricefield managed by 31 households at Xinji Village, Chengbei Township, Fengtai County, was selected. The plot was smooth and had medium soil fertility and a convenient irrigation and drainage system. The cropping pattern was wheat–rice. Field preparation began in early June after the wheat harvest. Trenches were dug and ridges constructed. Ditches (1–1.7 m deep and 1.5–2 m wide) were dug in 3–7% of the ricefield. Three types of ditches were used:

- Ridge type. Ridges 50 cm wide with two rows of rice seedlings spaced 25 x 12 cm; 165 000–168 000 plants/ha with each hole

[27] Anhui Aquatic Product Technique Extension Station, Hefei, Anhui Province.

[28] Fengtai Animal Husbandry and Anhui Bureau of Aquatic Product, Fengtai, Anhui Province.

[29] Chengbei Township, Fengtai County, Anhui Province.

containing 1-2 transplanted rice plants; trenches 50 cm wide and 40 cm deep.

- Wide ridge type. Ridges 1 m wide with six rows of transplanted rice seedlings, rows and plants spaced 20 x 20 cm; 180 000-186 000 plants/ha; trenches 50 cm wide and 40 cm deep.
- Bed type. Bed 2 m wide with 12 rows in the bed, rows and plants spaced 20 x 22 cm; 195 000-201 000 plants/ha; trenches 60 cm wide and 40 cm deep.

### Plot Management

Before the rice seedlings were transplanted, 600-900 kg/ha ammonium sulphate and 450-600 kg/ha calcium superphosphate and manure were applied. From 15 to 20 June, seedlings of hybrid rice varieties (Xianyou 3 and Xianyou 6) were transplanted. A week later, fish fingerlings were released. For adult fish culture, 2 700-3 000 fingerlings (10-20 cm in length) were released. The major varieties for fish culture were grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) mixed with a few variegated carp (*C. carpio*), silver carp (*Hypophthalmichthys molitrix*), and crucian carp (*Carassius carassius*). For fingerling production, about 225 000-300 000/ha *C. idella* and *C. carpio* fingerlings 3-5 cm long were released into the ricefield.

To accommodate the water requirements of both the rice and fish, the depth of the irrigated water was controlled according to the needs of the different growing stages of the rice. A week after the rice seedlings were transplanted, the ridge was flooded to a depth of 3-6 cm. After the seedlings turned green, the field was irrigated frequently. The trench was kept full of water to saturate the ridge and promote the growth of the plant-root system. The time from booting to milking is the peak period when both rice and fish need water; therefore, the ridge was flooded to a depth of 7-10 cm with irrigation water. After the rice had reached the milking stage, the trench was filled with water to continuously saturate the field and ensure full development of the rice grains. During the growth period for the rice plants, 7-10 kg of urea applied as one or two top dressings were used according to the soil fertility of each plot. Two or three applications (one or two times less than that applied in ricefields without fish) of pesticide were used depending on the rate of insect-pest infestation.

In early September 1987, the fields surrounding the experimental plot at Chengbei Township were attacked by rice planthoppers. The farmers shook the rice plants with sticks to knock the planthoppers into the water. This method of controlling insect pests did not use chemicals that pollute the environment and provided fish with additional food.

Fish management included control and prevention of disease, prevention of fish escape, the timed supply of feed in the ricefield, and the culture of adult *C. idella* mixed with secondary fish varieties. The feed consisted of fodder grass (10 500-12 000 kg/ha) and concentrated feed (450 kg/ha). In ricefields in which

Table 1. Rice yields from different culture types.

| Type | Area (ha) | Harvest (kg/ha) | Hills/ ha | Panicles/ Hill | Grains/ Panicle | 1 000-Grain Weight (g) | Empty Grains (%) |
|---|---|---|---|---|---|---|---|
| Ridge | 0.5 | 7 125 | 165 000 | 13.9 | 107.9 | 30.2 | 18.6 |
| Wide ridge | 0.8 | 6 870 | 195 000 | 12.3 | 115.6 | 28.6 | 19.7 |
| Bed | 2.9 | 6 990 | 195 000 | 10.9 | 112.2 | 30.0 | 23.2 |
| Conventional | 4.3 | 6 795 | 232 500 | 9.1 | 114.0 | 29.1 | 25.6 |
| Control | 0.3 | 6 150 | 249 000 | 8.8 | 105.0 | 29.0 | 21.6 |

grass carp were the main fish variety, concentrated feed and green feed were used; in ricefields with fingerlings 450 kg/ha of concentrated feed and some green feed were applied.

### Rice and Fish Yields

**Rice yields.** On 10 September, before the rice was harvested, a sample was taken of ridge-cultured rice integrated with fish farming. There were 15.5 panicles/bunch, 175 kernels/panicle, and 19.2% empty grains. With the other types of rice–fish farming, there were 12 panicles/hill, 166.8 kernels/panicle, and 19.3% empty grains. An estimate of yield was made by selecting a representative plot from each experimental model. The yield of each experimental plot was independently calculated after the harvest (Table 1). The rice yield from the ridge-cultured rice integrated with fish farming was 1–5% higher than from conventional rice–fish farming (Table 1). The ridge-cultured rice–fish system produced 12–16% more rice than ricefields without fish.

**Edge effect.** Experiments on wide-ridge rice–fish farming in Huo Shan County in 1987 indicated that the number of panicles per bunch, grains per panicle, and weight per thousand grains were higher in outside crop rows than in the rows at in the centre (Table 2). However, the ridge and wide-ridge systems require excessive labour to dig the trenches. Field preparation and transplanting is done during the busy season; therefore, it is difficult to popularize this method.

**Fish yield.** Before the rice harvest, adult fish with commercial value were marketed;. the remaining fish were counted, weighed, and put into the trenches and fishpond. The fingerlings were 10–20 cm in length, the adult *C. idella* weighed 0.5–1.5 kg, and *H. molitrix* weighed about 0.5 kg. The total harvest of fish from the wide-ridge treatment was over 800 kg of adult fish and 312 kg of fingerlings per hectare (Table 3).

Table 2. Growth indicators and harvest of rice cultured on wide ridges in Huoshan County (1987).

| | Panicles/Hill | | | Grains/Panicle | | | 1 000-Grain Weight (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| Project/Head of Household | OR[a] | CR | RI (%) | OR | CR | RI (%) | OR | CR | RI (%) |
| Ye Liping | 16.0 | 12.4 | 29.0 | 230.0 | 135.0 | 70.0 | 24.4 | 24.0 | 1.7 |
| Ye Youmiao | 14.5 | 9.3 | 56.0 | 127.0 | 88.0 | 44.0 | 27.3 | 24.5 | 11.5 |
| Tang Qiancun | 25.0 | 21.0 | 19.0 | 164.0 | 107.0 | 53.0 | 28.0 | 25.0 | 12.0 |

[a] OR outside row; CR central row; and RI rate of increase.

Table 3. Comparison of fish yield between different culture types.

| | Fingerlings | | Adult Fish | | |
|---|---|---|---|---|---|
| Type | Yield (kg/ha) | Survival Rate (%) | Yield (kg/ha) | Survival Rate (%) | Growth Factor |
| Ridge | 396 | 46.5 | 97.5 | 79.3 | 7.3 |
| Wide ridge | 312 | 44.7 | 804 | 74.5 | 6.8 |
| Bed | 204 | 47.1 | — | — | — |
| Conventional | 167 | 38.4 | — | — | — |

### Economic Efficiency Analysis

Production value and cost accounting showed that income from the ridge and wide-ridge fish farming systems was much higher than from conventional rice-fish culture. Income from the ricefields with adult fish culture was also higher than the income from the field with fingerlings. Net income was 2-3 times greater than that from ricefields without fish culture (Table 4).

## Discussion and Conclusion

Ridge-cultured rice integrated with fish farming in trenches has several advantages. It is suited to lowland ricefields, cold waterlogged fields, and level ricefields. The optimum sizes for the ridges and trenches are being studied in different parts of the country. The economic efficiency of the ridge-based system is higher than for conventional rice-fish farming. The rice plants grow vigorously and have many

Table 4. Comparison of economic efficiency of different culture models.

| Treatment | Area (ha) | Income (CNY/ha) Rice | Fish | Total Income | Expenditure (CNY/ha) Rice | Fish | Total Income | Total Net Income |
|---|---|---|---|---|---|---|---|---|
| **Adult Fish** | | | | | | | | |
| Ridge | 8 | 1963.5 | 3690.0 | 5653.5 | 469.5 | 760.5 | 1230.0 | 4423.5 |
| Wide ridge | 24 | 2080.5 | 3216.0 | 5296.5 | 487.5 | 751.5 | 1239.0 | 4057.5 |
| **Fingerlings** | | | | | | | | |
| Ridge | 8 | 2287.5 | 1980.0 | 4267.5 | 507.0 | 313.5 | 820.5 | 3447.0 |
| Wide ridge | 12 | 2325.0 | 1561.5 | 3886.5 | 499.5 | 289.5 | 789.0 | 3097.5 |
| Bed | 43.5 | 2376.0 | 1018.5 | 3394.5 | 495.0 | 237.0 | 732.0 | 2662.5 |
| Conventional | 6.5 | 2310.0 | 831.0 | 3141.0 | 501.0 | 171.0 | 672.0 | 2469.0 |
| **Control** | 4.5 | 2089.5 | — | 2089.5 | 589.5 | — | 589.5 | 1500.0 |

large panicles and full grains. The wide-ridge system requires less labour than the ridge system and is therefore easier to popularize.

The wide-ridge system and especially the ridge system are more economical and efficient than conventional rice–fish culture because:

- Frequent irrigation with shallow water is the most appropriate environment for rice growth and development. The model of ridge-cultured rice integrated with fish farming in trenches is suited to irrigation with shallow water.
- Hybrid rice, the high-yielding varieties, need wider spaces between rows and narrow spaces between plants. Ridge-cultured rice integrated with fish farming in trenches fulfils these requirements and provides suitable growing conditions for high-yielding varieties.
- The ridge and wide-ridge systems can alleviate the conflicts between the water requirements of rice and fish. These systems meet the need of rice for water depth at different growing stages, provide a good environment for fish, and enlarge the holding capacity for fish. They also make full use of edge effects for the rice by improving ventilation and light penetration, which enhance photosynthesis, reduce diseases and pests of rice, and deepen the symbiosis of rice and fish to increase the yields of both crops.

Based on previous experiments, experiments have been initiated using zero tillage in high ridges, deep trenches, and wheat–rice cropping patterns. This system could reduce the need for field preparation and trench digging, improve conditions of water, fertility, atmosphere, and heat, and prevent damage to the soil structure. In addition, mechanical diggers must be designed to replace manual labour. If successful, this system could play an important part in improving economic efficiency.

# Development of Rice–Fish Culture with Fish Pits

*Feng Kaimao*[30]

The model for rice–fish culture with fish pits was developed as an improvement to traditional rice–fish culture. It has now become the main type of rice–fish culture and, in some regions, the major way for farmers to increase their incomes.

China has a long history of rice–fish culture. The traditional method of rice–fish farming in flat fields faces many conflicts between rice and fish and is easily upset by changes in natural conditions. Farmers often have to sacrifice the fish to save the rice, which has diminished the role of rice–fish farming and hindered its development. Before 1980, rice–fish farming in Dazu County yielded only 22.5–52.5 kg of fish per hectare. In 1981, rice–fish farming in flat fields advanced to some extent, but fish yields were still very low (Table 1).

Before the 1980s, aquaculture scientists in China experimented with fish troughs combined with fish trenches, which had been adopted in ricefields in the southern part of Jiangsu Province. However, during the midsummer droughts in Dazu County, the shallow troughs and small trenches did not provide sufficient water for the rice and fish. As well, the fish were not able to adapt to the high temperatures experienced during the drought.

Researchers in Dazu County studied the factors that influenced fish growth, e.g., the relationship between temperature and depth of the different water layers, the upper and the lower limits of temperature that suit fish growth, the relationship between the appropriate temperature range and the environment of the ricefield, the quantities of dissolved oxygen produced and consumed during the day and at night, and the form of oxygen molecules moving in the water. Based on their research, they developed a new approach to solve the conflicts between fish and rice. They dug 1-m deep fish pits that covered about 6–8% of the ricefield and connected the pits to trenches. Field experiments were conducted in many areas between 1980 and 1983. This new model of rice–fish farming was verified and accepted by farmers and the county government.

## Development of the Method

At the beginning of the trials in 1981, the area for rice–fish farming with fish pits was 0.2 ha. In 1982, the area reached 1.1 ha. Multiple-plot trials totalled 14 ha in

[30] Agriculture, Animal Husbandry, and Fish Bureau, Dazu County, Dazu, Sichuan Province.

Table 1. Fish yields from flat-field rice–fish farming.

| | Area (ha x 1000) | Total Yield (tonnes) | Unit Yield (kg/ha) |
|---|---|---|---|
| 1981 | 2.7 | 187 | 69.0 |
| 1982 | 8.8 | 977 | 99.0 |
| 1983 | 10.2 | 1 371 | 133.5 |
| 1984 | 9.7 | 1 043 | 106.5 |
| 1985 | 10.5 | 920 | 88.5 |

1983. By October 1984, the area had expanded to 3 080 ha, and by the end of 1985, 3 570 ha had been developed. Farmers had discovered that the economic benefits from the new model were 3–8 times greater than from flat field rice–fish culture. Fish yields as high as 3 195 kg/ha were obtained. From 21 July to 31 August 1985, Dazu County experienced a midsummer drought and 5 800 ha of flat-field rice–fish farming (58.8% of the total area devoted to rice–fish farming) were damaged. However, good harvests of both rice and fish were obtained from rice–fish farming with fish pits. This convinced the farmers of the value of using the new model and the technique became popular. By the end of August 1986, the total area of rice–fish culture with fish pits reached 41 474 ha. It is expected that new developments will move toward combining fish pits with shallow ponds.

## Results

Aquaculture production in Dazu County from all types of water areas has increased (Table 2). Rice–fish farming has developed most quickly. Rice–fish farming includes rice–fish farming with fish-pits and flat field rice–fish farming. In the past few years, production changes from both types of farming have been remarkable (Table 3). The fish-pit method shows greater resistance to natural disasters compared with the flat-field style. Although adult fish yields from the fish-pit method increased remarkably in 1984–1985, the unit yield of fish from flat fields decreased, apparently because of the midsummer drought. Since then, the area devoted to the fish-pit method has increased each year. Fish production from fish-pits varies depending on the progress of experiments, demonstrations, and extension efforts. Actual production levels in 1985 are presented in Table 4.

Although the environment in the fish-pit method is superior to the environment in the flat-field style, production of adult fish was directly influenced by management level (Table 5). Large-scale experiments, demonstrations, and extension were carried out in 1984–1985. Yields decreased as the level of researcher involvement decreased. Yields were highest in experimental areas and lowest in the extension areas.

Table 2. Aquatic production.

| | Total Aquatic Production (tonnes) | Rice–Fish | | Other | |
|---|---|---|---|---|---|
| | | (tonne) | (%) | (tonne) | (%) |
| 1981 | 625 | 187 | 29.9 | 447 | 70.1 |
| 1982 | 1 380 | 878 | 63.6 | 503 | 36.4 |
| 1983 | 2 180 | 1 380 | 63.3 | 800 | 36.7 |
| 1984 | 3 295 | 3 425 | 73.6 | 870 | 26.4 |
| 1985 | 3 271 | 2 465 | 75.4 | 806 | 24.6 |

Table 3. Changes in fish yields from two types of rice–fish farming.

| | Total Yield | | Fish-Pit | | | Flat-Field | | |
|---|---|---|---|---|---|---|---|---|
| | Area (ha) | Yield (t) | Area (ha) | Yield (t) | % of Total Yield | Area (ha) | Yield (tonne) | % of Total Yield |
| 1982 | 8 800 | 878 | 1.1 | 0.6 | 0.1 | 8 799 | 876.9 | 99.9 |
| 1983 | 10 200 | 1 380 | 14 | 8.4 | 0.6 | 10 186 | 137.6 | 99.4 |
| 1984 | 12 600 | 2 425 | 2 933 | 1 382 | 57.0 | 9 667 | 1 043 | 43.0 |
| 1985 | 13 400 | 2 465 | 2 933 | 1 536 | 62.3 | 10 467 | 929 | 37.7 |

Table 4. Actual fish yields from rice–fish farming using fish pits (1985).

| | Average Yield (kg/ha) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Over 3750 | 3735–3000 | 2985–2250 | 2235–1500 | 1485–1125 | 1110–750 | 735–375 | Under 375 | Total |
| Number of households[a] | 2 (0.2) | 2 (0.2) | 20 (1.5) | 23 (1.7) | 67 (5.0) | 172 (12.7) | 521 (38.5) | 560 (41.4) | 1 367 |
| Area (ha) | 0.2 | 0.1 | 1.6 | 2.5 | 8 | 23.7 | 72.4 | 46.1 | 155 |
| Total yield (kg) | 925 | 405 | 376 | 4 302 | 9 875 | 23 488 | 41 652 | 1 536 | 82 559 |
| Average yield (kg/ha) | 4625 | 4050 | 235 | 1721 | 1234 | 991 | 575 | 33 | 534 |

[a] Number in parentheses equals percentage of total households.

Table 5. Comparison of fish yields from rice-fish culture with fish pits in different districts.

| | Experimental District | | Demonstration District | | Extension District | |
|---|---|---|---|---|---|---|
| | Area (ha) | Unit Yield (kg/ha) | Area (ha) | Unit Yield (kg/ha) | Area (ha) | Unit Yield (kg/ha) |
| 1984 | 27.1 | 693 | 679 | 534 | 2 255 | 444 |
| 1985 | 40.5 | 860 | 679 | 768 | 2 255 | 434 |

These large-scale areas where used to obtain economic data. The ratios of input and output in 1984 were 1:2.86 for the flat fields, 1:3.59 for the fish-pit method, 1:3.35 for demonstrations, and 1:3.43 for extension. In 1985, the ratios were 1:2.61, 1:3.98, 1:3.16, and 1:3.23, respectively. Average profits from raising fish in flat ricefields was CNY1 833/ha, with 92.5% of the profit from rice and 7.5% from fish in 1984. In 1985, profit was CNY1 600/ha with 90.5% from rice and 5.5% from fish. Because of the midsummer drought in 1985, profits decreased by 2%. In ricefields with fish pits, profits (CNY3 204/ha with 58% from rice and 42% from fish) were highest from the experimental district. The income from ricefields with fish pits was 6.3-9.8 times greater than from the flat fields in 1984 and 17.7 times greater in 1985. Practice has proven the remarkable beneficial results of the new model, and additional developments of this model are expected.

# Techniques Adopted in the Rice–Azolla–Fish System with Ridge Culture

*Yang Guangli, Xiao Qingyuan, and He Tiecheng*[31]

The rice–azolla–fish system features an ecological three-dimensional approach to agriculture. Rice (the main crop), azolla, and fish are combined in a symbiotic complex. Rice is planted on the ridge, azolla grown on the water surface, and fish raised in the water. This new farming system was studied between 1984 and 1987.

Experiments were conducted on two plots of land, each with an area of 0.2 ha and a 6-$m^2$ fish pit. Double-cropping rice was planted in one plot, single-cropping rice in the other. Each plot was randomly arranged with three replications and planted with local high-yielding varieties or hybrid combinations of rice and azolla (*Azolla filiculoides* or *A. caroliniana)* (6 000 kg/ha). Fish species selected for mixed raising were grass carp *(Ctenopharyngodon idella)*, tilapia *(Oreochromis nilotica)*, lotus carp, dull carp, and Hunan crucian carp *(Carassius auratus)*. Growth of rice, azolla, and fish was recorded. The nutrient content of azolla and fish dung was determined by standard methods of analysis.

## Results and Discussion

### Proportion of Ridges to Ditches

Ridge width had a bearing on the yields of rice, azolla, and fish (Table 1). The yield of double-cropped rice on the 106-cm wide ridge (13 834.5 kg/ha) was 4.1% higher than in the control (conventional planting), 5.1% higher than on the 53-cm ridge, and 2.5% higher than on the 80-cm ridge. The yield of azolla grown on the water surface between the 53-cm ridges (72 930 kg/ha), was 70.3% higher than in control, 13.4% higher than between the 80-cm ridges, and 55.6% higher than between the 106-cm ridges.

Yields of fresh fish increased as ridge width decreased. The yield of fresh fish with the 53-cm ridges (841.5 kg/ha) was 89.3% higher than the control, 12.2% higher than with the 80-cm ridges, and 22.2% higher than with the 106-cm ridges. Therefore, wide ridges favoured rice yields, and the narrow ridge favoured growth of azolla and fish.

When ridge width was uniform and ditch width was varied, rice yields differed. With a 40-cm ditch, rice yield was 10 462.5 kg/ha, the same as in conventional

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Table 1. Effect of different ridge widths on yields of rice, azolla, and fish.

| Ridge Width (cm) | Rice (kg/ha) Early Rice | Late Rice | Total | Azolla (kg/ha) | Fish (kg/ha) |
|---|---|---|---|---|---|
| 53 | 6463.5 | 6697.5 | 13161.0 | 72931 | 841.5 |
| 80 | 6750.0 | 7651.5 | 14401.5 | 64320 | 736.5 |
| 106 | 7072.5 | 6762.0 | 13834.5 | 46875 | 676.5 |
| Control | 6675.0 | 6616.5 | 13291.5 | 42825 | 436.5 |

Table 2. Effect of different ditch widths on yields of rice,[a] azolla, and fish.

| Ditch Width (cm) | Rice (kg/ha) Early Rice | Late Rice | Total | Azolla (kg/ha) | Fish (kg/ha) |
|---|---|---|---|---|---|
| 40 | 4965.0 | 5497.5 | 10462.5 | 56242 | 613.5 |
| 46 | 4762.5 | 5347.5 | 10110.0 | 50258 | 702.0 |
| 106 | 4425.0 | 4965.0 | 9390.0 | 61995 | 784.5 |
| Control | 5175.0 | 5385.0 | 10560.0 | — | — |

[a] Early rice variety (2106); late rice variety (Wei-You 35); ridge width 53 cm.

planting, 3.5% more than with 46-cm ditches, and 11.4% more than with 53-cm ditches. Yields of azolla and fish were directly related to increases in ditch width (Table 2).

Production practices have proven that to determine the proportion of ridges to ditches for to obtain high rice yields, it is necessary to consider soil fertility, the characteristics of the rice varieties, whether the proportions favour growth of azolla and fish, and whether rice, azolla, and fish are well coordinated. In a ricefield in which rice is planted on the ridges, azolla is grown on the water surface, and fish are raised in fish pits, the water area of the fish pit should be 5–10% of the total area of the ricefield.

Best results are obtained if the ridge width is 53–106 cm and the ditch width is 40 cm. On each ridge, 4–8 rows of rice are planted 13–16.5 cm apart to obtain 300 000–375 000 hills of seedlings per hectare. If hybrid rice varieties are used, plant spacing should be 16.5–20 cm with 3–7 rows on each ridge to obtain 225 000–300 000 hills of seedling per hectare.

### Planting Rice During Different Seasons

When ordinary rice varieties were planted in the early crop season and hybrid rice varieties were planted in the late crop season, yearly rice yield was 12 925.5 kg/ha or 1 405.5 kg less than that obtained from two crops of hybrid rice (Table 3). However, there were no differences in the yields of azolla and fish between ordinary rice + hybrid rice and hybrid rice + hybrid rice. To increase rice yields, it is important to determine the proper time for planting hybrid rice varieties in the early and late crop seasons.

When early- or medium-maturing rice varieties (growth duration 100–110 days) are used as the early crop, the rice varieties used in the late crop season should be late-maturing (growth duration about 120 days). If late-maturing rice varieties (growth duration 115–120 days) are used as the early crop, the rice varieties used in the late crop season should be early or medium-maturing (growth duration 100–110 days). When two crops of hybrid rice are grown in a year, the hybrid combinations used in the early and late seasons should be all early or medium-maturing (growth duration about 110 days). If a single crop of medium rice is planted, ordinary rice varieties or hybrid combinations that are late maturing (growth duration 130–135 days) should be used. Conditions of location, cultivation practice, and soil fertility should also be considered.

### Yields of Fresh Azolla

Annual yields of fresh azolla grown in ridged ricefields that use the rice-azolla-fish system can reach 113 877–132 235 kg/ha. Yields of different azolla species vary. The yield of *A. filiculoides* (132 235 kg/ha) was 15.5% higher than that of *A. caroliniana*. In a mixed culture of *A. filiculoides* and *A. caroliniana*, yield (124 417 kg/ha) was between the yield of pure cultures of the two species.

Yields of azolla also varied with different locations (Table 4). In winter (8 November–16 March), *A. filiculoides* propagated more rapidly in the hilly region of Hunan and the yield of fresh azolla reached 47 010 kg/ha. On average, yields doubled in 18.8 days. Yield of *A. filiculoides* were 59.7% greater than yield of *A. caroliniana*. Mixed cultures of these two azolla species, on average, doubled yields in 19.1 days.

During the spring propagation stage in Changsha, in the hilly region of Hunan, *A. filiculoides* also propagated faster than *A. caroliniana*, and the propagation rate of mixed cultures was between the rate for pure cultures. In the region along Dongting Lake in northern Hunan, the yield of *A. filiculoides* was higher than *A. caroliniana*, and the yield of the mixed culture was lowest. Differences in yield were related to the slow rise in temperature in the spring. In the mountainous region of southern Hunan, the propagation rate of different azolla species was the same as in middle Hunan because the temperature rose rapidly in early spring.

Table 3. Effect of the proper arrangement of rice varieties on rice yield.

| Treatment[a] | | Yield (kg/ha) | | |
|---|---|---|---|---|
| | | Early Rice | Late Rice | Total |
| I | Ordinary rice in early season[b] | | | |
| | Rice-azolla-fish | 6364.8 | 6567.4 | 12932.2 |
| | Hybrid rice in late season | | | |
| | Control (rice only) | 6932.6 | 6092.1 | 13024.7 |
| II | Two crops of hybrid rice[c] | | | |
| | Rice-azolla-fish | 7291.6 | 7039.6 | 14331.2 |
| | Control (rice only) | 7613.4 | 7216.5 | 14829.9 |

[a] Ridge width 53 cm; ditch width 40 cm.
[b] Rice varieties used in treatment I: early rice Xiangzao indica I; late rice Wei-You 6.
[c] Rice varieties used in treatment II: early rice Wei-You 49; late rice Wei-You 64.

When azolla was grown between ridges, yields of fresh azolla in the mountainous region of southern Hunan was highest, followed by middle Hunan and northern Hunan. The rapid temperature rise between May–June in northern Hunan affected the propagation rate of azolla. In southern Hunan, the day temperature was high and the difference in temperature between day and night was great, which favoured growth of azolla.

When azolla was cultured on the ridge to over-summer, no matter where it was grown (in middle, northern, or southern Hunan), the propagation rate of *A. caroliniana* was highest, *A. filiculoides* was lowest, and the mixed culture was intermediate. These results reflect the fact that *A. filiculoides* is unable to tolerate high temperatures. Therefore, in winter or spring, it is better to grow *A. filiculoides*, which can tolerate low temperatures; and in summer or autumn, it is better to grow *A. caroliniana*, which can tolerate high temperatures. To compensate for deficiencies in each species, a mixed culture is recommended.

## Yields of Fish

**Effect on azolla.** Four fish species (grass carp, tilapia, crucian carp, and lotus carp) were raised with azolla for 110–112 days. The fish species best suited to the rice-azolla-fish system are grass carp and tilapia (Table 5). Both like to eat azolla and adapt easily to the ricefield environment. The omnivorous crucian carp and lotus carp (which are benthic and planktivorous feeders) can be raised in the ricefield in lower numbers (Table 5). Grass carp and tilapia eat over 60% of their body weight in azolla each day; whereas, crucian carp and lotus carp eat about 8% of their body weight in azolla.

Table 4. The speed of propagation of different azolla species in different locations.

| Location | Winter | | | Spring | | | Growing Between Ridges | | | Summer | | | Autumn | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I[a] | II | III | I | II | III | I | II | III | I | II | III | I | II | III |
| **A. Changsha** | | | | | | | | | | | | | | | |
| *A. filiculoides* | 47 010 | 6.3 | 18.8 | 33 825 | 4.5 | 8.2 | 33 206 | 4.4 | 9.0 | 4 808 | 0.7 | 43.9 | — | — | — |
| *A. caroliniana* | 25 380 | 3.9 | 30.1 | 23 850 | 3.2 | — | — | — | — | — | — | — | — | — | — |
| Ux mixed culture | 46 410 | 6.2 | 19.1 | 25 800 | 3.4 | 10.8 | 24 144 | 3.3 | 12.4 | 6 162 | 0.8 | 35.4 | — | — | — |
| **B. Nan County** | | | | | | | | | | | | | | | |
| *A. filiculoides* | — | — | — | 18 998 | 2.5 | 16.2 | 26 249 | 3.5 | 12.3 | 1 245 | 0.2 | 88.2 | 26 400 | 3.5 | 14.5 |
| *A. caroliniana* | — | — | — | 15 933 | 2.1 | 19.3 | 23 000 | 3.1 | 14.0 | 17 499 | 2.3 | 17.6 | 28 350 | 3.8 | 15.6 |
| Ux mixed culture | — | — | — | 14 490 | 1.9 | 21.2 | 20 123 | 2.7 | 16.0 | 6 162 | 0.8 | 35.4 | 28 073 | 3.7 | 15.8 |
| **C. Guidong** | | | | | | | | | | | | | | | |
| *A. filiculoides* | — | — | — | 36 449 | 4.9 | 8.3 | 42 800 | 5.7 | 7.0 | 29 291 | 3.9 | 11.5 | — | — | — |
| *A. caroliniana* | — | — | — | 21 341 | 2.8 | 14.1 | 43 187 | 5.8 | 7.0 | 60 110 | 8.0 | 5.2 | — | — | — |
| Ux mixed culture | — | — | — | 28 605 | 3.8 | 10.5 | 50 768 | 6.8 | 5.9 | 43 715 | 5.8 | 7.7 | — | — | — |

[a] I = Yield (kg/ha); II = Multiplying (-fold); III = Period of multiplying (days); A = the hilly region in middle Hunan; B = the region along Dongting Lake in Northern Hunan; and C = the mountain region in southern Hunan.

Of the four species, grass carp and tilapia had the highest growth rate. Their body weights increased 4.2 and 6.2 times, respectively. The body weights of crucian carp tended to decrease when they grew to a certain stage, and when lotus carp were fed only azolla, their body weight decreased. The digestibility of *A. filiculoides* (18.1%) was higher than *A. caroliniana* (12.9%) for grass carp and tilapia, respectively. Therefore, *A. filiculoides* is a better food for fish than *A. caroliniana.*

If it is assumed that fish yield was 750 kg/ha and that the amount of azolla eaten per gram of fish daily was 0.605 g/day, the amount of dung excreted by the fish would be 52.9% and it would contained 2.7% N. Therefore, when fish are raised in a ricefield for 100 days, they provide the ricefield with 85.5–103.5 kg N per hectare.

**Effect of different fish species.** When fingerlings bred in spring were raised, yields of rice and azolla were correlated negatively with the proportions of grass carp and tilapia, but yields of fish were correlated positively with the proportions of grass carp and tilapia. To fully use the azolla and the natural resources of the ricefield, the proportion of fish raised should be 60–70% grass-eating grass carp and tilapia and 30–40% omnivorous crucian carp and lotus carp (Table 6).

**Effect of stocking density.** When fingerlings bred in spring were raised, the yields of fish were correlated positively with stocking density. With 30 000 fingerlings/ha, yield of fish was 630 kg, which was 15% higher than the yield obtained from 15 000 fingerlings/ha and 5.6% higher than from 22 500 fingerlings/ha. Therefore, stocking density has an important bearing on fish yields.

Survival rate of fingerlings (e.g., grass carp) was correlated negatively with stocking density. At a density of 15 000 fingerlings/ha, survival rate was 3% higher than at 30 000 fingerlings/ha. Increases in body weight of fish followed a similar trend. When stocking density was 15 000 fingerlings/ha, body weight was 11.4 g heavier than at 22 500 fingerlings/ha and 20.6 g heavier than at 30 000 fingerlings/ha (Table 7).

**Effects of pesticides.** In general, pesticides are applied in the rice-azolla-fish system to control rice pests and diseases. The routine doses of pesticides such as methamidophos, dimethoat, dichlorphos, chlordimeform, trichlorfon, MIPC, and kasugamysin did not harm grass carp, tilapia, crucian carp, and lotus carp. Malathion and EBP were safe for crucian carp and dull carp, but had lethal effects on tilapia. Phenthoate was harmful to all the fish tested. The toxicity of various pesticides to fish was in the order: kasugamucin < methamidophos < trichlorfon < dimethoat < chlordimeform < tetra chlorvinphos < dichlorphos < malathion < phenthoate (Table 8).

Table 5. The total amount of azolla eaten by four fish species (GC grass carp; CC crucian carp; TL tilapia; and LC lotus carp) and the feed conversion efficiency (CF) (plot area 66 $m^2$; water depth 1.2 m; 30 fish stocked; 30 fish harvested 31 July).

| Fish | Stocking Date | Body Weight (g/fish) | Body Weight (g/fish) | Days Raised | Survival Rate | Body Weight Increase (g/fish) | Weight Increase (%) | Azolla Eaten (g) | CF |
|---|---|---|---|---|---|---|---|---|---|
| GC | 9 April | 54.7 | 228.7 | 112 | 100 | 174 | 5 220 | 25 590 | 49.0 |
| CC | 9 April | 75.0 | 110.8 | 112 | 100 | 35.9 | 1 075 | 33 550 | 31.2 |
| TL | 21 April | 24.7 | 163.1 | 100 | 100 | 138.7 | 4 162 | 217 100 | 52.2 |
| LC | 9 April | 96.8 | 92.2 | 112 | 76.7 | 4.6 | 104.2 | 17 810 | 0 |

Table 6. Effect of the proportion of different fish species on yields of rice, azolla, and fish.[a]

| Treatment | Species | Yield of Rice (kg/ha) | | | Yield of Azolla (kg/ha) | Yield of Fish (kg/ha) |
|---|---|---|---|---|---|---|
| | | Early | Late | Total | | |
| I | Grass carp 45% | 4 636.5 | 6 600.0 | 11 236.5 | 47 670 | 628.5 |
| | Tilapia 25% | | | | | |
| | Lotus carp 15% | | | | | |
| | Crucian carp 15% | | | | | |
| II | Grass carp 25% | 4 761.0 | 6 529.5 | 11 290.5 | 51 975 | 633.0 |
| | Tilapia 45% | | | | | |
| | Crucian carp 15% | | | | | |
| | Lotus carp 15% | | | | | |
| III | Crucian carp 35% | 4 458.0 | 6 301.5 | 10 759.5 | 59 700 | 568.5 |
| | Lotus carp 35% | | | | | |
| | Grass carp 15% | | | | | |
| | Tilapia 15% | | | | | |

[a] 22 500 fingerlings bred in the spring are raised per hectare; rice variety used in early season was Zhefu 802; hybrid rice variety used in late season was Wei-You 6; ridge width 53 cm; ditch width 40 cm.

Table 7. The survival rate of fingerlings raised at different densities and their weight increase.

| Species | Fingerlings (per ha) | No. Fish Raised (per ha) | No. Fish Harvest (per ha) | Surv Rate (%) | Avg Body Weight (g) | Yield (kg) | Total Yield (kg) | Total Yield (kg/ha) |
|---|---|---|---|---|---|---|---|---|
| Grass carp | 15 000 | 2220 | 1755 | 79.1 | 53.4 | 93.0 | | |
| Tilapia | | 2220 | 1095 | 49.3 | 45.2 | 49.5 | | |
| Lotus carp | | 555 | 450 | 81.1 | 61.7 | 27.0 | | |
| Crucian carp | | 555 | 450 | 86.5 | 64.1 | 31.5 | 201.5 | 535.5 |
| Grass carp | 22 500 | 3330 | 2535 | 76.1 | 62.0 | 106.5 | | |
| Tilapia | | 3330 | 540 | 16.2 | 47.2 | 25.5 | | |
| Lotus carp | | 840 | 630 | 75.0 | 54.8 | 34.5 | | |
| Crucian carp | | 840 | 705 | 83.9 | 51.1 | 36.0 | 202.5 | 592.5 |
| Grass carp | 30 000 | 4440 | 2925 | 65.9 | 32.8 | 96.0 | | |
| Tilapia | | 4440 | 1110 | 25.0 | 43.2 | 48.0 | | |
| Lotus carp | | 1110 | 615 | 55.4 | 56.1 | 34.5 | | |
| Crucian carp | | 1110 | 1005 | 90.5 | 50.8 | 51.0 | 229.5 | 630.0 |

## Conclusion

In a rice-azolla-fish system that includes ridge culture, the ricefield should be constructed with: ridges 53-106 cm wide, ridge ditches 40 cm wide and 20-25 cm deep, a main ditch (50 cm wide and 50 cm deep) in the centre of the field, and deep ditch (50 cm wide and 50 cm deep) surrounding the ricefield. A fish pit (80-100 cm deep) should occupy 3-10% of the total area of the ricefield. Of the fingerlings raised in the pit, 3-5% are bred in spring and 8-10% are overwintering fingerlings. Soybean and melon can also be planted around the pit.

High-yielding rice varieties are used. Two crops of hybrid rice are planted with wide row spacing and narrow plant spacing to increase the border effect and enhance the use of light. In a ricefield of ordinary rice, 300 000-375 000 hills of seedlings per hectare (5-7 seedlings/hill) are planted; if hybrid rice is used, 225 000-300 000 hills of seedlings per hectare (1-2 seedlings/hill) are planted.

Table 8. The safe concentration of different pesticides to four fish species in 72 hours.

| | Crucian Carp | | Tilapia | | Dull Carp | | Lotus Carp | |
|---|---|---|---|---|---|---|---|---|
| Pesticides | I[a] | II | I | II | I | II | I | II |
| Methamidophos | 23-30 | 110 | 18-22 | 50 | 23-27 | 78.5 | 18-20 | 79.5 |
| Dimethoat | 25-30 | 53 | 23-26 | 21.2 | | | 23-25 | 53 |
| 4049 | 21-24 | 6.9 | 22-25 | 2.1 | 23-27 | 17.6 | 23-26 | 10.6 |
| Dichlorphos | 25-28 | 12.9 | 24-26 | 9.2 | 24-30 | 11.7 | 22-23 | 10.7 |
| Tetrachlorvinphos | 25-28 | 25.2 | 21-23 | 31.5 | | | 21-24 | 31.5 |
| Trichlorfon | 25-28 | 50 | 22-24 | 8.3 | | | 21-24 | 25 |
| Chlordimeform | 21-24 | 55.5 | 22-24 | 22.2 | 23-27 | 92.5 | 23-27 | 22.2 |
| MIPC | 23-24 | 1 250 | 23-30 | 420 | 23-27 | 416 | 23-25 | 665 |
| EBP | 25-28 | 6.1 | 24-26 | 3 | | | 22-27 | 9 |
| Kasugamucin | 21-24 | 4 590 | 22-26 | 2 750 | 23-27 | 3 500 | 23-25 | 4 440 |

[a] I = water temperature (°C); II = safe concentration (ppm).

More P and K fertilizers and less N fertilizer are applied in deep placement. Late rice seedlings can be transplanted without tillage. Attention must be paid to field management. The water level on the ridge surface should be regulated according to the growth stage of the rice.

Low-temperature tolerant *A. filiculoides* and high-temperature-tolerant *A. caroliniana* can be grown. In general, 300-500 kg of *A. filiculoides* are planted in the field in early or middle March, and 200-400 kg of *A. caroliniana* are planted 7 days after transplanting early or medium rice. Mixed culture of these two azolla species is possible.

Suitable fish species are grass carp, tilapia, crucian carp, and lotus carp. All four species like to eat azolla, grow rapidly, and adapt themselves to the ricefield environment. The fingerlings (grass carp and tilapia 60–70%; crucian carp and lotus carp 30–40%) are released into the ricefield in early May. Generally, 6 000–12 000 overwintered fingerlings or 30 000–45 000 fingerlings bred in the spring are raised per hectare.

Routine dosages of common pesticides are safe to these four fish species. However, malathion and EBP are lethal to tilapia, and phenthoate is harmful to all of the fish.

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# Semisubmerged Cropping in Rice–Fish Culture in Jiangxi Province

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Most of the 0.5 million ha of croplands in Jiangxi Province are pit fields, ridged fields, alluvial fields, and low grounds near the lakeside. These areas make up about 20% of the total ricefields in Jiangxi, but they are mostly cold, waterlogged, middle- or low-yield plots. The high water table is mainly responsible for the poor drainage of accumulated water. Constant water saturation has turned the soil to gley, which is cold, infertile, acidic, poisonous and lacks oxygen. Under these conditions, water, nutrients, air, and temperature are unfavourable to the growth and development of rice. Most regions yield one crop of rice a year, i.e., middle–late rice, but yield is low. To transform these low-yielding lands and increase crop production, a semiarid rice production initiated by Professor Hou Guangjiong was introduced in 1986 into the mountainous area of Gannan Prefecture, Jiangxi Province. This method of *semisubmerged cropping in rice–fish culture* has been improved to suit local conditions and has increased crop yields.

## Main Principles

This method makes drastic changes to the system of rice cropping: planting on mounds instead of in furrows, putting ridges and ditches side by side to change the conditions in the field and add an active layer, planting rice on dikes, and culturing azolla and fish in the ditches. The physical changes raise the temperature of the soil and water, speed the catabolism of organic matter and the release of nutrients, and decrease the effect of toxic substances. As a result, seedlings revive sooner after transplanting, grow quickly, and have more white roots.

This method of rice–fish culture can turn single-crop agriculture into a double or multiple-harvest system and the slack winter season into a busy time. It is an excellent model of ecological agriculture that is applicable in all districts.

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### Continuous Nontillage

After the topsoil is ploughed for the first time, ridges and ditches are constructed side by side in the fields. Rice is planted on the ridges and fish are cultured in the ditches. Thereafter, the topsoil is not ploughed or harrowed to ensure that the active top layer is not destroyed. The soil does not become a caked mass; it grows softer with time. If the topsoil is ploughed, pockets of air and water capillaries in the soil are blocked. This decreases the percolation ratio, destroys the soil structure and the balance of water, nutrients, air, and temperature, and, as a result, reduces crop yields.

### Continuous Ridge Tillage

Ridge tillage raises both the temperature of the water and soil and the oxidation-reduction potential of the soil. It activates soil nutrients and reduces toxic substances. This stabilizes the water, nutrients, air, and temperature and makes conditions more suitable for the growth and development of rice.

### Continuous Infiltration

Capillary water in the soil is the only form of water that contains available nutrients and can flow freely, aerate the soil, and conduct heat. The key to semisubmerged cropping is improving the hydrological system of the soil. The continuous infiltration of capillary water aerates the soil, conveys nutrients, and prevents the soil from becoming a caked mass. The water level must be controlled according to the growth of the rice and the needs of the fish.

## Demonstration and Application

### No Tillage, Rice on the Ridge, Fish in the Ditch

Experiment were carried out for the first time in 1986 in Longhui Village, Nankang County, Ganzhou Prefecture, in cold, waterlogged mountain fields with an area of 0.3 ha. In 1987, the area was increased to 2 ha. Experiments were also carried out in lateritic low-yield plots at Luoding Village, Xingjiang County, and in a waterlogged lowland area near the lakeside at the Dongfeng Branch Farm of the Hongxing State Reclamation Farm. The total experimental area in these two areas was about 1.3 ha. In 1988, the method was popularized in over 1 330 ha in several counties (Ruijing, Nankang, Shicheng, Xingfeng, and Shangyou). In Ruijing County alone, there were 667 ha. Rice and fish were equally emphasized. In a few of the experimental plots, azolla was also cultured. The method was extended by the Agriculture, Animal Husbandry and Fish Department to an area of 200 ha in the counties of Fuzhou Prefecture.

Table 1. Output (kg/ha) of rice–fish culture (rice-on-ridge ROR; rice-on-bed ROB) compared with output (kg/ha) of conventional flat cropping (CONV). Values of output expressed as CNY.

| | ROR | CONV | Increase kg/ha | Increase % | ROB | CONV | Increase kg/ha | Increase % |
|---|---|---|---|---|---|---|---|---|
| Rice yield | 10 896 | 8 673 | 2 223 | 25.6 | 7 504 | 6 825 | 680 | 10.0 |
| Value of rice | 3 886 | 3 456 | 430 | 27.5 | 2 979 | 2 554 | 425 | 15.4 |
| Value of fish | 2 012 | 0 | 2 012 | — | 1 539 | 0 | 1 539 | — |
| Total value | 5 898 | 3 456 | 2 442 | 86.3 | 4 518 | 2 554 | 1 964 | 75.7 |

Table 2. Fish output (kg/ha) and economic benefits of two new methods (CNY/ha).

| | Number of Households | Fish Output | Breeding Cost | Net Income |
|---|---|---|---|---|
| Rice-on-ridge, fish-in-trench | 8 | 3 333.0 | 885.0 | 2 448.0 |
| Rice-on-bed, fish-in-trench | 6 | 1 288.5 | 109.5 | 1 179.0 |
| Difference | — | 2 044.5 | 775.5 | 1 269.0 |

## Rice on the Bed, Fish in the Ditch

In 1987, this method was demonstrated on 2.8 ha in Shangyon County, Ganzhou Prefecture. The method features a wide ridge (0.8–1.2 m) that is constructed after the topsoil is ploughed. Rice is planted 13–17 cm apart on beds in rows that are 20 cm apart; fish and azolla are cultured in the ditch.

## Benefit Analysis

Because management of agricultural production is presently carried out by individual households, the experiments, demonstrations, and applications were arranged at the household level. During the entire production period, technicians were sent to the areas to provide technical advice, conduct quality inspections, and observe and record results. The results are analyzed and compared in Tables 1–3.

Compared with conventional flat cropping, there were considerable increases in rice output and income from fish whether the rice-on-ridge or the rice-on-bed method was used. For example, 11 households used the rice-on-ridge method.

Table 3. Comparison of economic benefits of different combinations of fish species reared using the rice-on-ridge, fish-in-trench method.

| | Area (ha) | Cost (CNY/ha) | Output Value (CNY/ha) | Net Income (CNY/ha) |
|---|---|---|---|---|
| Grass carp | 0.21 | 199.2 | 698.4 | 499.2 |
| Common carp | 0.31 | 38.2 | 651.0 | 612.8 |
| Grass carp, common carp, and silver carp | 0.14 | 889.4 | 2 988.9 | 2 099.5 |
| Grass carp, common carp, and variegated carp | 0.10 | 501.0 | 2 299.9 | 1 798.9 |
| Grass carp, common carp, silver carp, and variegated carp | 0.28 | 1 258.4 | 4 190.1 | 2 931.7 |

Their average rice output increased by 2 223 kg/ha (range 420–7140 kg/ha) and average net income from fish was CNY2 010/ha (range CNY450–4 935/ha). When the value of the fish and the increased amount of rice were both counted, the total rate of increase in value was 36.5–216.9% (average 86.3%). In another four households that used the rice-on-bed method, the increase in rice production was 680 kg/ha (range 530–990 kg/ha) and the net value of the fish was CNY1 540/ha (range CNY531–3 170/ha). The total net value of fish and rice increased by 76% (Tables 1 and 2).

The rice-on-ridge method is superior to the rice-on-bed method because it improves the ecological environment of the farmland (and enhances the growth of rice) and because it has a larger area of water, which is favourable for fish breeding. Higher economic benefits were obtained from the rice-on-ridge method when mixed species of fish, instead of a single species, were raised (Table 3).

## Soil Improvement

Professor Hou Guangjiong has reported many improvements in the soil using the rice-on-ridge, fish-in-trench, no-tillage method of semiarid rice cultivation. Preliminary observations, suggest that unit weight of the soil decreases, temperature increases, and that the soil contains more organic matter, total nitrogen, available nitrogen, phosphorus, and potassium (in some cases, there was a tendency toward less total phosphorus compared with conventional flat cropping) (Tables 4–6).

Table 4. Reduction in soil unit weight (g/cm$^3$) as a result of semiarid fish culture.

| Household | Semiarid Fish Culture | Flat Cropping | Reduction |
|---|---|---|---|
| Zhu Longpeng | 1.11 | 1.21 | 0.10 |
| Zhu Changrui | 0.96 | 0.98 | 0.02 |
| Zhu Qiusheng | 0.84 | 1.14 | 0.30 |
| Zhu Xiaoping | 0.85 | 0.93 | 0.08 |
| Zhu Changfa | 0.74 | 1.01 | 0.27 |
| Lin Yuanxiao | 0.84 | 0.95 | 0.11 |
| Lin Chuanrong | 0.98 | 1.00 | 0.02 |
| Lin Yuanrong | 0.97 | 0.99 | 0.02 |
| Mean | 0.91 | 1.03 | 0.12 |

## Remaining Problems

In experiments and demonstrations, the semiarid rice-on-ridge, fish-in-trench method has remarkably increased production and income and improved soil conditions. In 1989, the Prefectural Department of Ganzhou planned to apply the new method on 33 330 ha. Farmers who had become aware of the benefits of the method were happy. But, to extensively disseminate any new technique, potential problems should be examined and addressed.

Farmers do not believe that rice can be grown without ploughing the field. For thousands of years, rice has been planted in water using the flat basin irrigation cropping method. Ricefields with ridges are new. Most farmers doubt that the rice plants can absorb water and nutrients when they are planted on the ridges. Some farmers also complain that the ridges make it difficult for them to put their threshing tubs and machines in the fields at harvest time. More demonstration and extension efforts are needed to overcome these problems.

Many places have no previous experience with raising fish in ricefields. There are also some social problems. Fish in the fields are often stolen, especially in cold, waterlogged fields that are usually located in remote mountain areas. Farmers worry about this. Local governments must strictly enforce the law to protect farm production from theft. The villagers could also develop some protective measures.

The farming activities in the new method (e.g., digging trenches, forming ridges, clearing mud from the trenches, and applying fertilizer) require much labour. In Longhui Township, Nankang County, a small iron spade that was light and handy for clearing mud from trenches was popularized. Labour-saving tools or devices

Table 5. Soil temperatures (°C) at different depths with different cropping systems.

| | | Semiarid Rice and Fish Culture | | Flat Cropping | | Differences in Temperature | |
|---|---|---|---|---|---|---|---|
| Households | Time | 0–10 cm | 10–20 cm | 0–10 cm | 10–20 cm | 0–10 cm | 10–20 cm |
| **Zhu Longpeng** | | | | | | | |
| May 11 | 11:00 | 24.5 | 24.2 | 24.1 | 23.7 | 0.4 | 0.5 |
| May 14 | 10:00 | 23.7 | 23.6 | 23.4 | 23.2 | 0.3 | 0.4 |
| May 17 | 10:00 | 25.0 | 24.8 | 24.6 | 24.5 | 0.4 | 0.3 |
| Mean | — | 24.4 | 24.2 | 24.0 | 23.8 | 0.4 | 0.4 |
| **Zhu Changgui** | | | | | | | |
| May 11 | 12:00 | 24.5 | 24.3 | 24.0 | 23.8 | 0.5 | 0.5 |
| May 14 | 11:00 | 23.9 | 23.7 | 23.5 | 23.2 | 0.4 | 0.5 |
| May 17 | 11:00 | 25.1 | 24.9 | 24.5 | 24.3 | 0.6 | 0.6 |
| May 19 | 11:00 | 21.0 | 20.8 | 20.5 | 20.3 | 0.5 | 0.5 |
| Mean | — | 23.6 | 23.4 | 23.1 | 22.9 | 0.5 | 0.5 |
| **Zhu Changfa** | | | | | | | |
| May 11 | 11:00 | 25.0 | 24.8 | 24.6 | 24.4 | 0.4 | 0.5 |
| May 14 | 11:00 | 24.0 | 23.7 | 23.5 | 23.3 | 0.5 | 0.4 |
| May 17 | 11:00 | 25.1 | 24.9 | 24.5 | 24.3 | 0.6 | 0.6 |
| May 19 | 14:00 | 21.4 | 21.3 | 21.0 | 20.7 | 0.4 | 0.6 |
| Mean | — | 23.9 | 23.7 | 23.4 | 23.2 | 0.5 | 0.5 |

Table 6. Analysis of soil nutrients (semiarid SA; conventional C).

| | Organic Matter | | Total N | | Total P | | Available N | | Available P | | Available K | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SA | C | SA | C | SA | C | SA | C | SA | C | SA | C |
| (1)[a] | 4.30 | 3.49 | 0.146 | 0.102 | 0.019 | 0.012 | 76.5 | 64.9 | 6.69 | 3.11 | 28.3 | 29.8 |
| (2) | 4.91 | 3.34 | 0.111 | 0.115 | 0.007 | 0.003 | 51.0 | 56.9 | 4.48 | 3.12 | 48.3 | 39.8 |
| (3) | 4.62 | 2.60 | 0.116 | 0.094 | 0.014 | 0.020 | 42.2 | 40.7 | 5.22 | 3.37 | 46.1 | 41.0 |
| (4) | 4.46 | 3.46 | 0.165 | 0.113 | 0.007 | 0.016 | 178.3 | 92.0 | 7.70 | 6.45 | 54.4 | 35.4 |
| (5) | 3.42 | 2.79 | 0.114 | 0.100 | 0.013 | 0.022 | 87.4 | 71.7 | 4.53 | 3.84 | 99.1 | 43.6 |
| (6) | 4.30 | 3.66 | 0.149 | 0.138 | 0.012 | 0.007 | 69.5 | 67.2 | 4.52 | 7.44 | 87.5 | 49.5 |
| Avg | 4.34 | 3.21 | 0.134 | 0.110 | 0.012 | 0.013 | 84.2 | 65.6 | 5.52 | 4.56 | 60.6 | 39.8 |

[a] Households were (1) Zhu Longbin, (2) Zhu Changrui, (3) Zhu Longze, (4) Zhu Xiaoping, (5) Zhu Xidi, and (6) Lin Yuan Xiao.

for trench digging, ridge forming, and row fertilization need to be developed. When a new technique is applied in a large area, farmers, because of their different levels of understanding, sometimes fail to follow the technical requirements for certain farming activities. Because of this, not only should extension and guidance be stressed, but input supplies, such as chemical fertilizers and pesticides, must also be made available.

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# Rice–Azolla–Fish Symbiosis

*Wang Zaide, Wang Pu, and Jie Zengshun*[35]

Rearing fish and *Azolla* spp. in ricefields is an important component of traditional organic farming in China. Rice–azolla–fish symbiosis is a new development in ecological agriculture. The results of a 2-year field experiment indicate that rearing fish and azolla in ricefields increases the output of rice, azolla, and fish.

The highest output of rice was obtained from the rice–azolla–fish system (7 096.2 kg/ha). This was an increase of 9.3% compared with the control. The rice–azolla system had the next highest yield, followed by rice–fish culture and the control. The coefficient of use of light energy was highest for the rice–azolla system, followed by rice–azolla–fish, rice–fish, and the control (Table 1).

Output of fish was highest in the rice–African catfish fry field (717.0 kg/ha), followed by food fish reared in the rice–azolla–fish field (536.3 kg/ha). The lowest fish output (265.4 kg/ha) was obtained from food fish (Table 2).

The cost of inputs of seed, fertilizer, labour, and fry were compared with the outputs of rice, straw, and fry. Total net income was highest for the rice–azolla–fish field (CNY8 814.5/ha); an increase of CNY4 521.8/ha over the control. The incomes from the other systems were: rice–fish (CNY7 968.3/ha), rice–azolla (CNY4 637.9/ha), and the control rice plot (CNY4 292.7/ha) (Table 3).

Table 1. Effects of rice–azolla–fish symbiosis on rice output (CLE coefficient of light energy).

| Treatment | Rice Output (kg/ha) 1985 | 1986 | Average | Increase | (%) | Biomass (kg/ha) | CLE |
|---|---|---|---|---|---|---|---|
| Rice–azolla–fish | 5 713.5 | 8 478.0 | 7 096.2 | 602.8 | 9.3 | 19 877.1 | 1.12 |
| Rice–azolla | 5 277.8 | 8 531.3 | 6 904.6 | 411.1 | 6.3 | 20 370.0 | 1.14 |
| Rice–fish | 5 177.3 | 8 288.3 | 6 732.8 | 239.3 | 3.7 | 14 792.5 | 0.83 |
| Rice (control) | 4 846.5 | 8 140.5 | 6 493.6 | – | – | 14 328.0 | 0.81 |

[35] Beijing Agricultural University, Beijing, Beijing Municipality.

Table 2. Effects of rice and rice-azolla-fish on fish growth and output.

| | Size of Fish (cm) | Fish per ha | Fish Survival (%) | Weight of One Fish (kg) | Output of Fish (kg/ha) |
|---|---|---|---|---|---|
| Rice-azolla-African fish fry | 2.5 | 22 500 | 62.0 | 0.023 | 324.4 |
| Rice-azolla-carp fry | 1.5 | 7 500 | 93.1 | 0.060 | 418.7 |
| Rice-azolla-grass carp fry | 2.5 | 22 500 | 61.5 | 0.020 | 280.4 |
| Rice-azolla-food fish | 1.5 | 7 500 | 93.2 | 0.075 | 536.3 |
| Rice-African fish fry | 3.0 | 11 625 | 84.1 | 0.073 | 717.0 |
| Rice-carp fry | 2.5 | 22 500 | 49.0 | 0.023 | 249.4 |
| Rice-grass carp fry | 3.0 | 11 625 | 78.6 | 0.049 | 450.8 |
| Rice-food fish | 2.5 | 22 500 | 51.5 | 0.023 | 265.4 |

Table 3. Economic effects of rice-azolla-fish symbiosis [RAF rice-azolla-fish; RA rice-azolla; RF rice-fish; and R rice (control)].

| | Inputs (CNY/ha)[a] | | | Output (CNY/ha) | | | | Net | |
|---|---|---|---|---|---|---|---|---|---|
| | Labour | Fry | Total | Rice | Straw | Fry | Total | Income | Increase |
| RAF | 1 245 | 120 | 1 879 | 5 765.5 | 423.9 | 6 000 | 10 689.0 | 8 814.5 | 4 521.9 |
| RA | 1 080 | — | 1 590 | 5 801.3 | 426.6 | — | 6 227.9 | 4 637.9 | 345.2 |
| RF | 1 245 | 120 | 1 879 | 5 634.0 | 414.3 | 5 060 | 9 850.8 | 7 968.3 | 3 675.8 |
| R | 1 140 | — | 1 650 | 5 535.6 | 407.1 | — | 5 992.7 | 4 292.7 | — |

[a] All treatments included the following inputs: seed CNY120/ha, chemical fertilizer CNY352.9/ha, and agricultural chemicals CNY37.5/ha.

The rice-azolla-fish system had obvious economic benefits. In the rice-azolla-fish system, rice output and net income were higher than the control, and there were good ecological effects as well. Soil organic matter was highest in the rice-azolla-fish system (1.4), followed by rice-azolla and rice-fish (1.25) and the control (1.09). The pH was highest in the control (8.66) and lowest in the other fields (8.03-8.02). Nitrogen content was the highest in the rice-azolla field (0.081), followed by rice-azolla-fish, rice-fish, and the control.

Table 4. The ecological effects of rice-azolla-fish symbiosis on the chemical properties of soil.

| | Organic Matter | Total Nitrogen | pH | Total Salts | Cl | $HCO_2$ |
|---|---|---|---|---|---|---|
| Rice-azolla-fish | 1.4 | 0.0771 | 8.02 | 0.016 | 0.008 | 0.026 |
| Rice-azolla | 1.25 | 0.0810 | 8.02 | 0.019 | 0.008 | 0.027 |
| Rice-fish | 1.23 | 0.0742 | 8.03 | 0.016 | 0.008 | 0.028 |
| Rice (control) | 1.09 | 0.0724 | 8.66 | 0.042 | 0.009 | 0.032 |

The rice-azolla-fish, rice-azolla, and rice-fish systems improved the physical and chemical properties of the soil (Table 4), reduced cost, diseases, pests, and weeds, and avoided environmental pollution.

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# Economic and Ecological Benefits of Rice-Fish Culture

*Li Xieping, Wu Huaixun, and Zhang Yongtai*[36]

Research on the economic and ecological benefits of rice-fish culture was conducted in 1985-1987. The objectives were to more fully exploit agricultural resources in rural areas and to improve field productivity. A 0.1-ha experimental field at the Li-Xia-He Regional Agricultural Institute was used. In total, there are more than half a million hectares in Li-Xia-He where the cropping system is wheat and rice. In general, the soil is a heavy clay that is low in elevation and has good water retention. Conditions for rice-fish are good.

Normal hybrid rice (Xian-you 63) and a hybrid (Xian-you 63P, developed by the Yangzhou Regional Agricultural Institute) were planted under single factorial designs for 3 years. The variable factors were density, planting pattern, fertilization strategy, and amount of nitrogen. Experiments were carried out simultaneously in 0.001-ha plots with three replicates, and in 0.04-ha test fields with two replicates. Two types of cultivation were used, one for fry, the other for mature fish. Each method of cultivation was subjected to a number of treatments to test the effects of different proportions of fish species, stocking size of fish, and density. A ricefield without fish was used as the control.

The main fish species used were Fu-shou fish (*Oreochromis mossambicus* x *O. niloticus* $F_1$), grass carp (*Ctenopharyngodon idella*), and common carp (*Cyprinus carpio*) with a small proportion of bighead carp (*Aristichthys nobilis*) and white crucian carp (*Carassius cuvieri*).

After the fields were ploughed, fish trenches, 0.33-m wide and 0.40-m deep, were dug in an X pattern. At the cross points of the trenches, two fishponds (each 2.5-m long, 1-m wide, and 1-m deep) were constructed. The area of the trenches and ponds was 3.5% of the total area of the field. Fingerlings were stocked in the ricefield 10-17 days after the rice was planted and were fed mainly azolla and fresh grass and a small proportion of grain products. For 30 days after stocking, the fish were fed 4.5-6.0 kg/ha of wheat flour with small amounts of azolla each day. After 30 days, 7.5-15 kg of grain products and 75-150 g/ha of fresh grass were fed each day. The amount of feed was increased as the fish grew. The water in the field was normally kept at a depth of 3-10 cm, but the level was lowered for several days before differentiation of the rice panicles to dry the field slightly. The

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[36] Li-Xia-He Regional Agricultural Research Institute, Yangzhou, Jiangsu Province.

field was drained twice during the filling stage. The control plot was under regular water management.

The number of rice stems and tillers, the number of weeds, plant and soil nutrients, and the amount of sunlight penetrating to the bottom of the rice plants were determined. After harvesting, the ears and characteristics of the rice plants were measured. The number of fish harvested, their individual weights, and the yields of rice and fish were determined.

## Economic Benefits

### Yield of Rice

Yields of rice each year were 9 054 kg/ha (1985), 7 929 kg/ha (1986), and 7 848 kg/ha (1987) in the control field and 8 662, 7 884, and 7 997 kg/ha in the ricefield with fish. Rice yields in the field with fish were lower by 4.3% in 1985, but in 1986–1987, the yields were almost the same. Because the area of fish trenches and ponds occupied 3.5% of the total area of the field, and the actual planting area had been reduced by 7.0%, it can be concluded that the yields of individual rice plants in the rice-fish field increased in 1986-1987. This increase offset losses from the reduction in planting area; therefore, yields of rice with or without fish in the field were about the same.

### Yield and Value of Fish

In 1985, the average yield of fish from two ricefields was 524 kg/ha valued at CNY1 730/ha. In 1986, despite predation by snakehead fish (*Ophiocephalus argus*), the average yield of four plots was 442 kg/ha valued at CNY1 750/ha. The highest yield was 615 kg. In 1987, there was a shortage of fingerlings and appropriate species, and a large number of fish escaped. The average yield of four plots was 208 kg/ha valued at CNY989/ha. The highest yield was 300 kg. The average value of fish for the three years was CNY1 490/ha with a net income of CNY991/ha.

### Net Income

The average investment in rice-fish culture was CNY1 009/ha. This was CNY406 more than the control and an increase of 67.3%. The reduced use of pesticide and chemical fertilizer in the rice-fish field lowered costs by 16-25% (1986-1987). When the increase in yield and the reduced costs are considered, the net income for the rice-fish field each year was CNY1 090/ha (1985), CNY1 222/ha (1986), and CNY796/ha (1987) more than in the control. The average was CNY1 036/ha, which is 40% of the total income from the control (Table 1). These results indicate that the cultivation of fish in ricefields does not significantly reduce rice yields and that cost reductions and increases in net income are significant.

Table 1. Yield, cost, and net income from rice-fish (1985-1987).

| Year | Type of Field | Yield (kg/ha) | | Cost (CNY/ha)[a] | | Net Income (CNY/ha) |
|---|---|---|---|---|---|---|
| | | Rice | Fish | Rice | Fish | |
| 1985 | Control | 9054 | – | 459 | – | 2438 |
| | Rice-fish | 8667 | 525.2 | 459 | 516 | 3528 |
| 1986 | Control | 7929 | – | 717 | – | 2422 |
| | Rice-fish | 7884 | 441.8 | 601 | 625 | 3644 |
| 1987 | Control | 7998 | – | 636 | – | 2854 |
| | Rice-fish | 7996 | 207.8 | 473 | 353 | 3650 |

[a] Includes insecticide, chemical fertilizer, fingerlings, and fish food.

## Ecological Effects

### Weed Reduction

In 1985, the ricefields had four species of weeds [wild arrowhead (*Sagittaria* sp.) was the main species]. Before the fingerlings were stocked, there were 408.6 weeds/$m^2$ in the control and 519.3 weeds/$m^2$ in the rice-fish field. Twenty days after the fingerlings were stocked, there were 131.4 weeds/$m^2$ in the rice-fish field (a reduction of 75%). Although the number of weeds in the control plot (289.8/$m^2$) also decreased, there were still twice as many as in the rice-fish field. The weight of the fresh weeds in the control plot was 2 268 kg/ha, which was 5.5 times more than in the rice-fish field. The number of weed species in the control increased to more than ten.

When the rice plants in the rice-fish field reached the stages of booting and filling, the lower part of the plants were clean and the surface of the field had only 9 weeds/$m^2$. There were 248.4 weeds/$m^2$ in the control with a fresh weight of 244.8 kg, which was 17 times more than in the field with fish. Before stocking, the number of weeds in the control increased from 408.6 in 1985 to 501.3 in 1987. In the field with fish, the number of weeds decreased from 519.03 in 1985 to 176.4 in 1987. Apparently, the cultivation of fish in a ricefield reduces weeds during that year, and also has long-term effects.

### Soil Fertility

The fish in a ricefield can transform insoluble nitrogen in the soil into a soluble state, which increases soil fertility. Although the control plot used less fertilizer, the fertility in the rice-fish field improved significantly from 1985 to 1987. The

Table 2. Effects of rice-fish culture on unit weight and porosity of topsoil.

| Year | Depth (cm) | Type of Field | Weight ($g/m^3$) | Porosity (%) |
|---|---|---|---|---|
| 1985 | 0–10 | Rice-fish | 1.378 | 48.40 |
| | | Control | 1.417 | 46.82 |
| | 10–20 | Rice-fish | 1.504 | 43.32 |
| | | Control | 1.554 | 41.36 |
| 1986 | 0–10 | Rice-fish | 1.310 | 50.57 |
| | | Control | 1.279 | 51.73 |
| | 10–20 | Rice-fish | 1.462 | 44.83 |
| | | Control | 1.527 | 42.38 |

percentage of organic material in the soil increased from 2.0 to 2.4%, total nitrogen from 0.14 to 0.16%, soluble phosphorus increased by 76.1%, and potassium by 20.69%. These results are similar to those reported by the Sanming Agricultural Research Institute in Fujian Province.

### Physical Characteristics of Soil

The stirring movements of the fish aerate the soil and improve its structure. Vertical sections of the soil at depths of 0–20 cm were tested in 1985 and 1986. In rice-fish fields, the unit weight of topsoil was 2.1% lower than in the control, and porosity was greater by 1.2%. This effect was more obvious for subsoil. At depths of 10–20 cm, the unit weights of soil in rice-fish fields were 3.2 and 4.3% lower than in the control, and porosity was greater by 2.0 and 2.4% (Table 2).

### Losses from Insects

Fish eat insects that float on the water surface and mosquito larvae in the water. Fu-shou fish and carp jump to catch rice lice (*Sogata furcifera*) in the lower stems of rice plants. In early September (the season during which rice lice emerge), the number of rice lice per 100 holes of rice was 234 in the control and 424 in the rice-fish plots. Ten days later, the rice-fish plot had only 42 rice lice, and the control had 138.1% more lice although insecticide was used in the control. Therefore, less insecticide can be used in rice-fish fields.

### Nitrogen in Rice

The cultivation of fish in the ricefield increased the amount of nitrogen in the soil and the amount of nitrogen absorbed by the rice plants. In 1987, the total nitrogen

Table 3. Effect of planting density on yields of different rice hybrids.

| | Regular Xian-you 63 | | | | Xian-you 63P | | | |
|---|---|---|---|---|---|---|---|---|
| | 1985 | | | | 1986 | | 1987 | |
| Planting density ($10^4$/ha) | 37.5 | 30.0 | 22.5 | 15.0 | 30.0 | 22.5 | 28.1 | 22.5 |
| Control yield (kg/ha) | 9 315 | 9 051 | 9 105 | 8 543 | 7 638 | 7 929 | 7 917 | 8 081 |
| Rice-fish yield (kg/ha) | 8 615 | 8 697 | 8 838 | 8 471 | 6 170 | 7 884 | 7 944 | 8 049 |

content of rice plants during the booting stage was higher by 35.9% in the field with fish than in the control field, although the control plot had used 22.7% more fertilizer. Therefore, in the rice-fish field, more nitrogen is transported to the rice grains. The nitrogen content of rice from the rice-fish field was 11.2% in 1986 and 10.9% in 1987 (or 0.8% and 1.0% higher than the control). The quality of the rice in the fields with fish was better.

## Factors Affecting Yields of Rice in Rice-Fish Fields

### Planting Density

The yield of rice for a specific variety usually correlates positively with planting density. In practice, the upper limit of density is usually used. However, the same variety planted in a rice-fish field, would produce a different yield. In an experiment in 1985, densities within the range of 150 000-375 000 holes/ha were used for hybrid rice. The yield of the control plot increased with density,; whereas, yield in the rice-fish field decreased. With densities of 300 000 holes/ha and 375 000 holes/ha, yields from rice-fish fields were lower than the control by 3.9% and 7.5%; however, the decreases in yield were not statistically significant. Similar results obtained in 1986 and 1987 (Table 3) indicated that densities of 300 000 holes/ha or below did not affect the yield of hybrid rice.

The main reason for this effect on yield is the type of water management used in the rice-fish field. Taller plants, larger leaves, and longer nodes are produced, and at high densities, the population becomes too large, which decreases ventilation and illumination at the bottom of the rice plants. The development of the rice plant is stunted, which makes it vulnerable to insect pests, diseases, and lodging during bad weather. In contrast, at relatively lower densities, rice plants grow fast, individuals are strong, and plants are more resistant to lodging.

Therefore, the appropriate planting density for rice-fish fields is the lower limit for the variety (usually 10-20% lower than the density used under regular cultivation). For hybrid rice (Xian-you 63) the following parameters are suggested: distance

Table 4. Ear characteristics of rice under different nitrogen levels [Treatments (Treat.) C control; RF rice-fish].

| Year | Hybrid | Treat. | Nitrogen (kg/ha) | Number of Grains per Ear | Green Seed Grains per Ear (%) | 1 000-Grain Weight (g) | Yield (kg/ha) |
|---|---|---|---|---|---|---|---|
| 1985 | Xian-you 63 | C | 218 | 152.2 | 91.4 | 29.8 | 9 054 |
| | | RF | 218 | 153.3 | 89.1 | 29.1 | 8 667 |
| 1986 | Xian-you 63P | C | 280 | 142.6 | 87.9 | 28.2 | 7 929 |
| | | RF | 226 | 138.3 | 87.6 | 28.6 | 7 884 |
| 1987 | Xian-yo 63P | C | 275 | 152.7 | 83.6 | 28.9 | 7 998 |
| | | RF | 224 | 152.5 | 82.6 | 28.8 | 7 996 |

between rows (26-33 cm), distance between holes (11-13 cm) with 270 000 holes/ha and 1 200 000-1 350 00 stems and tillers per hectare. As the rice grows, the highest number of stems and tillers will reach 3 900 000/ha and there will be 2 400 000-2 700 00 ears/ha. This planting density produces a good population structure, well-developed individuals, and high yields.

### Fertilizer

If the amount of fertilizer used for regular cultivation is used in rice-fish fields, it will upset the carbon-nitrogen ratio and reduce soil fertility, weight per 1 000 grains, and yield. For Example, in 1985, the same amount of fertilizer was used in both the control and the rice-fish field. Grain-seed percentage decreased by 2.3%, weight per 1 000 grains by 0.7 g, and yield by 4.3%.

In 1986 and 1987, the amount of fertilizer applied in the rice-fish field was 19.2% and 18.5% less than in the control. The grain-seed percentage, average weight per 1 000 grains and yield were about the same as in the control. However, the level of nitrogen was 22.8% higher in rice from the rice-fish field. To achieve high and stable yields of rice from rice-fish, 20% less fertilizer should be applied (Table 4).

The strategy for rice-fish culture is low planting density, less fertilizer, a small population, and strong individuals. Improved ecological conditions (ventilation and illumination) prevent lodging and help produce larger ears, heavier grains, and high and stable yields.

## Factors Affecting Fish Yield

### Species

In 1985, the effects of mature fish and fry were compared. Mature fish grew quickly and individual weights at the time of harvest reached 79.3 g for grass carp, 60.0 g for common carp, and 76.9 g for Fu-shou fish. The largest individual weighed 150 g. White crucian carp, however, grew slowly (individual weight only 28.4 g) although the same size fingerlings were used for all species.

The fry were small and the densities high, but results were about the same as for mature fish. Average individual weights of grass carp, common carp, and Fu-shou fish were 3–5 times greater than white crucian carp and bighead carp (Table 5). Grass carp, common carp, and Fu-shou fish are the ideal species for rice–fish culture because they adapt easily and produce high yields. However, bighead carp and white crucian carp grow slowly and should only be used in small proportions.

### Stocking Density

Yield correlates positively with stocking (Table 6). In 1986, two parts of the rice–fish field (A and B in Table 6) were used. There were 56.9% more fish in A than in B; 26.3% more fish were harvested from A, and yield increased by 37.6%. There were 65.9% fry in A than in B; 4.1% more fry were harvested from A and yield increased by 45%. Results were about the same in 1987 except that percentage yield increased. For densities of between 4 500 and 18 000 fish/ha, yields increased with density (regression equation of $y = 0.370 + 0.0312x$; where $y$ = yield of fish per hectare and $x$ = number of fish harvested per hectare; $r = 0.9778$). Higher densities inhibits the development of individual fish.

### Stocking Size

Stocking size has a significant effect on individual weight gain during one season. Experiments using different densities and species, showed that the larger the fingerlings, the higher the individual weight gain (Table 7). When the stocking size of fish was increased from 4.0–5.0 cm to 8.3 cm in 1985 and from 6.6 cm to 8.3 cm in 1986, average individual weight increased by 131.4% (1985) and 18.8% (1986). In 1987, stocking size was 4.0 cm and individual weight was only 34 g, or 40% of the weight of the 8.3-cm individual fish stocked in the previous two years. The performance of grass carp and common carp were similar to that of Fu-shou fish. Increases in stocking size increase individual weight and improve the final yield of fish.

## Discussion

Rice–fish culture is a feasible and efficient way to improve the use of agricultural resources. It improves soil fertility, reduces damage from weeds and insects (and therefore reduces costs for insecticides and chemical fertilizers), and improves the quality of rice. With a stocking rate of 15 000–30 000 fingerlings/ha, the rice yield

Table 5. Individual weights at harvest of different fish species stocked at different densities.

| Type of Cultivation | Species of Fish | Stocking Density (fish/ha) | Harvest (fish/ha) | Size of Young Fish (cm) | Individual Weight (g) |
|---|---|---|---|---|---|
| Mature fish | Fu-shou | 6 870 | 5 430 | 8.2 | 76.9 |
| | Grass carp | 870 | 915 | 5.9 | 79.8 |
| | White crucian carp | 1 860 | 1 965 | 8.2 | 28.4 |
| | Common carp | — | 420 | 6.6 | 60.0 |
| Fry | Fu-shou | 7 320 | 5 835 | 4.0-5.0 | 27.8 |
| | Grass carp | 22 110 | 8 565 | 4.0-5.0 | 22.7 |
| | Common carp | 7 320 | 3 390 | 4.0-5.0 | 38.7 |
| | White crucian carp | 4 200 | 5 910 | 2.6-3.3 | 6.7 |
| | Bighead carp | 3 720 | 6 375 | 5.0 | 8.4 |

Table 6. Fish yields at different stocking densities.

| Type of cultivation | Year | Field | Stocking Density (fish/ha) | Harvest (fish/ha) | Yield (kg/ha) |
|---|---|---|---|---|---|
| Mature fish | 1986 | A | 24 945 | 7 425 | 420 |
| | | B | 15 900 | 5 880 | 305 |
| | 1987 | A | 18 000 | 9 375 | 286 |
| | | B | 11 580 | 7 560 | 246 |
| | | C | 11 220 | 3 690 | 130 |
| | | D | 4 500 | 5 430 | 168 |
| Fry | 1986 | A | 41 490 | 12 915 | 615 |
| | | B | 25 000 | 9 120 | 424 |

Table 7. Effect of different stocking sizes on weights of individual fish.

| Species | Year | Stocking Size (cm) | Growth Period (days) | Individual Weight (g)[a] | | |
|---|---|---|---|---|---|---|
| | | | | Largest | Smallest | Average |
| Fu-shou | 1985 | 8.2 | 90-91 | 142.5 | 50.0 | 83.0 |
| | | 4.0-5.0 | 90-91 | 74.0 | 14.8 | 35.9 |
| | 1986 | 8.2 | 90-94 | 112.1 | 37.0 | 82.4 |
| | | 6.6 | 90-94 | 109.1 | 30.1 | 69.4 |
| | 1987 | 4.0 | 103 | 62.3 | 19.9 | 34.0 |
| Common carp | 1985 | 4.0-5.0 | 90-91 | 83.7 | 26.5 | 42.7 |
| | 1986 | 4.0 | 90-94 | 83.8 | 11.9 | 28.1 |
| Grass carp | 1985 | 5.9 | 90-91 | 148.8 | 15.6 | 78.7 |
| | | 4.0-5.0 | 90-91 | 63.0 | 20.0 | 34.0 |
| | 1986 | 2.6-4.0 | 90-94 | 68.4 | 11.4 | 28.3 |

[a] From 40 randomly selected individuals.

is 7 500 kg, fertilizer can be reduced by 37.5-75 kg/ha N, and 7.5 kg/ha less herbicide can be used. As a result, net income can be increased by over CNY750/ha.

To ensure good rice yields from rice-fish fields, planting density should be lowered and less fertilizer should be applied. This helps develop a plant population with strong individuals and minimizes shading and lodging. Strong seedlings should be plated at a density that is 10-20% lower than the density used in a regular fields. Nitrogen fertilizer should be reduced by 20%; 85-90% should be applied early in the growing season, and the rest applied during later stages. The fish species should be adaptable, resistant, high-yielding, and be able to tolerate heavy doses of fertilizer.

The difficulties in rice-fish culture are the limited growth period, the small amount of water, changes in water levels, and unstable ecological conditions. To achieve high yields, it is important to choose the appropriate fish species and to use the proper stocking density and size. Grass carp, common carp, and Fu-shou fish are ideal species for rice-fish culture. They should be used as the main species are be combined with small proportions of other species. To produce mature fish, 70-80% Fu-shou fish and 20-30% grass carp and common carp should be used. For fry, 80% grass carp and common carp and 20% Fu-shou fish are recommended.

To produce 750 kg fish/ha, the stocking density should be 12 000–15 000 fingerlings for mature fish and 30 000–37 500 fingerlings for fry. It is best to use large fingerlings. To produce mature fish, the stocking size should be greater than 6.3 cm for Fu-shou fish and 4.3–6.3 cm for grass carp and common carp.

Although productivity of the individual rice plants was enhanced when fish were raised in the ricefield, the yield per unit area remained about the same. The improvement in the quality of the individual rice plants compensated for the reduced planting area. Results from this study show demonstrate that rice-fish culture maintains rice yields at the same level as regular cultivation. In contrast to other reports, this study did not find a tendency for rice-fish culture to increase yield.

# Cultivating Different Breeds of Fish in Ricefields

*Wang Banghuai*[37] *and Zhang Qianlong*[38]

Experiments were conducted in Shanggao, Shangyou, and Shuichuan Counties in 1985–1986 to study the adaptability of certain breeds of fish to ricefields. Experiments were carried out simultaneously in double-cropped ricefields in three separate villages. Soil fertility was poor in one village, average in one, and good in another. At each site, the experiment was replicated. The method of rice–fish culture with trenches and ponds was used at all three sites. The trenches and ponds took up 4–10% of the total area of the ricefield.

In 1985, each site had 30 ricefield plots and a total area of 1.3 ha. In 10 plots (0.05-ha each), the fish breeds were cultured separately (monoculture) and given no supplemental food. In 10 plots (0.003-ha each), the fish were cultured separately and given supplemental feed. In the final 10 plots (0.06-ha each), different polyculture mixtures of fish were given supplemental food (single replicate per trial).

The polyculture mixtures contained nile tilapia, *(Oreochromis niloticus)*, grass carp (*Ctenopharyngodon idella*), silver crucian carp (*Carassius auratus*), local carp, and six other local breeds. In one trial, equal quantities of each breed was used (200 fish per breed). In the unequal mixed cultures, the main species (one of nile tilapia, grass carp, silver crucian carp, or local carp) made up 50% (1 000 fish) of the total number of fish raised. Chub and variegated carp made up 2.3% (45 fish) each, and the other seven fish species made up 6.5% (130 fish).

## Culture of Different Fish Breeds

The breeds chosen for culture were fish that could grow to 3–4 cm in length in that year. Ten breeds of seven fishes were selected: nile tilapia, grass carp, silver crucian carp, local breeds of red carp (Xingguo red carp, pouch red carp, and glass red carp), shortnose catfish, chub carp, and variegated carp. The three red carps, the silver crucian carp, and the shortnose catfish were distributed by the local government; the other breeds were produced on-site. The fish were stocked before the end of May, except for nile tilapia, which were put into the ponds from late May to early June.

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Table 1. Results of monoculture of 10 fish breeds.

| | Without Feeding | | With Feeding | | Average | |
|---|---|---|---|---|---|---|
| | Survival Rate (%) | Unit Yield (kg/ha) | Survival Rate (%) | Unit Yield (kg/ha) | Survival Rate (%) | Unit Yield (kg/ha) |
| Nile tilapia | 14.3 | 247.5 | 51.6 | 364.5 | 33.0 | 306.0 |
| Grass carp | 29.3 | 193.5 | 41.9 | 412.5 | 35.6 | 303.0 |
| Silver crucian carp | 36.7 | 165.0 | 52.4 | 162.0 | 44.6 | 163.5 |
| Local carp | 37.8 | 223.5 | 50.7 | 310.5 | 44.3 | 267.0 |
| Xingguo red carp | 30.7 | 228.0 | 40.8 | 309.0 | 35.8 | 268.5 |
| Pouch red carp | 9.3 | 241.5 | 54.6 | 298.5 | 32.0 | 270.0 |
| Glass red carp | 25.2 | 159.0 | 49.7 | 415.5 | 37.5 | 288.0 |
| Short-nose catfish | 0 | 0 | 0 | 0 | 0 | 0 |
| Variegated carp | 7.1 | 69.0 | 8.6 | 150.0 | 7.9 | 109.5 |
| Chub | 20.1 | 120.0 | 50.6 | 342.0 | 35.4 | 231.0 |
| Average | 21.1 | 165.0 | 40.1 | 276.0 | 30.6 | 220.5 |

Lime was used to sterilize the ricefield before the fish were stocked. The main fish fed was natural food in the ricefield; however, concentrated feeds, such as fine chaff, wheat bran, and rapeseed cake, were added as needed.

The rice plants were grown and managed in the same way as rice in fields without fish. Although the area for growing rice was reduced because of the fish trenches and ponds, rice yields were not reduced because rice was planted along the edges of the trenches and ponds. When fertilizers or pesticides were applied or when the field was sun-dried, the fish were drawn into the trenches or ponds. The ricefields with fish did not need weeding.

All plots were inspected during the last 2 weeks of October. Each fish species was counted, weighed, and measured, and field management notes were examined (Tables 1-3).

## Adult Fish Culture in Ricefields

In 1986, eight breeds were cultivated in the three sites (silver chub and shortnose catfish were not used). The number of plots was decreased from 30 to 24, and the area was decreased from 1.3 ha to 1 ha. Eight plots were used for monoculture

Table 2. Results of equal-quantity mixed culture (with feeding) for 10 fish breeds.

| | Survival Rate (%) | Unit Yield (kg/ha) |
|---|---|---|
| Nile tilapia | 23.8 | 39.0 |
| Grass carp | 35.7 | 124.5 |
| Silver crucian | 53.0 | 24.0 |
| Local carp | 53.6 | 117.0 |
| Xingguo red carp | 27.1 | 31.5 |
| Pouch red carp | 15.7 | 7.5 |
| Glass red carp | 21.4 | 61.5 |
| Short-nose catfish | 0.5 | 4.5 |
| Variegated carp | 57.5 | 27.0 |
| Chub | 70.8 | 82.5 |
| Average | 35.9 | |
| Total | | 519.0 |

with and without feeding (without replicate experimental plots). The area of each plot was the same as in 1985. Two plots were used for equal-quantity mixed culture with feeding; the rest were used for 3-breed mixed culture with feeding (the three breeds were nile tilapia, grass carp, and local carp). Each breed was cultivated separately as the main breed in two plots using the same techniques used in 1985. For each breed, 4 500 fish/ha were stocked in the ricefield. In equal-quantity mixed culture, 562 fish of each breed were stocked per hectare (each breed made up 12.5%). In unequal-quantity mixed culture, 2 250 fish were stocked per hectare: 50% of the main breed plus 7% chub, 3% variegated carp, and 20% each of two other breeds. Breeds cultivated the previous year were harvested at a length of 10 cm, and stocking was completed by early May. Results are presented in Tables 4–6.

## Results

### Growth of Different Breeds (1985)

**Nile tilapia.** Even without feeding, high unit yields were obtained when nile tilapia was monocultivated or used to supplement mixed cultures. Survival rates, however, were not high because the fingerlings were small when stocked.

**Grass carp.** Survival rates were average; however, when grass carp were used to supplement mixed cultures, survival was high. Unit yield was low in monoculture without feeding. With feeding in both monoculture and mixed cultures, yields were higher than for other breeds.

Table 3. Results of unequal-quantity mixed culture (with feeding) for 10 fish breeds (SR survival rate; UY unit yield).

| | Nile Tilapia as Main Fish | | Grass Carp as Main Fish | | Silver Crucian Carp as Main Fish | | Local Carp as Main Fish | | Average Proportion of Fish Breeds | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SR (%) | UY (kg/ha) | SR (%) | UY (kg/ha) | SR (%) | UY (kg/ha) | SR (%) | UY (kg/ha) | SR (%) | UY (kg/ha) |
| Nile tilapia | 18.6 | 241.5 | 60.3 | 94.5 | 29.8 | 45.0 | 34.2 | 51.0 | 41.4 | 63.0 |
| Grass carp | 33.9 | 45.0 | 23.9 | 111.0 | 43.2 | 147.0 | 59.0 | 96.0 | 45.4 | 96.0 |
| Silver crucian | 66.5 | 19.5 | 39.8 | 15.0 | 53.3 | 99.0 | 55.7 | 48.0 | 54.0 | 27.0 |
| Local carp | 38.8 | 52.5 | 39.6 | 48.0 | 48.9 | 25.5 | 45.2 | 129.0 | 42.5 | 42.0 |
| Xingguo red carp | 30.2 | 21.0 | 24.2 | 25.5 | 43.8 | 9.0 | 22.3 | 18.0 | 30.1 | 18.0 |
| Pouch red carp | 24.0 | 6.0 | 13.0 | 7.5 | 35.0 | 13.5 | 25.9 | 6.0 | 24.5 | 9.0 |
| Glass red carp | 16.0 | 48.0 | 19.7 | 36.0 | 20.5 | 51.0 | 29.5 | 58.5 | 21.4 | 48.0 |
| Short-nose catfish | 1.0 | 4.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.3 | 1.5 |
| Variegated carp | 43.2 | 12.0 | 56.5 | 15.0 | 55.0 | 21.0 | 52.8 | 24.0 | 51.9 | 21.0 |
| Chub | 45.9 | 13.5 | 73.2 | 27.0 | 88.9 | 31.5 | 77.5 | 39.0 | 71.4 | 28.5 |
| Average | 31.8 | | 35.0 | | 41.8 | | 40.2 | | 38.3 | |
| Total | | 313.5 | | 25.3 | | 442.5 | | 469.5 | | 354.0 |
| Average survival rate = 37.2% | | | | | | | | | | |
| Average unit yield = 402.0 kg/ha | | | | | | | | | | |

**Silver crucian carp.** Survival rates were usually higher than for other breeds, but because the fish took longer to grow and body size was small, unit yields were low.

**Local carp.** Survival rates were high. Unit yields were high in mixed cultures. When local carp were used as the main breed in mixed cultures, unit yield was higher than for any of the other nine breeds. In monoculture, yields were low.

Table 4. Results of monoculture experiment.

| | Without Feeding | | With Feeding | | Average | |
|---|---|---|---|---|---|---|
| | Survival Rate (%) | Unit Yield (kg/ha) | Survival Rate (%) | Unit Yield (kg/ha) | Survival Rate (%) | Unit Yield (kg/ha) |
| Nile tilapia | 53.5 | 265.5 | 98.1 | 393.0 | 75.8 | 330.0 |
| Grass carp | 49.0 | 348.0 | 69.4 | 639.0 | 59.2 | 493.5 |
| Local carp | 53.0 | 273.0 | 74.8 | 423.0 | 63.9 | 348.0 |
| Xingguo red carp | 64.2 | 208.5 | 79.8 | 339.0 | 72.0 | 274.5 |
| Pouch red carp | 34.1 | 330.0 | 42.6 | 240.0 | 38.4 | 285.0 |
| Glass red carp | 54.5 | 280.5 | 43.9 | 240.0 | 49.2 | 261.0 |
| Variegated carp | 72.9 | 153.0 | 64.9 | 231.0 | 68.9 | 192.0 |
| Chub | 67.5 | 133.5 | 62.4 | 199.5 | 65.0 | 166.5 |
| Average | 56.1 | 249.0 | 67.0 | 337.5 | 61.6 | 294.0 |

Table 5. Results of equal-quantity mixed culture with feeding.

| | Survival Rate (%) | Unit Yield (kg/ha) |
|---|---|---|
| Nile tilapia | 94.7 | 75.0 |
| Grass carp | 70.7 | 108.0 |
| Local carp | 52.9 | 63.0 |
| Xingguo red carp | 63.8 | 45.0 |
| Pouch red carp | 21.5 | 30.0 |
| Glass red carp | 40.9 | 43.5 |
| Variegated carp | 56.9 | 39.0 |
| Chub | 64.8 | 48.0 |
| Average | 58.3 | |
| Total | | 451.5 |

**Pouch red carp.** In monoculture or mixed culture, survival rate and unit yield were low.

**Xingguo red carp.** In monoculture without feeding, both survival rate and yield were fairly high, but in mixed culture, both survival rate and unit yield were rather low.

**Glass red carp.** Survival rates and unit yields were high in monoculture. In mixed cultures, survival rates were low, but unit yields were high.

**Shortnose catfish.** Survival rates and unit yields were low because the fingerlings used were small. Outside the experimental sites, some farmers stocked larger fingerling and obtained good harvests.

**Variegated carp.** In monoculture, survival rates and unit yields were the lowest of any breed. In mixed cultures, unit yields were low, but survival rates were high.

**Chub.** In monoculture, survival rates and unit yields were low. In mixed cultures (in the proportion 2.5-6.5%), survival rates and unit yields were the highest among the 10 breeds. Chub also grow fast.

### Stocking Methods

Survival rates were lower in monoculture (30.6%) than in mixed cultures (36.6%) and lower in monoculture without feeding than in monoculture with feeding. Survival rates in equal-quantity mixed cultures were slightly lower than in unequal-quantity mixed cultures. For example, when used as the main breeds in mixed cultures, survival rates were: silver crucian carp > local carp > grass carp > nile tilapia. In mixed cultures, the survival rate of the main breed was usually lower than when that breed was used to supplement other breeds either in unequal-quantity mixed culture or in equal-quantity mixed culture.

Unit yields were lower in monoculture without feeding (16.5 kg) than in monoculture with feeding (276 kg); lower in monoculture with feed (276 kg) than in mixed cultures with feed (460.5 kg); and lower in unequal-quantity mixed cultures (354 kg) than in equal-quantity mixed cultures (519 kg). In unequal-quantity mixed culture, unit yields were: local carp > silver crucian carp > grass carp > nile tilapia.

### Growth of Different Breeds (1986)

**Nile tilapia.** Fingerlings can be bred in the ricefield. In monoculture without feeding, the survival rate was not high, but in the other culture methods, survival rates were higher than for other breeds. Unit yields, however, were lower those for grass carp and local carp.

**Grass carp.** Survival was low, especially when grass carp were cultivated as the main breed in mixed culture without feeding. Unit yields were highest with most culture methods.

**Local carp.** Survival rates were higher than grass carp in most cases, but were lower than grass carp in equal-quantity mixed cultures with feeding. Unit yields were lower than grass carp with most culture methods.

Table 6. Results of unequal-quantity mixed culture with feeding.

| | Nile Tilapia as Main Breed | | Grass Carp As Main Breed | | Local Carp As Main Breed | | Average of Supplementary Breeds | |
|---|---|---|---|---|---|---|---|---|
| | Survival Rate (%) | Unit Yield (kg/ha) | Survival Rate (%) | Unit Yield (kg/ha) | Survival Rate (%) | Unit Yield (kg/ha) | Survival Rate (%) | Unit Yield (kg/ha) |
| Nile tilapia | 59.5 | 174.0 | 67.6 | 57.0 | 89.1 | 127.5 | 78.4 | 91.5 |
| Grass carp | 29.5 | 105.0 | 36.1 | 291.0 | 41.0 | 106.5 | 35.3 | 106.5 |
| Local carp | 51.8 | 120.0 | 54.4 | 66.0 | 58.8 | 192.0 | 53.1 | 93.0 |
| Variegated carp | 65.0 | 37.5 | 67.6 | 40.5 | 48.0 | 27.0 | 60.2 | 34.5 |
| Chub | 62.0 | 60.0 | 80.5 | 61.5 | 85.1 | 78.0 | 75.9 | 66.0 |
| Average | 53.6 | | 61.2 | | 64.4 | | 60.6 | |
| Total | | 496.5 | | 516.0 | | 531.0 | | 391.5 |
| Average survival rate of all breeds 59.7% | | | Average unit yield 34.6% | | | | | |
| Average survival rate of main breeds 51.4% | | | Average unit yield of main breeds 14.6% | | | | | |

**Xingguo red carp.** Survival rates were the highest of the four carp breeds, but unit yields were lower than local carp. In monoculture without feeding, unit yield was lower than pouch red carp and glass red carp.

**Pouch red carp.** Survival rates were the highest. Unit yields were low in mixed culture, but fairly high in monoculture, especially in monoculture without feeding.

**Glass red carp.** In monoculture without feeding, survival rates and unit yields were high. In monoculture with feeding as well as in mixed culture, survival rates and unit yields were low.

**Variegated carp.** Survival rates were fairly high, especially when cultivated without feeding. Unit yields, however, were low.

**Chub.** Survival rates were fairly high, but unit yields were low. In monoculture, survival rates and unit yields were lower than variegated carp. In equal-quantity mixed culture, both survival rate and unit yield were higher than variegated carp.

### Stocking Methods

Survival rates in monoculture (61.6%) were slightly higher than in mixed cultures (59%) and lower in equal-quantity mixed cultures than in unequal-quantity mixed cultures. When cultivated as the main breeds in three kinds of unequal-quantity mixed culture, survival rates were nile tilapia > local carp > grass carp.

Unit yields in monoculture (19.6 kg) were much lower than in mixed cultures (32.4 kg); lower in monoculture without feeding than in monoculture with feeding; and higher in unequal-quantity mixed culture than in equal-quantity mixed culture. The unit yields of the three breeds cultivated as the main breeds in unequal-quantity mixed culture were ranked from lowest to highest as follows: grass carp > local carp > nile tilapia.

## Discussion

The 2-year experiment on rice-fish culture was conducted under natural conditions (e.g., floods, droughts, and birds) and certain artificial factors (e.g., management level of staff, funds, the quality of fish breeds). It involved 50-60 farmers and was carried out in several sites in three counties, one in the South, one in the North, and another in the centre of Jiangxi Province. A lead group and a technical group were organized to undertake the experiment on the basis of unified leadership, unified planning, and unified standards. Limitations in the experimental methods included differences between sites in soil fertility, biological resources, water temperature, water quality, and water sources. There were also differences in rice-growing skills, management level, stocking, and time of harvest.

## Conclusion

The fish breeds best suited to rice-fish culture are grass carp, common carp, and nile tilapia. These breeds can be used as the main breeds for rice-fish culture. The breeds most suitable for use as supplementary breeds in rice-fish culture are crucian carp (mainly silver crucian carp), local red carps, chub, and variegated carp. Shortnose catfish can be used as a commodity fish under certain conditions.

In this method of rice-fish culture, trenches and ponds occupy 6-8% of the total area of each plot. The trenches should be 0.35-m deep and the pond 1-m deep. Rice-fish culture can be carried out while a stable increase in rice yield is maintained. Fish yields of 450-600 kg/ha of adult fish and 150-225 kg/ha of fry can be obtained.

# Rice–Fish Culture in Ricefield Ditchponds

*Luo Guang-Ang*[39]

Rice–fish culture has been traditionally practiced in rural areas. Modern rice cultivation techniques such as intercropping, fertilizers, and chemical sprays often conflict with fish growth. In addition, other problems such as monoculture of fish, delays in putting fish into the pond, short growing periods, and lower output and economic profits have arrested the development of rice–fish farming. Recent reforms in the economic system have sparked new initiatives in agricultural production.

Renewed interest in rice–fish culture has prompted scientists to study different patterns of rice–fish culture (e.g., ditch-and-pit, wide ditches, and ditchponds). Research suggests that rice–fish culture in ditchponds can eliminate the conflicts between fish and rice and take full advantage of the symbiosis between rice and fish.

Rice–fish culture in a ditchpond is a three-dimensional agricultural production system. The artificial ecosystem simulates the biostructure of the natural ecological system and consists of an economic crop (rice) and a commercial animal (fish). The system provides the high output of an intensive fishpond farming system and makes full use of the ecological conditions in the ricefield. Fish feed on the abundant aquatic organisms and coexist with the rice. Both fish and rice develop harmoniously, each promoting the growth of the other, and problems between fish-rearing and field care can be reasonably handled. Both crops can achieve their full productive potential. At the same time, liana can be grown on an awning above the pond, taro and beans can be grown on the bank, duckweed can be cultivated with the fish in the water, and loach can be grown in the mud. This integrated and intensive farming system produces higher yields of rice, fish, and vegetables.

## Management Techniques

The pond, which takes up 5% of the field area, is dug to a depth of 1–1.5 m on one side of the ricefield. On a third of the pond, a shed with an awning is built. Ditches are dug 40–60 cm wide and 20–30 cm deep. The ditches are dug according to the size of the field: if the field is less than 0.07 ha, ditches are dug in a straight line; if the field is about 0.07 ha, ditches are dug in the shape of a cross; and if the field is larger than 0.14 ha, parallel ditches are dug in both directions (in the shape of a double cross).

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### Engineering Construction and Management

Five basic steps are undertaken.

- Select a suitable field. The soil must be fertile, have moderate texture, and hold water well. The water supply must be adequate and drainage and irrigation must be available to ensure stable yields during droughts or excessive rain.
- Construct a bank around the field. The bank is raised to a height of 50–70 cm and a width of 30–40 cm. The bank must be solid enough to withstand heavy rains.
- Install fish screens. A semicircle of fish screens about 0.8-m high and 1-m wide are installed in the water inlets and outlets. The gaps between fish-screen bars should be 0.3–0.4 cm. A screen with a gap of 1.5-2.5 cm is placed at the juncture of the ditch and pond to prevent large fish from damaging rice seedlings. This screen is removed after the rice heads.
- Monitor water and fertilizer. Water and fertilizer have a significant effect on the growth of fish and rice. Excess nitrogen makes rice seedlings spindly and results in the closing of crop rows too early and densely, which is fit for neither fish nor rice growth. Therefore, the amount of base manure, potassium, and phosphorus fertilizer should be raised but nitrogen should be controlled to prevent the rice from becoming spindly. Water management is also important. Irrigation and drainage should be controlled separately. The water level should be kept at a depth of 1-1.2 m in the pond; however, the water in the ricefield should be 5-10 cm deep before rice tillering and 10–16 cm deep after rice tillering. When pesticides and fertilizers are needed, the water level in the field should be lowered slowly and the fish should be driven into the ditch and pond to separate the fish and rice for a short period.
- Patrol fields. Care is required to identify and deal with problems such as drought, waterlogging of the fields, diseases, insect pests, escapes of fish, and theft.

### Improvements in Culture Techniques

To improve rice–fish culture ditch ponds, several changes are needed in traditional techniques.

- Transform monoculture into polyculture. Traditionally, common carp are the only fish grown in the ricefields. However, now many other species are available, e.g., local carp, wuyuan pouch red carp, wang-an glass red carp, xingguo red carp, feng carp, mirror carp, grass carp, black carp, silver carp, big-head carp, nile tilapia, and crucian carp.
- Change from single-cropping to double cropping of fish. Traditional systems of rice–fish production raised fish once a year However,

new techniques now mean that fish can be grown in ricefields throughout the year.

- Institute earlier stocking of fish. In traditional systems, the fish are stocked after the rice heads. New techniques allow the fish to be stocked after the rice is transplanted because of the ponds and ditches in the ricefield.
- Increase stocking density of fish. In the past, less than 1 500 fish were stocked per hectare of rice-fish field. Currently, 15 000–30 000 fish per hectare are used. The density depends on the objective of the rice-fish system. For fish fry, the density of summer fry is usually 19 500-30 000 fish/ha; for food fish, 6 000-9 000 spring fish fingerlings per hectare are recommended. In both cases, grass carp, common carp, and nile tilapia make up about 90% of the total and black carp, silver carp, bighead carp, and crucian carp make up about 10%.
- Introduce feeding of fish. Water plants, plankton, and aquatic animals in the ricefield were the traditional sources of food for the fish. Green grass, duckweed, algae, rice bran, bean residue, distillers' grains, and manure are now added to supplement the feed for the fish.

### Integrated Management

In addition to fish and rice, diverse agricultural products can be obtained from ricefields. For example, soybean, peppers, tomatoes, sorghum, corn, taro, mustard can be grown on the banks; vine crops such as musky pumpkin, wax gourd, balsam pear, *Lagenaria vulgaris*, and cow gram can be grown on the awning of the shed; and duckweed can be grown under the shed awning as pig feed.

## Impact of Rice-Fish Culture

Production experience has demonstrated that fish farming in ditchpond makes good use of the land, water, and biotic and abiotic resources of ricefields. The rate of use and conversion efficiency of material and energy in the rice-fish ecosystem are higher than in rice-only fields. The system is a desirable production model that combines fish with rice.

### Economic Benefits

Fish rearing in ditchponds has a low cost of investment but yields diverse products, which in turn increase total agricultural income. This is demonstrated by some examples from Shangyou County, Jiangxi Province.

In 1984, fish were raised in ditchponds on 86.5 ha of ricefields. The output of fresh fish averaged 760.5 kg/ha, and the yield of rice increased by over 2 900 kg/ha. The value of the total output increased by CNY5 780/ha. Zhong Linying, a farmer in Qixing, practiced monoculture of nile tilapia in a late ricefield and produced 3 200 kg of fish per hectare. Cai Yunging, in Henglin, adopted polyculture of grass carp, silver carp, bighead carp, and common carp and produced an output of CNY15 860/ha (net income CNY14 700/ha).

In 1985–1987, experiments in various parts of Shangyou County produced positive results. For example, a test of fish-rearing was undertaken by Kong Quingrong in a 0.08-ha double-cropped ricefield (area of pond 0.01 ha). The rice harvest was 976.7 kg (9% more than from the same field planted to rice the previous year). In addition, by using the field-bank ridge and shed awning to grow crops, he produced 5 kg of soybean, 5 kg of balsam pears, 15 kg of tomatoes, 30 kg of white gourds, 40 kg of musky pumpkins, 53 kg of kidney beans, and some other vegetables and livestock feeds. The net income, including CNY264 from the fish, was 3.6 times as much as in the previous year (an increase of CNY4 590/ha).

In 1986, this production system was extended in Dongshang Township. Results from a 0.9-ha field distributed into 23 pieces of land were 40.2 kg (603 kg/ha) of fish and a rice yield that averaged 11 063 kg/ha (1.8% higher than in the previous year). In addition, average income was CNY304/ha and total value reached CNY5 680/ha.

In 1987, results were obtained from five households in Dongshan Township. Kang Renhai obtained 15 018 kg of rice, 975 kg of fresh fish per hectare, and CNY294 from other interplanted crops (e.g., taro, soybean, and pumpkin) for a total output of CNY20 400/ha. In contrast, an adjacent field that was the same size but had no fish had an output that was 3.15 times lower in value.

### Ecological Effects

The rice–fish system is an artificially controlled ecosystem in which rice and fish coexist, depend on, and promote each other. Fish play several roles in the system.

**Weed control and preservation of soil fertility.** In the ricefield, weeds compete with rice for nutrients, land, water, space, and sunlight. As a result they greatly affect the growth of the rice plants. Experiments have shown that 1 kg of grass-carp fingerlings in a ricefield consume about 40-60 kg of weeds, which would absorb about 1.25 kg of nitrogen as they grow. In the rice–fish system, weeds are eaten by grass-eating fish and their waste becomes a field manure that helps conserve and enrich soil fertility.

Huang Xinlian, a farmer of Shuiyan Township in Shangyou County, adopted the rice–fish system with a ditchpond for 3 years. In 1983, from a 0.06-ha field, she obtained 1 083 kg of grain (138 kg more than the previous year) and 38 kg of food fish, 1 109 large fingerlings of grass carp, silver carp, and common carp, and 32 Japanese crucian carp. She obtained a total income of CNY652 and a net income of CNY451 (CNY7 114/ha). In addition, she saved CNY12 for chemical fertilizers and pesticides and no tillage or weeding were needed for 3 years. Soil fertility and yields have increased each year.

**Control of rice diseases and insect pests.** Insects that are harmful to rice are a good food for fish. For example, when they fall into the water, rice borers, rice hoppers, and rice weevils are quickly eaten by the fish. Observations in experiment plots have indicated that densities of pest populations were lower, as was the damage to rice plants, when fish were present in the field. For example, for the third and fourth generations of rice borer the density of the third generation was 1 305/ha and the rate of dead hearts in the rice was only 0.4% in the rice-fish field. In the fourth generation, pest density was 1 380/ha and the rate of white heads was only 0.9% in the rice-fish field, but in a rice-only field the density was 1 650/ha and the rate of white heads was 1.4%.

The vegetable and other crops grown on the field bunds also provide habitat for natural predators. The crops on the bunds and shed awning also enhance fish growth because they shade the water and lower water temperature.

The fish also reduces rice diseases by oxygenating the soil and speeding the decomposition of manure and the release of available nutrients. Large grass carp and common carp remove the basal leaves of the rice plant and diseased leaves, which allows air and sunlight to pass through easily. This promotes rice growth and reduces the incidence of rice diseases.

Early rice sheath-blight disease was investigated in Wangzai County. The incidence of diseased hills was 17.1% and rate of diseased plants was 2.7% in the rice-fish field, compared with 42% diseased hills and a rate of 6.1% for diseased plants in the ricefield without fish.

### Social Effects

Making multiple uses of the same field is an important advantage of this system. Large fish fingerlings and commercial fish for market are produced without additional land. For example, five farm households in Shanyou County produced, from an area of 0.2 ha, an average yield of rice of 13 760 kg/ha, 568.5 kg/ha of fish, and an income of CNY1 310/ha from vegetables. Total income reached CNY9 635/ha.

Fish consume weeds and pests, prevent disease, conserve and increase fertilize, reduce or eliminate chemical pesticides, and as a result, also save farm labour. Experiments have demonstrated that 8-10 units of labour power are saved when fish are present. The decrease in the amount of agricultural chemicals also reduces chemical poisoning and environmental pollution. At the same time, natural pest predators such as praying mantis, spiders, and frogs correspondingly increase. In addition, because fish are predators of mosquito larvae and snails, they help prevent malaria, flariasis, and snail fever.

## Conclusion

Agricultural production is being changed in Shanyou County. Farmers now know how to use the limited arable land for multiple purposes. There are several advantages to the new production system. First, the rice-fish system increases economic benefits two or three times compared with a single rice crop. Second, the production system integrates the main crop (rice) with fish and vegetables and improves agricultural production. Third, the principles of a natural ecosystem are borrowed to promote ecological balance and ecological cycles. Fourth, cropping and fish-rearing are linked in a simple way that uses land, water, and biotic and abiotic resources efficiently and features low inputs, quick effects, and excellent benefits.

Because fish-rearing in the ditch pond of a ricefield is a new production system, many items require further research. For example, the proportion of different fishes and the proportion of pond and ditch area must be tested and studied. To further improve the use of ricefield resources, cooperation is required between scientists working in the departments of agriculture, protection, and health.

Rice-fish culture in the ditch ponds of ricefields has great potential. There are 1.3 million ha of ricefields that are suitable for fish-rearing in Jianxi Province. If 25% of these fields were used for rice-fish culture and the unit output of fish was 750 kg/ha, then 250 000 tonnes of fish could be produced. This is 148 000 tonnes more than the total output of fish in 1984. At a market price of CNY3/kg, the output of fish would increase income by CNY750 million. If CNY250 million were produced from interplanted vegetables (CNY750/ha), the additional amount of revenue would be CNY1 000 million.

# Techniques for Rice–Catfish Culture in Zero-Tillage Ricefields

*Chen Huarong*[40]

Yunnan is situated on a low-latitude plateau that has a variety of physical features and many variations in climate. Agricultural production differs dramatically between regions and seasons. Ricefields in Yunnan cover 1 million ha, and more than 132 000 ha are suitable for rice–fish cultivation. The rice-growing regions vary from warm and sunny with plenty of rainfall and good soils to areas with low temperature and poor water-holding capacity.

The ricefields are not efficiently used and economic returns could be improved. Rice–fish fields only cover about 13 300 ha, which is only 10% of the area suitable for rice–fish culture. Average output is also rather low (45 kg/ha in 1982, 62 kg/ha in 1985, and 101 kg/ha in 1987) compared with the national average of 140 kg/ha.

Full exploitation of the potential productivity of the ricefields could remarkably increase economic benefits. Rice–fish cultivation is an important way to increase productivity. Experiments were conducted in Kunming, a rice-growing region of Yunnan Province, at an elevation of 1 900 m and with an annual average temperature of 14.5°C.

## Fish Species

The choice of species greatly affects fish harvests, the value of the output, and the economic benefits gained from ricefields. The characteristics of the rice-growing regions in the Yunnan plateau are low temperatures, low water temperatures, shallowly flooded ricefields. The traditional fish species grow slowly and the growing period is short. Given these conditions, it was important to find fish species that grew quickly (reached market size in 120 days), tolerated low-oxygen conditions, were of high quality, and produced high outputs. Experiments were conducted in 1986–1988 to compare different species.

### Vigour and Production

Different species were raised for 120 days in the ditches and beds of zero-tillage ricefields. Growth rates and yields varied greatly (Table 1). *Clarias leather* grew the fastest. Individual weights increased 168-fold and their average weights were four times that of nile tilapia and 10 times that of the carp. The length of the cat-

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Table 1. Growth rate and yield of different fish species.

| | | | Stocked Population[a] | | | | Harvest Characteristics | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Pattern | Species | Fish per ha | Total Wt. (kg/ha) | Body Length (cm) | Body Wt. (g) | Harvest (%) | Body Length (cm) | Body Wt. (g) | Length Increase (times) | Wt. Increase (times) | Output (t/ha) | % of total output |
| 1986 | Mixed[b] | *C. leather* | 7 500 | 9.0 | 5.8 | 1.2 | 79.0 | 30.4 | 203.0 | 4.2 | 168.2 | 1.2 | 67.7 |
| | | Nile tilapia | 7 500 | 87.0 | 7.1 | 11.5 | 81.0 | 13.2 | 50.1 | 0.8 | 4.5 | 0.4 | 21.8 |
| | | Carp | 15 000 | 9.0 | 3.3 | 0.6 | 61.8 | 10.0 | 20.1 | 2.0 | 32.5 | 0.2 | 10.5 |
| | | Total | 30 000 | 105.0 | — | — | 70.9 | — | — | — | — | 1.8 | 100.0 |
| 1987 | Mixed[c] | *C. leather* | 12 000 | 21.0 | 6.0 | 1.3 | 69.1 | 26.5 | 137.6 | 3.4 | 106.0 | 1.1 | 68.8 |
| | | Carp+ crucian carp | 12 000 | 276.0 | 10.0 | 23.0 | 55.1 | 15.0 | 78.2 | 0.5 | 2.5 | 0.5 | 31.2 |
| | | Total | 24 000 | 297.0 | — | — | 62.1 | — | — | — | — | 1.6 | 100.0 |
| | Pure[d] | *C. leather* | 15 000 | 16.5 | 5.0 | 1.1 | 91.7 | 28.4 | 146.0 | 4.7 | 133.0 | 2.0 | 100.0 |
| 1988 | Pure[e] *(C. leather)* | OYF | 9 000 | 531.0 | 17.5 | 59.0 | 99.0 | 32.5 | 217.1 | 0.9 | 3.8 | 1.9 | 63.0 |
| | | YF hatched in 1988 | 12 000 | 72.0 | 10.0 | 6.0 | 90.0 | 25.2 | 105.0 | 1.5 | 18.3 | 1.1 | 37.0 |
| | | Total | 21 000 | 603.0 | 13.7 | 28.8 | 93.9 | 28.5 | 155.7 | 1.1 | 4.4 | 3.1 | 100.0 |

[a] Wt. weight; OYF overwintered young fish; YF young fish. [b] Fish cultured from 4 June to 5 October. [c] Fish cultured from 29 May to 20 September. [d] *C. leather* cultured from 27 May to 28 September; OYF from 29 April to 22 September. [e] Fish cultured from 13 May to 22 September.

Table 2. Economic benefits of different fish species stocked in ricefields.

| Year | Stocking pattern | Species[a] | Input (CNY/ha) | | | Output | | | Economic benefits | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Young fish | Feed | Total | Output (t/ha) | Value (CNY) | Value (%) | Net income (CNY/ha) | % | Benefit ratio | Input/ total input (%) |
| 1986 | Mixed | *C. leather* | 1 050 | 555 | 1 605 | 1.2 | 7 245 | 73.5 | 5 640 | 92.7 | 1:4.5 | 42.6 |
| | | Nile tilapia | 600 | 555 | 1 155 | 0.3 | 1 522 | 15.5 | 367 | 6.0 | 1:1.3 | 30.7 |
| | | Carp | 450 | 555 | 1 005 | 0.2 | 1 080 | 11.0 | 75 | 1.3 | 1:1.1 | 26.7 |
| | | Total | 2 100 | 1 665 | 3 765 | 1.7 | 9 847 | 100 | 6 082 | 100 | 1:2.6 | 100 |
| 1987 | Mixed | *C. leather* | 1 680 | 525 | 2 205 | 1.1 | 6 849 | 68.8 | 4 644 | 77.1 | 1:3.1 | 56.1 |
| | | Carp + Crucian carp | 1 200 | 525 | 1 725 | 0.5 | 3 105 | 31.2 | 1 380 | 22.9 | 1:1.8 | 43.9 |
| | | Total | 2 880 | 1 050 | 3 930 | 1.6 | 9 954 | 100 | 6 024 | 100 | 1:2.5 | 100 |
| | Pure | *C. leather* | 2 100 | 1 950 | 4 050 | 2.0 | 11 898 | 100 | 7 848 | 100 | 1:2.9 | 100 |
| 1988 | | OYF | 4 140 | 2 490 | 6 630 | 2.0 | 17 415 | 70.9 | 10 785 | 71.8 | 1:2.6 | 69.5 |
| | Pure (*C. leather*) | YF hatched in 1988 | 1 950 | 960 | 2 910 | 1.1 | 7 137 | 29.1 | 4 227 | 28.2 | 1:2.4 | 30.5 |
| | | Total | 6 090 | 3 450 | 9 540 | 3.1 | 24 552 | 100 | 15 012 | 100 | 1:2.6 | 100 |

[a] OYF overwintered young fish; YF young fish.

fish increased 4.2-fold. Yields of *C. leather* were the highest. When stocked at 25% of the population *C. leather* yielded 71.4% of the harvest.

Yields of *C. leather* were twice as high in monoculture than in polyculture (average 3.1 t/ha in 1988; largest individuals weighed 450-600 g). The size of the young fish used for stocking influenced yield and economic return. Overwintered large-size young fish produced higher yields than smaller-size fish hatched the same year. The survival rate of overwintered fish to food fish was 90%, and the harvest increased significantly when larger-size young fish were used. Fish that were 15-20 cm in length constituted 63% of the average yield; whereas, fish less than 10 cm in length constituted 37% of the yield.

### Economic Benefits

Economic benefits were closely related to the species (Table 2). *C. leather* produced the best economic returns. In mixed culture, *C. leather* constituted 43% of the total input and produced 74% of the total output value. Net income from *C. leather* was CNY5 640/ha (93% of total net income) and the benefit ratio was 1:4.5. The output value of nile tilapia and carp was 15-21% of the total output, net income was CNY75-367.5/ha, and the benefit ratio was between 1:1.1 and 1:1.3. In monoculture, the output of *C. leather* amounted to CNY24 552/ha, net income was CNY15 000, and the benefit ratio was between 1:2.6 and 1:2.9

Experiments and demonstrations in ricefields over 3 years showed that *C. leather* grows quickly, produces high yields, and is of good quality. *C. leather* is considered to have 10 advantages. They grow exceptionally fast, individual fish are large, they are omnivorous and capable of eating coarse food materials, they tolerate "humble" living conditions, they are resistant to diseases, they have a high survival rate, they tolerate of low oxygen levels, they are suitable for cultivation in dense populations, they produce excellent output, and they produce good economic benefits for farmers.

## Rice-Fish Cultivation

The techniques for rice-fish cultivation have been improved. Different fish species have been used and economic benefits have been increased by better integrating the use of the ricefields. Two patterns of the cultivation are currently used.

### Traditional Method

This is the main method used in Yunnan. Although the method does produce some economic benefits, yields are limited because of deep ploughing, close planting of the rice, the use of shallow-flooded fields with few ditches, the stocking of small numbers of small fry, and no additional feeding and management. This pattern of production yields on average less than 150 kg/ha (maximum 300-450 kg/ha). It is important to improve the techniques and gradually encourage farmers to change from low-yield, extensive cultivation to the high-yield, intensive methods of cultivation.

### Improved Method

This method combines the culture of fish in ditches and beds in the ricefield with zero-tillage of the fields. This method has been successful in Kunming, a rice-growing region with an annual average temperature of 14.5°C (monthly averages from May to September are 18.9°C, 19.4°C, 19.7°C, 18.9°C, and 17.4°C). Corresponding water temperatures in the ditches are 21.6°C, 22.1°C, 23.3°C, 22.2°C, and 20.3°C. Several steps are involved in establishing this type of rice–fish system. First, choose a ricefield with good water supply and a convenient irrigation and drainage system, good water-retaining properties, and little shade. Second, dig ditches and divide the field into beds (zero-tillage) — ditches should be 0.4–0.6 m in depth and 0.4–0.5 m in width, the beds 2–3 m wide, and the ditch area should be 10–15% of the total area of the ricefield. Third, spread manure over the field before the ditches are dug, pulverize and level the top soil, and dig out the ditches to cover the manure before the rice seedlings are planted. Fourth, raise and reinforce the surrounding small dikes with the subsoil dug from the ditches. The ditches should be straight, level, and have a flat bottom. Tillage should not be needed for 5 years.

The main features of this cropping pattern are: zero-tillage fields with deep ditches and wide beds; rice planted in shallow water and rice and fish grown together; symbiosis of rice and fish, which reduces stress on both; intensive management and multiple use of water; and increased income from both rice and fish. Additional ditches can be added without reducing yield, the ricefield can be dried without damaging the fish, and chemicals can be applied to the rice without killing the fish.

**Income generation.** Rice–fish yields increased each year. Rice yields were 7–12% higher in the zero-tillage rice–fish system than in ploughed fields without fish. Fish yields were more than 3 000 kg/ha, which was over 10 times the yield of fish from ricefields cultivated in the traditional way. The value of rice plus fish was CNY27 525/ha and net income was CNY16 815/ha (an increase of 8.6- to 19-fold, Table 3).

**Ecological benefits.** Increases in yields of rice and fish were closely related to the patterns of zero-tillage, bed division in the ricefield, rice and fish being grown together, and the selection of specific fish species. The rice and fish derived mutual benefit from the system, and ecological conditions in the ricefield were improved in several ways (Table 4).

- Improved habitat. A mutually beneficially habitat was provided for the rice and the fish. Circulation of air and penetration of light were improved between beds and rows. Light penetration in fields with bed divisions was 12.6% higher than in fields without divisions. Water temperatures were 0.7°C higher, there were 6–10 more rice grains per panicle, and the rate of empty, shrunken grains was 5–10% lower. These changes in light and water conditions favoured growth of both fish and rice.

Table 3. Output and output value from different rice–fish cultivation patterns.[a]

| | | Input (CNY/ha) | | | Output (t/ha) | | Output Value (CNY/ha) | | | Economic Benefits | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Pattern | Rice | Fish | Total | Rice | Fish | Rice | Fish | Rice+Fish | Net Income (CNY/ha) | Benefit Ratio | Rice Yield Increase (%) |
| 1986 | Rice+mixed fish species | 1 425 | 3 510 | 4 935 | 6.5 | 1.7 | 2 745 | 9 864 | 12 609 | 7 674 | 1:2.6 | 12.1 |
| | Control | 1 560 | 0 | 1 560 | 5.8 | 0 | 2 450 | 0 | 2 450 | 890 | 1:1.6 | 0 |
| 1987 | Rice+pure fish species | 1 425 | 3 900 | 5 325 | 7.1 | 2 | 2 970 | 11 898 | 14 868 | 9 543 | 1:2.8 | 10.3 |
| | Control | 1 725 | 0 | 1 725 | 6.4 | 0 | 2 692 | 0 | 2 692 | 968 | 1:1.6 | 0 |
| 1988 | Rice+pure fish species | 1 170 | 9 540 | 10 710 | 7 | 3.1 | 2 973 | 24 552 | 27 525 | 16 815 | 1:2.6 | 7.4 |
| | Control | 1 875 | 0 | 1 875 | 6.5 | 0 | 2 740 | 0 | 2 740 | 866 | 1:1.5 | 0 |

[a] Values used in calculations were: CNY 3 for 1 labour-day input; CNY0.42 for 1 kg of rice output; CNY6 for 1 kg of fish output (CNY8 in 1988).

Table 4. Edge effect on rice in ditch-bed and zero-tillage rice–fish cultivation.[a]

| Cult.[b] | Treat. | No. Grains | No. Full Grains | ES Grains (%) | Tillers/ Plant | Prod. Pan.[c] | EB Tillers (%) | Pan. Wt. (g) | Wt./ Row (g) | Yield (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 80-2 | Edge 1-3 | 121.6 | 96.2 | 21.0 | 1.67 | 376.5 | 52.0 | 2.50 | 2 275 | 12.9 |
| | Control | 115.4 | 83.6 | 27.5 | 1.60 | 330.0 | 45.5 | 2.17 | 2 015 | 0 |
| 79-635 | Edge 1-3 | 84.8 | 70.4 | 17.0 | 2.24 | 684.0 | 60.5 | 1.54 | 2 125 | 19.0 |
| | Control | 74.3 | 54.0 | 27.2 | 2.11 | 618.0 | 56.3 | 1.24 | 1 900 | 0 |

[a] Plant population: single-row strip, 3 x 5, 600 000 stands per hectare; Control: edge 6 rows; weight per row: total weight of 108 stands in a row.
[b] Cult. cultivar; Treat. Treatment; ES empty-shrunken; pan. panicle; EB ear-bearing; Pan. wt. Panicle weight; Wt./row Weight per row.
[c] Values in this column are x 10 000.

- Higher yields of rice. Experiments have shown that in zero-tillage fields, shallow-planted plants constitute 94.6% of the population. In ploughed fields, deep-planted plants make up 77.2% of the population. (Shallow-planting less than 6.7 cm, deep planting more than 10 cm). Shallow-planted plants recover more readily, tiller earlier, and more vigorous, have a larger number of productive tillers, a higher percentage of ear-bearing tillers, a lower percentage of empty, shrunken grains, and have heavier panicles with less diseases (Table 5). Zero-tillage is a new practice that solves the problem of plants being planted too deep and also saves energy and labour.
- Improved soil fertility. Rice–fish culture is an efficient way to accelerate soil enrichment. Ricefields provide fish with a rich source of natural food, and the fish excrete manure, loosen the soil, and eradicate weeds. Soil analysis (Table 6) shows that rice–fish cultivation with successive zero-tillage increased organic matter and active nitrogen, but reduced phosphorus in the soil. It is necessary to apply large amounts of manure and smaller amounts of fertilizers. With successive rice–fish cultivation, it is particularly important to control nitrogen and increase phosphorus to maintain steady rice growth during the entire crop cycle.

Because the fish loosen the soil, the soil has higher permeability, which promotes decomposition of complex soil nutrients, manure, and fertilizer and improves rice growth. Root systems are also better developed (25.5% increase) and more widely and deeply distributed. Large amounts of weeds were eaten by *C. leather*, which has a good appetite and also devours insects. As a result, the ricefields were nearly free of weeds without cultivation or weeding.

Table 5. Effects of ditch-beds, zero-tillage rice–fish culture, and ploughing on planting depth of rice seedlings.

| | | Less than 6.7 cm | | 6.7 cm | | More than 10 cm | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cult.[a] | Till. Pat. | S[c] (%) | T (%) | S (%) | T (%) | S (%) | T (%) | No. Grains | Full Grains (%) | ES Grains (%) | Prod. Ears[b] | EB Tillers % | Pan. Wt. (g) | Dis. Plants (%) | Yield (t/ha) | Yield (%) |
| Dianyu No.1 | Plow | 29.0 | 30.4 | 71.0 | 69.9 | 0 | 0 | 87.2 | 70.4 | 19.3 | 529.5 | 75.4 | 1.4 | 20.8 | 5 | 12.2 |
| | Zero-tillage | 4.7 | 7.1 | 18.1 | 49.6 | 77.2 | 43.3 | 87.8 | 61.0 | 30.5 | 480.0 | 60.8 | 1.3 | 34.7 | 5.8 | 0 |
| 80-2 | Plow | 30.8 | 56.5 | 63.8 | 34.8 | 5.4 | 8.7 | 112.0 | 91.8 | 18.0 | 313.5 | 78.6 | 2.7 | 18.2 | 8.4 | 12.1 |
| | Zero-tillage | 9.5 | 32.7 | 14.3 | 49.0 | 76.2 | 18.3 | 108.5 | 84.2 | 22.4 | 313.5 | 70.1 | 2.4 | 25.6 | 7.7 | 0 |

[a] Cult. cultivar; Till. Pat. Tillage pattern; ES Empty-shrunken; Prod. productive; EB ear-bearing; Pan. Wt. panicle weight; Dis. diseased.
[b] Values in this column x 10 000.
[c] Planting depth sampled at tillering peak (on 30 June). S = seedlings; T = tillers.

Table 6. Soil nutrients in experimental rice-fish cultivation fields (zero-tillage practiced in successive years).

| Year | Treatment | pH | Organic Matter | Active N (ppm) | Active P (ppm) | Active K (ppm) | Total N (%) | Total P (%) | Total K (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1984 | Control (before fish stocking) | 6.73 | 4.101 | 161.2 | 94.50 | 61.69 | 0.208 | 0.160 | 2.055 |
| 1985 | 1st year of rice-fish cultivation | 6.38 | 4.848 | 167.3 | 74.10 | — | 0.228 | 0.111 | 2.454 |
| 1986 | 2nd year of rice-fish cultivation | 6.41 | 5.014 | 233.8 | 12.18 | 172.19 | 0.231 | 0.110 | 2.659 |
| 1987 | 3rd year of rice-fish cultivation | 6.24 | 5.269 | — | 10.46 | 84.9 | 0.245 | 0.122 | 2.643 |

In contrast, fields planted to rice, but not stocked with fish, require weeding twice during the growing season and still contained 2 000 kg of weeds per hectare at harvest. Oriental army worms and rice planthoppers were eaten by the fish; therefore, no pesticides were needed and labour for spraying was saved. The percentage of diseased rice plants decreased by 7–14% compared with fields without fish.

## Conclusion

The most desirable fish species for rice-fish cultivation in the Yunnan plateau is *C. leather*. It grows quickly, is of good quality, tolerates low oxygen, and can be stocked at high densities. The use of ditches and beds, combined with zero-tillage, produced the best economic returns from rice-fish cultivation in Yunnan. This system produces increased outputs and income from both rice and fish and imparts additional ecological benefits to the ricefield.

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# Demonstration of High-Yield Fish Farming in Ricefields

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Traditional fish farming in ricefields yields about 150 kg of fish per hectare. To improve economic efficiency and stimulate the development of a commodity economy in rural areas, improvements have been made in rice-fish culture since 1984 in several major rice producing provinces (e.g., Sichuan, Hunan, Hubei, Jiangxi, Guangxi, Anhui, Jiangsu, Zhejaing, Guizhow, Guangdong, and Yunnan). In 1986, the Science and Technology Commission of Guangxi Autonomous Region assigned a rice-fish project through the Spark Program to the Guangxi General Station of Aquatic Technical Extension. Demonstration experiments were conducted in ricefields for 2 years. High yields of rice and fish were obtained over large areas using a ditch and pit method. In 1986, the experimental area amounted to 48 ha and 29 657 kg of fish were harvested. The average yield was 620 kg/ha which was 3.8 times the average yield of other rice-fish systems in the region. The average rice yield was 10 700 kg/ha. In 1987, the demonstration area was increased to 55.5 ha, the total fish yield was 40 268 kg (average 725 kg/ha), and the average rice yield was 11 610 kg/ha. These results surpassed the target of the specialized contract by 525–600 kg/ha of fish and more than 7 500 kg/ha of rice.

## Experimental Methods

### Experimental Fields

The two methods that were used were the pit and ditch method and the ridge and ditch method.

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**Pit and ditch method.** In 1986, there were 48 ha of demonstration fields and 529 households participated. In 1987, there were 55.5 ha of fields and 658 households. The experimental fields were distributed from north to south in a total of 26 towns in 14 counties.

Water resources in the experimental fields were abundant, drainage and irrigation were convenient, and yields were ensured despite drought or flood. Before the early rice was transplanted, 6-8% of the ricefields were dug into fish pits that were 65-100 cm deep. At the same time, the footpaths between ricefields were dug 20 cm deeper to form fish ditches that connected all of the fish pits.

**Ridge and ditch method.** In 1987, in Cenqui County of Wuzhow District, experiments were conducted using a ridge and ditch method on 3.4 ha. Seven days before the early rice was transplanted, the ricefields were tilled and base manure was spread. All of the water was then drained from the field. A ditch (50 cm wide and 40 cm deep) was then dug around the field. If the field was large area, an x- or #-shaped ditch was dug. After the ditch was dug, the ridges were made in an East-West direction. The ridges were 24-26 cm wide and 20-22 cm high. The ditches were 36-40 cm wide and 20-22 cm deep.

### Stocking Methods

Two methods of stocking were used: single stocking and two stockings. Single stocking is usually done before the end of April. When two stockings are used, the first is between early April and early May when the early rice is transplanted. The second stocking occurs during the second half of July. Larger fish are partly harvested before or after the harvest of the early rice, and fish fry (4-7 cm long) are stocked.

In 1987, fish fry were stocked at the rate of 11 985 fry/ha. The fish stocked were 80% common carp, 6.1% grass carp, 11% nile tilapia, 2% silver carp, and 0.6% bighead carp. Various experiments were conducted to investigate the effects of: stocking carp at different densities, different species (common carp, grass carp, and nile tilapia), and different feeds (fresh plants, concentrates, and fresh plants mixed with concentrates). Additional comparisons were made between rice yields with and without fish in one ricefield divided into two parts. These experiments were carried out at all the 14 counties.

### Day-to-Day Management

Rice production in the demonstrations field was conducted according to the conventional methods used by farm households. In most demonstration fields no weeding was done. The depth of water in the ricefields was generally between 6 and 10 cm; however, during the flowering period the water depth was increased to 15 cm. Atmospheric temperature varied between 16.5°C and 39°C, water temperature was 20-36.5°C, and pH was 6.4-7. Bran cake, green forage, and fertilizer was applied as required.

### Collection of Data

In each of the 14 districts, one observation station was established for every 3.3 ha of ricefields and 37 farm households were used for observation. Aquatic scientists and technicians visited the experimental fields periodically to make observations and record data.

## Results

### Yield of Fish and Rice

Fish and rice were grown in the experimental fields for between 176 and 320 days. In 1986, the 48 ha of ricefields yielded an average 620 kg of fish per hectare. This represented an increase of 4.8 times the average yield of 106 kg/ha obtained from rice–fish culture in the district. The average rice yield with fish was 10 700 kg/ha, an increase of 4.8% compared with ricefields without fish at the same location.

In 1987, there were 55.5 ha of demonstration fields. The average fish yield was 725 kg/ha, which was an increase of 5.5 times compared with the average yield in the district. The average rice yield with fish was 11 605 kg/ha, an increase of 7.2% compared with fields without fish. There were 3.4 ha of rice–fish in the ridge and ditch method. The average rice yield was 12 307 kg/ha, an increase of 8.9% compared with other ricefields.

### Survival Rate and Average Weight

In 1987, 665 711 fish were stocked in the demonstration fields and 439 557 fish were harvested. The average survival rate was 66%. Survival rates for each species were: carp 65% (52–79%); grass carp 67% (52–75%); nile tilapia 65% (50–78%); silver carp 68% (62–76%); and bighead carp 75% (71–77%).

The average weights of the different fish varieties were: carp 69.6 g; grass carp 242.6 g (the largest fish was 400 g); nile tilapia 116.1 g; silver carp 255.3 g; and bighead carp 343 g. The yield proportion of the different species was: carp 60%, grass carp 16%, nile tilapia 14%, silver carp 6%, bighead carp 3%, and others 1.1%.

### Stocking Densities

In 1987, at Guangyang County, Guilin District 3, 0.16 ha were used for trials of different stocking densities (4 500, 9 000, and 15 000 fish/ha). Stocking at a density of 9 000 carp fry per hectare produced the highest yield (834 kg/ha). At a density of 4 500 carp fry per hectare yield was 495 kg/ha. At 4 500 carp fry per hectare, the average weight per fish was highest. The largest fish was 73.1 g. At a density of 9 000 fish per hectare, the largest fish was 70.8 g; at 15 000 fish per hectare the largest fish was only 37.9 g.

### Varieties

In 1986, trials were conducted with crucian carp, grass carp, and nile tilapia as the main stocked fish. High yields could be obtained for all species. When summer grass carp were stocked at 27 000 fish per hectare, with the objective of rearing large fingerlings, 14 400 fry larger than 10 cm were harvested per hectare (survival rate 53%).

### Feeding

In 1986, trials of different fish feeds were undertaken. No matter what kind of feed was used (e.g., farmyard manure, green fodder, bran cakes, or combinations of all three), the yield of fish could be increase. A combination of concentrated feed, green fodder, and farmyard manure produced the highest yields.

### Rice-fish Compared with No Fish

In 1987, in a total of 1.7 ha of ricefields owned by 22 households in four districts, experiments were conducted to compare rice-fish farming with rice-only farming. The heading rate, fruiting rate, number of grain per head, 1000-grain weight, and nitrogen, phosphorus, and potassium levels in the soil were higher in the rice—fish systems. The average yield from the rice-fish fields was 5.6% higher (Tables 1 and 2).

### Economic Efficiency

The direct economic gain from the experimental fields during the 2-year period was increased to CNY222 840 . Of this amount, CNY181 902 was net income derived from fish farming. The demonstration experiments on 1 070 ha of ricefields produced an average fish yield of 293 kg/ha and net income was increased to CNY11 530/ha. The total benefit (direct plus indirect benefits) was over CNY1 million. The ratio between input and output was 1:5.51.

### Ecological Effects

Fish grown in the ricefield eat mosquitoes and control diseases. Research conducted in 1987 in Quanzhou County by the Parasitic Disease Research Institute of Guanxi Autonomous Region, and the Sanitation and Antiepidemic Station of Quanzhou County. Carp and grass carp raised in ricefields successfully controlled mosquitoes. The relative density index (RDI) was between 0.9 and 42.9. In general, the number of larva and pupa in rice-fish fields was remarkably lower than in the fields without fish.

## Conclusion

Several new techniques have been introduced to help improve traditional rice-fish culture:

Table 1. Rice yields with and without fish culture in four districts (1987).

| | | 1 000-Grain Weight (g) | | Full Grains (%) | | Grains/Head | | Yield (kg/ha) | |
|---|---|---|---|---|---|---|---|---|---|
| District | Rice | RF[a] | Cont. | RF | Cont. | RF | Cont. | RF | Cont. |
| Guilin (0.1 ha) (1 household)[b] | early | 28.3 | 27.8 | 86.4 | 82.3 | 126.0 | 117.0 | 7632 | 6135 |
| | late | 27.0 | 26.9 | 82.1 | 78.4 | 118.0 | 105.0 | 6750 | 6225 |
| Wuzhou (0.3 ha) (2 households) | late | 25.3 | 24.8 | 80.2 | 78.8 | 127.7 | 109.6 | 6606 | 6206 |
| | early | 25.6 | 24.8 | 89.0 | 87.5 | 124.3 | 118.4 | 11654 | 11037 |
| Yulin (0.6 ha) (9 households) | late | 24.8 | 24.1 | 86.9 | 81.9 | — | — | — | — |
| Qinzhou (1.7 ha) (10 households) | | 26.6 | 25.3 | 83.0 | 72.2 | 125.4 | 121.1 | 5537 | 4857 |

[a] RF rice-fish culture; Cont. no fish culture.
[b] Weeds were reduced by 430 kg/ha in rice-fish fields in Yulin District; 3117 kg/ha in Qinzhou District. Weeds in rice-fish fields in Guilin District were 7.7% of the level in the control field.

Table 2. Weed and insect infestation and soil fertility of ricefields with and without fish culture.

| | | Weeds ($g/m^2$) | | Insects ($no./m^2$) | | Soil Fertility (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | RF | | | Cont. | | |
| District | Rice | RF[a] | Cont. | RF | Cont. | N | P | K | N | P | K |
| Guilin (0.1 ha) (1 household) | — | 1.5 | 19.5 | — | — | — | — | — | — | — | — |
| Wuzhou (0.3 ha) (2 households) | — | 2.8 | 3.6 | — | — | 0.19 | 0.06 | 1.22 | 0.19 | 0.06 | 1.27 |
| Yulin (0.6 ha) (9 households) | early | 79.0 | 103.6 | 0.67 | 4.97 | — | — | — | — | — | — |
| | late | 67.9 | 111.0 | 0.81 | 2.11 | 0.16 | 0.09 | 1.06 | 0.14 | 0.08 | 1.03 |
| Qinzhou (1.7 ha) (10 households) | — | 31.0 | 343.0 | 0.51 | 0.60 | 0.18 | 0.12 | 0.44 | 0.16 | 0.03 | 0.40 |

[a] RF rice-fish culture; Cont. no fish culture.

- Pit, ditch, and ridge and ditch fish-farming systems in ricefields are modifications of traditional methods. The objective of these new methods is to reduce conflicts between fish farming and rice growing and to increase the yields of both rice and fish and raise the economic efficiency of the ricefields.
- Carp, grass carp, nile tilapia, silver carp, and chub are now mixed for rearing. The traditional method of raising only carp was changed to increase fish yields, promote rice production, and improve sanitary conditions in the rural areas.
- The use of over-wintered fingerlings has significantly increased fish output compared with the traditional method of breeding fingerlings the same year.
- The combination of the production of edible fish with the culture of fingerlings has changed the habit of breeding only fingerlings or only edible fish. This has provided edible fish and abundant fish varieties for market.
- The introduction of appropriate feeding has promoted fish growth and increased income.
- One species of fish adapted to local conditions is now used as the major species. Selection of brood stock has also been improved.

The key techniques used to increase fish yields in ricefields are:

- Use reasonable stocking densities and ratios of multiple fish varieties. Grass carp, nile tilapia, silver carp, and variegated carp were stocked at a rate of about 12 000 fish/ha.
- Breed and stock over-wintered fingerlings.
- Dig fish pits and fish ditches to solve the contradictions between fish farming and rice management.
- Apply appropriate fertilizers and feeds to supplement natural feeds found in the ricefields.

# Rice-Azolla-Fish in Ricefields

*Chen Defu, Ying Hanquing, and Shui Maoxing*[46]

The yield per hectare of traditional fish-raising methods is only 75–150 kg in China. In Zhejiang Province, a high-yield rice-azolla-fish system was developed and extended to farmers. The technique has now been adopted in many regions in Zhejiang Province, and rice production and fish yields have both increased. In 1987, a demonstrative farmer, Shao Shousheng in Yuhang County, tested the high yield rice-azolla-fish system. The Zhejiang Academy of Agricultural Sciences, Yuhang Agricultural Committee, and Yuhang Science and Technology Society conducted the experiments. The techniques used to simultaneously raise rice, azolla, and fish are discussed.

## Test Methods

The test field was located in Xingqiao Village, Yuhang County, 2 km from Hangzhou City. The field was 0.3 ha and had been used in 1986 as a test field for high-yield fish culture. Therefore, the farmer, Shao Shousheng, had practical experience. The fish ditch was 3 m in width, 1 m in depth, and occupied 21% of the total ricefield. Fine feed was used as the main fish food, and organic manure and fertilizers were used as supplements. Omnivorous, carp and crucian carp were raised. In 1986, the yield of rice was 9 730 kg/ha and the net yield of adult fish was 3 426 kg/ha. A comprehensive experiment on rice-azolla-fish was started in 1987 and several changes were made in rearing techniques:

- Instead of using fine feed for the fish, the fine feed was first fed to pigs and the pig manure was fed to the fish.
- Rice-azolla-fish were grown together in 1987, and the azolla were used as the main feed for the herbivorous fishes.
- Herbivorous fishes were chiefly raised in 1987 (silver carps, common carp, and crucian carp).

## Test Results

### Yield of Rice and Fish

The rice yield was 9 786 kg/ha in 1986. The early japonica rice (Biyuzaonuo) grew well in 1987 and produced an additional 980 kg/ha. However, transplanting of the late rice was delayed to nearly the beginning of Autumn because the early rice was

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late to mature. It was also difficult to keep the grass carp in the fish ditches away from the rice on the sides of the ditches. Because the fish eat some of the rice, rice yield decreased to 1 233 kg/ha, but the yield of adult fish increased greatly (Table 1). In 1987, the yield of adult fish from the rice-azolla-fish system was 6 990 kg/ha, an increase of 71% over the 4 200 kg/ha in the rice-fish system in 1986. If the yield of fish fry is excluded, the net yield of adult fish was 5 500 kg in the rice-azolla-fish system, an increase of 60% over the 3 444 kg/ha in the rice-fish system.

### Feed Consumption and Cost

Fine feed was the main food source for the fish in 1986, and 7 300 kg/ha of feed were consumed. Therefore, the cost of fish raising was rather high. Major modifications were made in 1987. The fine feed was first used to feed pigs. The pig manure was then fed to the fish and used to fertilize the azolla. This modification made full use of material inputs and added four pigs to the output with limited input. The cost of feed for fish raising was also reduced. The unit cost of feed in the rice-azolla-fish system was only 47% of the cost in the rice-fish system, and the feed cost of fish per kilogram was 29% of the cost in 1986 (Table 2).

### Economic Efficiency

The cost of fish raising was almost equal both years. The output value and net profit in the rice-azolla-fish field increased significantly because the adult fish yield in the rice-azolla-fish field was higher than that in the rice-fish field. The output value was CNY17 100/ha and net profit was CNY9 278/ha in the rice-fish field in 1986; whereas, in 1987, the output value was CNY25 404/ha and the net profit was CNY17 528/ha in the rice-azolla-fish field (an increase of 89%, Table 3).

## Analysis and Discussion

There were several reasons for the yield increase and the cost decrease in the rice-azolla-fish fields.

### Use of Herbivorous Fishes

Herbivorous fishes (grass carp and bream), especially grass carp, are fond of azolla and grow quickly. When there is a sufficient supply of azolla there is great potential for yield increase. The omnivorous fishes (carp and crucian carp) require high-quality fine feed, but grow slowly. These omnivorous fishes were the most numerous in 1986 (79% of the fish and 72% of the total weight). Herbivorous fishes comprised 14% of the fish and 15% of the total weight. Among the herbivorous fishes, grass carps accounted for 5% of the fish and 4% of the weight. In 1987, azolla was grown in the ricefields and herbivorous fish were the main species raised (48% of the fish and 31% of the weight). Grass carp accounted for

Table 1. Yields of rice and fish in rice-azolla-fish and rice-fish systems.

| | Early Rice Yield (kg/ha) | Late Rice Yield (kg/ha) | Annual Yield (kg/ha) | Fish Yield (kg/ha) | Fingerling Yield (kg/ha) | Adult Fish Yield (kg/ha) |
|---|---|---|---|---|---|---|
| Rice-fish | 4208 | 5579 | 9786 | 4119 | 678 | 3443 |
| Rice-azolla-fish | 5190 | 4347 | 9537 | 7038 | 1535 | 5499 |

Table 2. Fine feed consumption and cost of rice-azolla-fish and rice-fish systems.

| | Fine Feed (kg/ha) | Beer Leftovers (kg/ha) | Pig Manure (kg/ha) | Fertilizer (kg/ha) | Azolla (kg/ha) | Cost (CNY/ha) | Cost/kg of Fish (CNY) |
|---|---|---|---|---|---|---|---|
| Rice-fish | 7301 | — | 11243 | 543 | — | 3206 | 0.93 |
| Rice-azolla-fish | 1023 | 575 | 34110 | 506 | 2471 | 1494 | 0.27 |

Table 3. Economic efficiency of rice-azolla-fish and rice-fish systems.

| | | Rice-Fish (CNY/ha) | Rice-Azolla-Fish (CNY/ha) |
|---|---|---|---|
| **Output value** | Rice | 3579 | 3503 |
| | Fish | 13515 | 21902 |
| | Total | 17094 | 25397 |
| **Cost** | Rice | 414 | 414 |
| | Fish | 7402 | 7468 |
| | Total | 7816 | 7882 |
| **Profit** | Rice | 3165 | 3089 |
| | Fish | 6113 | 14434 |
| | Total | 9278 | 17522 |

32% of the herbivorous fish and 29% of the weight, and bream 16% of the fish and 1% of the weight. Omnivorous fishes comprised 7% of the fish and 11% of the weight. Oligophagous fish (silver carp) accounted for 45% of the fish and 58% of the weight (Table 4). The azolla were consumed by the herbivorous fish, and the manure from the grass carp increased the amount of plankton, which raised the yield of silver carp.

### Proportions and Harvest of Fish

In 1986, too few fish were raised early in the year and too many were raised later. At high densities, all fish were almost the same size, which made batch harvesting impossible. The market size of the fish harvested at the end of a year was also low. In 1987, the density of the fish was reduced in rice-azolla-fish system. In addition, 983 larger fish (3 760/ha) were stocked, which accounted for 27% of the total number of fish raised (1 123 kg). Of these larger fish, 188 were the grass carp (719/ha), 300 were the common carp (1 148/ha), and 495 were silver carp (1 757/ha), with the mean weight of 0.42 kg, 0.15 kg, and 0.38 kg, respectively (Table 5). In this way, the fish-holding capacity early in the year increased to 102 kg in 1987 from 45 kg in 1986. Grass carp and common carp fed on azolla in mid-March; whereas, the larger grass carp fed heavily on azolla during April to June. Grass carp and silver carp were caught in batches to supply the market. During April to October, 851 kg of large fish were harvested.

### Azolla

The growth of fish and azolla in rice-azolla-fish system were different. Azolla grows quickly in the spring when the fish are small, grow slowly, and eat little. At this time, the azolla supply exceeds demand. In July and August, azolla grows slowly and the fish grow quickly; therefore, the demand for azolla exceeds supply. Three methods were used to mitigate this problem.

**Harvest adult fish.** At the end of June, adult fish were caught for market to decrease the fish-holding capacity of the field when the azolla were growing slowly. The grass carp grow very quickly during September, which is the second peak of azolla growth.

**Supplement supply of azolla.** The azolla supply in rice-azolla-fish fields could not satisfy the demand during July to August. Azolla from nearby ricefields, ditches, and ponds were used to supplement the supply. Green-stored azolla and dried azolla were also used.

**Adjust feed.** Less fine feed was used when azolla were plentiful, and more fine feed or grass was fed when azolla levels were insufficient.

## Stopping Fish From Eating Rice

Two methods were used to stop the fish from eating the rice. The fish were kept in the fish pits with dikes and nets after the rice was transplanted. In addition, a grass field and feed platform were established in the fish pit for the omnivorous fish. Tender grass was placed in the grass field. Fine feed was placed on the feed platform when the tender grass was almost completely eaten.

Table 4. Effects of use of different fish on yields from rice-azolla-fish and rice-fish systems.

| | Rice-Fish | | | | Rice-Azolla-Fish | | | |
|---|---|---|---|---|---|---|---|---|
| | Fish Raised per ha | | Fish Breed Ratio (%) | | Fish Raised per ha | | Fish Breed Ratio (%) | |
| | (No.) | (kg) | (No.) | (Wt.) | (No.) | (kg) | (No.) | (Wt.) |
| **Herbivorous fish** | | | | | | | | |
| Grass carp | 1 339 | 28.7 | 4.6 | 4.2 | 5 096 | 458.1 | 32.9 | 29.8 |
| Bream | 2 559 | 74.6 | 8.8 | 11.0 | 2 349 | 14.7 | 15.2 | 1.0 |
| Total | 2 398 | 103.2 | 13.3 | 15.2 | 7 444 | 472.8 | 48.1 | 30.8 |
| **Omnivorous fish** | | | | | | | | |
| Common carp | 13 711 | 281.3 | 46.8 | 41.6 | 1 148 | 172.2 | 7.4 | 11.2 |
| Crucian carp | 9 564 | 204.6 | 32.6 | 30.2 | — | — | — | — |
| Total | 23 274 | 485.9 | 79.4 | 71.8 | 1 148 | 172.2 | 7.4 | 11.2 |
| **Oligophagous fish** | | | | | | | | |
| Silver carp | 2 127 | 5.9 | 7.3 | 13.0 | 6 905 | 890.4 | 44.6 | 58.0 |
| Total | 30 491 | 677.1 | 100 | 100 | 15 497 | 1535.1 | 100 | 100 |

Table 5. The proportion of species and larger fish in rice-azolla-fish and rice-fish systems (0.26-ha ricefield).

| | Rice-Fish | | Rice-Azolla-Fish | | | | |
|---|---|---|---|---|---|---|---|
| | | | Old | | Winter Fish | | Proportion of Larger Fish (%) |
| | Size (g/fish) | No. Fish | Size (g/fish) | No. Fish | Size (g/fish) | No. Fish | |
| Grass carp | 21.4 | 350 | 417.5 | 188 | 36.1 | 1 144 | 4.6 |
| Bream | 29.2 | 669 | — | — | 6.3 | 614 | — |
| Common carp | 24.9 | 1 684 | 150.0 | 300 | — | — | 7.4 |
| | 16.6 | 1 900 | — | — | — | — | — |
| Crucian carp | 21.4 | 2 500 | — | — | — | — | — |
| Silver carp | 41.1 | 556 | 375.6 | 495 | 42.6 | 1 310 | 12.2 |
| Total | 23.1 | 7 659 | 305.7 | 983 | 32.9 | 3 068 | 24.3 |

### Raising Fish in Flowing Water

Flowing water has a high oxygen content, which favours fish growth. New irrigation water was added at regular intervals. During cloudy, muggy weather, when the fish lacked oxygen, a submersible pump was used to make the water flow and increase the oxygen content. Once a month, 75 kg/ha of quick lime were diluted in water and sprayed over the field to decrease the concentration of acid in the water. This treatment promotes the breakdown of organic materials and helps sterilize the water and prevent fish diseases.

### Pig-Azolla-Fish-Rice System

This system reduced the cost of raising fish. Pigs were fed with fine feed. Fish and azolla were fed with pig manure. Azolla were used to feed the pigs. Fish manure also enriched the field. In this way, costs were reduced while net profit was increased.

## Conclusion

Experiments in 1987 indicated that the high-yield rice-azolla-fish system was a success. Fish yields and net profit were increased and rice yields were maintained. This system can improve the economic efficiency of the ricefield; nevertheless, there are still some problems that require further study.

- Grass carp quickly grow to a large size. Silver carps are smaller and have a lower commercial value. The appropriate proportion of silver carp to grass carp must be studied. Bream grow slowly and should be raised in small proportions in rice-fish-azolla fields.
- In 1987, dikes and fish nets were used to prevent the fish from eating rice. This was expensive in both capital and labour. Many late rice seedlings were eaten by the fish in 1987, which resulted in a decrease in rice yield. Changes to the design of the fish ditch are proposed to allow the farmers to block the fish with one dike and one net. This would make the operation easier and more convenient.
- Azolla continue to grow in the winter and spring. This potential should be developed to build up resources that can be used as fish feed.
- The rice yield might be improved by transplanting the rice seedlings earlier. In 1987, rice seedlings were transplanted during the second 10 days of May. This caused the ripening stage to be postponed. The rice yield might be increased if seedlings were transplanted during the first 10 days of May.
- The harvesting method for the fish should be changed. Fish should be raised and harvested on a rotational basis. This means that different species should be raised in different proportions. The appropriate size and time of harvest also needs to be established for each species.

# Part III:

# Interactions

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# Material Cycles and Economic Returns in a Rice–Fish Ecosystem

*Ni Dashu and Wang Jianguo*[47]

In the rice–fish ecosystem materials move in a benign cycle and the energy flows in the direction favourable to both rice and fish. The ricefields nourish the fish, and the fish nourish the rice. Like other theories, the theory of rice–fish mutualism has only been adopted slowly. The meaning of the word mutualism has, in recently years, been extended from its original meaning in classical ecology. It has now taken on the meaning of functional mutualism in addition to the original organization sense. A mutual relationship is one in which two different species live together and promote and accelerate their growth.

Although rice and fish are mutually beneficial, they are not totally dependent on each other. Their coming together is based on scientific principles and the anticipation of greater economic returns. As the system is further developed, and rice–fish culture is widely recognized as the best way to increase yields, their mutualism will become more of a necessity.

Chinese ecologist Ma Shijun said *it is necessary to simulate mutualism of different species of plants and animals according to one's needs*. The theory of rice–fish mutualism was founded on both conceptional and practical principles.

**Rice–Fish Ecosystem**

Ecology, in a direct sense, is a branch of science that studies habitat. It is, indeed, very closely related with the development of the national economy. In nature, animals, plants, and microorganisms come together to form a unified entity, or ecological system. The close relationship among animals, plants, and microorganisms and between these organisms and the environment, is made possible by the flow of energy and the circulation of material.

Ecological systems are both large and small. The biosphere is a large system; a ricefield or pond is a small ecosystem. In addition to these natural ecological systems, there are other ecological systems, such as the rice–fish system. All agricultural systems are, in fact, anthropogenic.

The nonbiological factors in the rice–fish ecosystem include light, water, water temperature, pH, carbon dioxide, oxygen, and some inorganic matter. The biological factors in the ecosystem include producers, consumers, and

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decomposers. The main producers are plants with roots and large and small phytoplankton. In another words, there are three categories of producers in ricefields: rice plants, weeds, and algae. They are all involved in the circulation of carbon through photosynthesis and respiration, and they provide organic matter to consumers and decomposers.

There are also many consumers. They include zooplankton (protozoa, rotifers, and crustaceans); benthos (nematodes, molluscs, annelids, and water insects); fish reared in ricefields (common carp, crucian carp, bighead carp, nile tilapia, and grass carp); mosquito larvae, insects, and worms harmful to rice; natural enemies of harmful insects and worms (spiders and parasitic wasps); and the natural enemies of fry (chilopods, scorpions, dragonflies, frogs, otters, water rats, eels, loach, water snakes, sandpipers, ducks, kingfishers, gulls, and egrets). Many animals are both primary consumers and secondary or tertiary consumers. For example, water snakes feeds on frog, frogs feed on fry, and fish feed on plankton. Many animals are harmful to rice but useful to fish, and vice versa. For example, although frogs feed on fry, they also feed on many of other insect and worms that are harmful to rice. The composition of the producers, consumers, and decomposers in the rice-fish ecosystem is complicated and merits further investigation.

### Cycling of Material and Energy Exchange

To create a rice-fish ecosystem in a ricefield, it is necessary to pay attention to the appropriate time and size of the system to ensure that the rice and fish are truly mutually beneficial. Material must be made to circulate in a benign cycle and the energy flow must be in a direction favourable to both rice and fish (Figure 1). The rice-fish ecosystem is created by adding fish fry or fingerlings to the ricefield. In this system, the cycling of matter and the movement and storage of energy becomes more rational. The difference, compared with a natural ecosystem, is that the rice-fish system is controlled and adjusted by the farmer. Of course, to perfect such an ecological system, many improvements are needed.

In the rice-fish ecosystem, rice is the dominant biological community. It absorbs large quantities of light, carbon dioxide, water, and inorganic elements and manufactures organic matter by photosynthesis. The large quantities of weeds, plankton, and photosynthetic bacteria in the ricefield undertake the same processes. However, they do not provide useful products. On the contrary, they compete for fertilizer, space, area, and sunshine with the rice and in some cases are the intermediate hosts of rice pests. Of course, weeds and plankton are all primary producers that help fix and store energy. The primary consumers are mainly zooplankton, herbivorous animals, and plant pests. The secondary consumers are mainly carnivorous animals.

Fish in the rice-fish system can be primary consumers, secondary consumers, or tertiary consumers. This creates the problem of which fish to raise to make the system more efficient. It is also the leading factor that affects the density of other

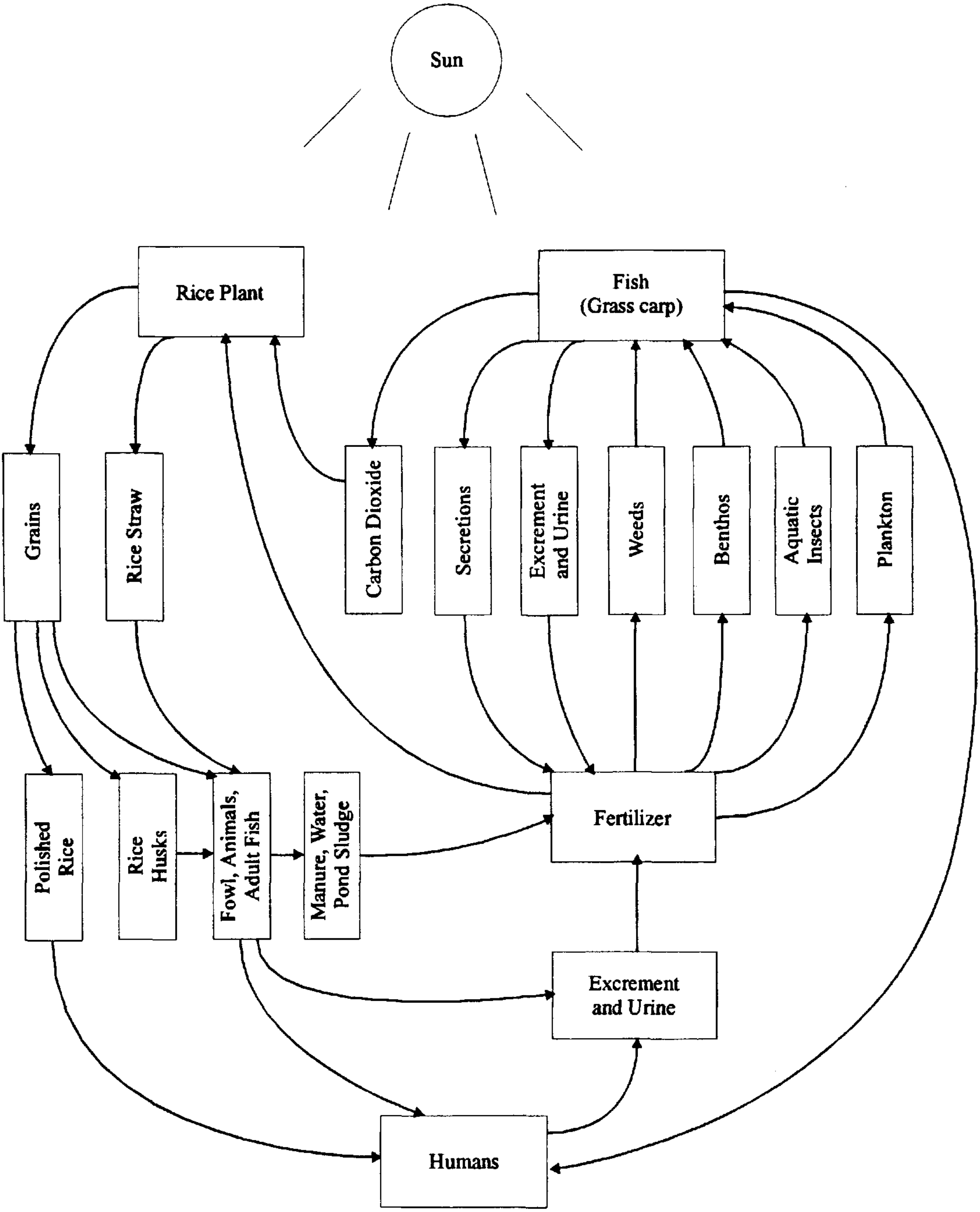


Figure 1. Flow of energy in the rice-fish ecosystem.

biological species and communities. Repeated experiments and comparisons have demonstrated that grass carp are the best fish to use for rice-fish culture.

In ricefields, grass carp eat a large quantity of weeds. There are more than 30 kinds of common weeds in ricefields. *Eleocharis yokoscensis*, *Hydrilla* sp., *Potamogeton crispus*, *Vallisneria spiralis*, *Najas marina*, *Potamogeton distinctus*, and *Lemna minor* are eaten by grass carp. In general, weeds can reduce rice yields by 10–30%. Therefore, if weeds could be totally eliminated, rice yields should increase by over 10%. Our experiments have indicated that early ricefield without fish have 13–15 times more weeds than fields with fish. When the fish are harvested there are about 33-435 kg/ha of weeds, but in ricefields without fish there are 450–6 520 kg/ha of weeds when the rice is harvested, even when weeding is done three times. The weeds eliminated by grass carp (coefficient of feed 1:80) provide about 5 kg of fish output. Furthermore, fewer weeds are available to compete for fertilizer. This stimulates increased rice output, purifies the water, and improves the environment.

By eating the plankton, weeds, and benthos in the ricefield, the grass carp grow quickly. The more they eat, the more excrement they discharge. A grass carp (6.5–13 cm) is estimated to eat 52% of its own weight and to excrete 72% of the amount of grass it eats. If 400 grass carp are reared for 110 days, fish excrement amounts to about 26 475 kg/ha. This excrement is rich in nitrogen and sulphide and therefore increases the fertility of the field.

In most cultivation systems, most of the weeds in the ricefield are pulled out and discarded. This causes a large loss of soil fertility and wastes the solar energy captured by the weeds. In addition, much of the bacteria, plankton, zooplankton, and part of the benthos, are usually discharged with the water. This accounts, either directly or indirectly, for loss of soil fertility and solar energy. From the point of view of circulation of matter and energy, this is a natural phenomenon that is unavoidable. However, from the point of view of maximizing bioproductivity, it is obviously a waste of matter and energy. The raising of fish in ricefields captures part of the matter and energy that would otherwise be wasted and transforms them into fish products. At the same time, the fish stimulate rice output. This is a very economical practice. It is desirable to continue to seek ways to improve the system and to strive for the highest possible yield using the least amount of energy and matter to produce the maximum economic returns.

The introduction of grass carp into the ricefield changes the composition of the biological species and communities and their mutual relationships. Grass carp and rice become codominant factors in the system.

In the rice-fish ecosystem, nonbiological and biological factors are important. Growth and development of rice requires light, heat, carbon dioxide, water, and nutrients. Of these factors, air, water, and nutrients undergo the most dynamic changes and exert an extremely large influence on the growth of the rice plants. For example, carbon dioxide is an indispensable raw material for photosynthesis. During the day, the amount of carbon dioxide in a ricefield with fish is higher than in a ricefield without fish. The fish respire carbon dioxide and feed on plankton that compete with the rice for nutrients. Generally, there is an increase of 1.5–8.2 mg/L (average 5.1 mg/L) in dissolved oxygen in ricefields with fish. The minimum level of dissolved oxygen at night is also tolerable for grass carp. Furthermore the fish tend to raise the dissolved oxygen content level because they stir up the water and increase the contact between water and air. The activities of the fish can also make the distribution of oxygen more uniform. Because they move the soil, the fish also improve the oxygen supply to the soil, which favours the breakdown of organic matter and reduced material in the soil. This is why many rice–fish fields that are not exposed to the sun and are not weeded still yield 10% more than fields in which fish are not reared.

**Economic Returns**

The first and foremost objective of raising fish in ricefields is to increase rice output while reducing the labour required for weeding. Rice yields are increased (by about 10%) in rice–fish fields. In addition, grass carp make full use of the water and feed provided by the ricefield, harmful insects and other rice pests are reduced, and the system retains and creates more fertilizer.

This new model of a rice–fish ecosystem is becoming increasingly popular. From 1980 to 1983, Hubei and Hunan Provinces devoted about 33 300 ha of ricefields to this new model. If the area devoted to raising fingerlings is assumed to be 2 000 ha, the area for growing food fish 2 670 ha, the average output of fingerlings 4 875/ha, and the output of food fish 525 kg/ha, the two provinces produced 9.75 million fingerlings and 1.4 million kg of food fish with an output value of CNY3.2 million. If the increase in rice output is assumed to be 10%, the added output would be worth CNY1 million. The total value of the rice and fish would be CNY4.2 million.

In 1984, China had nearly 0.7 million ha of ricefields devoted to rice–fish farming. This was an increase of more than 80% from 1983. The increase in rice output was estimated at 285 million kg and the output of fish at 47 000 tonnes. Sichuan Province, which leads the country, devoted 0.3 million ha to rice–fish farming, and Chongqing City alone reserved 77 330 ha for rice–fish farming. Hunan Province had 0.2 million ha for rice–fish in 1984, 33.7% more than in 1983. In addition, many households have reported collecting 7 500 kg of rice and 750 kg of fish from 1 ha ricefield.

If these improved methods of raising fish in ricefields could be applied to 6.7 million ha over the next 3–5 years, the rice output could be increased by 2 billion kg and the catch of fingerlings would amount to 20–50 billion, an abundant source of supply to raise adult fish. This would help China reach the goal of producing 4–5 million tonnes of fresh fish each year.

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# Fish Culture in Ricefields: Rice-Fish Symbiosis

*Xiao Fan*[48]

Fish culture in ricefields originated from natural symbiosis. The accidental discovery of wild fish in ricefields, and the subsequent catch of both adult fish and fry, induced people to make use of ricefields for fish rearing. Although the traditional rice-fish rearing was a modification of the natural system, modern rice-fish culture has undergone significant development in recent years. The improved systems have already surpassed traditional methods with respect to structure, carrying capacity, energy conversion and exchange, and use of materials, and produced ecological, financial, and social benefits.

Within the rice-fish ecosystem, the plants and animals complement and interact with each other. The organized food chains produce various materials (living and nonliving, organic and inorganic, molecular and ionic) that interact with the other biological, chemical, and physical activities in the ricefield. As a result, the food chains in the ricefield are rebuilt, soil in the fields is made fertile, the structure of the water and soil is improved, insect pests are diminished, diseases are controlled, and mosquitoes and weeds in the fields are reduced.

## Rice-Fish Food Web

The long history of rice production in China has affected the natural ecosystem. In Jiangsu Province, the use of large quantities of poisonous insecticides and chemical fertilizers since the 1960s has killed rice pests in large areas. However, at the same time, many other useful organisms have also been destroyed. The use of these chemicals has changed the characteristics of the natural ecosystem, brought about an imbalance in the ecology, and caused the gradual disappearance of ecological advantages. The current rice-fish culture system has reestablished the food chain of *fish eating insects and weeds* and made it possible to use little or no chemical herbicides to kill weeds and no insecticides to control insect pests.

### Microbes and mosquito larvae

When rice and fish are raised together in ricefields, the plants need fertilizers and the fish need rich food. In fields where fish are being raised, organic manure should be used as the basal fertilizer. Only chemical fertilizers that are not poisonous to fish should be used for supplementary applications. Ammonium bicarbonate can be used as a top dressing. The ammonium bicarbonate (15-20 kg)

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should be shaped into balls and placed under the soil in fields covered with 6–7 mm of water.

When manure is applied to the ricefield, benthos and plankton reproduce rapidly and provide the fish with sufficient food. However, as the fish grow, their need for food increases, but the availability of food in the fields decreases. A field investigation showed that the amounts of benthos with fish and without fish were, respectively, 4.3 g and 12.9 g in mid-June, 8.0 g and 25.1 g in early July, and 5.4 g and 10.2 g in mid-July. The Jiangxi Aquatic Research Institute compared fish and nonfish ricefields in 1984. There are fewer phytoplankton (625 500/ml or 2.4 mg/L of water) and fewer zooplankton (18 730 000/ml and 3.6 mg/L) in the fields with fish compared with fields with rice only.

Fish culture in ricefields differs greatly from pond culture because there is a lot of plankton in the fields and the amount of life decreases gradually. Fewer fish are stocked in ricefields (30 000/ha) than in fish ponds (3 million/ha). A study by the Hubei Aquatic Institute demonstrated that there was as much as 119 $g/m^3$ of benthos in ricefields, but only 39 $g/m^3$ in ponds. Moreover, the amount of potential food increased after the fry had been added to the fields and reached its peak 6 days later. As the fish grow and their appetites increase, the amount of food that is available begins to decrease. However, in ponds, the benthos began to decrease sharply only 3 days after the fry were introduced. After 5 days, the amount had dropped to less than 10 $g/m^3$, which is far too little to meet the needs of the fish.

Fish culture in ricefields also helps eliminate mosquito larvae. In these areas, the density of larvae in the ricefields was reduced by 50–90%, and in residential areas the number was reduced by more than 50%. The Chendu Municipal Health Station, Sichuan Province, surveyed three different areas severely affected by malaria. The incidence of malaria was 0.01% in 1981 when there was no rice–fish culture, but in 1982, the incidence dropped to 0.002% after rice–fish culture was started. Jiadian County Health Station, Shanghai Municipality, monitored the rice–fish fields of the Chuanjin Aquatic Production Farm from 2 July to 18 October. No larvae were found in the 18 samples from rice–fish fields, but in the nonfish fields, larvae were found in every sample. The average per sample was 2.2 larvae (1.7 in July, 3.3 in August, and 2.1 in September). The use of organic insecticides has killed large numbers of mosquitoes, but has also given rise to insecticide-resistant strains. Rice–fish culture is an effective control method for all types of mosquitoes, including the insecticide-resistant strains.

### Weeds

Fish eat many of the weeds in ricefields. Some herbivorous fish loosen the soil by tilling and digging holes, which uproots the tender roots and stalks of the weeds. Weeding by fish is timely and frequent and superior to chemical weeding.

When the fry are first put into the ricefields, they feed on plankton. When the weeds begin to sent out sprouts, the small fish eat these sprouts as well as small insects. As the fish grow, their ability to eat weeds increases. If there are sufficient fish in the fields, they grow synchronously with the weeds, and control them. Even the withered rice leaves that fall into the water are eaten. A study by the Zhejiang Provincial Academy of Agronomical Sciences showed that on 22 August there were 8.0 kg of weeds in a rice-fish field, compared with 30.3 kg of weeds in fields without fish. On 11 November there were no weeds in the rice-fish field, but 3.07 million green duckweed in the field without fish.

### Insect Pests

During the growth and development of rice, insects can be eliminated by fish if the proper measures are used and the habits of the insects are taken into consideration. For example, when rice planthoppers develop in the ricefields, they can be driven into the water if a rope is pulled over the rice plants. Because the planthoppers pretend to be dead when they fall from the rice plants, they are easily eaten by the fish.

During the incubation and developmental period for rice borers, a layer of water should be maintained in the ricefields. Because the rice borers transfer to a new rice plant after incubation, they will be forced to travel in the water where they can be eaten by the fish. If pest levels increase, the water level should be raised to drown part of the stalks and leaves and enable the fish to catch the insects. If the fish are close to the affected parts of the plant, they will jump to catch the insects.

Insect pests are normally not very serious and can be easily eliminated. Even during severe infestations, these methods can be used to reduce pest populations. According to materials published by the Rudong Botanic Protection Station in Jiangsu Province, in rice-fish fields there were 100 nest of rice planthopper with 984 eggs, compared with 4 468 eggs in fields without fish. An investigation in Rugao County showed that in rice-fish fields there were 30% fewer eggs of the yellow stemborer, *Tryporyza incertulas,* the rate of white ears was 50% lower, there were 50% fewer rice planthoppers, the rate of rice leafrollers was 30% lower, the rate of white leaves was decreased by 30%, and the number of rice leafhoppers was 30% lower.

Furthermore, in rice-fish fields, the rice plants are usually very strong and have good resistance to diseases. The possibility of rice diseases was also reduced because of the fertile water and good environment, improvements in varieties, reduction in density, good ventilation, and sufficient light. A study in Chenxian County, Zhejiang Province, demonstrated that under the same cultivation conditions, the indices of sheath and culm blight of rice were 11.8, 10.7, and 7.8 in fields without fish, rice-fish fields, and idle rice-fish fields, respectively,

## Improvements in Soil and Water Conditions

### Soil Fertility

In rice-fish fields, the activities of the fish help mix the manure with the soil. The fish swallow, digest, and assimilate 30-40% of the organisms living in the fields.

The rest of the organic matter is excreted into the fields and becomes manure. The fish faeces are a good quality manure that contains 42% phosphorus (a higher level than in pigs and cattle manure). Nutrient analysis has shown that are 1.2 times more phosphates in rice-fish fields than in fields without fish, and ammonia levels are 1.3–6.1 times higher. The Soil Fertilization Station in the suburbs of Yancheng County, Jiangsu Province, made a comparison of rice-fish fields with fields without fish and found that in rice-fish fields where fish had been raised for 2 years, the organic matter level was 1.8% in both fields and the nitrogen content was 0.12%.[49] In ditches with fish, the organic matter content was 1.9% and the nitrogen content 0.142%, which was much higher than in ditches without fish.

### Gases and Nutrients

Under normal conditions, the diffusion of oxygen in water is 10 000 times slower than that in air. This often results in anaerobic conditions at the soil-water interface. The activities of the fish increase the contact area of the water with air and profoundly change the gas structure of the water and soil and improve their physical properties and chemical composition. A gas determination of the soil has shown that in the fields where early rice is planted and fish are raised, oxygen is present to a depth of 5 mm in the soil, but not to 10 mm. In fields where late rice is planted and fish are raised, aerobic condition extend to 8 mm because the fish are larger and more active. In fields without fish, the surface of the soil-water interface is normally anaerobic.

Rice-fish culture helps raise rice production by:

- Increasing the oxidation of the soil and decreasing the reducing agents (e.g., $H_2S$, $Fe^{++}$, and $Mn^{++}$).
- Making it impossible for the medium matter (formed as a result of incomplete dissolution) to mineralize rapidly, to continuously release energy and produce various $NH_4^+$ and $PHO_4^-$ ions, and to renew the humus in the soil.
- Allowing the highly concentrated nutrients to spread to the roots of the rice plants because of the activities of the fish.

### Water Temperature and Oxygen Concentration

The water temperature and the conditions for oxygen solution in the ricefields are better than in fish ponds. The thin layer of water in ricefields puts large areas of water in contact with the air. There are also 100 times fewer fish in ricefields than in ponds. This is why fish do not come to the water surface as often in ricefields as in ponds.

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[49] The author suggested that there was a difference between the two fields in both organic matter and nitrogen based on a difference of 0.03%. In the absence of confidence limits, the editors have assumed there was no significant difference and changed the text.

### Fish Diseases

The water in ricefields is usually shallow and fresh and is replenished frequently. Rice plants absorb fertilizers and purify the water in the fields and, as a result, the water is continuously fresh and clear (much better than the water in ponds). The absolute number of pathogenic bacteria in pond water is 2.6 times higher than in ricefields. The number of bacteria in the water has a direct effect on the number of bacteria in fish gills. The number of bacteria on one side of the gills of fish in ponds was $160 \times 10^6$; whereas, in fish in ricefields there were only $18.5 \times 10^6$. The change in the bacteria content of the water in ricefields clearly reflects the incidence of fish diseases. From February to September, the number of bacteria in ricefields remains stable, and the incidence of fish diseases is low. July, the month during which fish diseases increase, is the time when the number of bacteria in ponds is highest.

Because fish live in the water, it is difficult to make any accurate diagnoses of diseases. Generally, sick fish have no appetite, and medicine cannot be applied or mixed with fish food. The significance of rice–fish culture is low fish density and a health environment, which promote normal growth of the fish and prevent stress.

### Biological Control of Rice Pests

Insecticides and herbicides are normally used to prevent and control insect pests and weeds. Part of the insecticide is absorbed by the rice and the rest drops into the water and soil. In fact, some insecticides are directly applied to water or soil and consequently contaminate them. For example, in the early 1980s, 9.6 kg/ha of BHC were used. Some of the BHC entered the soil and water, but most was dissolved and flowed away. The part that was absorbed as a residue in the crops was consumed by humans in the rice, and the by-products (bran and straw) were used as fodder for livestock or fish, whose eggs, meat, and milk were eaten by people. The residue of the insecticide is being transferred from one organism into another and in the end accumulates and concentrates in the human body. The Scientific Experiment Base, Taihu Lake Area, determined that insecticide residues are highest in rice stalks (4.3 mg) and leaves (5.1 mg) followed by rice husks and roots (both 3.8 mg). In the rice grain, the highest concentration was found in the husks and rice bran (3.4 mg). In crude rice, the level is 0.7 mg; in refined rice 0.3 mg.

Tests were carried out in 13 counties of Jiangsu Province in 1983 on the residues of organochloride insecticides in rice. In samples of middle rice (which accounts for 31% of the total rice output of the province), the BHC content ranged from 0.01 to 1.06 mg/kg (average of 0.16 mg/kg). Of the samples, 99.1% contained BHC and 13.7% exceeded the allowable limit. The highest content (1.06 mg/kg) was 2.5 times more than the allowable limit. In samples of late rice (which accounts for 49% of total rice production), the BHC content ranged from 0.07 to 1.21 mg/kg (average 0.34 mg/kg). All samples contained residues, and 54% exceeded the allowable limit.

The human body absorbs 34.4% of the insecticide residues in the grain. An investigation by the Scientific Experiment Base, Taihu Lake Area, found that the amount of BHC residue a person absorbs each day through grains, edible oil, meat, fish, and vegetables was 0.58 mg, which was 15 times higher than the maximum allowable limit suggested by the World Health Organization (0.039 mg per 65-kg person or 0.0006 mg/kg body weight). The insecticide remains in the fatty tissues and other organs and causes damage to human health.

Rice-fish culture reestablishes a symbiotic ecosystem, prevents environmental pollution, and preserves an ecological balance in agriculture. Farmers have made great achievements in irrigation, rice-strain selection, planting techniques, and fish culture. Consequently, rice-fish symbiosis has been further developed. At least, three advantages have been confirmed.

- The ecological benefits of rice-fish symbiosis are becoming more obvious. The elimination of insects and weeds by the fish directly protects large quantities of living organisms from pesticide use. Therefore, other useful organisms, natural enemies of insect pest in particular, survive and reproduce. This extends the possibility of biological pest control and consolidates the ecological benefits of rice-fish symbiosis.
- Rice-fish culture ensures production of fine-quality fish strains and market-size fish and increases the income of farmers. Despite the decrease of planting area, rice unit output increases. The income from rice-fish culture has increased, and in some cases doubled, the income from traditional ricefields. This fact can be used to popularize rice-fish culture.
- Rice-fish culture has also reduced soil and water pollution. Polluted areas become less contaminated or completely unpolluted through the process of self-purification.

# Ecological Effects of Rice–Fish Culture

*Pan Yinhe*[50]

Rice–fish culture is a traditional farming system. Since 1978, the area devoted to rice–fish culture has been expanded several fold, fish production has increased rapidly, and fish-farming technology has been improved. In many areas, good harvests of both rice and fish have been achieved (7500 kg of rice and 750 kg of fish per hectare).

Ni Dashu developed the theory of rice–fish mutualism, in which ricefields are used for fish culture and fish farming increases rice production. This paper discusses the ecological effects of rice–fish culture and its economic, social, and ecological efficiencies.

**Effects on the Ecosystem**

Abiotic factors (e.g., water, soil, light, heat, and air) and biotic factors (e.g., crops, animals, and microorganisms) are closely interrelated and interdependent and form an ecosystem in the ricefield. In this ecosystem, the biotic community is transfers and cycles energy and materials.

The ricefield is a typical anthropogenic ecosystem in which rice production is the main activity. The rice absorbs solar energy, carbon dioxide ($CO_2$), water, and various nutrients and through photosynthesis produces organic matter and energy, which are stored and converted into rice and straw. At the same time, wild grasses and other weeds, phytoplankton, and some photosynthetic bacteria grow in the ricefields. However, these products are not as useful and complete with the rice. In the ricefield, zooplankton, herbivorous animals, some insects, and pathogenic bacteria are the primary consumers. The carnivorous animals are the secondary consumers, and both bacteria and fungi in the soil decompose organic matter into inorganic matter.

In ricefields without fish, farmers must carry out regular and labour-intensive weeding. As a result, there is a heavy loss of soil fertility and solar energy and an increase of production cost. Because most of the bacteria, phytoplankton, and aquatic animals in the ricefield cannot be used by the rice, they are lost with the irrigation water. Moreover, insects, pests, and mosquitoes can reproduce rapidly and adversely affect both rice and human health.

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When fish are introduced into ricefield ecosystem, the population and composition of aquatic organisms, and the relationships among them, change. Population numbers change. Fish, the largest consumers, eat weeds, phytoplankton, zooplankton, aquatic insects, and other animals. Fish have the greatest effect on population density and mortality. Because they are primary consumers, grass carp, common carp, and crucian carp feed heavily on weeds. In China, more than 100 varieties of weeds grow in ricefields. Of these, *Hydrilla verticillata*, *Ptamogeton crispus*, *Vallisneriaa spiraalis*, *Potamogeton matainus*, and *Lemna* spp. are considered to be good feed for grass carp.

The Biological Department of Southwest Teachers College, Chongqing, Sichuan Province, stocked fish in ricefields at a rate of 3 000 fish/ha (grass carp 30%, common carp or crucian carp 60%, and silver carp 10%). After 75 days, the fish had consumed 12 465 kg/ha of weeds and only 360 kg/ha remained. If 50% of the weeds growing in ricefields were consumed by the fish, this would produce 78 kg/ha of grass carp based on a food conversion rate of 1:80. Therefore, rice-fish culture can effectively eradicate weeds and control the loss of energy from ricefields.

Rice-fish culture can change the direction of energy flow in the ecosystem. In the ricefield, the stocked fish transform *stagnant* energy (e.g., weeds) and *possibly lost* energy (e.g., phytoplankton, zooplankton, and aquatic insects) into useable products (fish and rice). Rice-fish culture also coordinates the interrelationship between the biotic and abiotic environments. In ricefield ecosystem, rice requires light, heat, air, water, and nutrients for its growth. Air, water, and nutrients have the greatest impact on rice production. Because the ricefield is usually flooded, the normal water requirements of rice can be ensured. However, an inundated field does not favour root development of the rice. Under inundated conditions, dissolved oxygen (DO) from the surface water can only be supplied to soil through diffusion and transpiration. In general, the level of dissolved oxygen in the surface water varies diurnally with algal photosynthesis during the day. Dissolved oxygen usually reaches a maximum (12-14 mg/L) when light is adequate. However, more than 95% of the DO is taken up by various organisms in the surface water and little of the DO diffuses and permeates into the soil.

Under these circumstances, as temperature rises, soil reduction increases and reducing substances (e.g., methane, organic acid, and hydrogen sulphate) increase and decay rice roots. This problem is normally solved by sun-drying the ricefield. However, as fish move about in the ricefield, they increase contact between the air and water. This increases oxygen content throughout the field. In addition, the fish disturb the soil, which accelerates decomposition of organic matter and reduces the concentration of reducing substances.

Although sun-drying and weeding are sometimes not practiced in rice-fish fields, rice production is higher than in fields without fish culture. From the viewpoint of aquaculture, the total dissolved oxygen level is low in rice-fish fields (less than 4 mg/L in the early morning). However, fish mortality due to the oxygen depletion has not been reported.

Table 1. Nutritional composition of four types of fish excreta (percentage dry weight).

| Fish Excreta | N (%) | P (%) |
|---|---|---|
| Grass carp | 1.102 | 0.426 |
| Common carp | 0.824 | 0.671 |
| Crucian carp | 0.760 | 0.403 |
| Silver carp | 1.900 | 0.581 |

Generally, the ricefield has a pH of about 7.0, which is optimal not only for the growth of rice and fish, but also for the reproduction of natural food organisms. Fish also have a positive effect on soil fertility because of the accumulation of fish excreta, which has a high nutritive value (Table 1). Silver carp excreta was the best, grass carp and common carp excreta second best, and crucian carp excreta the poorest. The concentrations of N and P in the fish excreta were higher than in pig and cow manure, similar to those of night soil and sheep manure, but lower than those of chicken and rabbit manure.

The daily manure production of one fish has been estimated to be about 2 g. If the average stocking density was 3 000 fish/ha (stocking size about 100 g), 6 000 g of fish manure would be produced every day. This would amount to 450 kg/ha of fish manure if the fish were reared for 75 days. The N content of the soil was reduced at the end of the production season by 1.1% in the ricefield with fish and 12% in the field without fish. The fish are able to transform the energy in the ricefield ecosystem and enrich the soil.

Fish can also minimize outbreaks of diseases and insect pests and reduce the application rate of pesticides, which can pollute water, soil, rice, and fish. When fish are cultured with rice, the main primary producer (rice) and consumer (fish) are combined to form a symbiotic rice-fish ecosystem.

In rice-fish fields, the rice reduces sudden changes in water temperature caused by sunlight, adjusts and stabilizes water temperature and quality, and, therefore, provides an environment that is conducive to the reproduction of natural organisms. Because the fish consume phytoplankton, zooplankton, and weeds that compete with rice, they play an important role in increasing and stabilizing soil fertility, eradicating harmful insects and pests, recovering lost energy, and adjusting energy flow. In the symbiotic rice-fish ecosystem, the mutualism between rice and fish is fully exploited to provide high-quality products and good environmental conditions.

## Efficiency of Rice-Fish Culture

### Economic Efficiency

Rice production is increased by 5-15% in rice-fish culture. Experiments in many locations have demonstrated that rice growth is improved in rice-fish fields. In particular, the rice developed evenly, tillering is improved, more rice grains are produced, ears are heavier, and the rate of false grains is lowered.

Rice-fish culture can also increase the production value of ricefields. Based on the collection of nation-wide information, net profit can be increased by CNY300-750/ha. Profits can be even higher (CNY1 500-15 000/ha) if fry are reared in the ricefields. The economic efficiency is increased because the fish have a high value.

Fish can also help eradicate weeds, minimize the loss of fertilizer, and reduce outbreaks of insects and pests. Therefore, fertilizers, pesticides, and labour can be saved. In experiments in Taoyuan County, Hunan Province, the concentration of quick-acting N and P in rice-fish fields was increased by 10% and 124%, respectively, compared with fields without fish. Fish are able to reduce populations of rice hoppers and rice leafrollers 2-6 times. As a result, the application frequency and quantity of pesticides can be decreased. Moreover, based on investigations in Jiangxi, Guizhou, and other provinces, about 120-180 labour units per hectare can be saved with integrated fish culture. In some places, farmers do not plough the field when rice-fish culture is practiced. This further reduces the inputs needed for rice planting, and therefore, reduces production cost and increases the economic efficiency of rice cultivation.

### Social Efficiency

Rice-fish culture expands the area for fish culture and produces more fish products. Rice-fish culture also produces (with less input) increased numbers of large-size fingerlings for the development of fisheries in ponds, reservoirs, and rivers. If the ricefield is used to culture food fish, average production is 300-750 kg/ha (maximum 750-2 250 kg/ha). This practice is an effective way to increase fish production in hilly areas. At the same time, rice-fish culture effectively increases the income and living standard of farmers, particularly those living in hilly, rural areas.

Rice-fish culture also increases rice production. It makes multiple use of the ricefield to maximize the utilization of land and water resources. The proper combination of crop production and aquaculture will effectively promote the transformation of the structure of rice production.

### Ecological Efficiency

In rice-fish culture, harmful insects and pests are greatly reduced. Therefore, pesticide application can be reduced or eliminated, and toxicity accumulation is minimized. This is beneficial to human health and the ecological balance of the environment. For example, the number of predators of rice pests is higher in rice–fish fields without pesticides than in fields without fish and with pesticides. Rice–fish culture also improves the environment and reduces infectious diseases of livestock and humans. In ricefields, mosquito larval, maggots, snails, and leeches, which are the intermediate host of malaria, encephalitis, dysentery, blood fluke, and filaria, reproduce rapidly. Fish, particularly common carp, crucian carp, tilapia, and other omnivorous fish, consume and eradicate these pathogenic parasites and minimize the infestation rate of human beings, thereby creating an improved living standard and a better level of health for the farmers.

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# Ecological Mechanisms for Increasing Rice and Fish Production

*Pan Shugen,*[51] *Huang Zhechun,*[52] *and Zheng Jicheng*[53]

Experiments plus production practices have demonstrated that rice and fish production can be increased by raising fish in ricefields. Mechanisms to increase rice and fish production have been developed based on experiments and investigations in Sanming Prefecture, Fujian Province.

## Ecological Environment

### Physical and Chemical Environment

In a double-cropped field in Ningua Sanming, Fujian, the mean water temperature from May to October was 27.5°C and the accumulated temperature was 5 055.6°C. The highest temperature was 38°C on 27 July and the lowest was 17.5°C on 26 October. Compared with air temperature, the mean water temperature was 1.3°C higher and accumulated temperature was 231.1°C higher. Other observations in Yongan from 14 August to 30 November showed that the mean water temperature in a late ricefield was 25.5°C. Because the water was shallow, the temperature rose rapidly and sunshine reached the soil directly. Therefore, the water temperature was similar in the upper and lower layers, which favoured decomposition of organic matter.

In Ninghua, water levels in the fields used for rice–fish cultivation varied from 3 to 10 cm, and no water remained in the field after the field was drained field and the crop matured. The water level in the field for rice–fish rotation varied from 60 to 80 cm. The water demand for a field producing 7 500 kg/ha of rice was 36 000 $m^3$. Water for irrigation varied from 9 000 to 12 000 $m^3$. Because of water is shallow and there is a great exchange of water, the environment for fish was limited, and fertilizer and food flowed away easily.

The dissolved oxygen level was high in the fields because of the water exchange and the large amount of oxygen released by the rice and phytoplankton. In Ninhua,

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the average dissolved oxygen level varied from 3.9 to 5.6 mg/L (maximum 12 mg/L at noon on sunny days). Fish in the ricefields have a higher metabolism and a higher rate of food utilization than fish cultured in ponds.

Based on determination from many locations in Sanming, the pH of water in ricefields varies from 6.3 to 6.8. Most of the soils in the mountainous districts of Fujian are red, and the water in the fields is acidic.

In Ninghua, the rate of biological oxygen demand (BOD) in fields with fish was 33.4 mg/L; ammonia nitrogen 0.80 mg/L, nitrate nitrogen 0.68 mg/L, phosphate 0.06 mg/L, hardness 0.42 mg equivalent weight/L, and alkalinity 0.65 mg equivalent weight/L. These parameters are comparable with the levels found in rich water in reservoirs. This is why the fish cultured in ricefields have a high level of productivity. In Shangmin, there was less phosphate and lower hardness in the ricefields, and because of uneven fertilizer application and greater water exchange, the richness and stability of the fertilizer were decreased.

### Energy

Sunlight is the most important energy source in ricefields. Based on data from meteorological observations, annual light duration ranged from 1 708 to 1 898 h and total irradiation from 91.3 to 106.4 kcal/cm$^2$. The rice used less than 1% of the light energy, therefore before the rice covered the field, most of energy was used by weeds and phytoplankton. This means that the light is also the major energy source that will eventually be used by the fish in the ricefields.

Rice roots, straw, flowers, and grain are the products of photosynthesis, and much of them remain in the field. In Ninghua, experiments indicated that in 1 ha of ricefield there was 48 210 kg of roots, 17 745 kg of stubble, and 14 385 kg of straw. Straw contains 9-13% cellulite, 1.6-3% potassium, and 35-40% cellulose, which favours growth of microorganisms and diatoms. Results from pollen-chamber studies show that 1 400-1 500 grains are produced per flower, and the blossoms drop to the field after the flowers are fertilized. In Ninghua, two seasons of rice blossoms amounted to 1 559 kg/ha. Rice blossoms are rich in protein. There is a saying *the more fragrant the rice blossoms, the fatter the carp*. During harvest, about 3-5% of the grain drops into the field. Rice-plant trash was 81 000 kg/ha, or about one-quarter of the products produced by photosynthesis. These products provide organic matter and fertilizer for rice-fish culture.

In ricefields producing 7 500 kg/ha of rice, the demand for nitrogen is 120-188 kg/ha, phosphorus 60-113 kg/ha, and potassium 135-270 kg/ha. In Shangmin, the amount of fertilizer applied to a field producing 7 500 kg/ha of rice was 1 125 kg/ha ammonium carbonate, 450 kg/ha calcium superphosphate, and 1 200 kg/ha organic fertilizer. About one-third of the volatile section was absorbed by the rice and about half was drawn into the soil and dissolved in the water to become nutrients for food organisms. This is the major source of fertilizer for rice-fish culture.

### Food Organisms

In the ecological environment of the ricefield, there are many organisms besides rice and fish. Investigation in Ninghua indicated that there were 25 families and 433 species of vascular plants in the ricefields. In the late ricefields without fish, the amount of biomass was determined at three times (before harvest, after the field was drained, and when the grain was filled). The amount of biomass averaged 6 045 kg/ha, and most of the species were suitable food for fish.

Both the number of species and the quantity of plankton in ricefields were reduced compared with levels in fish ponds. Based on investigations in Jianning, Sanming Prefecture, there were 6 phyla and 61 genera of plankton, of which 20 genera were diatoms, 29 genera were green algae, 5 genera were blue-green algae, 1 genus was golden algae, and 1 genus was Dinophyceae. There were also 3 species of protozoa, 10 species of rotifer, 1 species of Cladocera, and 2 species of copepods.

The concentration of phytoplankton was 15–65/L; zooplankton was 900–2 800/L. The recommended fertilizer rate and time of application also encouraged rapid plankton growth. Biomass reached 75–119 mg/L, which was 4–6 times higher than in fish ponds and easily satisfied the food requirements of fish fry.

Based on investigations in Jianning, there were 22 species of benthos, of which 17 species were insects, 3 species were gastropods, and 2 species were nematodes. Studies in Ninghua showed that the biomass of benthos can reach 109.3 kg/ha. All these species are good food for fish.

In fish stomachs, organic detritus was found most frequently. In Jianning, 42 carps were dissected and large amounts of organic detritus were found in all fish (1 g of organic detritus contains 450 bacteria, which weigh about 5% of organic detritus). Bacteria are rich in protein and are eaten by zooplankton and benthos animals as well as by fish. Bacteria play an important role in increasing rice and fish production.

### Pests and Diseases

Fish diseases are rare in rice-fish culture because the water is clear and the oxygen content is high. In addition, the lower stocking density and rich natural food produce strong fish that are more disease resistant. Fish pathogens are rarely seen in ricefields. Based on investigations by Han Xianpu, there were 4 100 bacteria per millilitre in ricefields compared with 8 800/ml in fish ponds. Pathogenic bacteria were 1.6 times lower than in fish ponds. There were no significant differences in the number of bacteria on the fish bodies between the field and fish ponds. However, in ricefields, the number of bacteria in the fish gills was 1 850/ml, compared with 16 000/ml in fish ponds (7.6 times lower). Therefore, rice-fish culture is an effective natural method of protecting fish (especially carp) from disease.

Because the water is shallow in the fields, it is difficult for fish to escape from predators (e.g., centipedes, leaches, birds, snakes, frogs, rats, and otters). In addition, the narrow levee of the ricefield can easily collapse if rats and eels dig holes in the bank. Fish can easily escape from ricefields if there is flooding; therefore, fish survival is not as high.

According to this analysis, organic matter and food organisms will provide more than 20 kg of natural fish productivity. In 1983, in Ninghua, a 21.9-ha field was used for rice-fish cultivation. Production averaged 316 kg/ha (without feeding). In Jianning, fish production from 20.6 ha of ricefields was 282 kg/ha (without feeding). In 1985, in Ninghua, Yongan, 133.3 ha of ricefields stocked with fish produced 720 kg/ha with the addition of some fertilizer and weeds.

These studies demonstrate that ricefields offer clean water, enriched food, less disease, and can provide over 300 kg/ha of natural fish productivity. However, there are still some problems to be solved (e.g., shallow water, unstable water quality, predators, and easy escape).

## Increases in Rice Production

### Controlling Weeds and Fertilizing Fields

Weeds compete with rice because they also need carbon dioxide, water, and nutrients for photosynthesis. Fish stocked in ricefields eat weeds continually and effectively control weed growth. Carp eat weeds at the rate of 30–50% of their body weight, and 1-year-old carp eat 25 g of weed seeds (about 4000 seeds) a day. Experiments during the late season in Ninghua showed that in ricefields stocked with fish, weed weight averaged 161.7 g/m$^3$, compared with 604 g/m$^2$ in the control field.

In Yongan, in a ricefield with rice-fish rotation, weeds numbered 23.3/m$^2$, compared with 137.1/m$^2$ in the control field (a decrease of 4.5 times). In Ninghua, weeds in the late-crop field stocked with fish decreased 4 425 kg/ha compared with the control field. Using the value of 3.3% as the mean amount of nitrogen needed by vascular plants, these reductions would preserve 9.7 kg of total nitrogen. In addition, fish kill weeds continually and more efficiently than humans.

### Accumulating Fertilizer and Increasing Fertility

Much of the food that fish consume is excreted and becomes a fertilizer for the rice. Only 30–40% of the weeds are digested by the fish, the remainder is excreted as faeces and urine. If a fish excretes 2% per day of its body weight as faeces, a field used for rice-fish culture that produces 315 kg/ha of fish without feeding for 180 days would produce 567 kg of faeces.

A field used for rice-fish rotation that produces 1 845 kg/ha (Yongan) for 120 days would produce 2 205 kg of faeces. Carp faeces contain 1.1% nitrogen and 0.4% phosphorus. In rice-fish culture, fish faeces contribute the equivalent of 31.5 kg of ammonium sulphate and 13.5 kg of calcium superphosphate. In rice-fish rotation, fish faeces contribute the equivalent of 121.5 kg of ammonium sulphate and 52.5 kg of calcium superphosphate.

Soil tests in Yongan in 1982 showed that with rice-fish rotation, organic matter, total nitrogen, and total phosphorus increased by 0.6%, 0.03%, 0.001% respectively, compared with the control field. Soil tests in Ninghua in 1984 demonstrated that rice-fish cultivation increased organic matter by 0.09%, total nitrogen by 0.04%, total phosphorus by 0.38%, available nitrogen by 22 ppm, and available phosphorus by 2 ppm compared with the control field. Analysis of the water in the ricefield showed similar results. In fields stocked with fish, BOD increased by 7.49 mg/L, ammonium nitrogen by 0.14 mg/L, and phosphate by 0.032 mg/L compared with the control field.

### Loosening of Soil and Promoting Fertility

When submerged in water, the soil of a ricefield experiences slow breakdown of organic matter, thorough decomposition of vegetation, stable fertility, and less loss of nutrients. If submerged for a long time, the soil has intensive reduction and anaerobic decomposition, which produce large amounts of organic acid. These acids are unfavourable for rice roots. When soil reduction is intense, methane and hydrogen sulphide are produced and damage rice roots. Therefore, the field must be tilled and dried during the middle growth stage to intensify soil oxidation and control the formation of reducing substances.

Fish move about in the ricefield looking for food. Consequently, they enhance contact between the water and air and increase the dissolved oxygen level. As the fish move, they stir the anaerobic layer of the soil. This accelerates the breakdown of organic matter and favours root growth. When rice roots draw nutrients from the soil, they decrease the concentration of nutrients around the root. The plants depend on infiltration of soil water that contains nutrients. This movement to the rice roots occurs very slowly. As the fish swim, they stir nutrient evenly and accelerate infiltration of nutrients into the soil. This helps the roots obtain nutrients more effectively.

### Controlling Rice Pests

Fish eat many pests (e.g., rice plant hopper and leafhoppers) when they drop into the water. Some pests (e.g., rich borers, rice root worms, and snout beetles) damage rice after they travel through the water. While in the water, they are easily eaten by fish. Fish also help control bacterial diseases (e.g., spotted wilt disease) because they eat the cysts of the bacteria. An investigation in Ninghua in 1984 indicated that leafhoppers and rice planthoppers in ricefields stocked with fish were reduced by 16%, yellow rice borer by 17%, and spotted wilt disease by 52% compared with the control field. In Jianning in 1985, spotted wilt disease was reduced by 28-51%, withered paddy by 15-32%, and rice planthoppers by 70-84% in the field stocked with fish.

These factors combine to increase rice production in fields stocked with fish. In 1984 in Ninghua, the height of the rice increased by 2%, effective rice ears by 14%, number of grains by 9%, rate of fruit bearing by 2%, weight of 1000 grains by 4%, and yield by 7.1% in the field used for rice-fish culture. Similarly in Yongan in 1983, the height of the rice increased by 6%, effective rice ears by 12%, number of grains by 2%, the rate of fruit bearing by 0.4%, the weight of 1000 grains by 2%, and yield by 18% in rice-fish fields.

## Conclusion

Ricefields provide an ecological environment that is suitable for both rice and fish. When ricefields are stocked with fish, the fish eat food organisms and organic detritus. Energy and material that used to be lost are captured and converted into fish protein. Fish kill pests and weeds and excrete faeces to the field. In addition, fish movements promote air exchange and distribution of fertilizer.

There are contradictions between rice and fish when applying fertilizer and pesticides and draining fields. In recent years, these contradictions have been resolved by digging ditches and pools, applying fertilizer to all layers of the field, and applying pesticides that are highly efficient and have low toxicity.

In ricefields used for fish culture, there are still some problems (e.g., shallow water, excessive water exchange, unstable water quality, predators, and fish escape). Therefore, further improvements are still required.

# Rice–Azolla–Fish Cropping System

*Liu Chung Chu*[54]

China has a long history of raising fish in ricefields. However, fish yields are low because of difficulties in applying feed to the large areas of fish-raising fields. Azolla is a small aquatic plant that contains abundant nutrients because it can fix atmospheric nitrogen, carry out photosynthesis, and uptake nutrients from its surrounding environment through its root system. It is also an excellent feed for fish. Azolla is rich in the amino acid arginine, which may play an important role in fish growth (Tables 1 and 2). Azolla grow quickly, produce high yields, are a suitable size for fish grazing, do not require harvesting or chopping, and can grow in the ricefield. To increase its ecological and economic benefits, a rice–azolla–fish cropping system was established in 1981. These experiments have indicated the potential of this cropping system.

## The Role of Azolla

### Fish Feed

Both grass-feeding and omnivorous fish eat azolla. Grass carp (*Ctenopharyngodon idella)* and nile tilapia (*Oreochromis niloticus*) consume the equivalent to more than 50–60% of their body weight in azolla each day. The amount of azolla consumed by the common carp (*Cyprinus carpio*) increases with increased size.

Feeding experiments with four fish species were conducted by the Soil and Fertilizer Institute, Hunan Academy of Agricultural Sciences. The feed conversion coefficient of azolla was 49.0 for grass carp, 52.1 for tilapia, 31.2 for Hunan crucian carp, and almost zero for lotus carp. The weight gain for these species was 174 g, 134 g, 36 g, and 5 g, respectively. There were high levels of $^{15}N$-labelled azolla in the internal organs of nile tilapia and low $^{15}N$-labelled azolla levels in the external organs at the start of the experiments. However, the level of $^{15}N$-labelled azolla in the internal organs gradually decreased, whereas the level of $^{15}N$-labelled azolla in the muscles greatly increased (Table 3). After uptake of $^{15}N$-labelled azolla for 96 h, $^{15}N$ recovery in the intestine, stomach, and liver decreased from 10.3% to 1.0%, 1.6% to 0.2%, and 2.4% to 0.7%, respectively. A similar trend was found in other internal organs. In contrast, $^{15}N$ recovery in muscles was 6.3% at 18 h and increased to 10.1% at 96 h. Metabolism balance estimates were obtained from a 4-day nile tilapia experiment. The amount of nitrogen accumulated

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Table 1. Nutrient contents (% dry weight) of various green feeds.

| Green Feed | Dry Matter | Crude Protein | Crude Fat | Crude Cellulose | N-free Extract | Ash | Ca | P |
|---|---|---|---|---|---|---|---|---|
| *Azolla filliculoides* | 6.93 | 25.0 | 3.1 | 11.5 | 34.9 | 17.3 | 1.52 | 0.96 |
| *Eichhorinia* sp. | 5.04 | 20.3 | 1.8 | 13.8 | 32.8 | 22.6 | 1.19 | 2.90 |
| *Trifolium* sp. | 11.57 | 16.6 | 4.0 | 26.1 | 34.4 | 11.3 | 1.24 | 0.82 |
| Sweet-potato vine | 12.27 | 17.7 | 3.1 | 13.9 | 41.5 | 9.8 | 1.81 | 0.43 |
| *Astragalus* sp. | 11.43 | 20.8 | 5.7 | 23.2 | 34.9 | 7.5 | 0.79 | 0.62 |
| Grass | 23.60 | 14.1 | 1.4 | 20.3 | 44.1 | 14.0 | 0.72 | 0.29 |
| *Pennisetum purpuremu* | 16.10 | 9.7 | 1.3 | 29.3 | 37.8 | 14.5 | 0.48 | 0.52 |

Source: Guangdong Academy of Agricultural Sciences.

Table 2. Amounts of 10 essential amino acids contained in various green feeds for fish (dry matter, mg amino-acid/100 g protein).

| | *Azolla filiculoides* | *Eichhornia* | *Pistia shatiotes* | Sweet-Potato Vine | *Astragalus* sp. | *Trifolium* sp. |
|---|---|---|---|---|---|---|
| Arg | 6.84 | 6.45 | 6.86 | 2.00 | 6.54 | 5.60 |
| His | 2.28 | 2.36 | 2.68 | 1.37 | 3.13 | 2.65 |
| Ile | 4.56 | 3.79 | 3.87 | 1.36 | 4.62 | 4.28 |
| Lea | 8.64 | 6.89 | 8.45 | 4.04 | 8.32 | 7.65 |
| Lys | 5.48 | 6.75 | 7.99 | 0.28 | 6.59 | 6.27 |
| Met | 1.40 | 1.87 | 1.56 | 0.72 | 1.29 | 1.33 |
| Phe | 4.68 | 4.58 | 4.89 | 2.36 | 5.00 | 5.12 |
| Thr | 5.00 | 3.84 | 5.05 | 2.37 | 3.85 | 4.39 |
| Trp | 7.44 | 11.92 | 7.53 | 8.55 | 8.75 | 8.19 |
| Val | 4.88 | 4.04 | 5.00 | 1.88 | 5.91 | 5.48 |

Source: Guangdong Academy of Agricultural Sciences.

Table 3. Recovery of $^{15}N$-labelled azolla from various organs of nile tilapia.

| | $^{15}N$ Abundance (%) | |
|---|---|---|
| Organ | 18-h Sampling | 96-h Sampling |
| Head | – | 3.22±1.10 |
| Skeleton | – | 3.73±0.08 |
| Muscle | 6.34±1.17 | 10.05±1.17 |
| Scales | – | 0.65 |
| Brain | – | 0.05±0.031 |
| Ovary | – | 1.31±1.08 |
| Intestine | 10.30±3.45 | 0.97±0.51 |
| Stomach | 1.64±0.80 | 0.24±0.21 |
| Liver | 2.36±0.80 | 0.68±0.11 |
| Heart | 0.064±0.0017 | 0.035±0.007 |
| Blood | 0.455±0.329 | 0.60±0.14 |
| Spleen | 0.28±0.22 | 0.06 |
| Gall | 0.219±0.010 | 0.24±0.23 |
| Gill | 2.96±0.50 | 1.35 |

Source: National Azolla Research Centre, Fujian Academy of Agricultural Sciences.

by the tilapia represented 30% of total azolla N. Tracer techniques (using $^{15}N$) were used to obtain a better understanding of nutrient abundance in fish faeces. During the 96-h excretion period, the highest determined $^{15}N$ level was 3.8%, the lowest was 2.1%. This was much lower than the level of $^{15}N$ in the azolla fed to the fish. This reduction was probably due to the dilution of $^{15}N$ from the azolla by the other nitrogenous matter excreted from the alimentary canal of the fish (which includes digestive juice, sloughed cells from the stomach, and azolla). These results demonstrate that azolla-N accounts for 30% of N in fish faeces. Because another 30% of total azolla-N accumulates in the fish body, it can be estimated that azolla-N is about 60% digested by the fish (N may also be excreted into the water in the form of urine, as excretions from the body surface, as falling scales, or as matter exchanged by the gills). The utilization of $^{15}N$ from azolla in the rice–azolla–fish system is increased to 67.8% (Table 4); whereas, the rice–azolla treatment using $^{15}N$-labelled azolla as a top dressing at the maximum tillering stage had a utilization rate of 46.1%.

Table 4. Utilization ratio of $^{15}N$-labelled azolla.

| Treatment | Utilization Ratio of $^{15}N$-Labelled Azolla (%) | | |
|---|---|---|---|
| | By Fish | By Rice | Total |
| Rice-azolla-fish (as fish feed) | 38.24 | 29.52 | 67.76 |
| Rice-azolla ($^{15}N$-labelled azolla, basal) | — | 46.06 | 56.06 |
| Rice-azolla ($^{15}N$-labelled azolla, top dressed) | — | 51.60 | 51.60 |

Source: National Azolla Research Centre, Fujian Academy of Agricultural Sciences.

Table 5. Effects of azolla on fish yields.

| Species | Fish Yield (t/ha) | | Weight of Fish (g) | |
|---|---|---|---|---|
| | With Azolla | Without Azolla | With Azolla | Without Azolla |
| Silver carp | 0.35 | 0.15 | 600 | 450 |
| Grass carp | 0.15 | 0.15 | 150 | 130 |
| Nile tilapia | 0.54 | 0.40 | 125 | 100 |

Source: National Azolla Research Centre, Fujian Academy of Agricultural Sciences.

### Fish Yields

In the traditional rice-fish system, fish grow slowly because there is insufficient feed. This problem can be solved by introducing azolla. Experiments over 3 years demonstrated that the rice-azolla-fish system will produce fish yields of 1 000 kg/ha. As well, yields can be further increased by using some other techniques (e.g., the polyculture of grass carp and nile tilapia). Fish yields were almost doubled compared with the traditional system for silver carp (Table 5). The yield of edible fish is also raised. The rice-azolla-fish system increased farm income by about CNY1 954/ha.

### Effect on Rice Yield

The rice-azolla-fish system provides an excellent growing environment for rice, fish, and azolla. Because of the high amount of organic fertilizer provided by fish, the rice grows well (Table 6), and because the fish eat azolla, rice pests, and weeds, the use of chemical pesticides can be reduced. However, the environment

Table 6. Agronomic characteristics of rice grown under different cropping systems.

| Season | Treatment | No. of Seedlings per Hill | No. of Effective Panicles per Hill | No. of Filled Grains per Panicle | Filled Grain Rate (%) | 1 000-Grain Weight (%) | Theoretical Yield (kg) |
|---|---|---|---|---|---|---|---|
| Early rice | Single rice | 11.38 | 10.13 | 47.0 | 65.9 | 22.4 | 4288.5 |
| | Rice-azolla | 12.25 | 11.38 | 33.5 | 65.2 | 21.7 | 4255.5 |
| | Rice-fish | 13.25 | 12.00 | 44.8 | 65.6 | 23.2 | 4969.5 |
| | Rice-azolla-fish | 11.75 | 10.63 | 50.0 | 69.7 | 23.5 | 5589.0 |
| Late rice | Single rice | 7.25 | 7.25 | 112.1 | 76.9 | 28.8 | 6930.0 |
| | Rice-azolla | 7.67 | 7.67 | 119.4 | 76.5 | 29.6 | 8085.0 |
| | Rice-fish | 8.08 | 7.92 | 113.2 | 76.5 | 29.0 | 7656.0 |
| | Rice-azolla-fish | 9.33 | 7.32 | 116.8 | 75.7 | 29.7 | 9324.0 |

Source: Fujian Academy of Agricultural Sciences.

Table 7. Growth of weeds in the rice-azolla-fish system.

| Cropping System | Weeds per $m^2$ | Weeds (g) | Average Weight ($g/m^2$) | Weed Weight (kg/ha) | Remarks |
|---|---|---|---|---|---|
| Rice (compared) | 48 | 446 | 454 | 4 500 | Floating azolla species 80%<br>Waterweed species 20% |
| Rice-azolla | 9 | 62 | 64 | 630 | Floating azolla species 50%<br>Waterweed species 25% |
| Rice-fish | — | — | — | — | Others 25% |
| Rice-azolla-fish | — | 9 | 9 | 112 | Weeds |

created by the rice-azolla-fish system is also conducive to the survival of the natural enemies of rice pests (e.g., spiders and black ants). This further decreases pesticide requirements. For example, during a plant leafhopper outbreak in Fuqing Country, Fujian Province, in 1984, four applications of pesticides were required in traditional rice-growing systems and provided incomplete control. In contrast, only one application was required under the rice-azolla-fish system. Observations from 1983 to 1986 indicate that the rice-azolla-fish system effectively suppresses weeds and rice pests (Table 7).

### Soil Fertility

In the rice-azolla-fish system, plant nutrients are provided by decomposition of azolla and by excretion of fish faeces. Improvements in fertility were greater in the ditches than on the field surfaces (Table 8). This can be attributed to the effect of the fish in the system, especially the role played by fish faeces in improving soil fertility. The rapid increase of available potassium is also apparent, which demonstrates the capability of azolla to enrich potassium levels. Although the rice yields from this system are similar to traditional systems, an extra 375-600 kg/ha of fish are harvested. The fish decrease the amount of mineral fertilizer required by the rice plants, maintain or improve soil fertility, and create an excellent ecological environment.

## Implementation of the Rice-Azolla-Fish System

### Field Design

Two forms of field design can be considered for the introduction of the rice-azolla-fish system. The first method involves digging pits and ditches in a traditional ricefield and transplanting rice seedlings in accordance with normal spacing practices. In the second method, rice seedlings are transplanted on ridges and fish are raised in the ditches between the ridges. The selection of fields is particularly important for both designs. In both cases, the field must have sufficient water and have good controlled of irrigation and drainage. In most cases, a rectangular pit(s) that occupies 5% of the total ricefield area will suffice. In all cases, pit depth should be between 1 and 1.5 m. Ditches are 30-50 cm deep, 40-50 cm wide, and occupy 3-5% of the total ricefield area. The field is designed according to the desired yields of rice and fish. In another words, to harvest more fish, pits and ditches should occupy more area, field ridges should be wide and thick to prevent fish escape, and drainage openings should provide for good irrigation.

### Combinations of Fish Species

Fish species should be chosen in accordance with their feeding efficiency. For example, grass carp are unable to fully digest cell walls of plants because their alimentary canal lacks cellulase. Consequently, they excrete feed residues into the water along with fish faeces. Nile tilapia excretions stimulate the propagation of plankton. Under these conditions, pure cultures of either species do not use azolla efficiently. However, this problem can be solved if a mixed culture (polyculture) of silver carp and common carp with grass carp, nile tilapia, and common carp (ratio of 100:300:100:7500 fingerlings/ha) is introduced after the rice seedlings are transplanted.

### Growing Season for Azolla

The key technological problem in the rice-azolla-fish system is a healthy and sufficient azolla biomass. Two methods are recommended to increase the azolla

Table 8. Characteristics of soil fertility under various rice-cropping systems.

| Season | Site | Treatment | O.M. (%) | Total N (%) | Total P $P_2O_5$ (%) | Alkali N | K (ppm) | $P_2O_5$ (ppm) |
|---|---|---|---|---|---|---|---|---|
| Early rice | Field surface | Single rice | 3.748 | 0.219 | 1.20 | 200 | 91 | 6.9 |
| | | Rice-azolla | 3.917 | 0.223 | 1.20 | 205 | 244 | 6.9 |
| | | Rice-fish | 3.896 | 0.226 | 1.19 | 218 | 86 | 8.5 |
| | | Rice-azolla-fish | 3.972 | 0.239 | 1.35 | 216 | 172 | 8.8 |
| Early rice | Ditch | Single rice | 3.928 | 0.228 | 1.29 | 202 | 172 | 5.2 |
| | | Rice-azolla | 3.977 | 0.239 | 1.36 | 219 | 253 | 6.0 |
| | | Rice-fish | 4.272 | 0.272 | 1.53 | 198 | 334 | 5.6 |
| | | Rice-azolla-fish | 4.548 | 0.283 | 1.59 | 219 | 494 | 5.3 |
| Late rice | Field surface | Single rice | 3.677 | 0.205 | 0.12 | 158 | 88 | 7.3 |
| | | Rice-azolla | 3.784 | 0.203 | 0.12 | 157 | 120 | 7.5 |
| | | Rice-fish | 3.849 | 0.198 | 0.14 | 172 | 172 | 8.2 |
| | | Rice-azolla-fish | 3.948 | 0.247 | 0.14 | 182 | 165 | 10.3 |
| Late rice | Ditch | Single rice | 4.107 | 0.239 | 0.13 | 200 | 157 | 6.9 |
| | | Rice-azolla | 4.108 | 0.206 | 0.14 | 209 | 197 | 7.4 |
| | | Rice-fish | 4.825 | 0.289 | 0.15 | 298 | 192 | 8.4 |
| | | Rice-azolla-fish | 4.954 | 0.296 | 0.16 | 264 | 259 | 9.1 |

Source: Central Laboratory, Fujian Academy of Agricultural Sciences.

biomass: increase the space between rice rows to give the azolla sufficient room to grow, and prolong the propagation period to ensure the fish have sufficient food to eat. Polyculture of different azolla species and other waterweeds can also be introduced. Various kinds of waterweeds (e.g., *Lemna minor* and *Wolffia arrhiza)* can be cultivated in the ricefield to supply fish feed in June and July (this method is called rotational cultivation of azolla).

### Field Management

Water management is the most important factor in the rice-azolla-fish system. During the early stage of rice growth, fingerlings can swim freely in the shallow water, which is good for tillering of early rice. Later, the larger fish need deeper water. At this time, the water temperature can sometimes reaches 40°C, and it is necessary to keep the irrigation water at the depth of 8-10 cm.

Fertilizer should be applied principally as green manure supplemented with chemical fertilizers. Basal application is stressed and should account for 70% of the total amount of fertilizer used. Deep placement of granules of N fertilizer decreases the loss of N, which benefits both fish and rice. To prevent disease and pests, it may be necessary to apply some insecticides, but the type, application rate, and application methods must be suitable for fish. Biological control methods are preferred.

# Effect of Fish on the Growth and Development of Rice

*Li Duanfu,*[55] *Wu Neng,*[56] *and Zhou Tisansheng*[56]

A rice-fish system was investigated for 3 years to determine its effect on the growth and harvest of rice and the income to farmers. A ridge-ditch cropping system was used.

## Method

An experimental ricefield of average fertility was plowed and levelled. A ridge-ditch system was used. The ditches were 20 cm wide and 30 cm long and the ridges were 30 m long and 50 cm wide. The ditch was 25 cm deep (from the surface of the ridge to the bottom of ditch). Rice was planted on the ridges and fish were stocked in the ditches. Rice plants were spaced at 17 cm x 13 cm, with 4-5 plant per clump and three line of rice plants per ridge. The ridges and ditches were estimated to cover 84% and 16% of the field area, respectively. There were three replicates for each of three different treatments. Treatments were randomly arranged. Nine small (0.02 ha) experimental areas were established. The total experimental field was 0.18 ha, and there was a 0.04-ha protective area around the field. The different treatments were separated by a low bank that was covered with a 50-cm plastic membrane that prevented fish escape and leakage of fertilizer.

Carp (7 500 fry/ha) and grass carp (450 fry/ha) were released immediately after the rice seedlings were transplanted. Supplemental feed (375-390 kg/ha) was given until the rice plants bloomed. Fertilization and management techniques were the same as used for ordinary ricefields.

## Results and Discussion

### Fertilization of Ricefield

When the ricefield was stocked with fish, the nitrogen, phosphorus, and potassium (NPK) contents of the soil and water were increased significantly. Total nitrogen was particularly high. Weeds and plankton in the ricefield normally compete with rice for fertilizer. However, they were eaten by the fish and converted to a

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fertilizer that could be used by the rice. The physical and chemical properties of the soil also became more suitable for growth and development of the rice.

### Oxidation and Reduction Potential of the Soil

A rice-fish ecosystem benefits both crops. Fish movements in the shallow water break the surface membrane formed by the microorganisms covering the soil. This increases the dissolved oxygen level in the soil and elevates its oxidation and reduction potential during the period of rice growth. These changes improve the oxygen content and effectively increase the utilization rate of soil nutrients. The ridge-ditch system allows water to be drawn into the soil in the ridge without having a negative impact on the fish. The sun can also increase the temperature of cultivation layer, which helps increase rice yields, especially of late rice. The ridge-ditch system can allows for the use of direct seedling, ratooning, and zero-cultivation method of rice planting.

### NPK Content of Rice Plants

The NPK contents of the leaves and culm of rice plants grown with fish were higher than in the control. These differences were correlated to the differences in NPK levels in the soils in the two plots.

### Chlorophyll Content of Plants

The chlorophyll content of rice plants at every developmental stages were significantly higher in the experimental ricefield. The high chlorophyll content indicates that the process of photosynthesis was more efficiency, which would lead to the accumulation of more carbohydrates.

### Surface Area of Leaves

The surface area of leaves has higher in the early developmental stages in the experimental ricefield. In the booting and mature stages the factors were 6.9 and 2.5, respectively. In the control fields, the corresponding figures were 5.6 and 1.4. The larger surface area of the leaves and the higher content of chlorophyll will increase the efficiency of photosynthesis, and therefore increase the number of effective ears, the number of grains per ear, and the weight of the grains.

### Activity of the Root System

The activity of the root system is expressed by the volume of water that flows through a wounded stem per unit of time. Strong activity means that the root system can absorb more nutrients from the soil. The root systems of rice plants grown in the experimental field always had stronger activity than the roots of plants in the control field at all developmental stages.

### Accumulation of Dry Matter

The NPK content, surface area of the leaves, chlorophyll content, and activity of the root system were all higher in the rice-fish system. These differences are also expressed in the accumulation of dry matter. The total dry weight of the whole rice plant in experimental ricefield was 17.1% higher than in the control field. This is a fundamental condition for an increase in rice production.

### Effect on Tillering

Tillering of the rice plant during the early stages of development is crucial stage to the production of effective ears. The number of ears and the time of earing are closely related to fertilizer level. The rice plants grown in the experimental field had a greater rate of tillering per day and more effective ears per plant. Although both fields originally received the same amount of fertilizer, the fish in the experimental field promoted more efficient use and distribution of NPK. The fish reduced the loss of fertilizer and increased soil fertility.

### Weeds Growth

Carp are omnivorous and grass carp are herbivorous. However, grass carp fingerlings also eat aquatic insects. When these two species of fish are stocked together, weeds are can be controlled in the ricefield. In the experimental field, there were significantly fewer weeds throughout the growing period.

### Economic Benefits

The rice-fish system creates a mutually beneficial ecosystem. In the ridge-ditch system, the production of fish can reach 642 kg/ha. At the same time, the fish add fertilizer and eliminate pests and weeds from the ricefield. Rice yields were increased by 14.4%. It has been estimated that the ridge-ditch system can double total earnings.

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# The Role of Fish in Controlling Mosquitoes in Ricefields

*Wu Neng, Liao Guohou, Lou Yulin, and Zhong Gemei*[57]

Starting in 1983, investigations were made for 5 years on the effect of controlling mosquitoes after rearing fish in ricefields. In 1987, further financial support was obtained and the research began to have economic impact.

## Experiment Sites

The test site was in Quangzhou County in northeast Guangxi. More than 26 700 ha of ricefields were suitable for fish culture (about 80% of the total cultivated land). Traditionally, farmers stock 6 000–9 000 common carp and 150–1 500 grass carp per hectare of ricefield after the rice is transplanted. No additional feed or management was used, and fish yields were about 150 kg/ha. However, because weeds were decreased and rice yields were increased, this type of cropping system has expanded. By 1987, rice–fish culture was practiced on half of the ricefields that were suitable for fish-rearing.

An isolated village in Quangzhou County was selected as an experimental site to study changes in mosquito population density in ricefields. The village had 127 ha of ricefields, and 90% of these fields were used for fish. The fish fingerlings were stocked into middle-rice fields after the rice seedlings were transplanted. When rice was harvested, the fish had grown to about 100 g and could be used as food or grown longer in the pond.

## Methods

### Mosquito Density in Ricefields

The main species of mosquitoes in the district are *Anopheles sinensis*, the main vector of local malaria, and *Culex tritaeniorhynchus*, the vector of Japanese encephalitis. Density measurements were taken once a week for a month before and after the fish were stocked. Larva and adult mosquitoes were also examined in a control village with no fish.

### Frequency of Mosquito Biting

Mosquitoes were attracted to a special mosquito net 0.5 h after sunset in the fields adjacent to both the experimental village and the control village.

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Table 1. The relationship between the annual incidence of malaria and the area of rice-fish culture in Quangzhou County.

| | Rice-Fish Area to Total Rice Area (%) | Annual Incidence of Malaria (1:100 000) | |
|---|---|---|---|
| | | Quangzhou | Entire District |
| 1978 | 0 | 11.6 | 6.6 |
| 1979 | 11 | 4.7 | 8.7 |
| 1980 | 25 | 2.4 | 23.7 |
| 1981 | 29 | 0.5 | 34.3 |
| 1982 | 35 | 0.6 | 35.4 |
| 1983 | 35 | 0.5 | 22.6 |
| 1984 | 34 | 0.4 | 14.0 |
| 1985 | 34 | 0.1 | 6.9 |
| 1986 | 43 | 0.1 | 6.5 |
| 1987 | 43 | 0.1 | 7.0 |

### Age-Class Distribution of Larva (Pupa)

Larva numbers of each age-class were recorded throughout the year at both the experimental site and the control site. The distribution of mosquitoes in each age-class was evaluated and the differences were calculated.

### Incidence of Malaria

The spread of fish culture in ricefields over the past 10 years in Quangzhou County was traced. The incidence of endogenous malaria was recorded over the same period and compared with the whole district.

## Results and Discussion

### Density of Mosquitoes

Compared with the control, the density of larva and adult mosquitoes was remarkably lower when the fish were reared in the ricefields. A comparison of the frequency of mosquito biting in the two locations also showed that contact between humans and mosquitoes was greatly reduced in the village where a large area of the ricefields was used for fish culture.

Natural mortality of mosquito larva is density dependent. The degree of the effect depends on the stage at which mortality occurs. If natural predators consume mosquitoes during the early stages of growth, increased survival is likely to make up for early losses. If mortality takes place in later stages, it is impossible to make up for the loss. This will greatly affect the density of adult mosquitoes. In the fish–rice field, the ratio of old larva and pupa was much lower than in the control field. This suggests that because the fish feed on old larva and pupa, density-dependent survival has no effect. Therefore, it is reasonable to suggest that fish are an effective biological control method for mosquitoes.

### Incidence of Malaria

One of the most important criteria for judging the control of mosquitoes is the incidence of diseases spread by the mosquitoes. Table 1 shows the increased area of rice–fish fields in Quangzhou County and the annual incidence of endogenous malaria within the county and within the whole district. As the area of rice–fish culture has increased in Quangzhou County, the annual incidence of malaria has decreased (correlation coefficient -0.9225). Although other measures were taken to prevent malaria in Quangzhou County (e.g., inspection and control of sources of infection), the relative number of cases was much lower than in other counties in the district.

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# A Comparative Study of the Ability of Fish to Catch Mosquito Larva

*Wang Jianguo and Ni Dashu*[58]

More than 100 species of fish eat mosquito larva, and many authors have suggested species that are good at eating mosquito larva. In 1959, Chen Jiangxing and Gao Kai achieved good results using common carp fry (*Cyprinus carpio*), and in 1979, the Antiepidemic Station of Chengdu City, Sichuan Province, used silver crucian carp (*Carassius auratus*) and grass carp (*Ctenopharyngodon idella*) to eliminate mosquito larva. In 1976, the Antimalaria Group of Henan Province reported good results when fish were raised in ricefields to control mosquitoes. Although *Dambusia affinis, Panchax panchax, Mocropodes apercularis*, and *Pseudorasbora parva* are good for mosquito control, they are difficult to breed and there is a limited supply of fry. In addition, these fish species are of little economic value and are difficult to popularize.

There have been no reports on the ability of such fish as grass carp, silver common carp (first generation of crosses between red carp and silver crucian carp), and nile tilapia (*Oreochromis niloticus*) to eat mosquito larva. Earlier indoor experiments reported by the World Health Organization were mostly conducted with fish that were starved for 1-2 days before the mosquito larva were introduced.

A comparative experiment was carried out to determine the differences between the amount of food taken by starved fish and by those reared in natural conditions. Three common types of fish raised in ricefields were studied. The density of mosquito larva in one midseason ricefield and two late ricefields where grass carp were reared was also measured.

## Materials and Methods

The research was conducted both indoors and in the field. The experiment on the feeding rate was done indoors under controlled conditions. Fish of different sizes were raised separately in a white round drum (40 cm in diameter, 20 cm of water). To test the food intake of hungry fish, the fish was starved for 24 h after they had adapted to their new environment. To test the food intake of fish under natural conditions, the feed most liked by fish was added after the fish had adapted to their new environment. Mosquito larva were added in batches. The amount of feed added or unconsumed, and the number of mosquito larva of different ages eaten by the fish, were recorded.

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The survey of the density of mosquito larva in ricefields with and without fish was carried out by collecting water samples with a 500 ml aluminium ladle. If water depth in the ricefields is assumed to be 6 cm, every hectare of ricefield stores 600 $m^3$ of water, which is equal to 1 200 000 of the ladles used to collect samples. A sample consisted of 150 ladles of water collected along the banks of a field. The mosquito larva were separated from the water using a glass pipette and fixed in a bakelite-capped tube that contained 30% alcohol. The larva were counted according to three categories: *Anopheles sinensis*, *Culex* spp., and others. Between July and August 1984, four samples were collected once every 2 weeks from the middle ricefield. In 1985, the survey on a large area of two seasons of late rice was conducted.

The survey of the mosquito larva density in the middle ricefield was conducted in the Lianhu Fish Farm, Mianyang County, Hubei Province. The farm had 57.7 ha of intensive fish-farming ponds and 31.7 ha of ricefields in continuous blocks. The ricefields were surrounded by 1.6 ha of ditches. The ricefields were divided into four blocks and managed by four different fish-farming teams. The area of the four blocks of ricefields was 1.8 ha and the three fields were about 7.8 ha each. The adjacent 5.3 ha of ricefields in which fish were not raised were used as the control field. The strains of rice in the fields were different, but all were middle rice (the distance between rows and plants was 13 cm x 20 cm). Tillage was not done in ricefields in which fish were raised. No fertilizer was applied, and pesticides were used only when necessary.

On 18 April 1984, sodium pentachlorophenate was used to eliminate weed, fish, and leeches from the ricefields, and fry were raised in the 0.8 ha of straight ditches around the four blocks of ricefields. On 19 May, 1.1 million grass carp fry were introduced. On 23 June, 2.6 million summer grass carp fingerlings were collected. In late June, 390 000 summer grass carp fingerling and 30 000 silver crucian carp fingerlings were released into the rice paddies (average 13 230/ha or 1-2/$m^2$). In ricefields with fish, fish ditches were dug. No feed was put into the ricefields. The surveys of the density of mosquito larva in the two seasons of late rice where grass carp was raised and in the control fields were conducted on 10 ha in Chongyang County, Hubei Province.

**Results**

The food intake of hungry fish and fish under natural conditions were quite different. The number of mosquito larva eaten by grass carp under natural conditions was 73.4% of the intake when the fish were hungry (Table 1). Silver crucian carp consumed 36.3% under natural conditions compared with hungry conditions (Table 2). The number of mosquito larva consumed by nile tilapia under natural conditions was only 32.5% of that under hungry conditions (Table 3). Nile tilapia showed the greatest differences in intake under the two conditions, followed by silver crucian carp and grass carp. In the indoor experiment, grass carp almost always preferred mosquito larva to duckweed when they were fed together. This may explain why grass carp normally eat more mosquito larva than the other two species. Tables 2 and 3 show that when feed is given, the silver crucian carp and

Table 1. Intake of mosquito larva by grass carp when hungry (H) and under normal feeding (NF) conditions.

| | Fish | | Feed in 24 h | | Intake in 24 h | | | Ratio of Normal to Hungry Feeding |
|---|---|---|---|---|---|---|---|---|
| | No. | Size (cm) | Larva (No.) | Duckweed (g) | Larva (No.) | Duckweed (g) | Intake of Each Fish (No.) | (%) |
| NF | 10 | 4.7 | 3 650 | 50 | 2 360 | 9.0 | 236 | |
| H | 10 | 4.1-5.2 | 4 000 | — | 3 130 | — | 313 | 75.4 |
| NF | 10 | 4.7 | 3 500 | 50 | 3 363 | 8.5 | 336 | |
| H | 10 | 4.1-5.2 | 4 800 | — | 4 670 | — | 467 | 72.0 |

Table 2. Intake of mosquito larva by silver crucian carp when hungry (H) and under normal feeding (NF) conditions.

| | Fish | | Feed in 24 h | | Intake in 24 h | | | |
|---|---|---|---|---|---|---|---|---|
| | No. | Size (cm) | Larva (No.) | Fish Powder (g) | Larva (No.) | Fish Powder (g) | Intake of Each Fish (No.) | Ratio of Normal to Hungry Feeding (%) |
| NF | 10 | 5.0 | 3 000 | 14 | 742 | 11.5 | 72 | |
| H | 10 | 5.0 | 4 000 | — | 2 016 | 2 | 202 | 36.8 |
| NF | 9 | 5.0 | 2 350 | 10 | 1 290 | 2 | 143 | |
| H | 9 | 5.0 | 4 000 | — | 3 575 | — | 397 | 36.1 |

nile tilapia eat more fish powder than mosquito larva. The intake of mosquito larva is not correlated with increased body size (Tables 1-3). In both groups, grass carp eat the greatest number of mosquito larva, followed by silver crucian carp and nile tilapia.

The number of *Culex* spp. larvae consumed can be determined by counting the respiratory ducts that survive digestion intact. During the experiment, of the 300 *Culex* larva fed to the fish, only 261 respiratory ducts were recovered (253 from fish excrement and 8 from the sediment). This is only 87% of the number consumed. This suggests that when the number of mosquito larva consumed by fish is assessed, the number should be corrected by 13%.

Table 3. Intake of mosquito larva by nile tilapia when hungry (H) and under normal feeding (NF) conditions.

| | Fish | | Feed in 24 h | | Intake in 24 h | | | Ratio of Normal to Hungry Feeding (%) |
|---|---|---|---|---|---|---|---|---|
| | No. | Size (cm) | Larva (No.) | Fish Powder[a] (g) | Larva (No.) | Fish Powder (g) | Intake of Each Fish (No.) | |
| NF | 10 | 4.4–6.0 | 2 000 | — | 790 | 2.05 | 79 | |
| H | 10 | 4.4–6.0 | 5 000 | — | 2 802 | — | 280 | 28.2 |
| NF | 10 | 4.4–6.0 | 1 500 | — | 1 002 | 1.85 | 100 | |
| H | 10 | 4.4–6.0 | 3 800 | — | 2 709 | — | 271 | 37.0 |

[a] Figures missing in original Chinese publication.

Table 4. Mosquito larva density in middle ricefields with and without fish culture.

| Date | Middle-rice | *Anopheles* spp. (No./ha x 1 000) | | *Culex* spp. (No./ha x 1 000) | | Others (No./ha x 1 000) | Total (No./ha x 1 000) |
|---|---|---|---|---|---|---|---|
| 12 July 1984 | With fish | 8 | II. | 8 | II. | 8 | 24 |
| | Without fish | 24 | II.III.VI | 16 | II.III. | 0 | 40 |
| 25 July 1984 | With fish | 8 | II. | 0 | | 0 | 8 |
| | Without fish | 16 | II.III. | 0 | | 8 | 24 |
| 12 Aug 1984 | With fish | 0 | | 0 | | 8 | 8 |
| | Without fish | 8 | II. | 16 | II.II. | 16 | 40 |
| 24 Aug 1984 | With fish | 0 | | 0 | | 8 | 8 |
| | Without fish | 16 | II.II. | 8 | III. | 0 | 24 |
| Average | With fish | 4 | | 2 | | 6 | 12 |
| | Without fish | 16 | | 10 | | 6 | 32 |

The field surveys of the middle ricefields in Mianyang County (Table 4) show an average of 32 000 larvae when no fish were present, and one-third of that number when fish were present. The fields without fish had four times the number of *Anopheles sinensis* and five times the number of *Culex* spp., but the same number of other mosquito larvae. In a more extensive survey in Chongyang County, the

Table 5. Density of mosquito larva in two seasons of late ricefields with and without fish culture, Chongyang County.

| Location | Ricefields | *Anopheles* spp. (No./ha x 1 000) | *Culex* spp. (No./ha x 1 000) | Others (No./ha x 1 000) | Total (No./ha x 1 000) |
|---|---|---|---|---|---|
| Agro-Science Institute | Rice-fish culture | | | | 0 |
| Xiexing village, Taishan township | Rice-fish culture | | | | 0 |
| Xiaxing village, Shaping district | Rice-fish culture | | 8 IV | | 8 |
| Wugang village, Shaping district | Rice-fish culture | | | | 0 |
| Bailuo village group 6, Guikou township | Rice-fish culture | | | | 0 |
| Bailuo village group 9, Guikou township | Rice-fish culture | | | | 0 |
| Nanlin village, Qingshan town | Rice-fish culture | | | | 0 |
| Taiping village, Huaqi township | Rice-fish culture | | | | 0 |
| Lukou village group 9, Lukou town | Rice-fish culture | | | | 0 |
| Bailuo village, Shaping district | Without fish | 96 I.V. | 24 II | 8 I. | 128 |
| Nanlin village, Qingshan town | Without fish | | 16 II.IV | 24 IV.II.II | 40 |
| Lukou village group 9, Lukou town | Without fish | 16 II.IV | | 16 II.III | 32 |
| Average | Rice-fish culture | 0 | 0.9 | 0 | 0.9 |
| | Without fish | 37.3 | 13.3 | 16 | 66.6 |

fields with grass carp had 900 larvae per hectare compared with 66 700 in the fields without fish (a difference of 99%, see Table 5). In this area, only one field with fish had any mosquito larva. This field monitoring clearly shows that grass carp can eliminate large numbers of mosquito larvae from ricefields.

## Discussion

Grass carp more effectively eliminate weeds and mosquito vectors in the ricefield than silver crucian carp and nile tilapia. Their body shape also seems to be better adapted to the shallow water in ricefields. Grass carp also have a higher economic return. When the excrement of grass carp that have eaten mosquito larva was examined, only the respiratory ducts were found entirely intact. Although the head of the mosquito larva is shell-like, it was ground to pieces and could not be counted. However, *Anopheles* spp. do not have respiratory ducts and this method of computation requires further discussion.

According to a report by Yi Mengjie and his colleagues in 1984, a 4.9-cm grass carp can catch 141 mosquito larva per night. In our experiments, each night grass carp the same size could catch 236 mosquito larva, which weighed 8.3 g (100 II-IV stage larva weighed 3.5 g).

Generally, the peak period for mosquito larva in ricefields is between late August and early September. Because of the field work needed for watering and harvesting, our survey continued only until late August when there was no peak and mosquito density was not high.

## Summary

There are differences among the three species of fish in their food intake. The number of mosquito larva eaten under normal conditions is lower than when the fish are hungry. When the fish are the same size, grass carp eat the most larva, followed by silver crucian carp and nile tilapia. Fish reared in ricefields can eliminate up to 99% of the mosquito larva, Based on the indoor experiments, 100% of the mosquito larva in the ricefield could be eaten and this would still not fully satisfy the food requirements of the fish. Based on our experiments, grass carp would be the best species to control mosquitoes in ricefields.

# Ability of Fish to Control Rice Diseases, Pests, and Weeds

*Yu Shui Yan,[59] Wu Wen Shang,[59] Wei Hai Fu,[60] Ke Dao An,[60] Xu Jian Rong,[61] and Wu Quing Zhai[62]*

From 1985 to 1987, a series of tests on rice-fish culture were conducted in Shangyu, Xiaoshan and Huangyan Counties, Zhejiang Province, to determine if grass carp, common carp, and nile tilapia could be used as biological control agents in ricefields.

## Material and Method

### Field Arrangements

A suitable ricefield was selected as the test plot. Before the field was ploughed, the border dikes were raised to 40 cm, and earth dams were built to separate the different test plots. Space for fish ditches and pits was left when the seedling were transplanted. After the rice was transplanted, fish ditches and pits were dug and a fish screen was installed at the outlet.

### Selection of Fry and Breeding Fish

Fry that had a body length of 3–4 cm and were able to swim against the current were selected. Healthy, strong fish with shining body colour, no injuries, and a body weight of 20–50 g were chosen as breeding fish.

### Rice Cultivation

Fish were stocked in the test plot 7 days after the early rice was transplanted. The fish were moved into the fish ponds before the early rice was harvested and returned to the test plot after the late rice was transplanted. Fish were harvested just before the late rice was harvested. In the test plot, water was kept at a depth of about 10 cm, and basal fertilizers and top dressing were used. No pesticides, seed treatments, or herbicides were used.

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[60] Agricultural Bureau of Shangyu County, Shangyu, Zhejiang Province.

[61] Agricultural Bureau of Huangyuan County, Huangyuan, Zhejiang Province.

[62] Agricultural Bureau of Xiaoshan County, Xiaoshan, Zhejiang Province.

### Fish-Farming Treatments

Six different treatments were carried out in Shangyu County in 1986, and each treatment was repeated three times. The treatments were: (1) grass carp (5 250/ha), (2) common carp (5 250/ha), (3) nile tilapia (5 250/ha), (4) grass carp (600/ha) and common carp (3 000/ha) together, (5) long-term deep-watering for fish-farming, and (6) normal water irrigation for fish-farming. In 1987, three different species of fish (grass carp, common carp, and nile tilapia) were raised. For polyculture, 1 500 fish of each species were used per hectare. For pure cultures 4 500 fish were raised per hectare. The control plot was the same as in 1986. No comparisons between fish and no-fish plots were made in Xiaoshan and Huangyan.

### Survey Methods

Twenty clumps in the small plots and 50–100 clumps in the large plots were inspected for rice planthoppers, 500 clumps were examined for rice borer, 40 clumps in the small plots and 100 clumps in the large plots were examined for rice leafrollers, and 50 clumps in the small plots and 200 clumps in the large plots were examined for rice sheath and culm blight. Weeds were sampled at five locations (0.11 $m^2$ each) in the ricefield, and records were kept of variety and fresh weight.

## Results and Analysis

### Control of Diseases, Pests, and Weeds

**Control of rice planthoppers.** The raising of fry in early ricefields provided poor control of rice planthoppers; however, raising breeding fish provided good control. As the fish grew in size during the growing period of late rice, they provided good control of rice planthoppers. A survey on 10 July 1985 in Xiaoshan showed that there were 1 900 rice planthoppers (third generation) per 100 clumps in early ricefields with fry, a decrease of 34.5% compared with 2 900 rice planthoppers per 100 clumps in the early ricefield without fish. In ricefields with breeding fish there were 1 030 rice planthoppers per 100 clumps in the early ricefields, a decrease of 64.5% compared with ricefields without fish. A survey on 20 September 1985 indicated that there were 2 410 rice planthoppers (fifth generation) per 100 clumps in the late ricefield with fish, a decrease of 734.3% compared with fields without fish.

Different varieties of fish had different effects. Investigations from 1986 to 1987 at the test plot in Shangyu showed that there was a relatively large difference (Table 1) in the control of rice planthoppers during the peak season. The ricefields in which only grass carp were raised showed the best control of rice planthoppers. The fifth and sixth generation planthoppers were decreased by 40.5% and 74.2% in 1986 and by 57.3% and 59.4% in 1987, respectively, compared with the control field. Polyculture of the three varieties of fish was less effective than pure cultures of grass carp.

Table 1. Effect of different treatments on the number of rice planthopper nymphs per 100 clumps in late ricefields.

| | Fourth Generation | | Fifth Generation | | Sixth Generation | |
|---|---|---|---|---|---|---|
| Treatment | 3 Sept 1986 | 8 Sept 1987 | 23 Sept 1986 | 26 Sept 1987 | 12 Oct 1986 | 26 Oct 1987 |
| Normal watering field without fish culture | 233 | 548 | 1 273 | 8 228 | 1 147 | 10 390 |
| Deepwater field without fish culture | 237 | 340[b] | 1 220 | 6 123[b] | 690[b] | 8 755[a] |
| Deepwater field with grass carp culture | 190 | 215[b] | 753[a] | 3 513[b] | 290[b] | 4 220[b] |
| Deepwater field with common carp culture | 123[b] | 260[b] | 526[b] | 4 750[b] | 456[b] | 6 728[b] |
| Deepwater field with nile tilapia culture | 53[b] | 305[b] | 840[a] | 5 100[b] | 390[b] | 6 938[b] |
| Deepwater field with mixed-fish farming | 167[a] | 218[b] | 567[b] | 4 013[b] | 530[b] | 4 625[b] |

[a] Significant difference.
[b] Highly significant difference.

There were several reasons that the fish could effectively control rice planthoppers. First, the rice planthoppers normally oviposit on plant leaves near the bottom of the plant. The grass carp consume these outer leaves, which controls hatching of ova. Second, fish eat rice planthoppers that fall into the water, which directly reduces the number of insects in the field. Third, the deep water protects parts of the rice plant on which rice planthoppers oviposit and feed. In 1987, there was a severe attack on late rice by the brown-back rice planthopper (*Nilaparvata lugens*). Some plants were infected with sheath and culm blight in normal and deep-water ricefields without fish; however, in the ricefields with fish, the rice plants continued to have green stems late in the growing season, and the crop ripened without the use of any pesticides. The plots with grass carp produced the highest yields.

**Control of rice stem-borer.** Observations in Shangyu from 1986 to 1987 indicated that there were, on average, 1 980 rice borers per hectare in ricefields with fish. This was a decrease of 51.1% compared with normal-water ricefield without fish, and a decrease of 47.2% compared with deep-water ricefield without fish. A survey on 1 July 1987 showed that the attacked rate per plant was 0.7% in ricefield with fish. This was a reduction of 44.3% compared with normal-water ricefields without fish and a reduction of 27.7% compared with deep-water ricefields.

There was a significant difference in the number of pests per hectare and the attacked rate per plant over the 2-year period in ricefields with fish compared with normal-water ricefields without fish. However, the differences were not significant compared with deep-water ricefields without fish. Observations in Xiaoshan showed that the attacked rate per plant was 0.7% in the ricefield with adult fish, a decrease of 80.6% compared with ricefields without fish. The main reasons that the fish were able to mitigate harm done by rice borer were that the pests were eaten when they fell into the water. In addition, grass carp eat the rice borers when they strip the lower leaves, which are often attacked by rice borers.

**Control of rice leafrollers.** A survey in Xiaoshan on 8 July 1986 showed that there were 90.5 rice leafrollers (second generation) per 100 clumps in the ricefields with fish. This was a 6.5-times increase compared with 12 rice leafrollers in the ricefield without fish. The survey on 22 September 1987 indicated that there were 15.4 rice leafrollers (fourth generation) per 100 clumps in the late ricefields with fish, an increase of 1.9 times compared with the ricefields without fish. In Shangyu, a survey on 10 September 1987 indicated that the highest number of larva of rice leafroller (fourth generation) per 100 clumps was observed in the late ricefields with grass carp. There were 234 larva with grass carp and 193 larva with polyculture. This was an increase of 57.2% and 29.5%, respectively, compared with the 149 larva in the control plot. The reasons that fish-farming increased the number of rice leafrollers in the ricefields were that the fish did not eat the larvae. As well, the great amount of fish waste, the tender, green rice plants, the deep water in the field, and high humidity in the microclimate all favoured oviposition, hatching, and feeding of larvae.

**Control of rice sheath blight and clump blight.** From 1986 to 1987 in Shangyu, plant morbidity and disease incidence were reduced in the early ricefields with fish. This was highly significant compared with normal-water ricefields without fish, but there was no significant difference compared with the deep-water control. Disease incidence declined by 9.9–19.6%. Plant morbidity in the late ricefields with fish was 13%, a decrease of 58.4% compared with the normal-water control and of 24.9% compared with the deep-water control (Table 2). There were several reasons why damage from rice sheath blight and culm blight were mitigated. First, the fish (mainly grass carp) stripped the diseased leaves near the bottom of the rice plant, which directly diminished sources for reinfection in the field. Second, after the bottom leaves of plants were ripped off, the microclimate in the field was unfavourable to infection because ventilation and light penetration

Table 2. Index of disease incidence for rice sheath blight and culm blight in early ricefields.

| | Plant Morbidity (%) | | Disease Incidence Index | |
|---|---|---|---|---|
| | 9 July 1986 | 20 July 1987 | 9 July 1986 | 20 July 1987 |
| Normal watering field without fish culture | 22.2 | 34.0 | 7.2 | 13.5 |
| Deepwater field without fish culture | 9.7[a] | 22.2[a] | 4.8[a] | 8.1[a] |
| Deepwater field with fish culture | 8.9[a] | 19.5[a] | 4.1[a] | 7.3[a] |

[a] Not significantly different.

were improved. Third, long-term deep-water conditions prevented germination of the spores and reinfection.

**Control of weeds.** Fish control weeds grown in ricefields. Grass carp eat 21 different species of weeds in 16 families (e.g., *Echinochloa crusgalli, Eleocharis yokoscensis, Cyperus difformis, Rotala indica, Sagittaria pygmaea, Monochria vaginalis,* and *Marsilea quadrifolia*). In addition, common carp eat young roots, buds, and underground stems of weeds in the ricefield. Observations in late ricefields in Xiaoxhan in 1987 showed that there were three different kinds of weeds in rice–fish fields without weeding. The fresh weight of the weeds was 117 kg/ha. This represented a decrease of one kind of weed and 29.7% in fresh compared with ricefields with manual weeding, and a decrease of six kinds of weeds and 97.2% in fresh weight compared with a ricefield without fish and without weeding.

Only *Echinochloa crusgalli, Paspalum distichum,* and *Alternanthera philoxeroides* survived in the rice–fish fields. *Echinochloa crusgalli* was transplanted in the field with the rice seedlings and the fish were unable to control it effectively. *Paspalum distichum* normally extended from border dikes into the ricefield. Young buds and stems of *Alternanthera philoxeroides* were eaten by the fish, but they were not well liked. The surface of the ricefields with fish was smooth and grass-free. Weed control was more effective than with either manual weeding or the use of herbicides.

## Economic and Ecological Benefits

**Economic benefits.** In Shangyu in 1987, rice yields in both early and late ricefields with fish reached 11 093 kg/ha, an increase of 12.9% compared with the control (9 821 kg/ha). With a fish yield of 600 kg/ha, the net increase in income was CNY1 986/ha. In Huangyan in 1986, early and late ricefields with fish produced 11 334 kg/ha of rice and 1 778 kg/ha of fish with a net income of

CNY9 230/ha. This was an increase of 25.7% in income compared with the control. The practice of rice-fish farming has been popularized to 16 650-20 000 ha in Zhejiang Province, and to a total of over 135 000 ha throughout China.

**Ecological benefits.** The interactions of fish and rice create changes in the ecology of the ricefield. The ricefields hold water all season because of the fish. The movements of the fish stir the soil, which plays a role in weeding the field and increases the dissolved oxygen content in the soil. Ventilation and light penetration are also improved. The fish eat weeds, damaged plant leaves, and some pests. In exchange, they discharge wastes that add organic manure to the ricefield. Experiments have shown that 3 000 grass carp per hectare (6.3-11.2 cm in length) discharge 1 440 kg of waste in a month. Therefore, they contribute a constant supply of fertilizer to the rice plants. Rice-fish fields require less farm chemicals. This diminishes problems related to pollution and toxic residues and to some extent, protects natural enemies of plant pests and increases their effectiveness for biological control.

## Issues and Discussions

Rice-fish farming still faces some problems. First, animals pests (e.g., rats and snakes) eat fish in ricefields and frogs eat fry. Surveys in Shangyu in 1986 indicated that the harvest rates for grass carp, common carp, and nile tilapia were 78.9%, 82.1%, and 92.3%, respectively. Second, the fish do not control *Echinochloa crusgalli*; therefore, herbicides were required. Third, large grass carp stocked with late rice may damage the ricefield. Fourth, the proper ratio of fish pits and fish ditches in the ricefield must be determined to achieve bumper harvests for both rice and fish.

# Distribution and Residue of Methamidophos in a Rice–Azolla–Fish Ecosystem

*Xu Yinliang,*[63] *Xu Yong,*[64] *and Chen Defu*[65]

Methamidophos (O,S-dimethyl phosphoramidothioate) is an organophosphorus insecticide that is used in great quantities in ricefields in China. Rice–fish culture is common in the southern parts of China as well as in many other rice-producing countries (e.g., Thailand, Malaysia, and the Philippines). It is necessary to apply pesticides to control rice pests in the rice–azolla–fish ecosystem. In this study, the distribution, degradation, and residual behaviour of methamidophos were measured in both simulated and natural rice–azolla–fish ecosystems.

## Materials and Methods

### Test Materials

Two rice varieties were used: Sifu 8512 (an early rice) and Xinshui 04 (a late rice). The soil was a silty loam with a pH of 7.1 and an organic matter content of 1.3%. The fish species used was nile tilapia (*Oreochromis niloticus*) that were 4-6 cm in length, and the azolla was *Azolla caroliniana*.

A 50% methamidophos emulsion was obtained from the Hangzhou Pesticide Factory. The Institute of Nuclear-Agricultural Sciences, Zhejiang Agricultural University, synthesized the $^{35}$S-methamidophos (specific activity 5 227 dpm/mg, radio chemical purity 99%). The 50% $^{35}$S-methamidophos emulsion was formulated in 59% $^{35}$S-methamidophos, 47% methanol, and 3% emulsifier (PP2).

### Trial Design

**Simulated ecosystem.** This part of the study was conducted under outdoor conditions. A glass aquarium (95 cm x 68 cm x 45 cm) held the soil (200 kg), rice plants (30 hills), fish (30), and azolla. Surface water was maintained at a depth of about 7–10 cm.

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Table 1. Trial design to measure the residual behaviour of $^{35}$S-methamidophos ($^{35}$S-M) applied at a rate of 0.75 kg/ha in simulated and natural ecosystems of rice-azolla-fish.

| Treatment | Spraying Date, Early Rice | | | Spraying Date, Late Rice | | | Total Pesticide Application (kg/ha) | Sampling Date, Early Rice (7 July) | Sampling Date, Late Rice | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 16 June | 26 June | 20 Aug | 30 Aug | 30 Sept | 14 Oct | | | 30 Oct | 14 Nov |
| **Simulated ecosystem** | | | | | | | | | | |
| 3 applications | — | x | x | — | x | — | 2.25 | x | x | — |
| 5 applications | x | x | x | x | x | — | 3.75 | x | x | — |
| Dynamic | x | — | — | — | — | — | 0.75 | Timing of sampling | | |
| **Natural ecosystem** | | | | | | | | | | |
| 3 applications | — | x | — | x | — | x | 2.25 | x | — | x |
| 5 applications | x | x | — | x | x | x | 3.75 | x | — | x |

Table 2. Extraction procedures using a tissue homogenizer for 2 minutes on a 5-g sample.

| Sample | Azolla | Straw | Fish |
|---|---|---|---|
| Solvent (ml, per extraction)[a] | EA, 40 | EA, 40 | A:M (7:3,V/V), 30 |
| $Na_2SO_4$ (anhydrous, g) | 10 | 10 | 5 |

[a] EA ethyl acetate; A:M acetone:methanol.

The trial was divided into two treatments. The first was one application on early rice and two applications on late rice, the second was two applications on early rice and three applications on late rice. The application rate was 0.75 kg/ha. The interval between the latest application and harvest was 35 days for early rice and 30 days for late rice. Samples of water, soil, rice plants, azolla, and fish were taken for analysis of $^{35}$S-methamidophos residue at different times. After the harvest of early and late rice, the residues of $^{35}$S-methamidophos in different parts of the ecosystem were analyzed.

**Natural rice-azolla-fish ecosystem.** The experiments were carried out in experimental plots that were each 430 m$^2$. The trial design was similar to the simulated rice-azolla-fish ecosystem (Table 1). All treatments were replicated three times.

### Sample Preparation and Measurements

Prior to fortification with $^{35}S$-methamidophos to give concentrations of either 0.5 or 0.1 ppm, plant tissues were macerated, soil was placed in Buchner funnels and stripped of excess water by aspiration, and whole fish (one per sample) were weighted and cut into small pieces.

**Extraction and clean-up.** Water samples (20 ml) were extracted with ethyl acetate three times (30 ml, 20 ml, 20 ml). The $Na_2SO_4$ was added before the first extraction. The straw, azolla, and fish extracts were filtered through a layer of activated carbon (Celite 545, 1:4, W/W) in Buchner funnels. All the fractions from the sample were combined in 250-ml round-bottom flasks, evaporated in rotary evaporator, and subjected to radioanalysis (Table 2).

The soil (5 g) was extracted with water and methanol (3:1, V/V, 40 ml). The extract was filtered through a glass funnel. The crude extract (equivalent to 2.5 g of soil) was analyzed following the analytical method used for the water. Husk and brown rice (10 g) were also extracted with methanol and ethyl acetate (1:4, V/V, 50 ml) using the method of vibrating extraction. Extract, equivalent to 5 g of husk or brown rice, was evaporated in a rotary evaporator and subjected to radioanalysis.

**Radioanalysis.** The radioactivity in the organosoluble fractions from extraction of the water, soil, straw, fish, azolla, husks, and brown rice was directly determined using a liquid scintillation counter (Model LKB-1217). Recoveries of $^{35}S$-methamidophos from the seven substrates are listed in Table 3.

**Gas chromatography analysis.** The residues of methamidophos in the samples from the field trial were detected by gas chromatography (GC) using AFID (alkali flame ionization detection). The operation parameters were: gas chromatography Perkin-Elmer Sigma 2000, column 120 cm x 2 mm ID, 2% Reoplex 400 on the gas chromQ, air 18 psi, $H_2$ 18 psi, $N_2$ 42 ml/min, column temperature 170°C, and inlet and outlet temperature 210°C. Quantification of methamidophos was based on the average peak heights of external standards that were injected before and after sample analysis. The GC recoveries of methamidophos from the seven substrates are listed in Table 4.

**Residue in the simulated rice-azolla-fish ecosystem.** After application of 50% $^{35}S$-methamidophos emulsion to the rice plants in the rice-azolla-fish ecosystem at the rate of 0.75 kg/ha, samples of water, soil, straw, azolla, and fish were taken for analysis of methamidophos residue at different times from immediately after application to 14 days. The dynamics of $^{35}S$-methamidophos residue are listed in Table 5. The $^{35}S$-methamidophos disappeared exponentially from the simulated rice-azolla-fish ecosystem.

Table 3. The recovery and background of $^{35}$S-methamidophos ($^{35}$S-M).

| | Sample size (g, ml) | $^{35}$S-M (mg) | Conc. (ppm) | Counting (x+s) dpm | CV (%) | Recovery (%) | Background (dpm) |
|---|---|---|---|---|---|---|---|
| Water | 20 | 2 | 0.1 | 1 030.4±32.2 | 3.1 | 95.7 | 76.6 |
| | 20 | 10 | 0.5 | 4 837.1±74.5 | 1.5 | 92.5 | 76.6 |
| Soil | 10 | 1 | 0.1 | 318.6±30.9 | 9.7 | 88.9 | 97.0 |
| | 10 | 5 | 0.5 | 1 302.6±54.6 | 4.2 | 93.7 | 97.0 |
| Azolla | 10 | 1 | 0.1 | 495.2±31.2 | 6.3 | 93.6 | 62.8 |
| Fish | 5 | 0.5 | 0.1 | 210.6±12.6 | 6.0 | 87.3 | 102.6 |
| Brown rice | 10 | 1 | 0.1 | 270.2±5.6 | 2.0 | 90.4 | 66.3 |
| Husk | 10 | 1 | 0.1 | 279.3±15.4 | 5.5 | 88.3 | 80.2 |
| Straw | 5 | 0.5 | 0.1 | 309.4±11.2 | 3.6 | 94.6 | 91 |

Table 4. Gas chromatography (GC) recovery of $^{35}$S-methamidophos.

| Item | Concentration (ppm) | Recovery (%) | CV (%) |
|---|---|---|---|
| Water | 0.1 | 95.6±1.3 | 1.5 |
| | 0.5 | 103.0±3.1 | 3.2 |
| Fish | 0.1 | 82.5±4.6 | 5.6 |
| | 0.5 | 81.3±3.8 | 4.7 |
| Brown rice | 0.1 | 83.6±4.0 | 4.8 |
| Husk | 0.1 | 82.4±3.3 | 4.6 |
| | 0.5 | 86.2±2.7 | 3.4 |
| Straw | 5.0 | 78.4±2.9 | 3.5 |
| Soil | 0.1 | 87.1±3.5 | 4.0 |
| Azolla | 0.5 | 83.3±2.7 | 3.3 |

Table 5. Dynamics of $^{35}S$-methamidophos residues (ppm).

| | Time Course (day) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 0.25 | 1 | 3 | 5 | 9 | 14 |
| Water | 0.132 | 0.164 | 0.303 | 0.259 | 0.184 | 0.072 | 0.013 |
| Soil | nd[a] | nd | nd | nd | nd | nd | nd |
| Fish | 0 | 0.187 | 0.606 | 0.328 | — | 0.178 | 0.127 |
| Azolla | 3.136 | 4.157 | 2.944 | 1.497 | 0.469 | 0.070 | 0.009 |
| Straw | 29.066 | 16.742 | 9.336 | 3.853 | — | 0.799 | 0.136 |

[a] nd nondetectable.

Table 6. Residues of $^{35}S$-methamidophos in the simulated ecosystem (ppm).

| | No. of Treatments | Water | Soil | Azolla | Fish | Straw | Husk | Brown Rice |
|---|---|---|---|---|---|---|---|---|
| Early rice | 1 | 0.002 | nd[a] | nd | 0.412 | 0.008 | 0.011 | 0.010 |
| | 2 | 0.004 | nd | nd | 0.552 | 0.036 | 0.034 | 0.010 |
| Late rice | 2 | Trace | nd | nd | 0.212 | 0.006 | 0.176 | 0.014 |
| | 3 | Trace | nd | nd | 0.400 | 0.122 | 0.346 | 0.043 |

[a] nd nondetectable.

Table 7. Effect of polishing on concentration of $^{35}S$-methamidophos in brown rice.

| | Weight (g) | Concentration (ppm) | Quantity (mg) | Ratio (%) | Total Quantity (mg) | Clearance Rate (%) |
|---|---|---|---|---|---|---|
| Polished rice | 17.5 | 0.005 | 0.0875 | 41.2 | 0.2125[a] | 50[a] |
| Bran | 2.5 | 0.050 | 0.1250 | 58.8 | — | — |

[a] Value for polished rice plus bran.

After 1 day of equilibrium, the residues of $^{35}S$-methamidophos in the azolla, water, and fish reached a peak (4.16, 0.30, and 0.61 ppm, respectively) then decreased exponentially. The half-lives of $^{35}S$-methamidophos in azolla, water, and fish were 1.5, 2.8, and 6.2 days, respectively. The half-life of $^{35}S$-methamidophos in the straw was 2.2 days. There was no residue detected in the soil.

**Residue in the simulated rice-azolla-fish ecosystem.** The $^{35}S$-methamidophos was applied to the early and late rice in the simulated ecosystem. The residues of $^{35}S$-methamidophos in the different parts of the ecosystem at harvest are listed in Table 6.

The interval between the last application and harvest was 35 days for early rice and 30 days for late rice. At harvest of early and late rice, there were trace residues of $^{35}S$-methamidophos in the water, but no residues in the soil of the azolla. The residues of $^{35}S$-methamidophos in fish were 0.41–0.55 ppm when harvested with early rice and 0.21–0.40 ppm when harvested with late rice. This decrease of concentration was related to the increase in the weight of the fish.

The distributions $^{35}S$-methamidophos residue in the parts of the rice plant differed. The residue was highest in the husk and lowest in the brown rice (e.g., for late rice the concentrations were 0.35 ppm in the husk, 0.12 ppm in the straw, and 0.04 ppm in the brown rice). With increases in application times, the concentrations of $^{35}S$-methamidophos residues in the rice plant increased. For example, in husks of early rice, the residue was 0.01 ppm for one application and 0.03 ppm for two applications. However, there was no linear correlation to the increase.

In the natural rice-azolla-fish ecosystem, there was only 0.09–0.10 ppm of methamidophos residue in the rice husks when the early rice was harvested. In the other parts of the ecosystem, no residues were detected.

**Influence of polishing brown rice.** Brown rice (20 g) that had a residue of 0.01 ppm was polished for 10 minutes. The residue of methamidophos in polished rice was decreased to 0.005 ppm (Table 7).

**Residue in fish.** When applied twice to early rice and three times to late rice, the distribution and residue of $^{35}S$-methamidophos in fish when late rice was harvested were determined (Table 8). The residue was highest in the viscera and lowest in the scales. The edible portion of the fish body contained 26.9% of the radioactivity and the nonedible portion contained 73.1%.

## Conclusion

Methamidophos is not well degraded by animals and plants. In female houseflies with different doses of $^{32}P$-methamidophos, the parent compound has only been detected in the extract of the houseflies, not in their metabolites or degradation products. Experiments with white mice and houseflies have also suggested that the metabolic pathway of methamidophos may be through the release of $CO_2$. However, the quantity of this metabolic product may be so low that it cannot be detected. When extracts from rice plants and fish were made, separated on thin-layer chromatography, and scanned with a radioscanner, only the parent compound was detected.

Table 8. Distribution of $^{35}S$-methamidophos in different parts of fish.

| | Weight (g) | Concentration (ppm) | Quantity (mg) | Ratio (%) |
|---|---|---|---|---|
| Head | 7.320 | 0.525 | 3.843 | 38.22 |
| Flesh | 10.568 | 0.256 | 2.706 | 26.91 |
| Viscera | 2.536 | 0.775 | 1.965 | 19.54 |
| Gill | 1.152 | 0.543 | 0.626 | 6.22 |
| Bone | 2.136 | 0.291 | 0.622 | 6.18 |
| Fin | 0.841 | 0.243 | 0.204 | 2.03 |
| Scale | 0.587 | 0.154 | 0.090 | 0.90 |
| Full fish | 25.139 | 0.400 | 10.056 | 100.00 |

These experiments with the rice-azolla-fish ecosystem have demonstrate that:

- The disappearance of methamidophos in the rice-azolla-fish ecosystem was exponential. The half-lives of $^{35}S$-methamidophos in azolla, water, fish, and straw were 1.5, 2.8, 6.2, and 2.2 days, respectively.
- When 2 x 0.75 kg/ha of $^{35}S$-methamidophos emulsion were sprayed on early rice there was 0.01 ppm of methamidophos in the brown rice and 0.55 ppm in the fish. When sprayed at 3 x 0.75 kg/ha on late rice, there were 0.04 ppm in the brown rice and 0.40 ppm in the fish.
- When brown rice was polished the concentration of methamidophos residue was reduced by about 50%.
- Methamidophos is not well degraded by animals and plants. No metabolic and degradation products were detected in the extracts from rice plants and fish.

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# Residue and Application of Fenitrothion in a Rice-Fish Culture System

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Fenitrothion (o,o-dimethyl-o-3-methyl-4-nitrobenzene phosphnothiocester) has low mamalian toxicity (white rat oral $LC_{50}$ 490–700 g/kg) and effectively controls stem borers. Fenitrothion is one of twelve pesticides recommended by the Chinese government for priority research and increased production. Pest and disease control is one of the most important measures in rice production. Rice-fish culture is a major component of freshwater fisheries. Pesticides with high efficacy and low residual effects are needed to integrate production and increase yields of both rice and fish. The effects of fenitrothion in rice-fish culture was studied in Sichuan Province from 1984 to 1987.

## Test Design

### Fenitrothion Residue in Ricefields

Five 30-$m^2$ treatment plots were designed to study degradation. Every treatment was divided into subplots with three replicates. Water depth was maintained at 6.6 cm during the experiment. Samples were taken at 2 h, and 1, 3, 5, and 7 days after application of 750 g/ha (50% EC 800 dilution). The residual experiment (Table I) included: using different dosages in ricefields (750–1 125 g/ha, 50% EC 500–800 dilution), spraying the pesticide at different times, and multiple applications of fenitrothion.

### Fenitrothion Residue in Fish

The designs and treatments were identical to those used to study the effects in ricefields, but the sampling interval was from 2 to 148 h at regular intervals after application of the pesticide. Tests on residue distribution were made in tanks (50 L) of clean oxygenated water.

Each tank contained 200 fish that weighed approximately 0.5 g. The range of test concentrations was 0.05–2 ppm. Samples from internal organs were taken at regular intervals. Benzene was used to extract residual pesticide from the rice and

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Table 1. Design of residual test on rice.

| Concentration | Number of Times | Time to Harvest (days) | | |
|---|---|---|---|---|
| 50% EC 750 g/ha | 1 | 28 | | |
| | 1 | 21 | | |
| | 1 | 14 | | |
| | 2 | 35 | 28 | |
| | 2 | 28 | 21 | |
| | 2 | 21 | 14 | |
| | 3 | 35 | 28 | 21 |
| | 3 | 28 | 21 | 14 |
| 50% EC 1 125 g/ha | 3 | 35 | 28 | 21 |
| | 3 | 28 | 21 | 14 |

fish. Dichlromethane and trichloromethane were used to extract residues from the soil and water.

## Results and Discussion

### Degradation of Fenitrothion in Aquatic Ecosystems

Tables 2–4 indicate the degradation rate (%) of fenitrothion in rice and in the environment. Fenitrothion broken down rapidly in rice. The degradation rate was up 50% when used at 750–1 125 g/ha (50% EC 500–800 dilution). The residue of fenitrothion in rice was generally less than 0.1 ppm 5 days after application. Straw and rice bran contained less than 25% after only 1 day. Over 90% of the fenitrothion had been broken down after 7 days (Table 2). The residual curve formula was:

$$y_{rice} = 2.8573\ e^{-0.3510x}$$

which indicates that the half-life ($HL_{50}$) in rice was 2 days. The rate of degradation was also fast in soils and water under similar conditions (Tables 3 and 4). The residue curve formulae were:

$$y_{soil} = 2.9404\ e^{-0.3470x} \text{ and}$$

$$y_{water} = 2.7897\ e^{-0.6053x}$$

Table 2. Degradation of fenitrothion in rice (ppm).

| Test Year | Time After Spraying (days) | Rice Grain | | Rice Bran | | Straw | |
|---|---|---|---|---|---|---|---|
| | | R[a] | D | R | D | R | D |
| 1984 | 0.08 | 0.441 | — | 9.690 | — | 6.878 | — |
| | 1 | 0.222 | 49.66 | 2.309 | 76.17 | 1.613 | 76.55 |
| | 3 | 0.140 | 68.25 | 1.428 | 85.26 | 0.983 | 85.71 |
| | 5 | 0.066 | 85.00 | 0.571 | 94.11 | 0.388 | 94.36 |
| | 7 | 0.024 | 94.56 | 0.221 | 97.72 | 0.222 | 96.77 |
| 1985 | 0.08 | 0.390 | — | 7.860 | — | 6.914 | — |
| | 1 | 0.171 | 56.15 | 1.948 | 75.22 | 2.263 | 67.27 |
| | 3 | 0.100 | 74.86 | 0.820 | 89.58 | 1.021 | 85.23 |
| | 5 | 0.066 | 83.08 | 0.291 | 96.30 | 0.295 | 95.73 |
| | 7 | 0.034 | 91.28 | 0.203 | 97.42 | 0.143 | 97.93 |

[a] R residue; D degradation.

Table 3. Degradation of fenitrothion in soil of ricefield (ppm).

| Interval After Using Pesticide (days) | 1984 | | 1985 | | Average | |
|---|---|---|---|---|---|---|
| | R[a] | D | R | D | R | D |
| 0.08 | 0.313 | | 0.290 | | 0.302 | |
| 1 | 0.264 | 15.65 | 0.248 | 13.80 | 0.256 | 14.78 |
| 3 | 0.155 | 50.48 | 0.124 | 58.62 | 0.140 | 54.55 |
| 5 | 0.050 | 84.03 | 0.058 | 80.00 | 0.054 | 82.02 |
| 7 | 0.03 | 90.41 | 0.029 | 90.00 | 0.030 | 90.21 |
| 9 | 0.015 | 95.21 | 0.015 | 94.83 | 0.015 | 95.03 |

[a] R residue; D degradation.

Table 4. Degradation of fenitrothion in water in ricefield.

| Interval After Using Pesticide (days) | 0 | 1 | 3 | 5 | 7 |
|---|---|---|---|---|---|
| R (ppm)[a] | 0.973 | 0.134 | 0.019 | 0.015 | 0.0098 |
| D (%) | — | 86.23 | 98.05 | 98.46 | 98.99 |

[a] R residue; D degradation.

Table 5. Residue of fenitrothion in rice, soil and water.

| Dosage (g/ha) | Number of Applications | Days from Using to Harvest | Residue (ppm) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Rice Grain | Rice Bran | Straw | Soil | Water |
| 750 | 1 | 28 | ND | 0.016 | 0.024 | ND | ND |
| | 1 | 21 | Trace | 0.042 | 0.038 | ND | ND |
| | 1 | 14 | 0.016 | 0.144 | 0.021 | ND | Trace |
| | 2 | 28 | ND | 0.044 | 0.032 | ND | Trace |
| | 2 | 21 | 0.003 | 0.076 | 0.054 | ND | 0.00010 |
| | 2 | 14 | 0.020 | 0.496 | 0.213 | ND | 0.00042 |
| | 3 | 21 | 0.010 | 0.162 | 0.057 | ND | 0.00033 |
| | 3 | 14 | 0.022 | 0.623 | 0.223 | Trace | 0.00051 |
| 1 125 | 3 | 21 | 0.016 | 0.212 | 0.131 | Trace | 0.00030 |
| | 3 | 14 | 0.032 | 0.810 | 0.304 | Trace | 0.00058 |

[a] ND = not detectable.

which indicated that the half-life in soil was 2 days and that the half-life in water was 1 day.

Table 5 gives the residual levels of fenitrothion in various parts of the rice and in the soil and water. There were differences between the different dosages, number of applications and intervals.

There was little contamination of the rice when it was sprayed from one to three times. Soil and water were not polluted under these conditions. Under similar dosages and number of sprays, residual levels were higher when the rice was sprayed closer to harvest time. The soil and water were not polluted at any frequency of spraying. There was more residue after application at 1 125 g/ha than at 750 g/ha under similar conditions.

### Accumulation of Fenitrothion in Fish

The level of fenitrothion in the fish increased as the level decreased in the water. The pesticide in the water was absorbed and concentrated by the fish (Table 6). When the fish were treated with different concentrations of the pesticide, the residual level of the pesticide in the fish increased as the amount of residue in the water increased. However, the coefficient did not increase without limit. After a certain concentration, the coefficient decreased. For example, when grass carp were kept in 0.05 ppm and 0.1 ppm, the coefficients after 2 h were 12.6 and 17.3, respectively. The coefficients increased to 38.3 and 61.4 after 8 h. When the concentration of the pesticide was higher (1 ppm and 2 ppm), the residue in the fish increased to 2.0 ppm and 3.2 ppm, but the coefficients were only 2.5 and 2.1.

When different fish species (Table 6) were exposed to the same concentration, the residue levels were different. Different species of fish have different shapes and feeding habits, fat contents, and distributions. In all species, fenitrothion was more concentrated in fish than in the water. The concentration coefficients were highest at low concentration. For example, in grass carp at application rates of 0.05 ppm, they were 12, 39, and 10 from 2 to 24 h; whereas, at 1-2 ppm the concentration coefficients ranged from 1 to 3. The concentrations were higher for common carp and crucian carp (5.4–7.5).

The amount of fenitrothion (Table 6) in water decreased from 2 to 8 h then increased by 24 h; whereas, in the fish, the amount increased from 2 to 8 h and then decreased. The amount in water probably reflects two processes: the natural breakdown of fenitrothion in water, and the accumulation (2-8 h) and elimination of the pesticide by the fish (24 h).

Table 7 indicates the elimination dynamics of fenitrothion from fish when used at 1 125 g/ha (50% EC 800 dilution) and shows a similar pattern to Table 6. The results show that some of the pesticide in the water is absorbed by the fish after application. The fish absorb fenitrothion quickly during the earlier stages, and the concentration of the pesticide decreased in the fish 24 h after application. Other experiments showed no difference between fish raised in ricefields and fish raised indoors (Table 7).

The half-life of fenitrothion was 2 days and the residue curve formula was:

$$y = 1.6282\, e^{-0.3559x} \quad (r=0.9648)$$

Table 6. Accumulation and elimination of fenitrothion by different species of fish.

| Hours after Application | Grass Carp | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.05 ppm | | | 0.1 ppm | | | 1 ppm | | | 2 ppm | | |
| | Water | Fish | CC[a] | Water | Fish | CC | Water | Fish | CC | Water | Fish | CC |
| 2 | 0.0489 | 0.600 | 12.3 | 0.0781 | 1.348 | 17.3 | 0.915 | 1.581 | 1.7 | 1.812 | 2.851 | 1.6 |
| 8 | 0.0394 | 1.522 | 38.6 | 0.0652 | 4.000 | 61.4 | 0.82 | 2.014 | 2.5 | 1.539 | 3.234 | 2.1 |
| 24 | 0.0720 | 0.730 | 10.1 | 0.104 | 2.920 | 28.1 | 0.843 | 0.962 | 1.1 | 1.781 | 2.091 | 1.2 |
| | Common Carp | | | | | | Crucian Carp | | | | | |
| | 1 ppm | | | 2 ppm | | | 1 ppm | | | 2 ppm | | |
| 2 | 0.824 | 3.981 | 4.8 | 1.820 | 5.612 | 3.1 | 0.651 | 2.96 | 4.6 | 1.225 | 5.442 | 4.4 |
| 8 | 0.605 | 4.674 | 7.7 | 1.239 | 7.510 | 6.1 | 0.533 | 4.018 | 7.6 | 1.06 | 7.085 | 6.7 |
| 24 | 0.771 | 2.586 | 3.4 | 1.523 | 6.361 | 4.2 | 0.632 | 3.27 | 5.2 | 1.741 | 5.825 | 3.3 |

[a] CC concentration coefficient.

Table 7. Elimination of fenitrothion from fish in ricefields when used at 1 125 g/ha (50 EC 800 dilution).

| | 2 h | | 8 h | | 24 h | | 72 h | | 120 h | | 148 h | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | W[a] | F | W | F | W | F | W | F | W | F | W | F |
| Residue | 0.39 | 1.25 | 0.35 | 2.53 | 0.06 | 1.75 | 0.03 | 0.33 | 0.02 | 0.09 | 0.01 | 0.05 |
| Rate | — | — | — | — | 81.18 | 30.74 | 92.20 | 95.38 | 95.38 | 96.48 | 97.46 | 98.22 |

[a] W water; F fish; R digestion rate.

Table 8. Residues of fenitrothion in fish that underwent purification.

| | Common Carp | | | | Crucian Carp | | | | Grass Carp | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24.815[b] | | 25.827 | | 26.315 | | 28.210 | | 18.513 | | 20.007 | |
| IBT[a] | Fish | ER | Fish | ER | Fish | ER | Fish | ER | Fish | ER | Fish | ER |
| 1 | 14.915 | 39.9 | 16.018 | 38.0 | 18.210 | 35.8 | 16.515 | 37.2 | 12.001 | 35.2 | 13.015 | 35.0 |
| 3 | 4.510 | 81.9 | 4.785 | 81.5 | 5.860 | 79.2 | 5.003 | 81.0 | 3.212 | 82.7 | 3.810 | 80.9 |
| 5 | 0.713 | 97.1 | 0.815 | 96.8 | 0.880 | 96.9 | 0.850 | 96.8 | 0.071 | 99.6 | 0.075 | 99.7 |
| 7 | 0.031 | 98.8 | 0.041 | 98.4 | 0.048 | 99.8 | 0.043 | 98.4 | 0.011 | 99.9 | 0.014 | 99.9 |

[a] IBT interval between treatments (days); ER elimination rate (%).
[b] Numbers in this row are the concentrations of fenitrothion at the beginning of the test.

Table 9. The distribution of fenitrothion in fish and viscera in 0.346 ppm water.

| | Distribution of Fenitrothion | | | |
|---|---|---|---|---|
| | Fish | | Viscera | |
| | Residue (ppm) | Concentration Coefficient | Residue (ppm) | Concentration Coefficient |
| Common carp | 18.21 | 52.95 | 65.11 | 188.18 |
| Crucian carp | 19.38 | 56.01 | 68.21 | 197.21 |
| Grass carp | 12.11 | 35.00 | 25.31 | 73.16 |

When fish are exposed to fenitrothion, they both absorb and accumulated and degrade and eliminate the chemical. Accumulation and elimination of fenitrothion are kept in a dynamic balance. In a polluted environment, toxic pollutants are concentrated and accumulated by fish. When the fish are in a nonpolluted environment, the chemical is eliminated. Fish are an important part of the food chain. Fenitrothion was accumulated in the polluted ricefield ecosystem. Different fish concentrated the fenitrothion at different rates.

Experiments were also carried out to determine the rate of fish purification. Table 8 shows the results of the purification experiments. Although the pesticide broke down quickly in the fish and the ricefields, these purification measures could speed up the elimination of pesticides from the fish.

### Distribution of Fenitrothion

Residual fenitrothion was detected in fish in ricefields in 12 cities and counties in Sichuan Province. Middle-season rice is normally treated with 560–750 g/ha (50% EC 800 dilution) sprayed from one to three times through the season. Three hundred samples of rice and fish were obtained through out Sichuan. The residue level in rice grains was 0–0.027 ppm, the residue level was from trace to 0.077 ppm in rice bran, and the level was 0–0.037 ppm in fish. The concentration of fenitrothion was higher in the viscera than in the meat of the fish (Table 9).

## Summary

Fenitrothion is a pesticide with high efficacy, low residues, and low toxicity. Contamination should not occur in the aquatic ecosystem of the ricefield when fenitrothion is used. Fenitrothion could be promoted to increase outputs of rice and fish.

The residual standard for fenitrothion in rice grains has been set at 0.2 ppm in China. There is no standard for the maximum residue in fish, but in Japan it is 0.05 ppm. If the pesticide is applied as recommended and not close to the harvest time for the rice and fish, the residues should be well below acceptable levels.

Fenitrothion should not produce lasting accumulations in rice and fish because its degradation rate is fast ($LH_{50}$ 2 days). If the concentration of toxic pollutants is controlled in the water, there should be no long-term contamination of fish.

# Part IV:

# Economic Effects

# Economic Analysis of Rice–Fish Culture

*Lin Xuegui, Zhang Linxiu, and He Guiting*[68]

Rice–fish culture has received much attention since the 1980s. Rice–fish farming methods have increased both rice yields and economic benefits. The area devoted to rice–fish culture has expanded rapidly from 345 000 ha in 1982 to 558 000 ha in 1984, an increased of 62%. The yield of fish products has also increased from 24 000 tonnes 56 300 tonnes, an increase of 135%. Fish culture in ricefields has become an important component of freshwater fish production.

To evaluate rice–fish culture, its economic benefits must be compared with single-crop rice production. Moreover, comparisons between rice yields in rice–fish culture and in single-crop ricefields are needed to estimate the effects of rice–fish coexistence on rice yields. Twelve farm households in Hong'an and Hanchuan Counties, Hubei Province, were interviewed in June 1988. Among these households, four planted only rice and were used as the control. The other households adopted various types of rice–fish culture. The study used cost–benefit analysis to assess the various economic criteria of rice–fish culture.

## Comparison with Single-Crop Rice Production

Survey data were collected from four farm households in Hong'an County, Hubei Province. The households practiced two farming types: rice–fish and single-crop rice. Although the two groups of households had similar conditions (e.g., scale of production, soil fertility, and production technologies) both the production value and economic benefits of the rice–fish households were higher (Table 1).

### Yield Increase

In addition to the 253.5 kg/ha of production of fresh fish, rice yields with rice–fish culture were 7.8% higher. Rice and fish together produced a total product value that was 41% higher than from rice alone. In terms of protein output, rice–fish culture was 26.8% higher. Of the increase in protein, more than 70% was accounted for by fish protein (Table 2).

### Relative Economic Benefit

Whether rice–fish culture can substitute for single-crop rice production depends on its relative economic benefit. Various resource productivity criteria (e.g., land pro-

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Table 1. Basic characteristics of sample households.

| | Rice-Fish Culture | Single-Crop Rice |
|---|---|---|
| Sample size (no.) | 2 | 2 |
| Education level of householder | middle school | middle school |
| Average area of ricefield (ha) | 0.2 | 0.2 |
| Soil fertility of ricefield (Grade) | middle | middle |
| Seeds (kg) | 12.5 | 12.5 |
| Fertilizer (CNY) | 13.2 | 12.7 |
| Animal labour (days) | 3.5 | 3.5 |
| Farm tools (type) | manual | manual |

Table 2. Outputs of different farming types.

| Farming Type | Yield (kg/ha) | | Value Product (CNY/ha) | | | Protein Yield (kg/ha) |
|---|---|---|---|---|---|---|
| | Rice | Fish | Rice | Fish | Total | |
| Rice-fish | 8 250.0 | 253.5 | 2 970.0 | 912.0 | 3 882.0 | 394.5 |
| Single-crop rice | 7 650.0 | – | 2 754.0 | – | 2 754.0 | 310.5 |
| Increase | 600.0 | 253.5 | 216.0 | 912.0 | 1 128.0 | 84.0 |
| Percentage increase | 7.8 | – | 7.8 | – | 41.0 | 13.4 |

ductivity, labour productivity, and capital productivity) were used to measure the relative economic benefit of rice-fish culture. The analysis showed that net income per unit input, net return to labour, and benefit-cost ratio were significantly higher for rice-fish culture (Table 3).

When extending new agricultural technologies, changes in socioeconomic factors (e.g., market institutions and new farming practices) can affect efficiency. The risk and uncertainty associated with of agricultural production mean that the economic benefits of new technologies must reach a certain level. Many countries use two indicators (the increment in economic benefit and marginal benefit-cost ratio of new technology) and set their critical values at 30% and 2, respectively. In China, these two values are 18-22% and 1.2-1.5, respectively. The results of our analysis indicate that these two indicators for rice-fish culture are 45% and 2.5, respectively.

Table 3. Economic benefits of different farming types.

| Farming Type | Rice-Fish Culture | Single-Crop Rice | Percentage Difference |
|---|---|---|---|
| Net benefit (CNY/ha) | 2185.50 | 1506.90 | +45.0 |
| Net return to labour (CNY/person-day) | 10.06 | 8.93 | +12.6 |
| Net return to material inputs (CNY) | 3.15 | 3.28 | -4.0 |
| Benefit-cost ratio | 2.29 | 2.20 | — |

The economic benefits of rice-fish culture were related to:

- The increase in rice yields and the saving in labour and material inputs. Compared with single-crop rice production, rice yields in rice-fish culture were 7.8% higher, labour input were 19.4% lower, and material costs were 7% lower because of savings in the control of plant diseases and pests.
- The increase in net benefits because of fish production (CNY286.5/ha).

**Different Patterns of Rice-Fish Culture**

After the system of rice-fish culture is adopted, further increases in economic benefit can be realized by improving the combinations of rice and fish and by designing and choosing different kinds of component technologies.

In Hanchuan County, Hubei Province, three different patterns of fish culture are used: breeding fingerling in ricefields, breeding adult fish in ricefields, and breeding both fingerling and adult fish in ricefields.

To determine the best pattern of rice-fish culture, the economic benefits of the different patterns of rice-fish culture were compared using relative indicators of economic benefit (Table 4). The values of both indicators (increment in net benefit and marginal benefit-cost ratio) exceed the lowest limit (critical value) for spreading new technology. It is difficult to determine which method is the best just by studying these two indicators. There are trade-offs between them. Based on the net benefit, mixed culture was the best pattern. Based on marginal benefit-cost ratio, breeding fingerlings is the best pattern. Therefore, it is necessary to consider some other indicators. It is generally agreed that the criterion of economic assessment for new technologies should be the maximum value of economic results. To modify the criteria, three indicators (net profit/area, output value/input costs, and net profit/input costs) were used. These three indicators valued mixed culture the highest (CNY259.43, CNY3.76, and CNY2.76, respectively). The net

Table 4. Economic benefits of different rice-fish combinations.

| | Fingerling Breeding | Adult Fish Breeding | Mixed Breeding | Single-Crop Rice |
|---|---|---|---|---|
| Increment in net benefit | | | | |
| CNY/ha | 1180.65 | 2051.70 | 2217.75 | — |
| % | 70.5 | 123 | 132 | — |
| Marginal benefit-cost ratio | 5.26 | 4.93 | 5.11 | — |
| Net benefit per unit | | | | |
| CNY/ha | 2854.20 | 3725.40 | 3891.45 | 1673.70 |
| % | 171 | 223 | 233 | 100 |
| Value product per unit of cost | | | | |
| CNY/CNY | 3.48 | 3.68 | 3.76 | 2.90 |
| % | 119 | 126 | 129 | 100 |
| Net benefit per unit of cost | | | | |
| CNY/CNY | 2.49 | 2.68 | 2.76 | 1.92 |
| % | 130 | 146 | 144 | 100 |
| Cost per unit of value product | | | | |
| CNY/CNY | 0.27 | 0.27 | 0.27 | 0.34 |
| % | 80 | 80 | 78 | 100 |

Table 5. Component technologies of different rice-fish combinations.

| | Double Rice-Fish Culture (Group A) | Double Rice-Fish Culture (Group B) |
|---|---|---|
| Sample size | 2 | 2 |
| Average farm size (ha) | 0.21 | 0.15 |
| Area of rice (ha) | 0.19 | 0.13 |
| Area of fish (ha) | 0.02 | 0.02 |
| Inputs (CNY) | | |
| Fertilizer | 223.4 | 116.6 |
| Seeds | 35.2 | 24.2 |
| Pesticides | 32.0 | 22.0 |
| Fingerling | 65.6 | 41.4 |
| Feed | 144.0 | 48.4 |
| Others | 25.6 | 17.6 |

Table 6. Economic analysis of component technologies.

| | | Double Rice–Fish (Group A) | Double Rice–Fish (Group B) | Group A/ Group B Difference |
|---|---|---|---|---|
| Inputs (CNY/ha) | | | | |
| Materials | Rice | 1272.0 | 1020.0 | 252.0 |
| | Fish | 1192.5 | 822.0 | 370.5 |
| Labour | Rice | 720.0 | 780.0 | -60.0 |
| | Fish | 810.0 | 690.0 | 120.0 |
| Total | | 3994.5 | 3312.0 | 682.5 |
| Outputs | | | | |
| Rice | Yield (kg) | 16620.0 | 15150.0 | 1470.0 |
| | Value of product (CNY) | 5983.5 | 5454.0 | 529.5 |
| Fish | Value of product (CNY) | 1710.0 | 732.0 | 979.5 |
| Total | Value of product (CNY) | 7693.5 | 6186.0 | 1507.5 |
| Net benefit (CNY/ha) | | 3699.0 | 2874.0 | 825.0 |

profit was 1.3 times that of single-crop rice production, 4.5% higher than adult fish culture, and 36.3% higher than fingerling culture.

### Factors Affecting Economic Benefits

In rice–fish culture, there are differences in methods of using the ricefield, patterns of rice–fish culture, combinations of inputs, combinations of fish, and ways of breeding. All these differences can affect the economic benefits of rice–fish culture.

Tables 5 and 6 present data from Hanchuan County, Hubei Province. The inputs and outputs of two types of rice–fish culture were studied. The net benefit of group A was CNY825/ha higher than group B. The net benefits of rice increased by 41% and the net benefit from fish increased by 59%.

The benefit–cost ratio of group A was 3.9% higher than group B. The higher economic benefits of group A were mainly due to the effects of higher inputs and the combination of different kinds of fish species.

## Conclusion

Rice-fish culture is one way to increase the economic benefits from ricefields and develop freshwater fisheries. Rice-fish culture increases rice output. The average value of products can be increased by 41%, the rice yield by 7.8%, and the protein output by 26.8%. The increase in protein output is mainly animal (fish) protein.

When deciding whether to extend new agriculture technology, the economic evaluation usually requires that the increment in economic benefits and the marginal benefit-cost ratio must be more than 18-22% and 1.2-1.5, respectively. These two indicators in rice-fish culture were over the critical value. Compared with single-crop rice production, net profits from rice-fish culture were 45% higher, the rate of return to labour was 12.6% higher, and the benefit-cost ratio was 4% higher. The main reasons for higher economic benefits from rice-fish culture were:

- Increase in rice yields and saving on labour and material inputs.
- Increases in net profits from fish production.

Once rice-fish culture has been adapted, further increases in economic benefits can be realized. The net benefits from rice production combined with adult fish and fingerling production was 4.5% higher than from the combination of rice and adult fish, and 36.3% higher than from the rice-fingerling combination. Research to improve the component technologies may further increase economic benefits.

The ecological benefits of rice-fish culture were related to weeding, elimination of insect pests and diseases, preserving and increasing the fertility of the soil, environmental stability, and improving environmental conditions.

These results indicate that rice-fish culture provides technical, economic, social, and ecological benefits. In addition to technical knowledge, several conditions must be met to implement rice-fish culture:

- The field must have a good irrigation and drainage system to ensure that there is no water logging during the rainy season and that the field does not dry out during droughts.
- Field ridges and fish ditches must be created to meet the different water requirements of rice and fish.
- High efficiency, low toxicity pesticides must be selected to avoid toxic effects on fish.
- A resource plan must be implemented to use resources rationally, increase rice yields, and optimize economic benefits.

# Economic Research on Rice–Fish Farming

*Jiang Ci Mao and Dai Ge*[69]

Since 1978, rice–fish culture has developed very rapidly in China. The area under production has continued to expand, and aquatic production has increased each year. In some provinces, rice–fish production accounts for the largest percentage of freshwater fisheries production (Table 1).

The development of rice–fish farming differs from place to place. In China, rice–fish culture accounted for 2% of freshwater aquatic production in 1982. In 1983 and 1984, the proportion was 2.5% and 3.1% respectively. In Sichuan, rice–fish culture now accounts for 7.6% of freshwater aquatic production.

Rice–fish culture is important part of fisheries production in Sichuan, Guizhou, Hunan, and Jiangxi. In 1949, production from rice-fish culture accounted for 15.5% of the aquatic production of these four provinces. By 1984, this figure was 21.6%. In Guizhou, rice–fish culture represents 75% of total aquatic production. In these provinces, rice–fish farming is common in the hilly and mountainous areas. For example, in Sichuan and Guizhou, about 75% of the production comes from these areas; whereas, in Quin Dong Nan, Guizhou, 85% of aquatic production is supplied by rice–fish farming.

Ricefields are a suitable place for the culture of fry and fingerlings. In Hunan Province, 0.44 billion fish were breed in 38 430 ha of ricefields and ponds. These fry and fingerlings can be used to promote fish production in ponds, reservoirs, and lakes.

## Economics of Rice–Fish Farming

A survey of 23.8 ha of rice–fish fields was conducted in Jiangxi Province in 1984. The average input cost was CNY660/ha and the average net profit from breeding and selling fish was CNY4 590/ha. The cost–return ratio was 7.9. Similar surveys were undertaken in Hunan and Guizhou. In Hunan, a survey of 7.3 ha of ricefields in 1984 showed that the cost–return ratio was 16.0; whereas, in Guizhou, 222.4 ha were surveyed and the ratio was 7.8. For China as a whole, the maximum cost of the rice–fish farming is about 20% of the value of production (input:output ratio 1:5). From these calculations, it can be seen that rice–fish farming provides a good return on investment.

[69] Aquatic Bureau of Sichuan Province, Chengdu, Sichuan Province.

Table 1. Fish production from ricefields (as percentage of total fish production) in China and several provinces (1983 and 1984).

| | 1983 | 1984 |
|---|---|---|
| China | 2.54 | 3.11 |
| Jiangsu | — | 0.18 |
| Zhejiang | 0.77 | 1.28 |
| Anhui | 0.55 | 1.12 |
| Fujian | 3.90 | 5.39 |
| Jiangxi | 1.90 | 3.40 |
| Hunan | 4.31 | 5.76 |
| Guangdong | 0.21 | 0.45 |
| Guangxi | 3.82 | 4.59 |
| Sichuan | 22.29 | 25.16 |
| Guizhou | 79.25 | 71.08 |
| Yunan | 4.93 | 7.53 |

Table 2. Production value of rice-fish culture in Chengdu, Sichuan Province (1984).

| | Type of Ricefield | Area (ha) | Rice | | Fish | | TV[a] (CNY/ha) | Ratio TV to Rice Only (%) |
|---|---|---|---|---|---|---|---|---|
| | | | kg/ha | CNY/ha | kg/ha | CNY/ha | | |
| Plains | 2-season field | 206 | 7 895 | 2 053 | 373 | 1 119 | 3 172 | 54.5 |
| Hills | Winter ricefield | 80 | 7 670 | 1 994 | 688 | 3 945 | 5 534 | 177.5 |

[a] TV total value.

## Techniques and Management

Common carp, crucian carp, grass carp, and nile tilapia are raised in ricefields. The integration of fish and rice provides several benefits (e.g., pest control, fertilizer, and reduced need for pesticide). In general, rice-fish culture is a simple technique that is easy to popularize because there is little risk.

Farmers in economically developed areas are not as interested in rice-fish culture because they have relatively high incomes from other means. But for farmers in remote areas, the situation is quite different. In these areas, farmers have few income sources other than crop production. Therefore, rice-fish culture is attractive because of its low cost and good return. It is one of the best ways for remote areas to improve their economic development.

Rice–fish culture can also be easily popularized in the areas adjacent to cities and towns. Areas adjacent to cities and towns have the advantages of access to information and speed of market feedback. The site of production and the market are close together and the selling price of the fish is relatively high. Therefore, the return on investment is higher than in remote areas.

## Rice–Fish Farming and Agriculture

Rice and fish are mutually beneficial. Fish can accelerate the growth and increase the production of rice. A large-scale survey of rice–fish culture indicated that rice production was increased by 5-15%. Rice–fish culture, beyond doubt, can promote agricultural production and development.

### Economics

Before rice–fish culture was introduced in Sichuan, the average rice yield was about 6000 kg/ha and the income was CNY1 755/ha. However, when fish were raised in ricefields, the increase in income was CNY150/ha from rice and CNY750/ha from fish. In some areas, the income from selling fish was even higher (Table 2). The production value of rice–fish farming is much higher than rice production alone. Especially in hilly areas, there are many winter ricefields that have deep water storage and hold water for a relatively long time. Under these conditions, the value of rice–fish culture is about three times rice production alone.

Compared with the cost of rice production, which is about 30–50% or even 60% of the value of rice production, the cost of fish grown in ricefields is relatively low (about 20% of the value of production). The economic benefit of rice growing is not as high as fish culture. At present, the unit yield of rice is stable. It is difficult to raise the economic benefit of the ricefield by increasing rice yield. However, improved benefits and production values can be achieved by raising fish in ricefields. Generally, from rice–fish culture the net income will be about CNY600/ha. A maximum net income of about CNY1 500/ha is possible and is the goal of many farmers (Table 3).

Fish bring changes to rice cultivation and help achieve remarkable economic benefit. These changes mainly decrease inputs into rice cultivation. The fish eat weeds that compete with rice for fertilizer. The fish also help control plant diseases and insect pests and, therefore, reduce the need for pesticides and the amount of labour needed for weeding. Studies in Sichuan, Hunan, Guizhou, and Jiangxi showed that raising fish in ricefields saved about 8–12 days of labour.

Rice–fish culture improves labour productivity. Labour productivity is a measure of the total products produced in a certain period. Labour productivity reflects the

Table 3. Economic benefits from different forms of fish culture in Sichuan in 1984.

| | Area (x 1 000 ha) | Raising Days | Avg. Fish Harvest (kg/ha) | Avg. Rice Harvest (kg/ha) | Total Income (fish + rice) | Average Inputs per ha: Labour (1 day) | Average Inputs per ha: Net Invest. (CNY) | Avg. Income (CNY/ha) | Income Ratio (%)[a] |
|---|---|---|---|---|---|---|---|---|---|
| Hunan | | | | | | | | | |
| Rice only | 46.7 | — | — | 4 883 | 1 689 | 240 | 450 | 639 | — |
| Rice–fish | 4.8 | 65 | 113 | 5 250 | 1 913 | 285 | 480 | 720 | 113 |
| Rotation fish and rice | 0.5 | 200 | 600 | 6 750 | 3 534 | 311 | 750 | 2 001 | 313 |
| Intercrop. rice and fish | 0.7 | 35 | Raising fry | 5 250 | 2 484 | 285 | 858 | 998 | 156 |
| Sichuan | | | | | | | | | |
| Rice only | 8.2 | — | — | 5 273 | 2 109 | 240 | 675 | 1 434 | — |
| Rice–fish | 0.3 | 70–90 | 83 | 5 438 | 2 472 | 300 | 837 | 1 635 | 114 |
| Rotation fish and rice | 0.2 | 200–240 | 128 | 5 513 | 2 588 | 315 | 930 | 1 658 | 116 |
| Fish culture in half-dry fields | 0.08 | 90–100 | 879 | 8 513 | 6 026 | 375 | 1 320 | 4 706 | 328 |
| Fish culture (ponds + canals) | 0.08 | 90–100 | 885 | 7 575 | 6 216 | 27 | 1 335 | 4 881 | 340 |

[a] Net income from fish culture in ricefields as a percentage of income from planting only rice. Labour in Hunan is CNY2.5/day. Net income of Qingcheng in Sichuan includes labour price.

Table 4. Labour productivity of rice-fish culture in Hunan and Sichuan (1984).

| Form of culture | Area (x 1 000 ha) | Average Output (Fish + Rice) (CNY/ha) | Labour (days/ha) | Labour Productivity (Production Value/Labour Day) (CNY) | Labour Productivity of Ricefish Culture per Pure Rice Planting (%) |
|---|---|---|---|---|---|
| Hunan | | | | | |
| Rice only | 46.7 | 1 689 | 240 | 7.04 | — |
| Fish in ricefields | 4.8 | 1 913 | 285 | 6.71 | 95.3 |
| Rotation of fish and rice | 0.5 | 3 534 | 311 | 11.38 | 161.7 |
| Intercropping of rice and fish | 0.7 | 2 484 | 285 | 8.71 | 123.6 |
| Sichuan | | | | | |
| Rice only | 8.2 | 2 109 | 240 | 8.78 | — |
| Fish in ricefields | 0.3 | 2 472 | 300 | 8.24 | 94.7 |
| Fish culture in half-dry ricefields | 0.08 | 6 026 | 375 | 16.07 | 184.7 |

Table 5. Survey of rice-fish culture in Sichuan and Jiangxi in 1984.

| | Total Production of Fish + Rice (CNY/ha) | Fish Production Value (CNY/ha) | Increase Because of Fish Culture (%) |
|---|---|---|---|
| Sichuan | | | |
| Chengdu Plains | 3172 | 1119 | 35.3 |
| Hills | 5534 | 3945 | 71.3 |
| Jiangxi | 7779 | 5253 | 67.5 |

level of fish-raising in ricefields. Low-level rice-fish farming has lower labour productivity than rice farming. When the ricefield is used to cultivate fry and fingerling the labour input is increased a little. Much higher labour productivity can be achieved by adopting new technical improvements (Table 4).

## Land and Water Resources

China is a large country with a large population and a scarcity of agriculture land. Agricultural production occupies an important place in the national economy; therefore, comprehensive use of land and improvements in grain production are important. Rice-fish culture has many advantages: increases in grain yield, production of freshwater fish, an increase in the production capacity of arable land, increased economic returns, and a higher land-utilization ratio (Table 5).

Rice alone cannot make full use of the materials and energy in the ricefield. Rice-fish culture can greatly increase the use of fertilizer and energy, and transform these materials into human food. Water is a precious natural resource. Rice-fish culture makes more comprehensive use of available aquatic resources. The efficiency of water use is increased because more than one use is made of the water.

# Ecology and Economics of Rice–Fish Culture

*Quing Daozhu and Gao Jusheng*[70]

The hilly district in the south of Hunan Province is one of the birthplaces of fish-rearing in mountain ponds and in ricefields. The area devoted to rice–fish culture was 30 000 ha in 1987. In Qiyan County alone there were 10 000 ha. Rice yields range from 7 500 to 13 500 kg/ha, yields of fresh fish from 450 to 750 kg/ha, and output values from CNY6 000 to CNY10 500/ha. The economic and ecological effects of rice–fish culture are remarkable. Research on high-yield technology systems and the ecological and economic effects of rice–fish culture has been conducted since 1985.

**Materials and Methods**

Grass carp, silver carp, common carp, variegated carp, and crucian carp were tested. Summer fingerlings (3–5 cm long) were reared in the rice nursery of late rice for 20–30 days. They were stocked in the ricefields at the end of May or the beginning of June. Different rice varieties were grown each year: early rice (Zhuxi 26) and late rice (V64) in 1985, early rice (Zhuxi 26) and late rice (79-16, a strain with disease resistance) in 1986, and early rice (V49) and late rice (V64) in 1987. The size of the transplanted rice varied according to rice cultivars. The other planting conditions were: hill spacing 13 cm x 20 cm, 7–8 seedlings per hill, and 375 000 hills/ha for common rice, and hill spacing 17 cm x 20 cm, 2–4 seedlings per hill (including tiller), and 300 000 hills/ha for hybrid rice.

The experiments were conducted in a gleyed ricefield in Guangshanping Village in Quiyang County and in a ricefield with a green manure crop on the farm of the Hangyan Red Loam Experimental Station. The experiment included four treatments (no replications): ridge culture with tillage (RCT) in the gleyed ricefield (control, 0.03 ha), ridge culture with no tillage (RCNT) in the gleyed ricefield (0.03 ha), fish-rearing and ridge culture with no tillage (FRCNT) in the gleyed ricefield (0.12 ha), winter crop or green manure crop plus fish and early rice with ridge culture and tillage plus fish and late rice with no tillage (W-FRT-FRNT) (0.11 ha).

About 7–10 days before the rice seedlings were transplanted, 1.2-m wide ridges were made. The furrows were 30 cm wide and 20 cm deep (the main ridge furrow was 40 cm wide and 30 cm deep). The fish pit was 3 m x 3 m. Decomposed pig and cow manure (1 500 kg) was applied to the surface of soil before ridging. Urea

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Table 1. The number of weeds per square metre with two rice-fish culture methods using early rice cultivar Weiyou 49 (1987).

| | Species of Weed[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| RCNT[b] | 22.0 | 3.5 | 0.3 | — | few | few | many |
| FRCNT | 5.0 | — | — | — | | 0 | 0 |

[a] Weeds: 1 *Monochoria vaginalis*, 2 *Echinochloa crusgalli*, 3 *Scripus maritimus*, 4 *Ammannia baccifera*, 5 *Eleocharis acicularis*, 6 *Potamogeton franchetii*, and 7 *Azolla pinnata*.
[b] RCNT ridge culture with no tillage, FRCNT fish-rearing and ridge culture with no tillage.

(150 kg/ha), calcium superphosphate (450 kg/ha), and potassium chloride (150 kg/ha) were applied on the surface of the ridge before the rice seedlings were transplanted. In addition, 112.5 kg/ha of urea were broadcast.

## Analysis of Experimental Results

### Effect on Rice Growth

Rice–fish culture is a high-yield technology that makes good use of available resources and provides ecological benefits. To compare the effects on rice growth of different methods of planting and rearing, observations were made on the dynamics of rice tillering. There were no great difference in the number of rice stems (including tillers) in the early stage among RCT, RCNT, and FRCNT. The differences increased in the middle-late stage. The numbers of rice stems (including tillers) in the peak tillering stage were: 8 million/ha in the field with RCT, 6 million/ha with RCNT, and 5 million/ha with FRCNT. However, the difference in effective panicles became smaller at maturity. In the ACT field, the rice grew quickly and there were more tillers, but there were also more ineffective tillers and the percentage of ear-bearing tillers was low. In this field, there were 5.5 million ear-bearing tillers per hectare and the rate of ear bearing was 69.2%, with RCNT there were 4.7 million ear-bearing tillers per hectare and the rate of ear bearing was 78.1%, and with FRCNT there were 4.1 million ear-bearing tillers per hectare and the rate of ear bearing was 81.2%. The number of ineffective tillers was lower but the rate of ear bearing was higher in the rice–fish fields because the small tillers at the base of the rice plant were eaten by the fish.

### Weeds, Diseases, and Pests

During the vegetative cycle of the rice, there were almost no weeds with rice–fish culture because the weeds became the natural food of the fish. There were 15 species of weeds in ricefields with RCT and RCNT. *Monochoria vaginalis* (21.8 and 22.0 plants/m$^2$) and barnyard grass (*Echinochlea crugalli*) (4.0 and 3.5 plants/m$^2$) were the most common weeds (Table 1).

Table 2. Relationship between the incidence of rice diseases and insect pests and rice–fish culture in fields of the early rice cultivar Weiyou 49 (1987).[a]

| | Rice Sheath Blight Disease (%) | Rice Leafroller (No./100 hills) |
|---|---|---|
| RCT | 2.1 | 5.71 |
| RCNT | 3.9 | 4.25 |
| FRCNT | 6.3 | 4.08 |

[a] Data were obtained during the rice booting stage (21 June). RCT ridge culture with tillage, RCNT ridge culture with no tillage, FRCNT fish-rearing and ridge culture with no tillage.

Table 3. The influence of different forms of rice–fish culture on the economic properties and yield of the early rice cultivar Weiyou 46 (1987).

| | RCT[a] | RCNT | FRCNT |
|---|---|---|---|
| Effective panicles (1 000/ha) | 372 | 322 | 292 |
| Grains (no./panicle) | 103.5 | 106.4 | 137.2 |
| Setting percentage | 71.6 | 72.4 | 64 |
| Weight of 1 000 grains (g) | 26.8 | 26.5 | 27 |
| Yield (kg/ha) | 8 194 | 8 058 | 7 454 |

[a] RCT ridge culture with tillage, RCNT ridge culture with no tillage, FRCNT fish-rearing and ridge culture with no tillage.

Table 4. Economic benefits of fish-culture and rice ridge culture.

| | Year | Annual Rice Yield (kg/ha) | Rice Value[a] (CNY/ha) | Fish Income (CNY/ha) | Annual Total Income (CNY/ha) | Percentage Total Income from Fish |
|---|---|---|---|---|---|---|
| Field with winter crop or green manure | 1985 | 9 774 | 3909 | 813 | 4723 | 17.2 |
| | 1987 | 11 282 | 4513 | 2650 | 7159 | 37.0 |
| Gleyed ricefield | 1985 | 12869 | 5147 | 2258 | 7405 | 30.5 |
| Field (winter) | 1986 | 11162 | 4465 | 1664 | 6 129 | 27.2 |
| Winter-water field | 1987 | 13124 | 5249 | 3611 | 8860 | 40.8 |

[a] Price of rice CNY40/100 kg; fish at market price each year.

The results were different for insect pests and rice diseases. The incidence of rice sheath blight disease was 6.3% in the rice-fish fields compared with 3.9% and 2.1% in the field with RCNT and RCT, respectively. The number of rice leafrollers in the rice-fish fields was 4.1 heads per 100 hills compared with 5.7 and 4.3, respectively, in the fields with RCT and RCNT (Table 2).

Fish rearing reduced the amount of pesticides and the frequency of spraying. As a result, beneficial organisms were increased. For example, there were 380 000 red mites per hectare in the rice-fish fields compared with 65 500-86 000 in ricefields without fish. There were also nearly twice as many frogs.

### Soil Fertility

Ridges help raise the soil temperature of the cultivated layer, which promotes the conversion of potential nutrients. Fish in the ricefields fertilize the soil with their excrement. Analysis of soil samples taken from the cultivated layer after rice and fish were harvested indicated that organic matter content was 4.11%, total nitrogen 0.21%, total phosphorous 0.09%, alkali-hydrolyzable nitrogen 152.72 ppm, and content of available phosphorus 9.85 ppm. The same measures of soil samples from fields without fish were slightly less: 4.0%, 0.2%. 0.08%, 127 ppm, and 4.5 ppm, respectively. Soil nutrients were higher in rice-fish fields than in rice-only fields.

### Rice Yield

Fish culture lowered rice yields. The number of effective panicles was highest in the field with RCT and lowest with FRCNT. Rice yields were 8 195 kg/ha with RCT, 8 058 kg/ha with RCNT, and 7 454 kg/ha with FRCNT (Table 3).

An analysis of 13 samples taken between 1984 and 1986 showed that the difference in rice yield between RCT and RCNT was not significant. The rice yield from ridge culture was not significantly different between RCT and RCNT, but both were higher than the yield from the rice-fish field. However, in the gleyed field, zero tillage not only saved labour, but shifted the time of transplanting to earlier in the season. The adoption of no tillage also greatly reduces mechanical damage to fish and enhance their survival. This promotes higher yields of both rice and fish and increases the total value of the output.

## Economic Benefits

When developing a plan for field engineering and cultivation technologies, the basic principle is that rice is the main crop and fish is the secondary one. The establishment of a good ecosystem makes full use of space, land, and water in the ricefield and to greatly raises the biomass and total value of the output of the ricefield with little extra more input or cost.

From 1985 to 1987, the experiment on fish-farming and ridge culture of rice with no tillage produced 9 774-13 124 kg/ha of rice (both early and late rice). The value

Table 5. Cost and survival rates of fish reared in 0.6 ha of ricefields (1985–1987).

| | No. of Fish Stocked | No. of Fish Harvested | Survival Rate (%) | Cost of Fish (CNY) | Income from Fish (CNY) | Net Income (CNY) | Percentage of Each Species |
|---|---|---|---|---|---|---|---|
| Grass carp | 16000 | 4928 | 30.8 | 49.0 | 854.2 | 805.2 | 65.5 |
| Silver carp | 2460 | 522 | 21.2 | 10.7 | 157.6 | 146.9 | 12.0 |
| Common carp | 2650 | 1 025 | 38.7 | 24.6 | 150.4 | 125.8 | 10.2 |
| Crucian carp | 300 | 160 | 53.3 | 3.5 | 31.6 | 28.1 | 2.3 |
| Other | 42500 | 6 920 | 16.3 | 26.9 | 149.5 | 122.6 | 10.0 |
| Average/ha | 114120 | 24 210 | 21.2 | 204.9 | 2398.5 | 2193.8 | — |

Table 6. Economic effects of rice-fish culture.

| | | Cultivating Method[a] | | | Rice Yield (kg/ha) | Value of Rice (CNY/ha) | Fish Income (CNY/ha) | Increased Income (%) |
|---|---|---|---|---|---|---|---|---|
| | | Early Rice | Late Rice | Winter | | | | |
| Gleyed field (control) | 1985 | T | T | WWF | 12192 | 4877 | — | — |
| | 1987 | ZT | ZT | WWF | 11637 | 4655 | — | -4.8 |
| Green manure or winter crop | 1985 | T | ZT | GM | 9774 | 3909 | 813 | -3.3 |
| | 1987 | ZT | ZT | Barley | 11282 | 4513 | 2647 | 31.9 |
| Gleyed field | 1985 | T | ZT | WWF | 12519 | 5008 | 2258 | 32.9 |
| | 1986 | ZT | ZT | Fish | 11162 | 4465 | 1664 | 20.4 |
| | 1987 | ZT | ZT | Fish | 13124 | 5249 | 3769 | 45.9 |

[a] T tillage, ZT zero tillage, WWF winter-water fields, GM green manure.

of the rice was CNY3 909–5 349/ha and the value of the fish was CNY813–3 610/ha. Total income increased by 17-41%, a significant economic benefit. Among different types of ricefields, rice yields and fish income differed greatly. In the fields of winter rice or winter green manure, water deficits during growth of late rice affected both rice and fish. As a result, rice yields were only 9 774–11 282 kg/ha, which was 12–14% lower than from the winter-water fields.

The income derived from fish in the winter-rice or green-manure field was CNY813–2 650/ha and the fish income in the gleyed ricefield was CNY2 258/ha (Table 4).

The best choices for rice-fish fields are winter-water gleyed fields that have plenty of water, but are easy to drain. Under these conditions, good growth of both fish and rice are ensured.

### Polyculture

There are many types of rice-fish farming. Most farmers still use the traditional method of a level field to rear small-size common carp fry in natural water. As a result, fish output is low, commonly 150–300 kg/ha from one-season ricefields. Because the price of common carp is only CNY2–3/kg, fish income is also low. Some farmers also maintain 3–4 cm of water in the field for a long time for the sake of fish. This affects the growth and development of the rice and leads to a reduction of rice yields and only slightly higher income from the fish.

A complete set of technological measures were applied in these experiments: the rice was planted on ridges, early rice (middle-late maturing variety) was selected, plant spacing was reduced, and tillage was increased in late ricefields. Problems of long-term submergence of the ricefield after the fish were reared were avoided. Moreover, polyculture of 3–5 varieties of fish raised the survival rate and increased the income generated from the fish (Table 5).

With polyculture, the value of grass carp contributed 65.5% of total fish income. The survival rates for the different species were: variegated carp 53.3%, common carp 38.7%, silver carp 21.2%, and other fish (e.g., crucian carp) 16.3%. From 1985 to 1987, the experimental area for fish farming in ricefields was 0.56 ha and the average income from fish was CNY2 194/ha.

The main ecological models for rice-fish culture in ricefields are rice-fish-duckweed and rice-fish. Rice-fish with ridge culture and no tillage was compared with RCT and RCNT. For the rice-fish system, two types of fields (winter ricefields and winter-water gleyed ricefields) were used (Table 6). The field with RCT had an output value of CNY4 876/ha, which was 4.8% higher than with no tillage. In the green-manure crop or winter-crop field with rice-fish, the output value was 31.9% higher than with RCT. In the gleyed field with FRCNT, there was an increase of 20–46% compared with RCT. There are clear the economic benefits to fish-rearing and ridge culture of rice with no tillage.

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