Food and Agriculture Organization of the United Nations

AGROECOLOGICAL RICE PRODUCTION IN CHINA:

RESTORING BIOLOGICAL INTERACTIONS

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EDITED BY
LUO SHIMING

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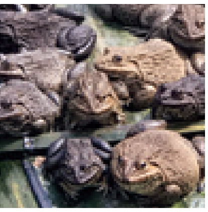

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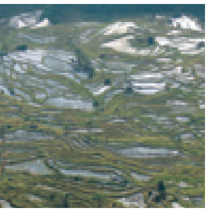

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PHOTO Terrace paddy field in Yuanyang, Yunnan, China

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Luo Shiming

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PHOTO A traditional local rice variety in Jiangxi Province, China

INTRODUCTION
THE CRITICAL ROLE OF BIODIVERSITY IN AGROECOLOGICAL RICE PRODUCTION

Biodiversity can be understood as the variation of life at all levels of biological organization. Four organization levels of biodiversity are often recognized: genetic diversity, species diversity, ecosystem diversity and landscape diversity. **Landscape diversity** refers to the spatial arrangement patterns of different patches, corridors and matrix elements. **Ecosystem diversity** refers to the structural arrangements of different primary producers, secondary producers and decomposers, including plants, animals and microorganisms with their environmental components such as soil and water, and flows of material and energy. **Species diversity** refers to the number of species (richness) and their abundance in a location. **Genetic diversity** is related to the variation of genetic background of a specific species.

Biodiversity is an important characteristic to keep ecosystems stable and to make efficient use of environmental resources. Although often overlooked, biodiversity also plays a very important role in agro-ecosystems. However, industrial agriculture tends to simplify the composition and structure of agricultural production systems. Consequently, natural processes are replaced by artificial processes. For example, soil fertility is no longer maintained by biological process, and it becomes necessary to input large amounts of chemical fertilizer into the system. The rich interactions among insects and their natural enemies, among different microorganisms, and between host crops and their pests are weakened, or even eliminated. Without the natural balance of self-regulation, chemical pesticides become indispensable. A vicious cycle is established whereby the more artificial interference is introduced to an agro-ecosystem, the weaker the biological processes within the system become, creating more need for intervention. In such a way, agriculture has become a major consumer of energy and a major polluter around the world. Likewise, food safety is a growing concern in many countries because of the residues of chemicals, antibiotics and hormones.

These trends of simplification of agro-ecosystems, loss of biodiversity, and degradation of ecosystem services need to be averted. Agroecology is a promising approach to restore biodiversity and ecosystem services to agro-ecosystems, and transition towards sustainable food and agricultural systems. Agroecology has already been recognized and endorsed by a significant and growing body of scientific literature, government officials and policies, farmers, and international organizations. The major aspects of agroecology in China include: (1) **sustainable landscape arrangement**; (2) **circular design of agro-ecosystems**, and; (3) **diversification of species and genetic resources used in fields**. Biodiversity is of critical importance in each of these three aspects.

Rice is the most important food crop, both worldwide and for China. To achieve a transition towards sustainable rice production based on agroecology, biodiversity is a crucial component. Through China's long history of agricultural development, many rich experiences of harnessing biodiversity in traditional rice production have been accumulated. This agricultural heritage is complemented by new experiences developed over the past 30 years, associated with agroecology, ecological agriculture or eco-agriculture as it is variously termed in China. Eight typical methods of agroecological rice production are introduced in this report, with an emphasis on the role of biodiversity in this production. The first method is based on the genetic diversity of rice. The second to seventh methods each emphasize diversity at the species level. The second method involves intercropping rice with lotus. The third and fourth methods involve the use of green manure in rice fields. The fifth, sixth and seventh methods are based on the co-culture of rice with ducks, fish or frogs in paddy fields. The eighth method is based on the use of biodiversity in rice production at the watershed scale. It is related to the ecosystem and landscape levels of biodiversity and agroecology outlined above.

These agroecological methods for harnessing biodiversity in rice production can be learned, modified, improved and integrated into rice production across different regions around the world according to the specific context in each place. It is intended that the principles and ideas behind these methods can stimulate broader thinking on how to harness biodiversity for the sustainable production of other crops and for broader agricultural practices.

PHOTO A diversified watershed arrangement for rice production in Fujian Province, China.

METHOD 1

INTERCROPPING OF TWO RICE VARIETIES

- TECHNIQUE USED FOR INTERCROPPING OF TWO RICE VARIETIES
- TYPICAL CASES AND BENEFIT ANALYSIS

The use of biodiversity to manage crop diseases has gained increasing attention in recent years. Rice blast disease is one of the most significant rice diseases, and controlling it without the use of chemical pesticides has been a challenge. Youyong Zhu and colleagues from Yunnan Agricultural University have conducted in-depth studies on the control of rice blast disease through rice genetic diversity, selecting the best combination of varieties, and optimizing planting patterns (e.g. Zhu *et al.*, 2000). Through this research, technical parameters and procedures were established, alongside a large application demonstration area. The method resulted in the effective control of the epidemic of rice blast disease without using pesticides, while simultaneously increasing rice yields and protecting a large number of rice genetic resources. It set a successful example for the use and protection of genetic biodiversity for crop production.

1.1 TECHNIQUE USED FOR INTERCROPPING OF TWO RICE VARIETIES

PRINCIPLES OF USING RICE GENETIC DIVERSITY FOR PEST MANAGEMENT

The intercropping of two different rice varieties can effectively control rice pests from their outbreak. It is one of the important biodiversity-based methods used in rice production. Managing the genetic diversity of rice during planting demands an understanding of the genetic differences between intercropping varieties. In selecting the combination of crop varieties, differences at the morphological, cellular, biochemical and molecular levels needs to be considered. First, the differences in disease resistance gene homologous sequences and the differences in disease resistance genes among varieties can be used as molecular markers. Then, the differences in agronomic traits of the two varieties, including morphology type, plant height, growth period and yield components, should be considered. Finally, the spatial and temporal arrangement of the two varieties should be well designed.

KEY TECHNIQUES

The selection of two rice varieties for intercropping

The differences in genetic diversity parameters between the two cultivars should be identified by checking the similarity of their pest resistance genes. This can be evaluated by comparing their resistance gene analogies (RGA), microsatellite or simple sequence repeat (SSR), or Indel markers for genetic diversity among different cultivars (Mundt, 1994). If resistance genetic similarity is determined using the RGA method, this should be less than 0.75. As a rule of thumb, if one cultivar is a disease susceptible one, another must be a disease resistant variety.

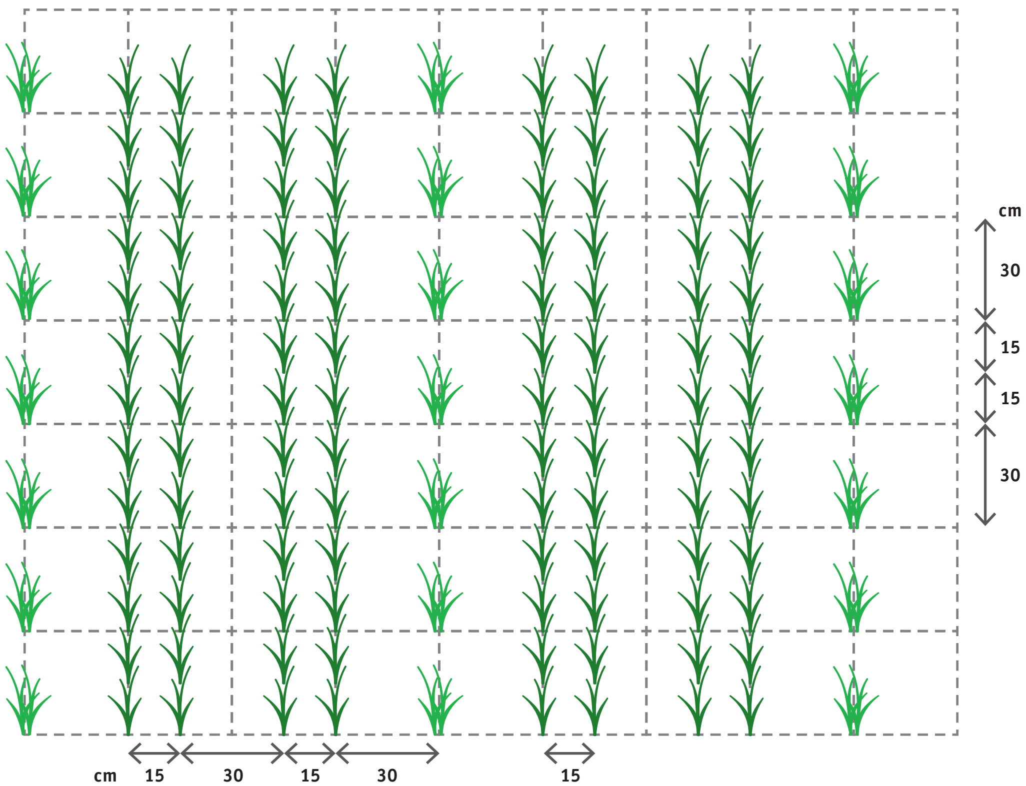
Phenotypic parameters used for the selection of rice cultivars include plant height and growth duration. A combination of long-stalked and short-stalked varieties is preferred. The difference in plant height between long-stalked and short-stalked rice varieties should be about 30 cm. The two varieties should mature almost at the same time. The maximum difference of the growth duration should not be more than 10 days.

High yield and good quality varieties are important. The combination of varieties with high yield and good quality can meet both market demand and farmers' needs. In Southwest China, hybrid rice (short-stalked, blast resistance) combined with a high-quality glutinous landrace (long-stalked, less resistance to blast, special quality with a high market price) were widely accepted by many farmers in the intercropping of two rice varieties to control blast disease.

Sowing management

It is necessary to adjust the sowing date of each variety according to the difference in their maturity duration to ensure that the maturation and harvest of both varieties occurs at the same time. Rice seed of early-maturing variety should be sowed later and rice seed of late-maturing varieties should e sowed earlier.

FIGURE 1.1 **Field arrangements for intercropping of two rice varieties**



The dark green represents seedlings of the high-yielding and disease resistant, short-stalked hybrid rice variety.
The light green represents seedlings of the high-quality and disease susceptible, tall-stalked local rice variety.

Source: Adapted from Luo Shiming

Filed planting pattern

During rice transplantation, a configuration of one row of the high-quality rice variety within 4–8 rows of the high-yielding, short-stalked rice variety is recommended. The short-stalked and high-yielding hybrid rice variety should be planted with a single seedling per hill and a spacing of 15 cm between plants along the row. The row spacing between the hybrid rice varieties should be 15 cm for narrow space between rows and 30 cm for the alternative wide space between rows. The row spacing between the two varieties should be 30 cm. The number of seedlings of the high-quality local variety should be 3–5 seedlings per hill, and the distance between seedlings along the row should be 30 cm (Fig. 1.1, Fig. 1.2).

FIGURE 1.2 Intercropping of a high-yielding hybrid rice variety with a local high-quality rice variety in Yunnan Province, China

Field management

Fertilizer and water management protocols should be kept the same as for the main variety in the intercropping system, the hybrid variety in this case. Pest management should be conducted based on the monitoring of the occurrence of diseases and pests. Integrated pest management practices are recommended. The risk of blast disease outbreak can be greatly reduced using this method of intercropping.

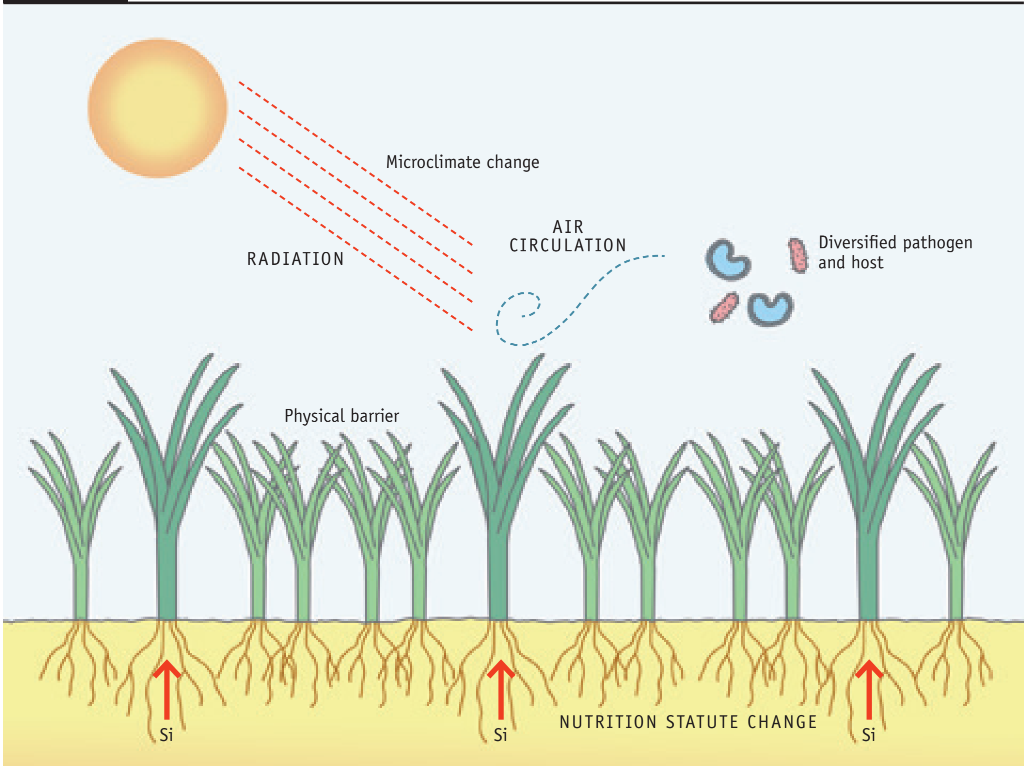
Rice Harvest

A common practice is the artificial harvest of the high-quality variety first, followed by the harvest of the short-stalked varieties, mechanically or manually. Mixed harvest of the two varieties is another option available depending on the preferences of the farmer and demand of the market.

1.2 TYPICAL CASES AND BENEFIT ANALYSIS

The field survey conducted by Zhu *et al.* (2000) showed that the diseased rate of rice blast for susceptible varieties averaged 5 percent in the intercropping system, compared with 81.1–98.6 percent in a monoculture of high-quality rice. Moreover, there was no logging in the intercropping rice. The amount of rice yield increase ranged from 630–1 040 kg per hectare, and income from rice production increased by US$ 143 per hectare. These results suggest that economic and ecological benefits can be achieved simultaneously by using the rice genetic diversity in forms of intercropping.

FIGURE 1.3 The mechanisms of intercropping two rice varieties to control the outbreak of rice blast disease



Source: Luo Shiming

PHOTO Traditional rice variety in Jiangxi, China

The mechanisms through which rice genetic diversity is used to control the outbreak of diseases include the following (Fig. 1.3): (1) Increasing the abundance of genetic diversity in the rice field serves to reduce the selective pressure on pathogens, reduces the emergence and spread of a dominant race, and prolongs the persistence of disease resistance genes; (2) Optimizing the microclimate in the field through the choice of varieties used to form a plant community with enhanced ventilation, better radiation penetration, lower field humidity, shorter plant dew-holding time. Such an improvement in the micro-ecological environment in the field is conducive to crop growth and disease prevention; (3) Building a physical barrier to prevent pathogens from spreading, to dilute the relative concentration of pathogens, and to reduce the chance for the spread of a particular strain of pathogen; (4) Promoting a more efficient use of water, soil nutrients, light and other resources through synergies and complementary effects. The higher transpiration rate of the tall local variety can promote the absorption of silicon, which is important to increase rice resistance to pests. Taken together, these factors can promote robust plant growth and enhance resistance to diseases and pests.

Since 2001, this approach of harnessing genetic diversity by intercropping two rice varieties for disease control and increased yields has spread widely in the rice production regions of Yunnan, Sichuan, Hunan and 11 other provinces and cities in China. The impact of the technology has been striking – the control effect on rice blast reached 71–96 percent, the average pesticide reduction rate was 60.5 percent, the lodging resistance rate was 95–100 percent, and high-quality grain yield increased by 600–1 092 kg per hectare. Beyond China, the technique has been adopted by farmers in the Philippines, Indonesia, Thailand, Vietnam, Laos and other countries.

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PHOTO The biodiversity used in organic rice production in Fujian Province, China
In the next page: A rice-lotus intercropping field in the harvesting stage in Guangxi, China

METHOD 2

RICE INTERCROPPING WITH LOTUS

- TECHNIQUE USED FOR RICE-LOTUS INTERCROPPING
- TYPICAL CASES AND BENEFIT ANALYSIS

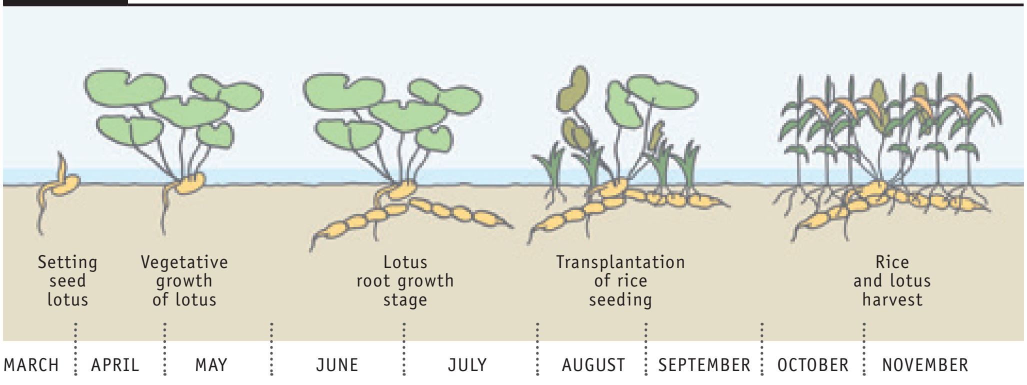
A very special intercropping system was developed by farmers in Litang Town, Binyang County, Guangxi Region, China. The region specializes in lotus production, with an area of 1 340 hectares under lotus production, producing 50 000 tonnes per year of lotus root. However, farmers had to buy rice from the market, they wondered, "can we produce our own rice in lotus fields?" Following several years of hard work, a very unique rice-lotus intercropping system was developed, capable of harvesting 37.5–45.0 tonnes of lotus root and 5.2–7.5 tonnes of rice per hectare (XieYidong, 2009).

2.1 TECHNIQUE USED FOR RICE-LOTUS INTERCROPPING

The general relationship between rice and lotus in the intercropping system is displayed in Fig. 2.1. Lotus is planted in late March or early April. The lotus root has well developed when rice is going to be transplanted in early to mid-August.

After the old and death leaves removed, rice seedling is transplanted by throwing method or hand transplantation method. After rice mature in mid-November, rice and lotus are both ready to be harvested.

FIGURE 2.1 General time arrangement for rice-lotus intercropping in Guangxi, China



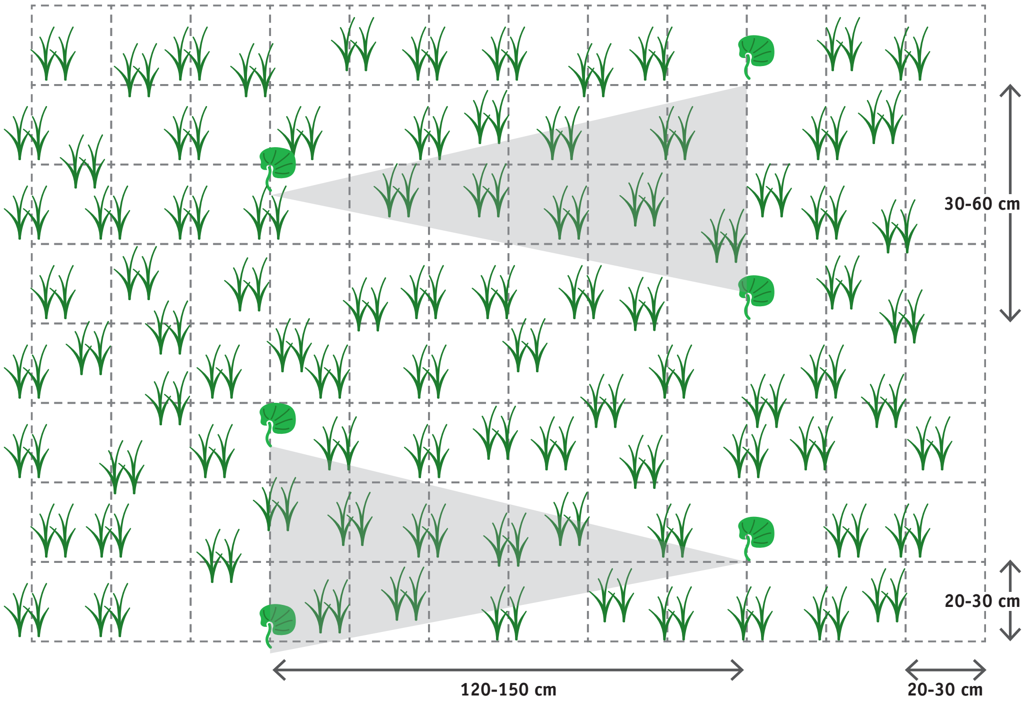
Source: Adapted from Luo Shiming

PLANTING OF LOTUS

In late-March and early-April, when the daily average temperature increases above 15 °C, it is a suitable season for planting lotus. The field should be ploughed and harrowed. 1 125–1 500 kg per hectare of lime should be applied for detoxification purposes every three years. 70 percent of the nutrition needed for lotus should be applied as a basal fertilizer. Well composted farmyard manure is suitable to be used as basal fertilizer.

The lotus variety used should be an early-to mid-maturing variety with a growth duration of 100–110 days. Lotus plants with at least two sections and one top bud can be used as seed. The spacing between rows should be 120–150 cm, and the spacing between plants within the row should be 60–80 cm, according to the soil fertility and lotus variety. The position of seed lotus in a row should be between the two seed lotuses in the adjacent row to form a triangle shape (Fig. 2.2).

FIGURE 2.2 Field layout of the rice-lotus intercropping system



From late-March to early-April, seed lotuses are planted with a spacing of 120–150 cm * 60–80 cm. The three lotus seeds from adjacent rows form a triangle shape.

Rice seedlings can be transplanted by throwing or ordinary manual methods, with an average density/spacing of about 20–30 cm * 20–30 cm in early-August.

Source: Adapted from Luo Shiming

FIELD MANAGEMENT OF LOTUS

Field management of lotus, including irrigation, fertilizer application and pest control is the same in the intercropping system as for a lotus monoculture (Fig. 2.3). Before transplanting rice seedlings in early-August, the old and yellow leaves of lotus should be removed. When rice enters the late tillering stage to early-spikelet initiation stage, 40 percent of the old leaves should be taken away. Before booting, 60 percent of the old leaves could be taken off (Fig.2.4).

PLANTING OF RICE

The rice variety used should be more shade tolerant. The final leaf of the lotus will appear in late-July when the lotus root begins to grow fast. This is the right time to raise rice seedlings. Rice seedlings with 3.5–4.5 leaves are suitable. In mid-August, rice seedlings can be transplanted by the common transplanting method, or by the throwing method, depending on the context. Transplanting rice seedlings by throwing is a labour saving technique. In this case, rice seedlings should be raised in a specially designed plastic plate (Fig. 2.5). The density of rice seedlings in the field should be in the range of 270 000–345 000 hills per hectare according to the soil fertility and rice variety. If rice seedlings are transplanted by the manual method, the spacing can be 20–30 cm by 20–30 cm (Fig.2.2).

FIGURE 2.3 The early growing stage of lotus

FIGURE 2.4 The rice-lotus intercropping system at the booting stage of rice

Lotus roots are already formed and lotus leaves give way to rice

FIGURE 2.5 Plastic seedling holder and rice seedlings ready to be transplanted

FIELD MANAGEMENT OF RICE

Since the lotus field is usually very fertile and the amount of fertilizer applied for lotus is ample, it is not necessary for further fertilizer application in the early stage of rice. Top dressing for rice can be applied from the early-spikelet initiation stage to the heading stage according to the specific growth situation. A shallow layer of water should be kept in the field to protect the quality of the lotus root. The intercropping system can reduce the risk of pest outbreaks in the early growing stage of rice. In the later stage, integrated pest management should be applied as necessary.

HARVESTING RICE AND LOTUS

When rice is mature in the middle of November, it should be harvested as usual. The lotus can be harvested from right after the rice harvest to March of the next year according to the market demand.

FIGURE 2.6 In mid-November, rice and lotus roots are ready to be harvested in Guangxi

2.2 TYPICAL CASES AND BENEFIT ANALYSIS

Farmers of Litang began experimenting with rice-lotus intercropping in 1995. They continued their efforts for seven years. In 2001 they introduced a high-yielding lotus variety from central China. The average lotus yield using the new variety reached 45 tonnes per hectare (representing a 30 percent increase compared with the old variety). The area devoted to intercropping extended to all 1 100 hectares of lotus field of the town by 2010. The intercropping system provided 4 800 tonnes extra rice each year to the farmers. A major benefit of the system is that it allowed farmers in the village to produce rice by themselves, which translated into significant cost savings. It is telling that the farmers are very happy to continue with the rice-lotus intercropping system. According to a yield test conducted by technicians, the yield of intercropping rice was 6 366 kg per hectare–a 786 kg per hectare (24.5 percent) increase compared with monoculture rice yields. The lotus root yield was 50 837 kg per hectare, which was 7 568 kg hectare (17.5 percent) higher than the yield from lotus monocultures. Net income increased by 15 000 Yuan per hectare in the intercropping system compared with the previous lotus monoculture (Nong Yun, 2010).

An investigation of pest prevalence in a monoculture rice field and the neighbouring rice-lotus intercropping field was conducted in 2010 in Litang Town, Guangxi (Table 2.1). It showed that the number of rice plant hopper and leaf roller pests were significantly reduced in the intercropping system. The sheath blight disease also decreased. The presence of green lotus leaves in the early stage of rice growth can misguide insects and give rice a "green cover". At the same time, the shading effect of the lotus leaves can delay and reduce the tillering number in rice community. In the later stage after lotus leaves die or taken away, light penetration and air circulation within rice community would become better than rice monoculture. Measures to further reduce sheath blight disease include choosing a sheath blight resistant rice variety, cleaning old and dead leaves of lotus on time and planting a lower rice density to improve air circulation and to facilitate light penetration in the field.

TABLE 2.1 **Pest and disease prevalence in monoculture rice and rice-lotus intercropping system***

TREATMENT		RICE PLANT HOPPER	LEAF ROLLER	SHEATH BLIGHT
		head/25hills	head/25hills	infected plant/25hills
CK-Rice monoculture		15.32a	2.79a	25.63a
Intercropping Rice	1	3.87b	1.24b	5.03b
	2	3.43b	0.73bc	4.94b
	3	4.61b	0.58bc	4.66b
	4	3.28b	0.5bc	3.44bc
	5	5.32b	0.42c	3.43bc
	6	5.16b	0.4c	2.31bc
	7	5.92b	0.37c	1.93bc
	8	6.11b	0.29c	1.55c

*There were 8 investigation points in the neighbouring fields of the monoculture field.
*The numbers in the table are the average of 8 results during rice growth from transplanting to ripening.

Source: Xin Deyu *et al*. (2012)

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PHOTO The newly harvested lotus from rice field in Guangxi, China
In the next page: Milk vetch grown in rice filed after the harvest of rice crop during winter time in Shanghai, China

METHOD 3

RICE-RICE-MILK VETCH ROTATION SYSTEM

- TECHNIQUE USED FOR RICE-RICE-MILK VETCH SYSTEM
- TYPICAL CASES AND BENEFIT ANALYSIS

Chinese milk vetch (*Astragalus sinicus* L.) is an important green manure used in paddy fields in southern China (Fig. 3.1). The milk vetch seed is sowed when second season rice is in the ripening stage and the field is drained. The over-wintered milk vetch grows steadily in spring. During the flowering state, milk vetch is ploughed, turned down and covered with soil for decomposition before the early season rice is planted. It can help to increase soil fertility and improve paddy field quality. Nitrogen fixing by milk vetch can support the growth of the rice crop.

FIGURE 3.1 Milk vetch in spring before ploughing

3.1 TECHNIQUE USED FOR RICE-RICE-MILK VETCH SYSTEM

PRE-TREATMENT AND SOWING

Chinese milk vetch belongs to legume family *Fabaceae* and subfamily *Faboideae*. The deep-rooted leguminous plant forms an upright bush with multiple stems, which can grow up to 30 cm. The variety of milk vetch chosen for production should be adapted to the specific climate and soil conditions, especially the temperature and moisture conditions. At present, the main milk vetch species in China include early-maturing varieties, such as Leping and Changde and Minzi 1, mid-maturing varieties, such as Yujiangdaye, Pingning 4, and Minzi 6, and late-maturing varieties, such as Ningbodaqiao, and Zhezi 5.

Milk vetch likes moist soil, but excessive water accumulated in the soil should be avoided. In the double rice cropping system, milk vetch is sown about 15 days before harvesting the second rice crop in late-September, or early-October. The optimum temperature for seed germination of milk vetch is 22-23 °C. The seeding rate of milk vetch is 15-30 kg per hectare. In order to have a higher germination rate, seed pre-treatment is recommended.

- The seed can be selected through soaking in a 10 percent salt solution. Those floating on the surface are either low-quality seed or not seed at all, hence can be taken away.
- The de-waxing process can be taken by mixing seed with sand that is about 10-15 percent of the seed weight. The seed mixture can be polished by hand or using a grinding machine.
- After soaking in water for 24 hours, seed can be mixed with a nodule bacteria product that is specifically made for milk vetch to stimulate more nitrogen fixing nodules in the root system.
- A compost of 300 kg of farmyard manure, which has been piled up for about 5-6 days, can be mixed with this 15-30 kg milk vetch seed for one hectare of paddy field.

The mixture of treated seed and compost can be broadcasted evenly in the rice field using the top dressing method 15 days before harvesting the rice. During the harvest, the field should be kept dry. The seedlings of milk vetch can tolerate trampling during the harvest operation and will recover after the harvest.

FIELD MANAGEMENT

- **Ditch system:** Right after the rice harvest, a ditch system should be created in the field for drainage purpose. The depth of the ditch should be about 15-20 cm. The width between two ditches should be about 3-4 m. These ditches are interconnected.
- **Irrigation and drainage:** Milk vetch like humid soil conditions, but do not like to be submerged in water. Therefore, whenever there is a water layer in the field, drainage is needed. When the colour of the soil turns white because of the dry situation, a quick and short irrigation is needed. There should be no water layer in field after irrigation.
- **Fertility management:** In order to protect milk vetch during the winter season, 1/3-1/2 of the rice straw can be used to cover seedlings of milk vetch. This method not only keeps milk vetch warm, it also increases organic matter and nutrient supply. Besides basal fertilizer during the sowing operation, top-dressing fertilizer before winter and in spring can help to increase the yield of milk vetch, especially if the soil is poor. Organic fertilizer is recommended to be used for top-dressing.
- **Pest control:** If moisture and nutrition control in the field is suitable, infection rate of disease and insect attacks can be greatly reduced. Since milk vetch is used as green manure, the tolerance thresholds for insects, diseases and weeds is quite high. Therefore, it is not necessary to conduct pest control operations for milk vetch.

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UTILIZATION AND HARVEST

- **Time for ploughing:** Milk vetch as a green manure is usually ploughed down into the field 10–15 days before rice transplanting or sowing in spring when it is in the peak flowering period. These 10–15 days will be long enough to avoid harmful impacts on rice in the first few days of milk vetch decomposition.
- **Amount used:** Milk vetch is very rich in nutrients (Table 3.1). The amount of milk vetch ploughed down into the soil should follow the nutrient requirements of rice according to the soil fertility level. The more fertile the soil is, the less milk vetch is required (Table 3.2). If the nutrients provided by fresh milk vetch exceeds the needs of the rice crop, it can be harvested for other fields or used as animal feed.

TABLE 3.1 Nutrient content in the upper ground part of milk vetch

	NITROGEN (%)	PHOSPHOROUS (%)	POTASSIUM (%)
Fresh weight	0.391	0.042	0.269
Dry weight	3.085	0.301	2.065

TABLE 3.2 Optimum amount of fresh milk vetch ploughed into soil (kg/ha)

SOIL FERTILITY LEVEL MEASURED BY RICE YIELD POTENTIAL	< 5 250	5 250–6 000	> 6 000
AMOUNT OF MILK VETCH	30 000	22 500	15 000

» **Ploughing method:** Dry tillage operated by rotary cultivator or farm cattle is needed to turn over milk vetch into soil. 350–750 kg per hectare of lime powder can be applied before ploughing to accelerate the decomposition. Then, a shallow water layer covers the field for about a week. After that, other field operations such as harrowing, fertilization, sowing and transplanting can be conducted as usual.

3.2 TYPICAL CASES AND BENEFIT ANALYSIS

ECONOMIC BENEFITS

Increased rice yields

Ploughing milk vetch into the soil makes organic matter decompose faster, and also increases crop production, by promoting rice growth, enhancing photosynthesis and increasing plant biomass. A long term study in Hengyang conducted from 1982 to 2007 in Hunan by Gao *et al.* (2008) showed that applying the rice-rice-milk vetch rotation system significantly improved rice production. Rice production increased by 54.1 tonnes per hectare compared with the rice-rice-fallow system. The order of rice yields of different rotation systems from highest to lowest was rice-rice-milk vetch > rice-rice-ryegrass > rice-rice-rape seed > rice-rice-fallow (Table 3.3, 3.4).

TABLE 3.3 Effect of different rotation systems on the grain yield of rice

ROTATION SYSTEM	EARLY RICE (t/ha)	LATE RICE (t/ha)	TOTAL PRODUCTION (t/ha)	COMPARED WITH CK (t/ha)	INCREASE (%)
Rice-rice-milk vetch	143.0	115.6	258.6	+54.1	26.4
Rice-rice-rape seed	133.3	110.7	244.0	+39.5	19.3
Rice-rice-ryegrass	133.7	112.0	245.7	+41.2	20.2
Rice-rice-fallow (CK)	118.8	85.7	204.5	0	0

Source: Gao *et al.* (2008)

TABLE 3.4 Effect of different rotation systems on the total straw yield of rice

ROTATION SYSTEM	EARLY RICE (t/ha)	LATE RICE (t/ha)	TOTAL PRODUCTION (t/ha)	COMPARED WITH CK (t/ha)	INCREASE (%)
Rice-rice-milk vetch	100.8	106.0	206.8	+44.1	27.1
Rice-rice-rape seed	90.8	97.8	188.6	+26.0	16.0
Rice-rice-ryegrass	90.6	99.2	189.8	+27.1	16.6
Rice-rice-fallow (CK)	80.8	81.8	162.6	0	0

Source: Gao *et al.* (2008)

TABLE 3.5 Economic benefits of different rotation systems from 2008–2009

ROTATION SYSTEM	COST OF PRODUCTION (Yuan/ha)	PRODUCTION IN WINTER (t/ha)	INCOME FROM WINTER CROP (Yuan/ha)	YIELD OF EARLY RICE (t/ha)	YIELD OF LATE RICE (t/ha)	INCOME FROM RICE (Yuan/ha)	NET INCOME (Yuan/ha)	COMPARED WITH CK (Yuan/ha)	INCREASE (%)
Rice-rice-fallow (CK)	7 890	0.0	0	6.2	4.6	18 073.5	10 183.5	0.0	
Rice-rice-milk vetch	8 040	85.7	17 148	9.5	8.1	46 677.0	38 637.0	28 453.5	285.4
Rice-rice-ryegrass	8 160	33.5	6 696	8.5	7.8	34 144.5	25 984.5	15 801.0	159.6
Rice-rice-rape seed	7 920	12.5	2 499	8.5	7.5	29 290.5	21 370.5	11 187.0	111.7

Note: The price of fresh weight of green manure was 0.2 Yuan/kg, early rice was 1.68 Yuan/kg, and late rice was 1.88 Yuan/kg

Source: Liang *et al.* (2011)

Increased economic returns

Liang *et al.* (2011) made a production and investment benefit analysis for the rice-rice-green manure system in Hengyang, Hunan from 2008 to 2009 (Table 2.5). The results show that the average annual net income from the rice-rice-milk vetch system was 38 637 Yuan per hectare, an increase of 28 454 Yuan per hectare compared with the rice-rice-fallow system. The rate of increase was 285.4 percent.

ECOLOGICAL BENEFITS

Improving soil properties

A 26-year long-term experiment using milk vetch in a double rice rotation system showed significant positive effects on soil organic carbon, total nitrogen content, soil microbial biomass carbon content and soil microbial biomass nitrogen content (Table 3.6). The annual rate of increase in soil organic matter was 0.31 g per kg (Fig. 3.2). It was the highest among four winter treatments, also including fallow (insignificant), rape seed (0.256 g/kg) and wheat (0.278 g/kg).

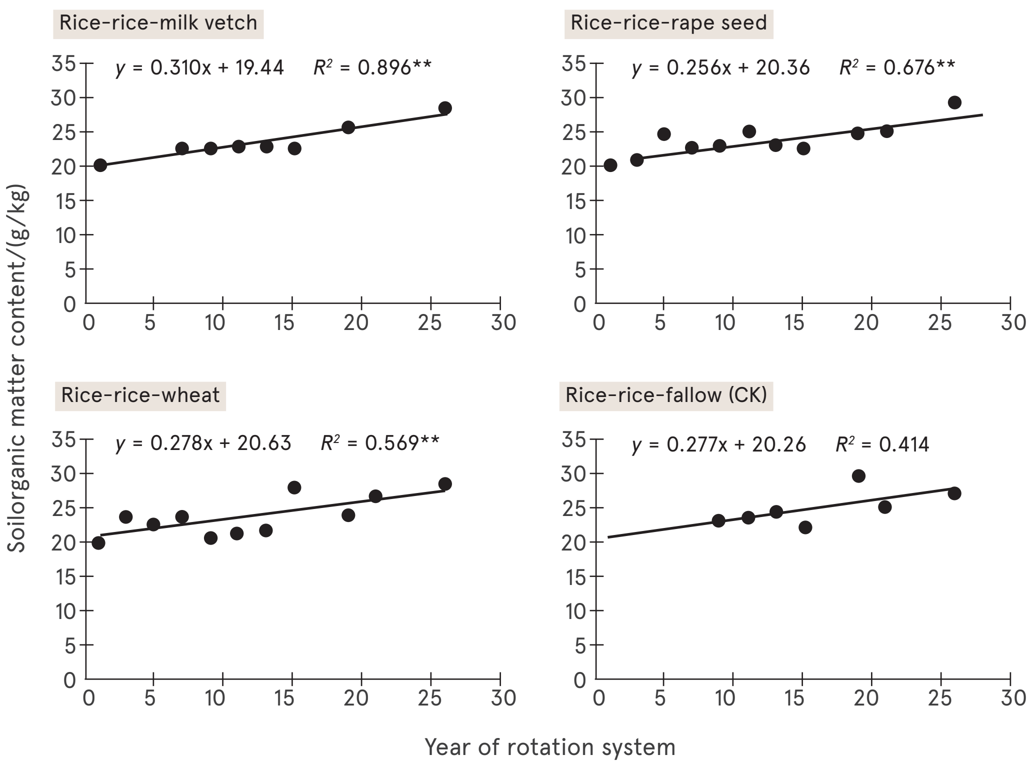
TABLE 3.6 Soil property test results of four double rice rotation systems

TREATMENTS	SOC (g/kg)	TN (g/kg)	SMB-C (mg/kg)	SMB-N (mg/kg)
rice-rice-fallow (CK)	15.71±0.18c	1.79±0.02c	576.9±1.81b	36.9±1.81b
rice-rice-ryegrass	16.77±0.11a	1.86±0.01b	759.9±5.50a	39.4±1.56a
rice-rice-rape seed	16.97±0.12a	1.88±0.01b	699.1±9.50b	37.9±0.50ab
rice-rice-milk vetch	16.49±0.10b	1.95±0.01a	748.9±10.48a	37.6±0.61ab

*SOC-soil organic carbon, TN-total nitrogen, SMB-C-soil microbial biomass carbon, SMB-N-soil microbial biomass nitrogen
* Different letters in the same column indicates the difference reaches 5% significant level

Source: Gao *et al.* (2011)

FIGURE 3.2 **Linear regression trend of soil organic matter change during a 26-year long-term experiment including four double rice rotation systems**



Source: Gao *et al.* (2011)

Increase in biological nitrogen fixation

There is a large amount of biological nitrogen fixation during milk vetch growth. For example, the production of 30 tonnes per hectare of fresh milk vetch contains about 130 kg total nitrogen, and about 80 percent of this nitrogen (100 kg) is from biological nitrogen fixation. This can supply up to 60 percent of the nitrogen needs of rice production (Lin *et al.*, 2011).

Reduced weed infection

Winter crop rotation can reduce weed seedbank communities (Koocheki *et al.*, 2009), and control some annual weed germination and regeneration (Carr *et al.*, 2013). Chen *et al.* (2014) showed that a milk vetch-early rice-late rice system could significantly reduce weed species and major weed densities in rice fields (Table 3.7).

TABLE 3.7 **Effect of winter green manure on weed communities**

INDEX	MILK VETCH-RICE-RICE	RYEGRASS-RICE-RICE	RAPE SEED-RICE-RICE
Species richness	5	10	9
Monochoia vaginalis (plant/m2)	3.23c	8.34a	7.22b
Echinochloacrusgalli (plant/m2)	4.50c	12.79a	10.27b
Eleocharisyokoscensis(plant/m2)	2.00b	3.93a	2.96ab

*Different letters in the same row indicates the difference reaches 5% significant level

Source: Chen *et al.* (2014)

SOCIAL BENEFITS

Milk vetch is not only a good leguminous crop for increasing soil fertility, the milk vetch can be used as feed for animals such as cattle. Before ploughing in spring, water buffalos like to feed on milk vetch fields. Bees also like the milk vetch flower and can make high-quality milk vetch honey during the flowering period. In recent years, agro-tourism and travel within rural regions has emerged as a new phenomenon in China. Water buffaloes, bees and the colours of the red flowers of milk vetch and yellow flowers of rape seed have together attracted tourists to rural areas (also refer to Fig. 8.9). This is an opportunity for villages to earn from providing accommodation and food to travellers.

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PHOTO In the next page: Azolla in rice filed during winter period in Jiangsu, China

METHOD 4

RICE-RICE-*AZOLLA* ROTATION SYSTEM

- TECHNIQUE USED FOR RICE-RICE-*AZOLLA* SYSTEM
- TYPICAL CASES AND BENEFIT ANALYSIS

Azolla is a type of green manure used in rice production. *Azolla* belongs to a genus of aquatic fern that has a symbiotic relationship with *Anabaena azollae*, a species of blue-green algae. *A. azollae* can fix nitrogen and form a symbiotic relationship with the host. The nitrogen fixing ability of *Azolla* can reach 150–450 kg N/ha a year. The nutrition content of *Azolla* is rich (Table 4.1), hence it can be used as an organic fertilizer for crops as well as feed for animals. The suitable temperature range for the growth of *Azolla* is 15–28 °C. *Azolla* can be grown in paddy fields together with rice or after the rice harvest. In the southern sub-tropical and tropical regions with a warm winter, *Azolla* can be grown in winter to form a rice-rice-*Azolla* rotation system. *Azolla* can also grow together with rice and form a rice-*Azolla* co-culture system.

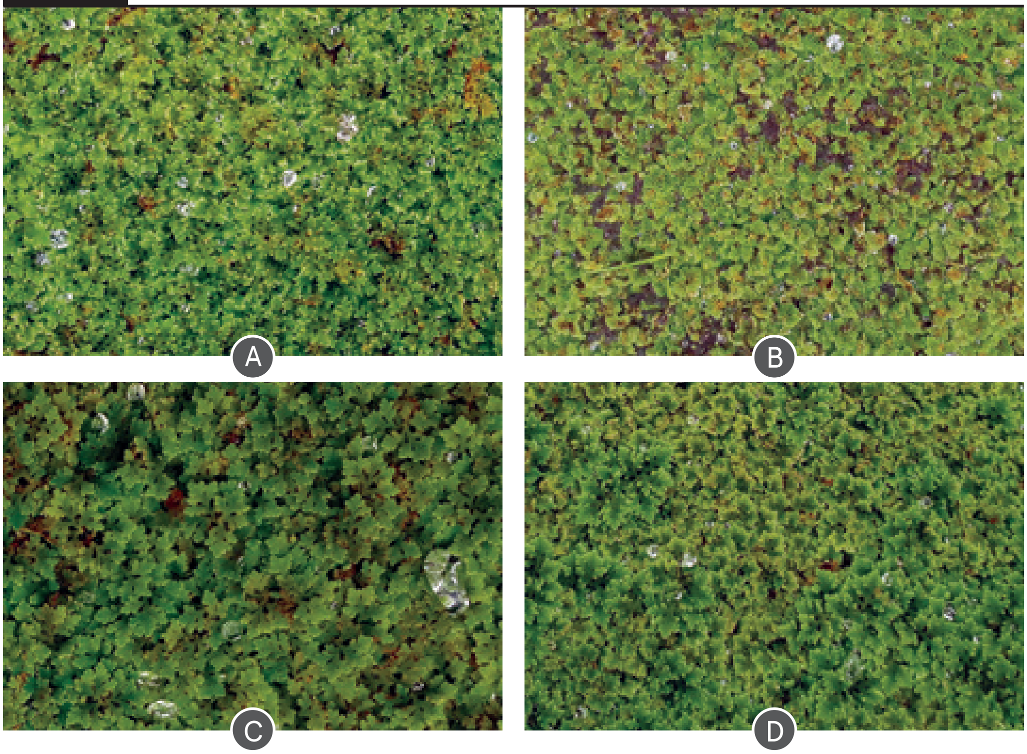
TABLE 4.1 Major nutrition content in *Azolla* (%)

FRESH WEIGHT BASE			DRY WEIGHT BASE			
N	P_2O_5	K_2O	Crude Protein	Crude Fiber	Methionine	Phenylalanine
0.30	0.04	0.13	28.29	7.06	0.2645	0.6479

4.1 TECHNIQUE USED FOR RICE-RICE-*AZOLLA* SYSTEM

- **Choice of *Azolla*:** There is a rich variety of genetic resources of *Azolla* with different climate and soil adaptations and different nitrogen fixing abilities (Fig. 4.1). It is important to screen suitable varieties for a specific location. There are more than 500 *Azolla* germplasm resources preserved in the Institute of Agroecology, Fujian Academy of Agricultural Sciences, China. *Azolla filiculoides* Lamarck is considered a good species and is commonly used in southern China (Lu Peiji *et al.*, 1994).
- **Cultivation method:** For the rice-rice-*Azolla* rotation system, *Azolla* can be released into the rice field right after the second rice harvest. The rice field can be ploughed or remain no-tillage before releasing *Azolla*. The fresh weight of *Azolla* seed released can range from 1.0–1.5 kg/m^2 – it should be just enough to sparsely cover the surface. An even coverage of *Azolla* on the water surface will help support fast growth of *Azolla*. If the *Azolla* seed is not enough for distribution over the whole field, it is better to separate a large field into several sections by temperate ridge. In suitable conditions, *Azolla* can double their weight within 5–7 days. A 15–30 mm shallow layer of water is needed for even distribution of *Azolla*. Shallow water can also help to increase field temperature during the winter season compared with deep water. Phosphorous and potassium supply are necessary for better growth of *Azolla*; organic fertilizers such as farmyard manure and compost can be applied for this purpose. At the point when *Azolla* jam together and start piling up – when it reaches a fresh weight of about 6 kg/m^2 – it is the time to move about two thirds to another field, to avoid the negative competition effect.

FIGURE 4.1 Examples of different species and varieties of ***Azolla***



A New back crossing variety Azolla Huijiao
B Cold tolerant species Azolla filiculoides Lamarck
C Heat tolerant species Azolla caroliniana Wild
D Local Azolla species in China

Source: Wang and Tang (2013)

- ***Azolla* use before transplantation:** *Azolla* can be turned down to the soil before rice transplantation as a basal organic fertilizer. In order to turn down *Azolla* into the mud, it is needed to drain the field before the operation. Applying about 400 kg per hectare of lime before ploughing can accelerate the decomposition of *Azolla*. Ploughing by farm cattle or tractor can mix *Azolla* into the soil. The recommended amount of *Azolla* to be used as basal fertilizer for early rice is from 30 to 37 tonnes per hectare fresh weight. Rice transplantation conducted 4–10 days after incorporation is required for *Azolla* decomposition.
- ***Azolla* use after transplantation:** If part of the *Azolla* remains in the field it can be used for rice-*Azolla* co-culture. It is better to incorporate *Azolla* into paddy mud about 5–15 days after transplantation (10 days before the jointing stage of rice is the latest possible time). The amount of *Azolla* used should not exceed 25 tonnes per hectare in order to avoid excessive nitrogen supply in the later stages of rice growth. It is necessary to drain the field before the incorporation process and to keep the field dry for another two days after incorporation. Human labour is required to push *Azolla* down into mud together with the weeding operation. Recently, a special machine for the incorporation of *Azolla* has been developed by the Soil and Fertilizer Institute at the Fujian Academy of Agricultural Sciences. The application of 300–400 kg per hectare of lime before incorporation can help the decomposition process.

FIGURE 4.2 Rice-*Azolla* co-culture in the early stage of rice growth

- **Use of other fertilizers:** Since *Azolla* is rich in nitrogen and other nutrients, it is necessary to reduce the rate of other fertilizers used in rice fields. The amount to reduce fertilizer use can be estimated by the amount of *Azolla* incorporated into the field and its nutrient content (Table 4.1).

4.2 TYPICAL CASES AND BENEFIT ANALYSIS

Azolla is a high quality green manure with a rich nitrogen content. It can replace chemical fertilizers in rice production. Long-term use of *Azolla* can help to improve soil quality. A field trial in Dongguan, Guangdong Province, found that both *Azolla* and milk vetch could replace chemical fertilizers and increase rice yield significantly (Table 4.2).

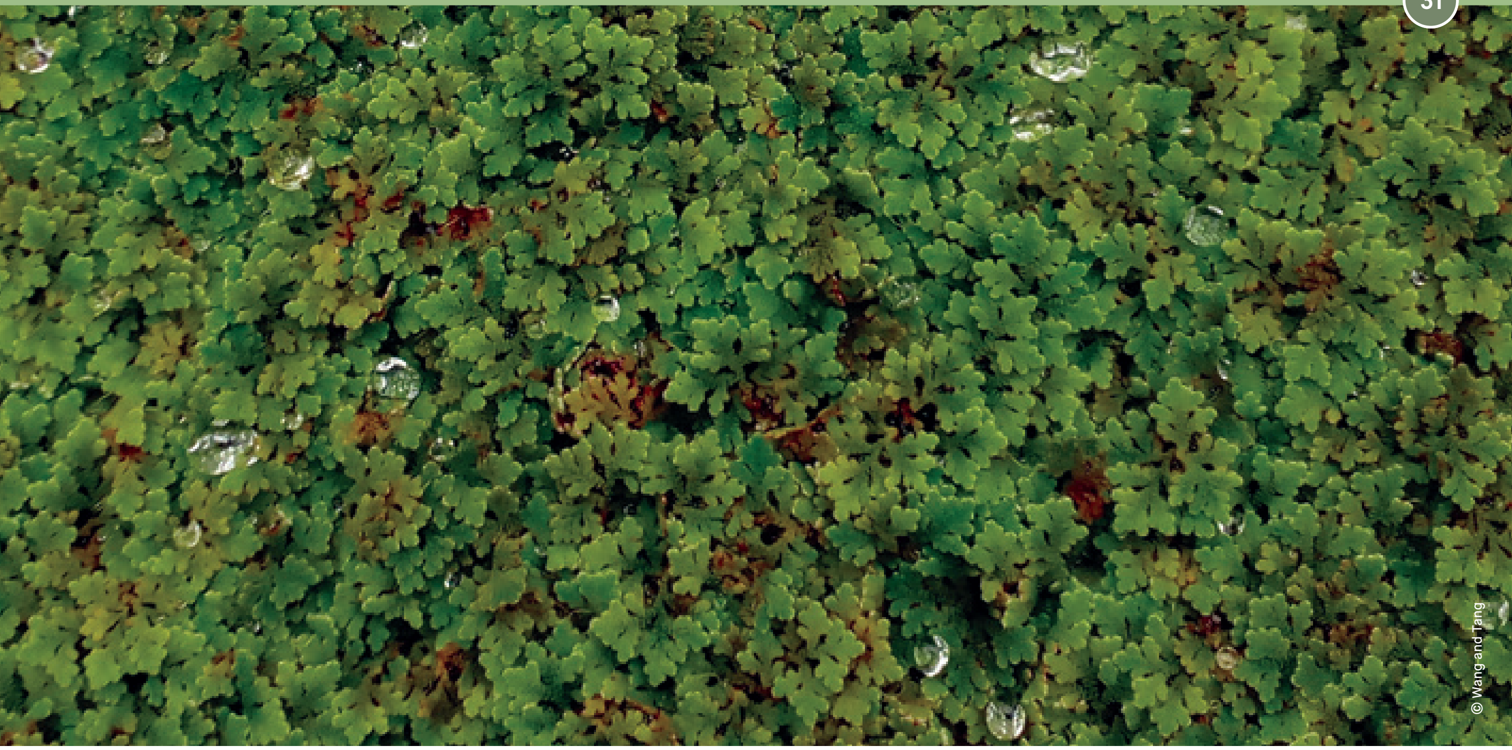


TABLE 4.2 **Rice yields with different fertilization treatments**

TREATMENT*	Rice yield (kg/ha)	Increase (%)
Azolla filiculoides Lamarck (15 tonnes/ha)	7 285.0	+22.87
Azolla from Japan (15 tonnes/ha)	7 100.3	+19.75
Azolla from local collection (15 tonnes/ha)	7 057.5	+19.03
Chinese milk vetch (15 tonnes/ha)	7 285.5	+22.88
Chemical fertilizer (450 kg/ha)**	6 684.8	+12.75
Without any fertilizer (CK)	5 928.8	

* Fresh weights
** Chemical fertilizer treatment includes 150 kg/ha ammonium carbonate, 150 kg/ha calcium superphosphate and 150kg/ha potassium chloride.

Source: Guo (1981)

Azolla is also a nice feed resource for poultry, animal and fish production. The contents of crude protein, crude fibre, methionine, and phenylalanine can reach 28.3, 7.1, 0.26 and 0.65 percent, respectively. *Azolla* can also be integrated into rice-duck or rice-fish production systems. *Azolla* can be used as a raw material for edible fungi production. By covering paddy fields, *Azolla* can help to absorb nutrients in the water and hence reduce the nutrition lost in drainage water. Tests showed that 38.9 percent NH_3-N and 38.4 percent total phosphorus could be removed with 5 ml/s water flow speed in the field (Wang Yibin, 2013).

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PHOTO Duck in the shelter in the rice-duck co-culture system in Guangdong, China
In the next page: During the early stage of rice growth in the rice-duck co-culture system

METHOD 5

RICE-DUCK CO-CULTURE SYSTEM

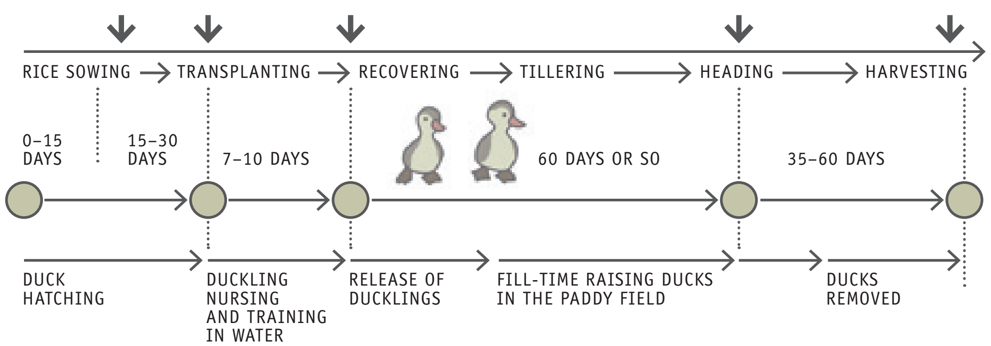
- TECHNIQUES USED IN THE RICE-DUCK CO-CULTURE SYSTEM
- TYPICAL CASES AND BENEFIT ANALYSIS

The rice-duck co-culture system originated is a typical form of traditional agriculture in China. It has been widely used in many Asian countries including China, Japan, South Korea, the Philippines, Malaysia, Thailand and Vietnam, as well as in other countries and regions of the world. This farming system is regarded as one of the common rice production techniques in Asia. In the rice-duck co-culture system, very complicated synergetic interactions exist among the various environmental and biological components. This farming system establishes a biological pest control to produce organic rice and duck.

5.1 TECHNIQUES USED IN THE RICE-DUCK CO-CULTURE SYSTEM

The general production procedure for the rice–duck co-culture is shown in Figure 5.1. Duck eggs are hatched for ducklings at the time when rice seeds are sown. About 7–10 days after the transplanting of rice seedlings, small ducklings that are about one week old are released into the paddy field in a density of about 225–375 ducklings per hectare. Subsequently, the ducklings are raised in the paddy fields day and night until the rice heading stage. This period usually lasts about 60 days and is referred to as the rice-duck co-culture phase. When rice growth enters the heading stage, the ducks should be taken out of the paddy field in order to prevent them from eating rice ears. This concludes their role in supporting rice growth in paddy fields. About a month after duck removal, the rice matures and is ready to be harvested (J.E. Zhang *et al.*, 2002). The details of the technique are described below.

FIGURE 5.1 The basic production procedure of rice-duck co-culture system



Source: Adapted from Zhang Jia'en

PREPARATION OF THE RICE-DUCK CO-CULTURE SYSTEM

- **Field selection:** In general, all rice fields are capable of being converted to the rice-duck co-culture system. However, it is necessary to keep this system away from pollution sources such as industrial factories and mining areas. A good irrigation and drainage system is essential to implement a successful rice-duck system.
- **Variety selection of rice and duck:** For the rice-duck co-culture system, it is recommended to select a high yielding and good quality rice variety, with resistance to pests and a whole growth duration of about 120 days. A duck breed with good adaptability, such as strong omnivorous behaviour and disease resistance is needed. The final weight of duck species should not be too big; within the range of 1.5–2.5 kg is recommended, because a smaller body size allows the ducks to move around the rice more easily without pressing down the plants. Local duck species in South China are suitable for this requirement and are usually the first choice of farmers for use in the rice-duck co-culture system.
- **Rice sowing and seedling growth:** Seedling time is based on local climate conditions. About 2–3 days before sowing, rice seeds need to be dried under sunlight for 3–4 hours, while being mixed constantly to keep them in a similar degree of aridity. Subsequently, disinfection, soaking and germination of the seeds are performed as usual. If the seed roots grow to about 2 mm long, they can be sown directly in rice seedling beds. When seedlings grow to a height of 12–18 cm, they are ready to be transplanted (Fig. 5.2).

FIGURE 5.2 Rice seedlings in a seedling nursery

© Zhang Jia'en

- **Duckling breeding:** The location of facilities for breeding ducklings should be close to a water body, such as a pond or small stream. Duck houses should be equipped with cages, drinking equipment, plastic film, heating lamps, and a straw bed. If ducklings are not produced by the farm, 3–5 day old ducklings should be purchased from the local market just before rice transplantation. Before releasing them to the rice field, ducklings can be fed with broken and pre-soaked rice. Ducklings should be trained in the water to enhance their cold-resistance and waterproof abilities for 15–20 minutes every day.
- **Farmland tillage preparation and basal fertilizer application:** Tillage preparation and basal fertilizer application can proceed as usual with an emphasis on using organic fertilizer options.
- **Rice transplantation:** To prevent trampling by ducks, rice seedlings with 5–6 leaves are preferred in the rice-duck co-culture system. The procedure for the transplantation of rice seedlings is as usual. If the body size of the duck species is larger, the spacing for rice should also be increased.

FIGURE 5.3 The nylon net fence along a rice field ridge

FIGURE 5.4 Rice-duck co-culture before the rice heading stage in Guangdong, China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- **Fences and shelter for ducks:** To prevent ducks from escaping it is necessary to build a fence around the field. If the field is big, it is better to separate it into fenced sections not bigger than 0.3 ha each, to ensure an even distribution of ducks in the field. The fence should be made of 60–100 cm of high nylon net, supported by sticks, installed 3–4 m apart and linked by ropes. The rope and the upper side of the nylon net should be clipped together. The bottom side of the nylon net should be buried by soil and covered with some bricks to resist the pushing force of the ducks (Fig. 5.3). A simple shelter on the dike or in a corner of field is needed to provide a place for ducks to rest and eat (Fig. 5.4).
- **Releasing the ducks:** About 5–7 days after transplanting, when the rice seedlings turn green, 7–10 day old ducklings can be released into the paddy fields. The number of ducks can range from 200–350 per hectare to enable the full exploration of the field by ducks, while also ensuring there are enough weeds and insects in the field to stimulate the active movement of ducks. Since ducks often move together in groups, one herd of ducks should not be more than 100. Otherwise, an excessive number of ducks in one herd can cause damage to rice plants and lead to a food shortage for the ducks. On the other hand, if the number of ducks is not enough, it is hard to control rice pests and to affect the paddy environment. The best time for releasing ducks is usually around 10:00 am on a sunny morning.

FIELD MANAGEMENT DURING THE CO-CULTURE STAGE

During the rice-duck co-existing period (Fig. 5.5), which lasts for about 50–60 days, water management, duck feeding and management, rice fertilization and pest control are the major operations in the field.

FIGURE 5.5 The rice-duck co-culture period in the paddy field

- **Irrigation and drainage:** In the early stage of the rice-duck co-culture, the depth of the water surface in the field should be about 3–5cm. With the growth of rice and ducks, the water level can remain at about 5–7 cm before the heading and flowering stages. Frequent drainage should be prevented to avoid nutrient loss. Drainage is needed only after heavy rainfall and during the ripening stage.
- **Rice fertilization:** According to measurements, about 10 kg of waste is produced by a duck during the co-culture period. This duck waste contains 47 g nitrogen, 70 g phosphorous and 31 g potassium. If 250 ducks per hectare are raised, the total nutrient content of duck waste can meet the basic nutrition demands of rice. Because of the nutrient lost during the co-culture period, fertilizer supply is still needed, but at a greatly reduced rate compared with a monoculture system. Since basal organic fertilizer is applied, only very few topdressings (or even potentially no topdressing) are needed according to the amount of duck and feed inputs, and the specific weather conditions. Over-fertilization would result in lodging and the outbreak of pests.

» **Feeding ducks:** A fixed duck feeding platform close to the field ridge and shelter should be established. During the first few weeks of the rice-duck co-culture period, ducks are fed with rice grains, table leftovers or commercial feed, twice daily, in the morning and evening. The amount of feed supply should be increased gradually according to the growth of ducks. The amount of feed should be reduced by 15–25 percent compared with the standard feeding rate for ducks to encourage exploration and predation of weeds and insects in the field based on a hunger or semi-hunger status. If a land resource is permitted, forage grass can be grown and harvested to partly replace commercial feed for ducks.

» **Duck management:** During the early stage of the rice-duck co-culture period, the ducklings are weak and cannot resist the extreme weather changes such as severe cold periods and rainy days, which can occur in March and April during the early stage of the first rice season in South China. At this stage, the ducklings are vulnerable to influenza and other diseases. To increase the resistance of ducks, increased feedstuffs should be supplied. In the case of a storm, the ducks should be driven into the shelter. If injured or sick ducks appear, they should be separated from the herd on time. Natural predators of ducks, such as snakes, rats, dogs, cats and weasels in surrounding environment should be investigated and controlled. To maintain a high survival rate of ducks, necessary countermeasures should be taken to protect the ducks from direct predation by those predators. In addition, the condition of the surrounding nets should be checked often to prevent the escape of ducks and the entrance of predators.

» **Control of rice pests:** The presence of ducks in the rice field can effectively control rice hopper, leafhopper, sheath blight in the fields, and can also control leaf roller, yellow rice borer, rice blast and bacterial blight to some extent. The ducks have good control effects on most weeds except some barnyard grasses. After successive years of applying the rice-duck co-culture system, very few weeds can be found in the paddy fields. For golden apple snails in paddy fields, the ducks can effectively feed on the small (diameter 1.0–1.6 cm) and medium sized snails (diameter 1.7–2.4 cm). Moreover, the activity of ducks can directly disturb and indirectly interfere with the normal behaviour of apple snails, including their feeding, mating and spawning activities, even for large sized snails (diameter 2.5–3.2 cm). Therefore, the rice-duck co-culture system can control and prevent most pests in paddy fields in normal circumstances. However, auxiliary measures should be applied to control rice pests in abnormal situations. In this case, physical measures such as the trap lamp and yellow board methods, and biological measures such as releasing natural enemies should be considered first.

DUCK REMOVAL AND RICE MANAGEMENT AFTER THE HEADING STAGE

When rice is at the heading stage, the ducks should be taken out of the paddy field to prevent them from eating the rice. This period lasts for about 35–40 days until the rice harvest.

- **Duck removal:** Usually, the ducks should be driven out from the paddy field between the heading stage and filling stage of rice (Fig. 5.6). At this stage, each duck weighs about 1.5–2.5 kg. They can be sold directly to markets or be further raised in nearby water bodies for fattening.
- **Rice pest control after the removal of ducks:** The removal of ducks also means the removal of the pest control mechanism. Some pests may appear and increase up to the threshold for control. In this case, a new technique of releasing the second batch of ducks can be applied alongside with other ordinary integrated pest control methods. As the ducklings released to the paddy fields at this stage are small, they will not be able to cause damage to the rice grain, but they can exert their effects on the control of pests and diseases to a certain extent in the late-growth period of rice.
- **Field water management:** After ducks are driven from the field, management of the water level in the field is dictated according to the need of the rice. It is kept shallow during the early filling stage, then lowered to the wet condition during the early ripening stage. Drying the field about 5–7 days before rice harvesting helps ensure rice maturity and can provide convenient conditions for the rice harvest.
- **Rice harvest:** The rice harvest can be operated as usual. After the rice harvest, ducks can be re-introduced to the field to pick up dropped rice grains, exposed weeds, pests and snails. This can help to further reduce the density of pests and can recycle rice grain that would otherwise be wasted.

FIGURE 5.6 Ducks are removed from paddy fields during the heading stage of rice

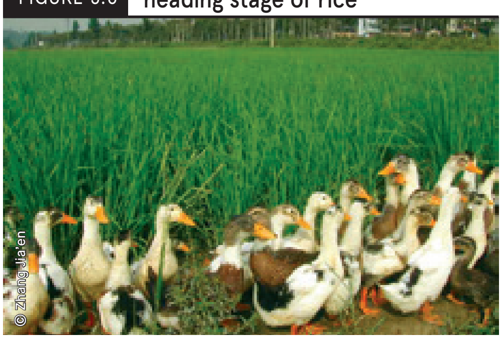
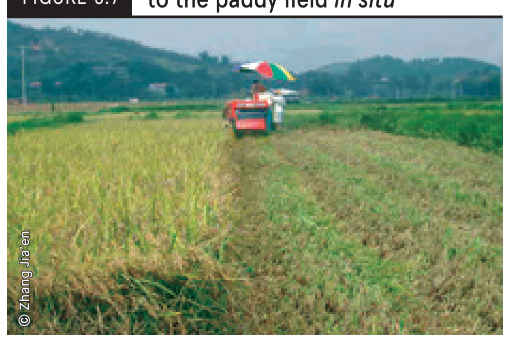


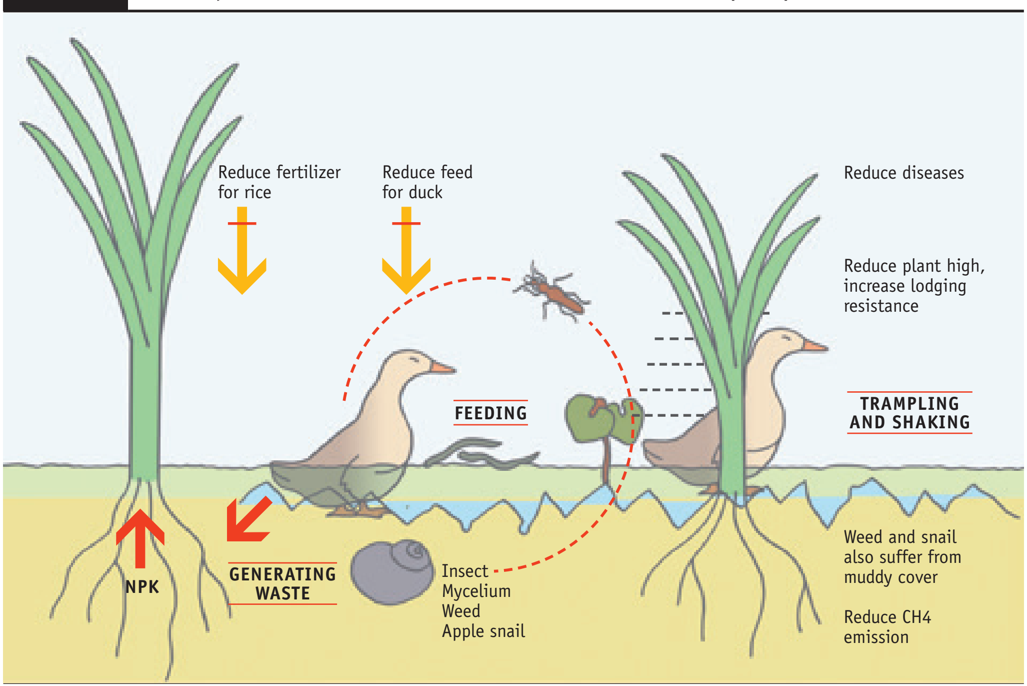
FIGURE 5.7 Rice harvest and its straw return to the paddy field *in situ*



5.2 TYPICAL CASES AND BENEFIT ANALYSIS

The rice-duck co-culture system has an internal nutrient cycling pathway, whereby nutrients from weeds and insect pests are taken up by the ducks, and nutrients from duck manure can be absorbed by rice plants. This can help reduce the feed used for ducks and fertilizer used for rice. Many rice pests can be effectively controlled by ducks through their activities such as feeding, trampling and shaking. The activity of ducks can also reduce the rice plant height and increase its lodging resistance (Fig. 5.8).

FIGURE 5.8 The major activities of ducks and their effects in the rice paddy field

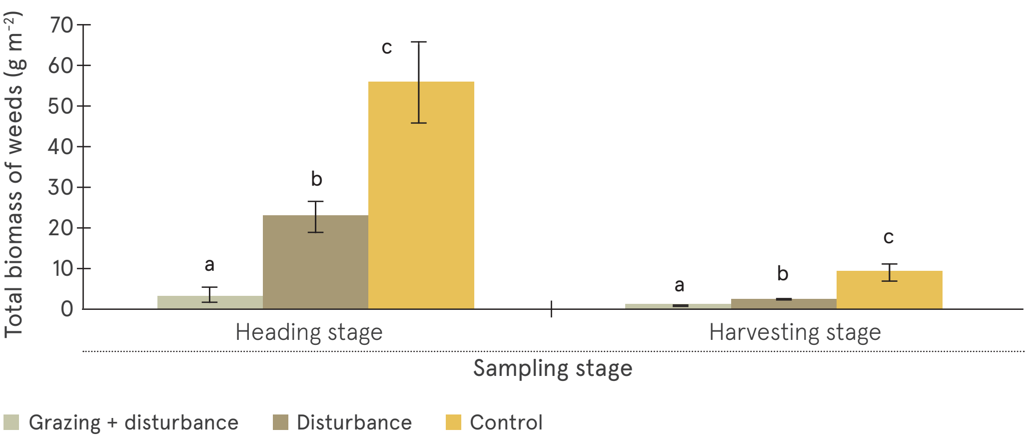


Source: Adapted from Luo Shiming

PEST CONTROL EFFECTS

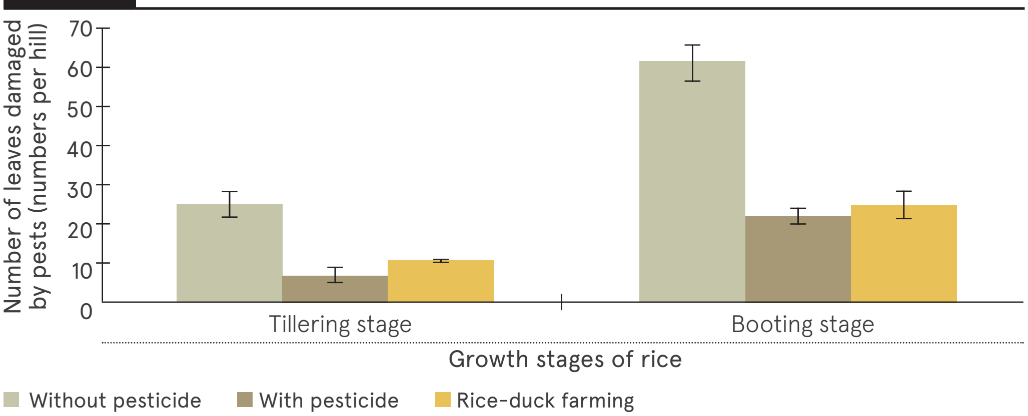
Field research has shown that the rice-duck co-culture system can reduce weed biomass by 90–100 percent through feeding, trampling and mud coverage effects (Fig 5.9). Leaf damage caused by insects can be reduced by more than 70 percent (Fig. 5.10). The number of stem deaths caused by the rice plant borer can be reduced by the rice-duck co-culture to similar levels of systems using chemical pesticides (Fig. 5.11). Small medium sized apple snails can be reduced by almost 100 percent, and even large adult snails could be reduced by more than 40 percent by 60–day old ducks in the rice-duck system (Fig. 5.12). Rice sheath blight disease can be reduced by 60 percent because of better ventilation caused by duck activity.

FIGURE 5.9 Total biomass of the weed community in a rice-duck system with grazing and disturbance or disturbance only, compared with a rice monoculture system



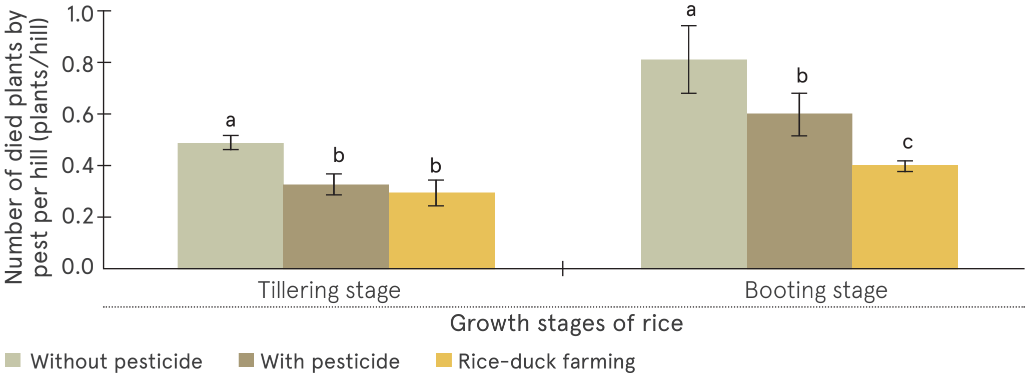
Source: Zhang Jia'en *et al.*, (2009)

FIGURE 5.10 Rice leaves damaged by chewing pests under different treatments



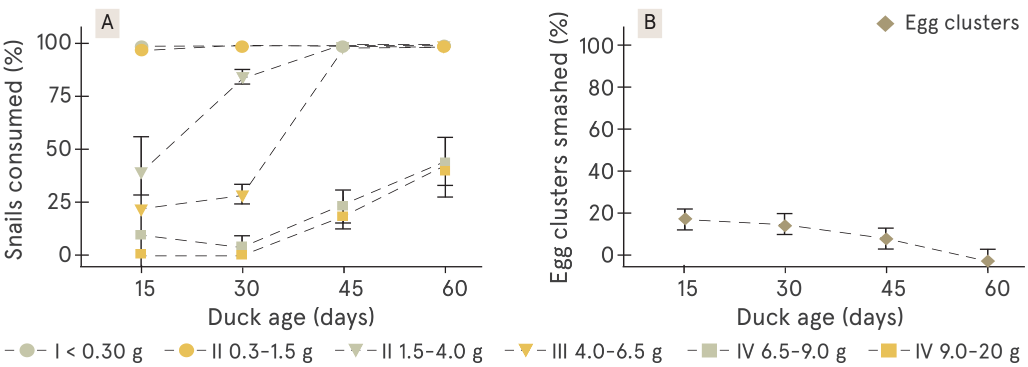
Source: Zhang Jia'en *et al.*, (2009)

FIGURE 5.11 Number of died plants per hill which killed by rice stem borer under various treatments



Source: Zhang Jia'en *et al.*, (2009)

FIGURE 5.12 Predatory potential of ducks on apple snails (A) and their egg clusters (B)*



* Values are means ±SD. In the legend, the ranges indicate snail sizes based on weight

Source: Kaiming Liang *et al.* (2013)

TABLE 5.1 Simulated effects of duck shaking on rice plants for 0 (CK), 5, 30 and 60 minutes/day on the morphological traits of rice

SIMULATED EFFECTS OF DUCK SHAKING ON RICE PLANTS FOR 0 (CK), 5, 30 AND 60 MINUTES/DAY ON THE MORPHOLOGICAL TRAITS OF RICE	CONTROL	5 min/day	30 min/day	60 min/day
Plant height (cm)	45.48±1.10 a	44.05±1.28 ab	40.50±2.25 bc	37.33±1.16 c
Stem diameter (cm)	0.36±0.01 b	0.39±0.01 a	0.40±0.01 a	0.33±0.02 b
Above ground biomass (g)	0.43±0.01 a	0.42±0.02 a	0.39±0.02 a	0.32±0.01 b
Root biomass (g)	0.08±0.01 b	0.11±0.01 a	0.12±0.01 a	0.09±0.01 b
Root to above ground biomass ratio	0.20±0.01 c	0.25±0.02 b	0.31±0.01 a	0.28±0.01 ab
Whole biomass (g)	0.51±0.01 a	0.53±0.03 a	0.51±0.03 a	0.41±0.01 b

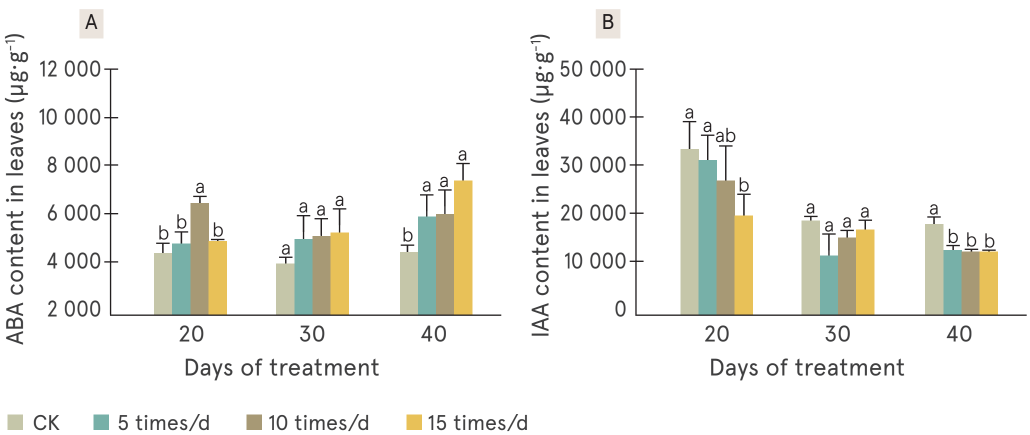
* Different letters in the same row indicates the difference reaches 5% significant level

Source: Zhao Benliang *et al.* (2013)

MORPHOLOGICAL EFFECTS

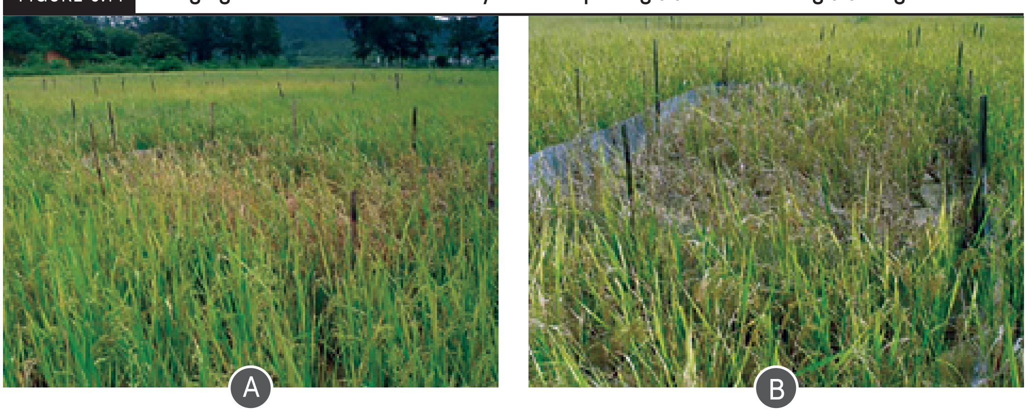
A study that simulated the shaking effect of duck movement on rice plants discovered that this movement could reduce plant height and increase stem diameter and root biomass (Table 5.1). The mechanism for these effects was an increase in abscisic acid (ABA) content and decrease in the 3-indoleacetic acid (IAA) content in the rice plant (Fig. 5.12). The lodging resistance of rice also increased (Fig. 5.13).

FIGURE 5.13 Dynamic changes in abscisic acid (ABA) and 3-indoleacetic acid (IAA) content in rice leaves under different mechanical stimulation treatments



Source: Liang Kaiming *et al.* (2013)

FIGURE 5.14 Lodging resistance status of early rice in ripening (a) and maturing (b) stages*



* Plots were isolated with a barrier for the treatment of rice without ducks (RND) and surrounded by the rice-duck treatment (RD). The rice in the RND treatment was taller and has lodged. The rice in the RD treatment was shorter and did not lodge

Source: Kaiming Liang *et al.* (2013)

YIELD AND ECONOMIC EFFECTS

A comparison between rice monoculture and the rice-duck co-culture system with different duck densities was conducted in Zhejiang Province, China (Yu Shengmiao *et al.*, 2008). The results showed that the best economic return was achieved using the rice-duck co-culture system with a duck density between 225–375 heads per hectare. The total net income increased by 70.9–71.1 percent for this system at various stocking rates. If stable and high rice yields are also considered, duck density should be around 225 heads per hectare (Table 5.2). The rice yield for this combination increased by 2.7 percent compared with monoculture rice.

TABLE 5.2 **The impact of duck density in rice-duck systems on rice yield and economic return**

DUCK DENSITY (head/ha)	RICE		DUCK		TOTAL INCOME (Yuan/ha)
	Yield (t/ha)	net income (Yuan/ha)	body weight (kg/head)	Net income (Yuan/ha)	
0(CK)	7.442	3 098.70	0.00	0.00	3 098.70
75	7.933	3 517.95	2.14	896.25	4 414.20
150	7.686	3 208.80	1.79	1 387.50	4 596.30
225	7.648	3 148.95	1.80	2 146.95	5 295.75
300	7.349	2 765.85	1.69	2 595.00	5 360.85
375	7.071	2 394.75	1.60	2 908.20	5 302.80
450	6.723	1 959.75	1.53	3 198.75	5 158.50

Source: Yu Shengmiao *et al.* (2008)

SOCIAL EFFECTS ON NUTRITION AND VILLAGE ECONOMY

The rice-duck co-culture system provides an opportunity to produce organic rice and organic duck in an integrated system. Because of the rapid development of the market for organic food in China, farmers found that the rice-duck system not only provides high quality food and nutrition for consumers, but also provides an opportunity to earn much more for themselves. Xiang Wenxiu is a farmer in Wangjia Tun Village, Beiquan County, Heilongjiang Province. The cost for rice-duck production in her field was 69 000 Yuan per hectare in 2015. The rice yield was about 2 550 kg per hectare. When the price of organic rice increased to 120 Yuan/kg, her total income from rice reached 306 000 Yuan per hectare and her net income was about 237 000 Yuan. The 270 ducks per hectare could earn another 15 000 Yuan. The total net income from the organic rice-duck production system was about 10 times as much as a traditional rice monoculture. Through her success, Xiang Wenxiu became the vice team leader of the farmer's cooperative in the village. All the farmers in the village join this cooperative and have now converted to the rice-duck system (Wang Jian 2015).[1]

[1] For more details refer to: http://hlj.people.com.cn/n/2015/0706/c220024-25472696.html

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PHOTO In the next page: Rice-fish co-culture system before rice harvesting in Zhejiang, China

METHOD 6

RICE-FISH CO-CULTURE SYSTEM

- TECHNIQUES USED IN THE RICE-FISH CO-CULTURE SYSTEM
- TYPICAL CASES AND BENEFIT ANALYSIS

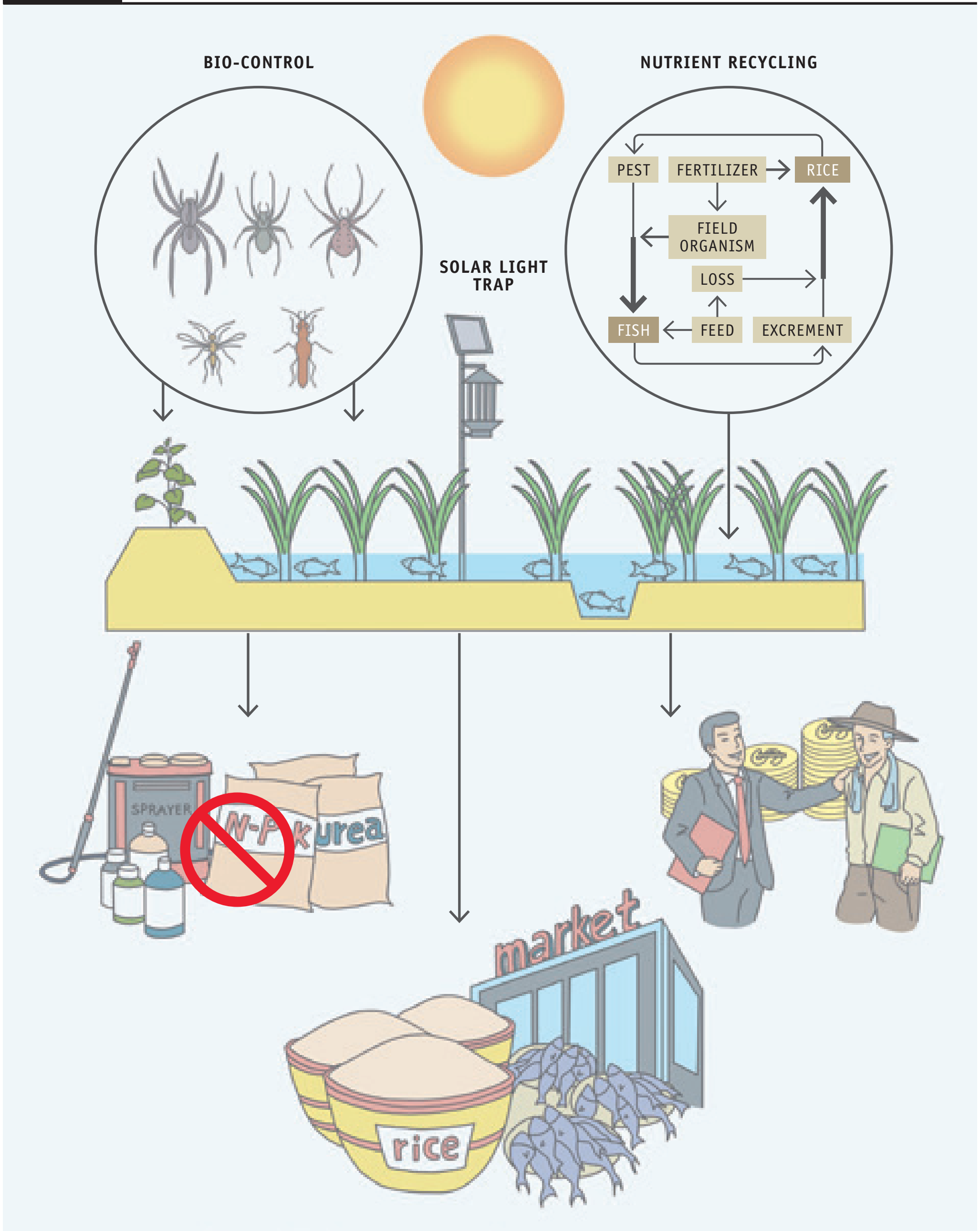
Rice fields provide an excellent environment for integrating aquaculture. In integrated rice co-culture systems, a wide range of aquatic animals can be used, including fish, freshwater prawns, marine shrimps, crabs, turtles, frogs, etc. The co-culture system combining rice and fish has long been practiced in many rice-growing areas. The rice-fish co-culture system is an efficient way of using the same land resource to produce both carbohydrates and animal protein, either concurrently or in sequence. In rice-fish farming systems, water is used to simultaneously produce the two basic foods (Fig. 6.1). Rice-fish farming systems have tremendous potential for increasing food security and alleviating poverty in rural areas.

FIGURE 6.1 Rice-fish co-culture system in Zhejiang Province, China

Rice-fish farming systems also hold a great potential for environmental and resource conservation. Raising fish in paddy fields can reduce or eliminate pesticide and insecticide use, since fish are able to eradicate weeds by eating or uprooting them, and they devour some insect pests. Raising fish in rice fields can also reduce fertilizer requirements for rice, because rice plants can use the unconsumed fish feed and fish excretions as organic fertilizers (Oehme, 2007). Thus, integrating rice cultivation with aquaculture results in an efficient resource use, which in turn leads to a cleaner and healthier rural environment. On the other hand, rice-fish farming can help to solve some problems generated by freshwater aquaculture.

For example, nutrients in effluents from raising fish are absorbed by rice plants rather than becoming a pollution source. Consequently, rice-fish co-culture is becoming widely recognized system that is well accepted in many areas (Fig. 6.2).

FIGURE 6.2 The rice-fish co-culture and its multiple benefits



Source: Adapted from Chen Xin

6.1 TECHNIQUES USED IN THE RICE-FISH CO-CULTURE SYSTEM

Achieving acceptable and sustainable levels of rice and fish production in the rice-fish co-culture system requires a technology package that is much more sophisticated than for either rice or fish monoculture. This technical package includes the following components: (1) installation of temporary physical structures such as trenches and pits to protect the fish during field operations and to prevent them from escaping; (2) rice and fish varieties that are better adapted to the rice-fish co-culture system, including rice varieties that are adapted to deeper water compared with rice monoculture, and fish species and varieties that are adapted to water that is shallower than in fish monocultures; and (3) daily field management procedures, including the coordination of irrigation, fertilization, pest control and fish feeding.

MODIFICATION OF RICE FIELDS FOR RICE-FISH CO-CULTURE

In principle, as long as there is enough water, rice fields can serve as a suitable site for fish culture. However, conventional rice fields are designed for rice and therefore the conditions are not optimized for fish. Thus, raising fish in a rice field requires several physical modifications for fish habitation (e.g. building ridges, fish refuges).

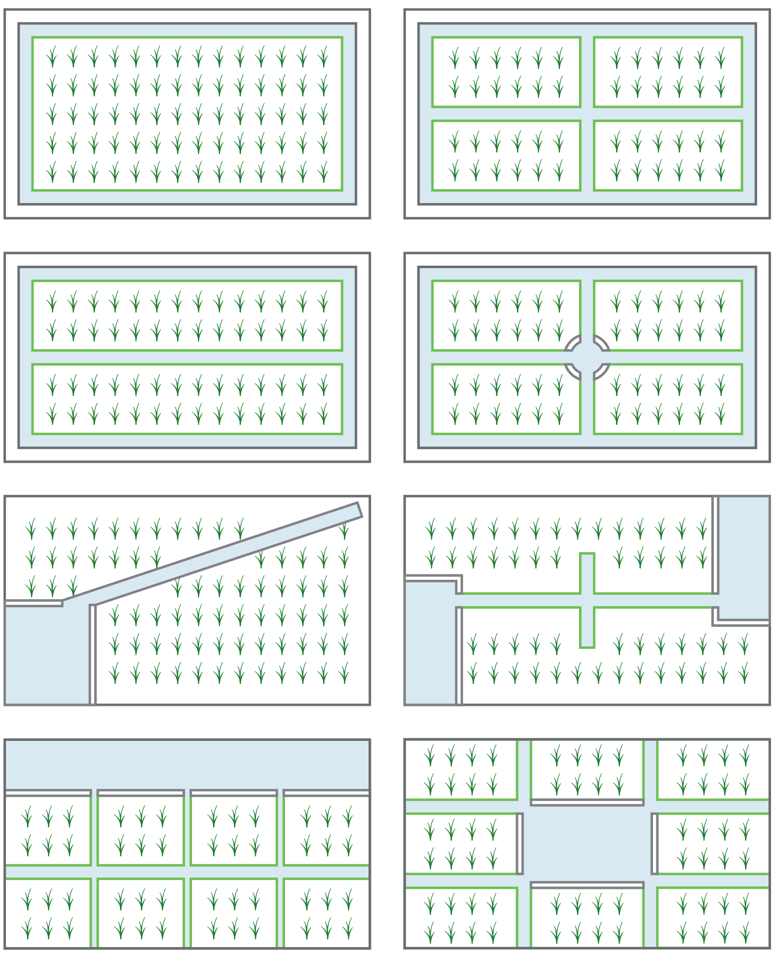
Before starting a rice-fish co-culture, conventional rice fields must be physically modified. The modifications are aimed at providing more space and deeper water for fish while minimizing negative effects on rice plants. The main modifications include the following aspects:

- **High ridge:** Since the field water level in rice-fish culture is higher than in conventional rice monocultures, rice field ridges must be high enough to prevent fish from jumping over or escaping. The height of the ridge needs to be raised up to 0.4–0.5 m for terrace fields and 0.5–0.6 m for plain fields. Dikes must also be reinforced to prevent collapse and leakage. We recommend building trapezoidal dikes that are 0.8–1 m wide at the bottom and 0.4–0.6 m wide at the top. This configuration is more stable than a vertical shape.
- **Water inlets and outlets:** As in a regular fishpond, it is necessary for a rice-fish field to install a specialized water inlet and one or more outlets at the ends of a diagonal line. Screens, like bamboo slats, baskets and fish nets, should be installed in inlets and outlets to prevent fish from escaping. Setting up several spillways beside the outlets is recommended to keep a stable water level.
- **Trenches and/or ponds:** A fish refuge (e.g. trench, pit) is a deeper area provided for fish within a rice field. This can be in the form of a trench or several trenches, a pond or even just a pit. The purpose of the refuge is to provide a place for the fish in case the water in the field dries up or is not deep enough. It also serves to facilitate fish harvesting at the end of the rice season, or to contain fish for further culture during rice harvest (Halwart, 1998). In conjunction with the refuge, trenches are often made to provide swimming paths for fish to gain easier access to feeding locations (Halwart, 2004).

There are many different possible designs of trenches and ponds (Fig. 6.3). Generally, peripheral trenches can be wider than central ones (e.g. 0.3–0.6 m wide and 0.3–0.4 m deep for central trenches, and 1–2 m wide and 0.7–0.8 m deep for peripheral trenches). Ponds are usually 0.8–1.5 m deep, surround by bricks, stones or other hard materials (0.2 to 0.3 m above ground), and set in the centre of the field or near the water inlet. All trenches and ponds in a field should be connected. In practice, the design of trenches and ponds should consider the area and shape of the field.

Trenches and ponds can also be used to concentrate fish for temporary storage and harvest. Although trenches and ponds definitely reduce the field area available for rice cultivation, with a good spatial arrangement and a low area ratio, they will not reduce rice yields because of the "edge effect" (i.e. rice plants close to trenches have higher yields than others) and the positive effects of fish on rice growth (Hu *et al.*, 2016; Wu *et al.*, 2010). We suggest that the total area of trenches and ponds should not be more than 10 percent of the field area.

FIGURE 6.3 **Examples of trenches and ponds (grey areas) in rice-fish co-culture systems**



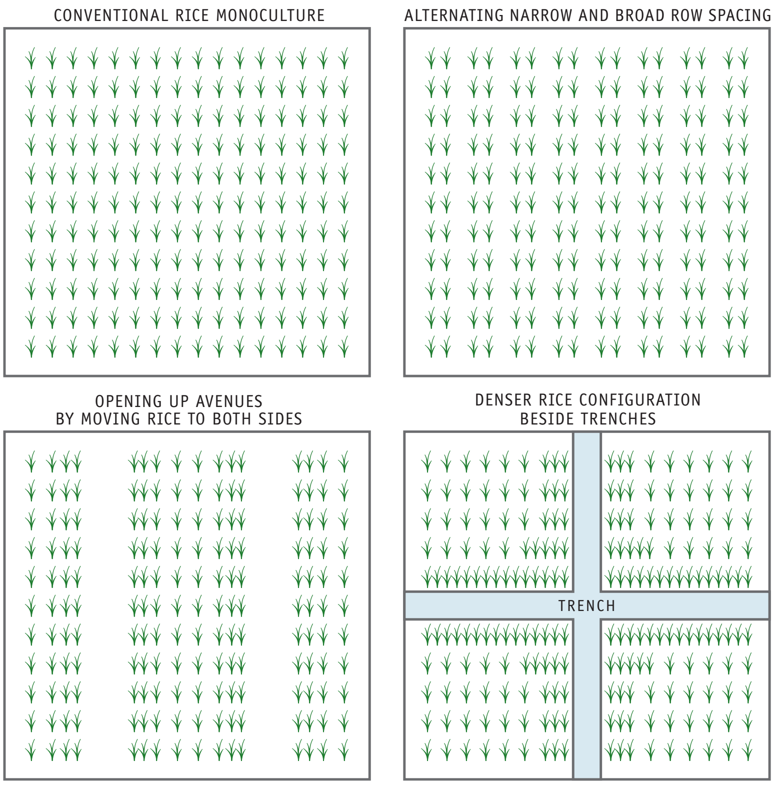
Source: Adapted from Chen Xin

SELECTION OF VARIETIES FOR RICE-FISH CO-CULTURE

- **Rice variety:** Rising fish changes the bio-community and nutrient cycling of rice fields. Thus, a compatible rice variety should be selected based on the following traits:
  1) Tolerance to lodging that might be caused by fish activity and a high water level.
  2) Tolerance to high fertility that is often caused by intensive fish culture (i.e. high fish density with high feed input).
  3) Resistance to pests so that pesticides can be reduced or even eliminated.
- **Fish variety:** The most suitable species of fish possess the following two traits:
  1) Tolerance to harsh environments. Compared with a fishpond, rice fields are characterized by shallow water, great variation in turbidity as well as extensive fluctuation in temperature, pH and dissolved oxygen. Fish tolerance to this harsh environment will increase their survival rate.
  2) Short culture cycle. Fast-growing fish are able to attain a marketable size by the time of rice harvest.

In China, the carp family species (cyprinids), particularly the common carp, have the longest documented history for rice-fish co-culture. In recent years, farmers have introduced more fish species of a high economic value and by way of poly-culture to diversify fish products as well as to increase economic profit. The most commonly raised species are herbivorous or omnivorous, such as the common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idellus*), crucian carp (*Carassius auratus*), tilapias (*Oreochromis* spp.), African catfish (*Clarias lazera*), rice field eels (*Monopterus alba*), loaches (*Misgurnus anguillicaudatus*), silver carp (*Hypophthalmichthys molitrix*), and bighead carp (*Aristichthys nobilis*).

FIGURE 6.4 Different spatial arrangements of rice seedlings to facilitate fish activity without changing the rice density



Source: Adapted from Chen Xin

RICE PLANTING

The rice planting pattern is important for both rice yields and fish yields. Compared with conventional rice monoculture, rice density in a rice-fish co-culture can be reduced to some degree so that fish can easily move around the field while the rice yield does not decrease. An experiment showed that lower spacing density (30×35 cm) did not reduce rice yields but did increase fish yields by 50 percent compared with regular spacing density (20×25 cm).

The spatial arrangement of rice seedlings is also important. Alternative narrow and broad row spacing will allow fish to easily move into the centre of the field. At the same time, increasing rice density next to the trenches can compensate for the rice plants removed from the trench area (Fig. 6.4).

FISH STOCKING

Like fishpond aquaculture, rice-fish culture also involves: (1) the stocking of young fish fries for the production of fingerlings (nursery operation); and (2) the growing of fingerlings into marketable fish (grow-out operation). The rice-fish co-culture may either include the cultivation of only one fish species (monoculture) or a combination of two or more fish species (poly-culture). Poly-culture fish production can increase resource use efficiency and diversify the fish products, thus increasing economic profit. The ratio of different fish species with different ecological niches can be manipulated to best use the natural resources of the rice field (e.g. weeds and plankton) and artificial inputs (e.g. organic fertilizers and supplementary feed).

The optimum stocking density varies depending on the type of culture, fish species, environmental capacity, rice planting pattern and daily management. Though fish stocking density has almost no negative effect on rice yield, it will negatively affect the fish survival rate and average body weight of fish.

Rice seedlings are vulnerable shortly after being transplanted, so large fingerlings should not be released into the whole field before rice seedlings recover and turn green. During this period, fingerlings can be concentrated in trenches or ponds or enclosed within a small range of the field.

FEEDING AND FERTILIZATION

- **Feeding Fish:** Fish graze and feed on a wide range of organisms in rice fields. In China, the fish yield of extensive rice-fish co-culture without any supplementary input is generally 150–375 kg per hectare. However, supplementary inputs can significantly increase the fish survival rate and fish yield. Supplemental feeds often consist of what is locally available, such as un-hulled rice, wheat bran, wheat flour, maize, oilseed cakes and green fodders. When supplemental feeds are used, the following criteria are suggested:
  1) Combine different kinds of feeds in a proper proportion to balance the nutrient status of fish and cut the costs.
  2) Commercial formula feeds should meet local fishery standards and must be non-toxic to fish.
  3) Applying the proper amount of daily feed supply prevents water pollution. If commercial formula feed is used, the daily amount should be within 2–4 percent of the fish fresh weight. The amount of green fodder should be within 15–40 percent of the fish weight.
  4) Applying a regular feeding schedule can improve the resource use efficiency. It is recommended to feed fish at a fixed location next to a trench or pond, and at a fixed time in the morning and afternoon respectively.
- **Rice Fertilization:** Application of fertilizers for rice is also beneficial to fish due to the stimulation of phytoplankton. Meanwhile, the presence of fish can increase field fertility through the unconsumed fish feed and fish excrements in the field. This is beneficial for rice and can lower the need to apply supplementary fertilizers to rice. The application of fish feed can be regarded as long-term topdressing for rice. Thus, when fertilizers are applied in the rice-fish co-culture, the amount of fish feed should be taken into account, especially under high fish densities. Usually 10–30 percent less fertilizers are used in rice-fish co-cultures than in rice monocultures. An optimum fertilization scheme should be developed through local field experiments.

RICE PEST AND FISH DISEASE CONTROL

» **Rice pests:** Raising fish in rice fields can reduce the occurrence of rice diseases, insect pests and weeds, because fish acts as a bio-control agent. Field conditions such as the water level, flooded time and rice planting density are also different from those of rice monoculture, which can influence pest and disease control. However, other methods of pest control are still necessary, such as light traps, insect-proof nets and bio-control measures (e.g. increasing vegetation diversity to attract more natural enemies).

» **Fish diseases:** The risk of fish disease in rice-fish co-cultures increases at higher fish densities. Thus, when fish are raised intensively in a rice-fish co-culture, with high fish density and high feed input, it is important to keep field water clean by avoiding excessive feeding, removing dead fish, changing water regularly and taking some disinfection measures. Before fish are released into fields, there are two simple but effective steps to reduce the risk of fish diseases: the disinfection of rice fields by using lime and the disinfection of fish fingerling body surfaces by using a 3 percent saline solution before releasing them into the field.

Fish predators like snakes and some small mammals might sneak into rice fields. Daily inspection can help to deal with the intruders on time. In some cases, wading birds are the main predator and disease disseminator of fish. For example, egrets, which are nationally protected animals in China, prey on fish in rice fields. To reduce the damage caused by birds without killing them, farmers must invest in field facilities, such as bird-proof nets and ultrasonic broadcasts. However, these facilities are usually expensive and not very effective. There are two alternatives that worth trying. One is to replace bird-proof nets with parallel nylon lines fixed above the fields, and the other is bio-control. Some farmers in South China have discovered that domestic geese (*Anser cygnoides*), which themselves do not eat fish, can actively drive away birds from rice fields because of their territorial consciousness.

WATER MANAGEMENT

» **Water level:** Water management in the rice-fish co-culture is different from rice monoculture, which uses an intermittent irrigation. The rice-fish co-culture needs continuous submergence to meet the demand of fish growth. Shallow water is generally preferable during the rice tillering stage, while deeper water is needed for the reproduction stage. Thus, the water depth should be adjusted according to rice growth stages and the demand of fish. A depth of 6–8 cm is reasonable between transplanting and late-tillering when fish are still small, increasing to 15–20 cm at the early-reproduction stage of rice when fish also need deeper water. Under a water depth of 15–20 cm in the rice planting area, the water depth in trenches can reach 65–70 cm, assuming the trench bottom is 50 cm below the field level. This is sufficient to provide fish with a comfortable habitat even though field water warms to as high as 40°C during summer days.

» **Water quality:** Water quality is crucial for the fish culture. Although rice plants can improve the environment for fish by absorbing excessive nutrients of feeds and providing shading in a hot season, water quality problems can still easily occur in intensive fish cultures. The main problems are low dissolved oxygen, accumulation of pollutions (e.g. S^{2-}, NH_{4+}, and NO^{3-}), and algal bloom. Conventional solutions include the changing of water regularly, the installation of aerators in trenches, the use of targeted microbial agents, and the inclusion of filter-feeding fish species. Besides these approaches, the following measures are helpful:

1) Regulating the water level. In spring, shallow water has a higher temperature and a better light transmission to promote algal photosynthesis. Compared with deep water, shallow water has a faster process of nutrient cycling and higher self-purification efficiency. However, in summer, deep water can protect fish from high temperatures. To deal with eutrophication, exchanging bottom water in trenches and ponds with fresh water can be effective.

2) Cleaning trenches and ponds. Long-term culture of fish and continuous submergence will accumulate organic matters, nutrients and pathogens in the sludge of trenches and ponds. Thus, it is important to regularly clean trenches, including measures such as disinfection, solar exposure, dredging and adding beneficial microbes.

3) Planting aquatic vegetation. Some species of aquatic plants can help regulate water quality and provide more food for fish, as long as they are kept within a proper area and quantity.

4) Stocking a reasonable fish density. There is a trade-off between environmental pressure and economic profit. Fish density should be kept under the rice field capacity and matched to the management system.

HARVEST

If reaping machines are used for rice harvest in large-scale fields, water should be drained about a week before the rice harvest to dry and harden the field soil. When field water drains off, fish will gather into trenches and ponds and can be harvested with fishing nets or other tools. After the rice harvest, fields can be re-filled with water and used as a fish pond. Through this method, the growing season of marketable fish can be extended or fish fingerlings for the next season of rice-fish culture can be preserved.

6.2 TYPICAL CASES AND BENEFIT ANALYSIS

Two contrasting cases of rice-fish co-culture systems are described here (located in hilly and plain areas). The benefits of the rice-fish co-culture include social, economic and ecological aspects.

SUCCESSFUL EXAMPLES OF RICE-FISH CO-CULTURE

Example 1: **Rice-fish co-culture in a hilly area**

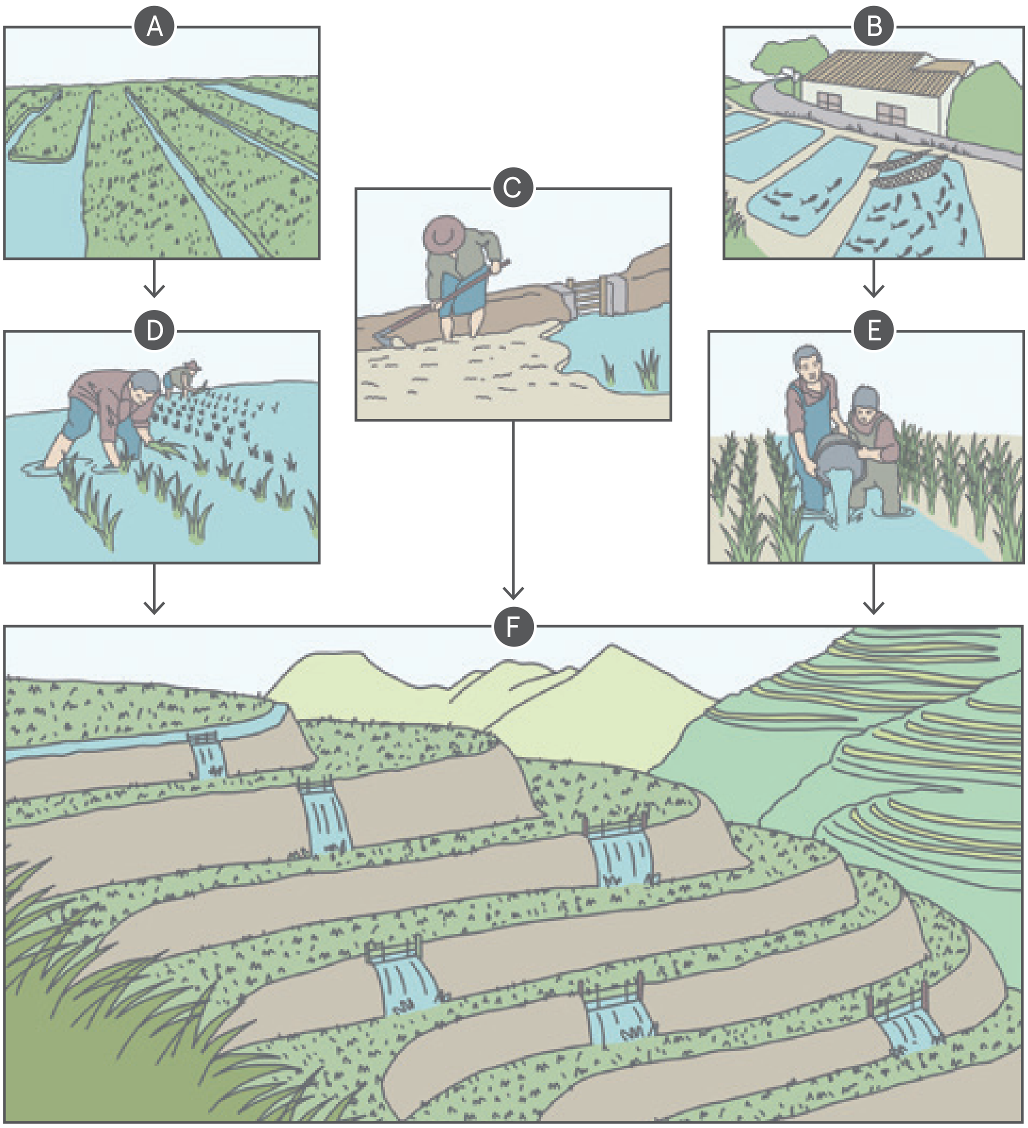
The rice-fish co-culture system is popular in Qingtian county of Zhejiang province in southern China. The area around Qingtian County is hilly and mountainous, and the principal crop is rice, which is grown in terraces and cropped once a year. There are about 6 670 ha of rice in the county, 90 percent of which is practicing the rice-fish co-culture system. The climate is subtropical monsoon with a mean annual air temperature of 17–18°C and a mean annual precipitation of 1 432 mm. The rice-fish co-culture system in this area was introduced by local farmers more than 1 200 years ago. The fish species used is an indigenous, soft-scaled common carp species (*Cypinius carpio* var. *color*). Local farmers call this the "Qingtian field carp". The rice varieties in this system have changed over time, with high-yielding hybrid rice varieties becoming the most commonly selected in recent decades. In this rice-fish co-culture system, the carp remain in the rice field all year. They are temporarily driven to a corner of the field when rice is transplanted in May and harvested in October (Fig. 6.5).

FIGURE 6.5 Rice-fish co-culture system in the hilly area of Qingtian County, Zhejiang Province

© Chen Xin

The farming methods and management system of this rice-fish co-culture are described in Figure 6.6. There are three steps to develop this rice-fish co-culture in the hilly environment where water is available. The first step is preparing seedlings, fish fries and the field (Fig 6.6 A–C). The second step is transplanting rice seedling and releasing fish fries in to the field (D–E). In the third step (F), a rice-fish system is setup for daily management.

FIGURE 6.6 Features of the traditional rice-fish system in a hilly area*



* A) rice seedling breeding;
B) carp fry breeding;
C) field preparation that includes field configuration for rice culture and fish, and building the water outlet and inlet;
D) rice transplanting;
E) fries released into the rice field;
F) an established rice-fish co-culture system.

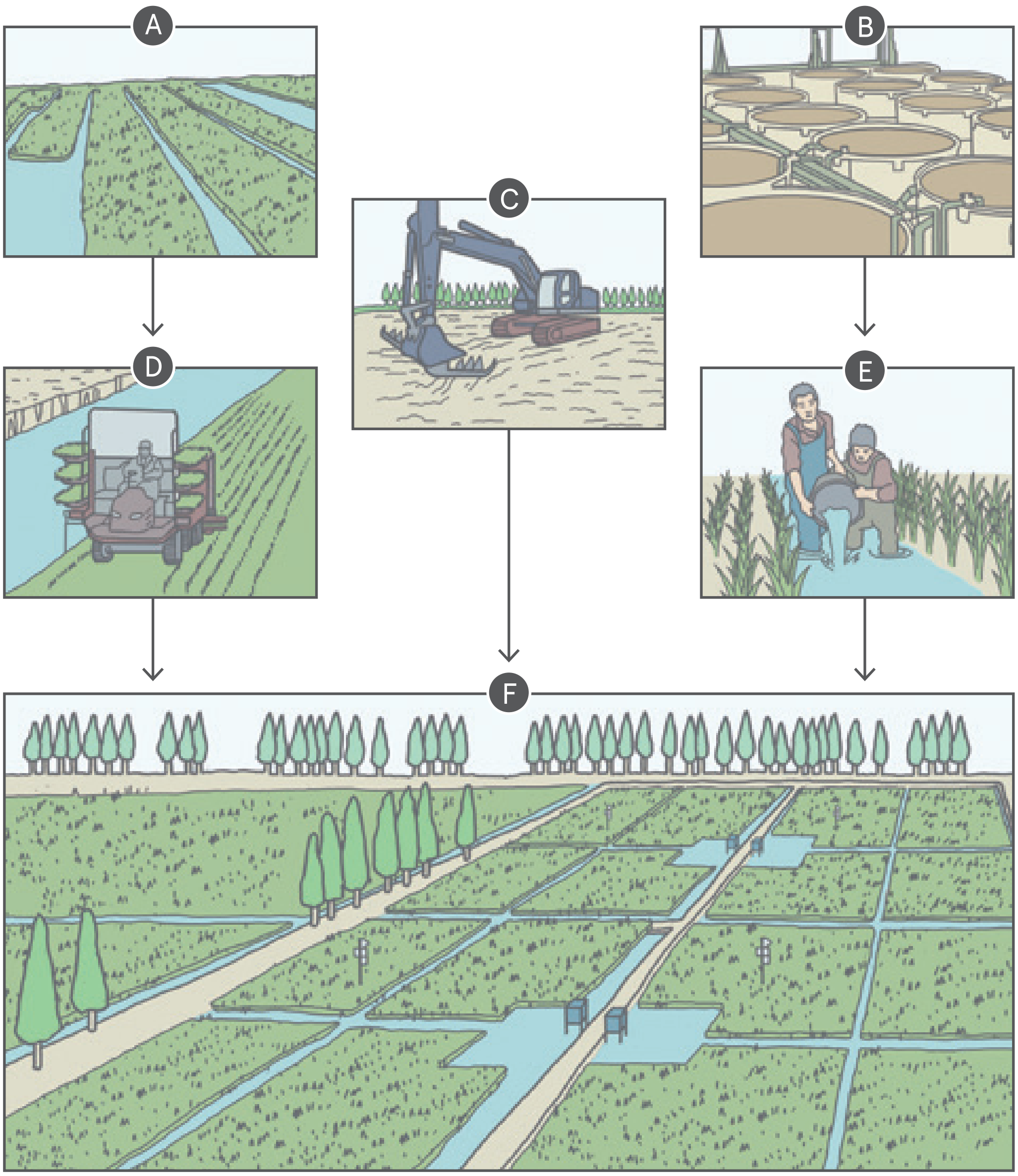
Source: Adapted from Chen Xin

Example 2: **Rice-fish co-culture in plains area**

The rice-fish co-culture as practiced in the plains area of Deqing County of Zhejiang Province in southern China is also successful (Fig 6.7). Deqing County is a flat area, and the principal crop is rice, which is grown from May to November. The climate is subtropical monsoon with a mean annual air temperature of 14°C and a mean annual precipitation of 1 379 mm. A well-designed refuge (trench and pit) is important in these conditions. The development of the rice-fish co-culture system in the plains area is described by Figure 6.8.

FIGURE 6.7 Rice-fish co-culture in plains area of Deqing County, Zehjiang Province

FIGURE 6.8 Features of the rice-fish system in the plains area*



* A) rice seedling breeding;
B) carp fry breeding;
C) field preparation that includes field configuration for rice culture and fish and development of the water outlet and inlet;
D) rice transplanting by machine;
E) fries released into the rice field;
F) an established rice-fish co-culture system.

Source: Adapted from Chen Xin

BENEFIT ANALYSIS

As an integrated form of rice production, rice-fish co-culture takes advantage of the synergy between rice and fish, and is regarded as an efficient and ecologically sound method. In China today, the system has already been widely accepted by farmers, consumers and the government, opening new possibilities for the sustainable development of rice production and aquaculture. In this section, we discuss the significance of rice-fish co-culture, focusing on the: (1) economic benefits, (2) ecological benefits, and (3) social benefits.

Economic benefits

The rice-fish co-culture requires a greater investment than rice monoculture (e.g. digging trenches and ponds, buying fish fingerlings and commercial feed), but this investment can deliver higher net returns to farmers. Rice-fish culture significantly improves the economic performance of rice fields in three ways:

» Higher rice productivity. Raising fish in rice field can improve the stability of rice yield and increase rice yield by up to 5 percent in most cases, although this is the least important aspect of the economic benefits of the rice-fish co-culture.

» Additional output of fish. Adding fish is the major reason for the increase in economic profits, because its market price is usually 5–15 times higher than that of rice. With complementary feeding, rice-fish co-cultures can reach an average fish yield of 970 kg per hectare, at which point the gross income of fish is much higher than that of rice in a monoculture.

» Marketing and certification possibilities. The rice-fish co-culture can reduce or even eliminate chemical inputs making the products eligible for high quality certifications such as organic. This leads to new marketing possibilities of identifiable brands of rice or fish products that are sought by consumers and can obtain higher prices than conventional products in the market.

Ecological benefits

The synergies between rice planting and fish growth provides an efficient way to produce more food from the same area of land while reducing the environmental impacts of production. This is mainly attributed to the positive changes in system functions and associated ecological benefits.

» Improving resource use efficiency. Rice and fish share the same water on the same land, improving rice production and saving an extra demand for land and water in aquaculture (e.g. through constructions of monoculture ponds). The diversified trophic levels in the rice-fish system and closed loop of nutrient flows can reduce the loss of nutrients and restore soil fertility.

» Reducing non-point source pollution. The rice-fish co-culture system significantly reduces and even eliminates the use of chemical fertilizers and pesticides, which are major sources of pollution associated with modern agriculture.

» Increasing the system stability and resistance. The positive interactions between rice and fish (e.g. pest control) reduce the dependence on chemical inputs and help to maintain a stable rice yield (Xie *et al.*, 2011). Trenches and ponds enlarge the water storage in rice fields, reducing the risk of drought.

Social benefits

When a rice-fish co-culture system adopts a commercial and standardized mode of production and operation and develops into a large-scale entity involving an entire community, the social benefits can be quite profound. Here, we underline the most critical social benefits of the rice-fish co-culture.

- Sustaining rice production. The rice-fish co-culture system can increase rice productivity and has a much better economic performance than rice monoculture, which can stimulate farmers' enthusiasm for rice farming and recover abandoned rice fields. Considering the strategic role of rice in China's national food security, rice-fish culture can contribute to social stability.
- Expanding the potential of aquaculture. Under the rapid development of freshwater aquaculture, the vast area of rice fields for fish production is attractive to the fishery sector. Although pond culture is still dominant among all current methods of freshwater aquaculture, rice-fish co-culture has its own advantages in many aspects of the production and sales chain.
- Providing healthy and safe food. Chinese consumers are paying more and more attention to the quality rather than the quantity of their daily diets. Rice-fish co-cultures reduce or even eliminate the use of chemicals and fish antibiotics, helping to satisfy the urgent demand for healthy and safe products in the Chinese food market.
- Boosting rural economic development. One of the direct benefits of the rice-fish co-culture is increasing farmer income. The extension of rice-fish co-culture increases the rural productivity of diversified food products and stimulates urban consumption. As the economic profits increases, rice-fish co-culture will draw more and more capital and labour back into rural development, and thus will improve rural employment and help address the challenge of rural labour shortage.

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PHOTO In the next page: Tiger frog during winter period for breeding in Shanghai

METHOD 7

INTEGRATED RICE-FROG CO-CULTURE SYSTEM

- TECHNIQUES USED IN THE RICE-FROG CO-CULTURE SYSTEM
- TYPICAL CASES AND BENEFIT ANALYSIS

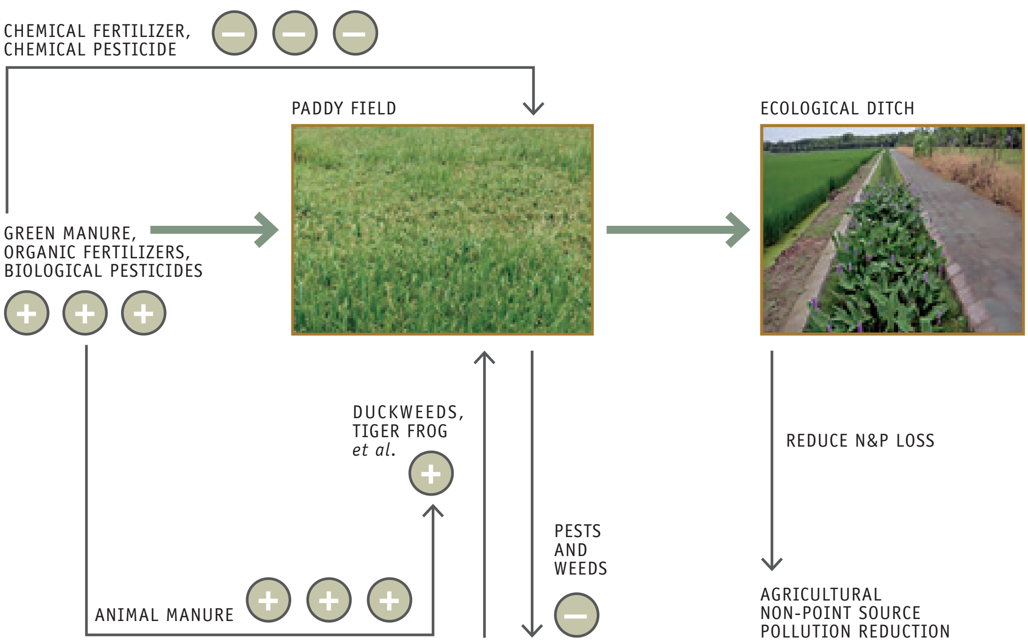
Chinese farmers have used frogs to control rice pests for a long time. During the Song Dynasty (420–490 A.D.), the poet Fan Chengda wrote that the "noisy voice of the frog lasting to the foggy morning predicts a bumper year". The famous poet Xin Qiji (1140–1207) wrote that, "People were talking about a bumper harvest while smelling the scent of rice flowers and listening to the song of frogs".The integrated rice-frog co-culture system makes good use of the natural symbiotic relationship between frogs and rice in paddy fields to increase rice production and protect the natural environment. In recent years, integrated rice-frog ecosystems were first tested and demonstrated in the Shanghai Qingpu modern agricultural park, Qingpu District, in 2007 (Fig. 7.1). The stocking density of tiger frogs, ecological planting structures, and pest control technology were explored. From 2009, with the technical support of the School of Agriculture and Biology, Shanghai Jiaotong University, further research and demonstrations were carried out. Meanwhile, the products of "Frog Rice" brand, produced by the Shanghai Zizaiyuan Agricultural Development Co. Ltd. Have been awarded green and organic certification. These developments indicate that integrated rice-frog ecosystems have achieved good pilot and demonstration effects and have shown significant ecological and economic benefits. The integrated rice-frog ecosystem has changed the conventional approach to rice production by reducing the use of chemical fertilizers and pesticides. It successfully controls non-point source pollutants by using ecological ditches and artificial wetland technology to intercept and adsorb run-off pollutants from drainage water.

FIGURE 7.1 Rice-frog co-culture system

7.1 TECHNIQUES USED IN THE RICE-FROG CO-CULTURE SYSTEM

In integrated rice-frog production, the paddy field is considered as an agro-ecosystem. The introduction of tiger frogs in the paddy field can greatly reduce, and even eliminate, dependence on pesticides. As natural enemies of many rice pests, tiger frogs can protect rice from damage by pests, achieving an ecological balance between "rice-frog-pests" without spraying pesticides. At the same time, the use of leguminous green manures such as milk vetch and waste from frogs can provide high quality organic fertilizer for rice. In the drainage ditches and wetlands downstream of the integrated rice-frog system, different aquatic plants are used to block, adsorb, deposit and transform nitrogen, phosphorus and other chemical substances in the run-off, effectively intercepting nutrient losses from the paddy field. Through a combination of controlling pollution sources, blocking pollution processes and interception of pollutants within this system, integrated rice-frog co-culture ecosystems can improve the paddy environment, maintain biodiversity and increase rice quality (Fig. 7.2). Organic production procedures for the rice-frog co-culture system such as the "organic frog-rice production technical regulations" and the "organic frog-rice product quality management manual" have been developed.

FIGURE 7.2 Rice-frog co-culture system management based on non-point source pollution control



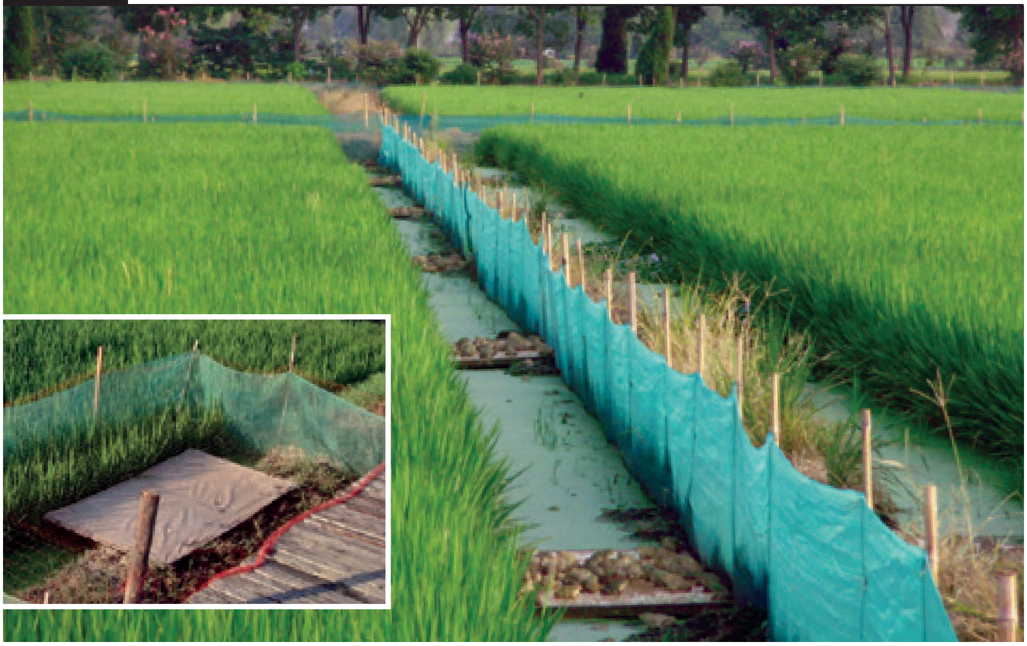
Source: Adapted from Cao Linkui

SETTING UP AN INTEGRATED RICE-FROG ECOSYSTEM

A good irrigation and drainage system with strong, wide ridges is an important precondition to prepare a field for rice-frog co-culture production. If the field is big, it can be divided into rectangle parts, each about 30–40 m x 30–40 m. A frog ditch, which is 0.5 m wide and 0.3 m deep, should be dug around the field. Three to four opened feeding platforms are set close to the field ridge (Fig. 7.3). The feeding platform is 4–5 cm higher than the field level. A nylon net strip around the field should be set up to prevent tiger frogs from escaping as their jumping and leaping ability is very strong. The nylon net should be at a height of 1–1.2 m above the ground and it should be buried at a depth of 20 cm under the soil. The net can be supported by bamboo sticks, spaced every 1.5 m.

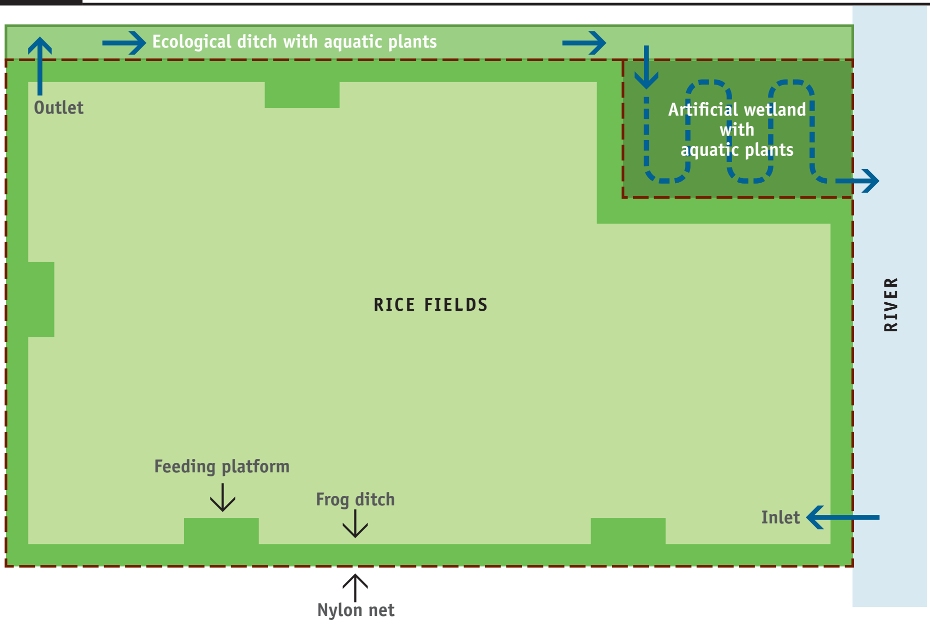
To prevent skin infections of tiger frogs, caused by jumping and hitting the hard nylon net, it is better to cover the nylon net with a soft black plastic sheet. The irrigation inlet and drainage outlet are positioned diagonally in the field. The inlet is about 30–50 cm wide, and the outlet is about 50–80 cm wide. If it is necessary to improve drainage water quality according to the regulation, ecological ditches and artificial wetlands can be built next to the outlet of the field (Fig. 7.4). Aquatic plants such as calamus (*Acorus calamus* L.) and iris (*Iris tectorum* Maxim.) can be planted on the drainage channel to form an eco-ditch (Fig. 7.5). A small piece of the field can be separated and used as an artificial wetland for further water purification (Fig. 7.6). Aquatic plants such as *Myriophyllum verticillatum* L., *Canna indica* L., *Acorus calamus* L. and *Iris tectorum* Maxim. can be used in this artificial wetland.

FIGURE 7.3 **Feeding platform for frogs in the paddy field**



Source: Cao Linkui

FIGURE 7.4 Field configuration for rice-frog co-culture



The Nylon net, frog ditch, inlet and outlet are essential for the system.
The ecological ditch and artificial wetland are beneficial to clean drainage water when necessary. An artificial wetland can be established outside the field and shared by a large field area.

Source: Adapted from Cao Linkui

FIGURE 7.5 Examples of ecological ditches planted with calamus (*Acorus calamus* L.) and iris (*Iris tectorum* Maxim.)

Source: Cao Linkui and Zhang Huanlin (2016)

FIGURE 7.6 Artificial wetland planted with *Myriophyllum verticillatum* L., *Canna indica* L., *Acorus calamus* L. and *Iris tectorum* Maxim

Source: Cao Linkui and Zhang Huanlin (2016)

RICE VARIETIES

High quality rice varieties with resistance to common rice diseases are best suited to the rice-frog co-culture system. In Qingpu District, Shanghai, the "Qingpu rice" series is chosen because of its properties of thin rice bran, high quality and good taste. The most popular varieties include Nanjing 46 and Qingjiao 307.

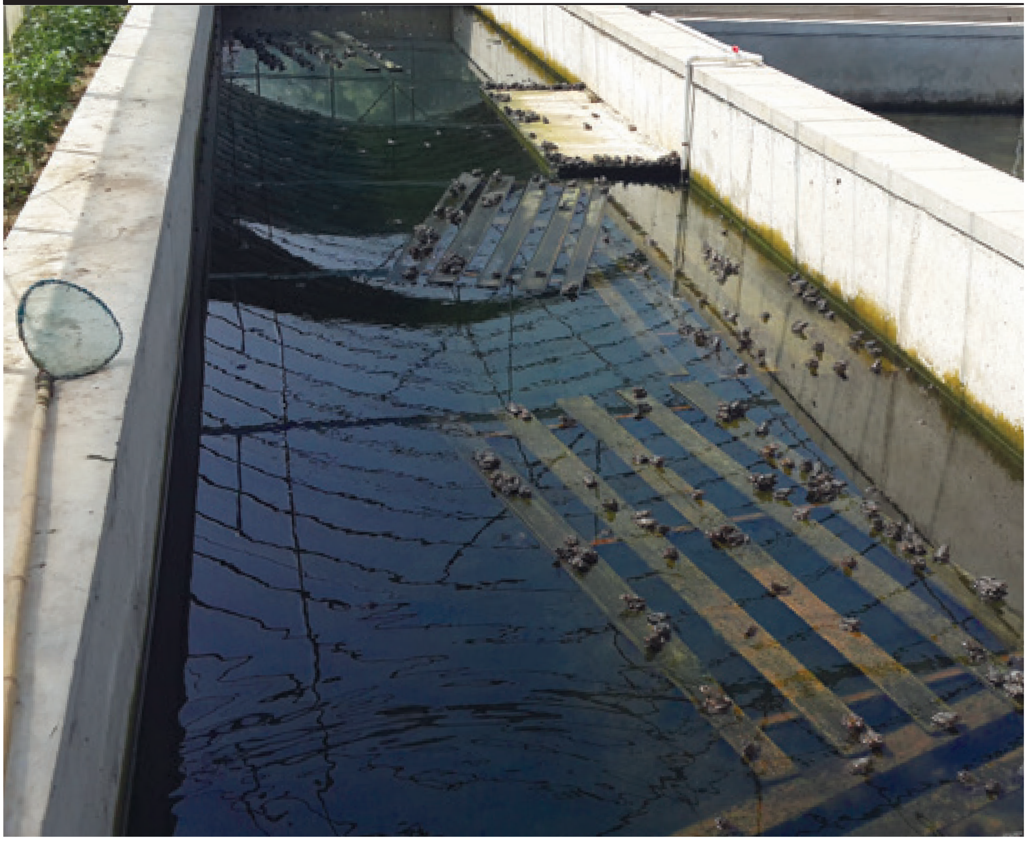
» Rice variety Nanjing 46. The plant height is about 110 cm. The rice plant is a compact type and the tillering ability is strong. The panicle type is large and erect. The panicle is about 15 cm in length. The total grain number is 140–150 per panicle with the seed setting rate more than 90 percent and a thousand grain weight of 25–26 g. It is highly resistant to stripe virus disease and moderately resistant to bacterial blight disease. The whole growth duration is about 165 days. Nanjing 46 is the late maturing rice type. The quality of rice reaches the second-grade standard of national high quality rice and was once praised as "the best rice in Jiangsu Province".

» Rice variety Qingjiao 307. The whole growth period is 155 days, belonging to the late maturing rice type. The plant height is about 95 cm. The number of effective panicles is 345–375 million per hectare. The total grain number is about 120 per panicle with a seed setting rate of 92 percent and a thousand grain weight 24–25 g. It is highly resistant to stripe virus disease and moderately resistant to bacterial blight. The quality of rice also reaches the second-grade standard of national high quality rice.

FROG SPECIES

Different types of frogs can be used in the paddy fields, such as bullfrog (*Rana catesbiana* Shaw), wetland frog (*Fejervarya multistriata*), and tiger frog (*Hoplobatrachus rugulosa*) among others. However, the most suitable frog in the paddy field is the tiger frog. It is also called "Asian frog" because of its robust appearance. The tiger frog is omnivorous. It predates mainly on Coleopteron insects, which make up 36 percent of its total dietary intake. Other insects eaten by the tiger frog include Hemiptera, Lepidoptera, Hymenoptera, Diptera and Homoptera. It also eats spiders, earthworms, millipedes, shrimp, crab loach and dead animal bodies. More surprisingly, tiger frogs even predate on other frogs and mice. The tiger frog is distributed through Burma, Thailand and southern China. A wild population of tiger frog exists in China in Hainan, Guangdong, Guangxi, Fujian, Hunan, Zhejiang, Jiangxi, Jiangsu and Shanghai. Unfortunately, the tiger frog is endangered because of large-scale capture by humans. It has been listed in the second class of national protected animals and recorded as an endangered species in the IUCN Red Data Book. Therefore, integrating frogs in the paddy field also provides a conservation benefit, helping to preserve this species.

FIGURE 7.7 A green house facility for tiger frogs in winter



Source: Cao Linkui and Zhang Huanlin (2016)

The tiger frog is a cold-blooded amphibious animal. The prevailing temperature has a significant impact on its resting, feeding, growth and reproductive behaviour. The suitable temperature range for its growth and reproduction is 20–30 °C. To overcome unfavourably low temperatures during winter and early spring in Shanghai, nutrition adjustment and heating facilities are needed to break their dormancy and make them safe in winter in order to ensure their proliferation for the next year (Fig. 6.7). In Shanghai, the active breeding period of frogs is from the end of April to early-July.

ORGANIC RICE-FROG CO-CULTURE MANAGEMENT

The organic rice-frog co-culture system does not require (or allow) chemical fertilizers, chemical pesticides or growth regulating agents. In Shanghai, one crop of organic rice is cultivated per year. Rice seedlings grow in May and transplantation is conducted in June. The rice is harvested in October. Seeds are soaked in 1 percent lime water for 48 hours before sowing. The seedling number per hectare is about 1.125 million. Tiger frogs are released into paddy fields at the end of June to early-July with a frog density of 25 000 per hectare. At this point, the frog body weight reaches about 20 g. To improve the survival rate of tiger frogs in paddy fields, they should be fed with fodder in the early stage, immediately after being released to the field. The fodder must be fresh and should be put on the feeding platform regularly, at short intervals, to improve the feeding efficiency. When the body weight of the tiger frog reaches about 50 g, they can totally rely on their predation activities without supplementary feeding. Light traps are used to trap tiger frogs for their harvest 10 days before harvesting the rice.

- **Weed control:** Artificial weed-pulling and the duckweed covering method can be used for weed control.
- **Fertilization:** Milk vetch is planted in the rice field during the winter period and turned down to the field as a green manure in May before rice transplantation. The average nitrogen requirement of rice is 120–135 kg N per hectare. Using a basal fertilizer in forms of 1 500 kg per hectare of rapeseed cake (or other organic fertilizer) is recommended. The fertilizer rate used in the tillering stage is 2 250 kg per hectare of rapeseed cake, applied 10–15 days after transplantation. Fertilizer use in the panicle emerging stage is only applied if symptoms of nutrition deficiency appear. All fertilizer should be applied before the flowering stage.
- **Irrigation:** From transplanting to the mid-tillering stage, shallow water should be kept at 2–3 cm depth. It is recommended to drain the fields twice during the late-tillering stage. A shallow water depth should be kept when the rice is at the booting stage. When rice is at its heading and flowering stage, alternating wet and dry conditions is recommended. The paddy field should be kept dry from 10 days before the rice harvest.
- **Pest control:** It is recommended to use agronomic, biological and other integrated methods to prevent and control rice pests. A suitable fertilization and irrigation scheme can help rice to grow vigorously and strongly to resist many diseases and insect pests. Frogs and other natural enemies in the rice field can prey on many insect pests. In case of pest outbreak, pesticides made from plants and micro-organisms such as matrine, azadirachtin and microbial BT could be considered.

7.2 TYPICAL CASES AND BENEFIT ANALYSIS

A summary of the first pilot area for the rice-frog system in Qingpu district, Shanghai and the background of Zizaiyuan Agricultural Development Co. Ltd. are included here for reference. Qingpu modern agricultural park now has an area of 17.07 km^2 with an arable land area of 9.6 km^2. Rice is the dominant crop with one rice crop produced per year. The climate is subtropical monsoon with a mean annual air temperature of 15.5 °C and a mean annual precipitation of 1 200 mm. The average annual sunshine is 1960.7 hours, mean relative humidity is 75 percent, and the soil pH value is 6.8. Qingpu District has flat terrain, a high groundwater level, mild climate, abundant sunshine, four distinct seasons and abundant rainfall. Many large fresh water lakes provide abundant water resources for the development of integrated rice-frog ecosystems. Shanghai Zizaiyuan Agricultural Development Co. Ltd. is located in Qingpu modern agricultural park with 467 ha of green frog rice paddy fields and 20 ha of organic rice paddy fields. The integrated rice-frog ecosystem has been extended to other production bases of the company around China. For example, there are 667 ha of production based in Heilongjiang Province and 70 ha of production in Yunnan Province, using the rice-frog co-culture technique. Organic frog rice passed the organic certification in June 2010 and green frog rice passed the national GAP certification in June 2011.

TABLE 7.1 The effects of reducing pesticide in rice-frog co-culture systems

TREATMENT	NUMBER PESTICIDE SPRAYS	PESTICIDE REDUCTION (%)	PESTICIDE REDUCED (g/ha	GRAIN YIELD (kg/ha)	INCOME (10^4 Yuan/ha)	COST (104 Yuan/ha)	INCOME/ COST
Ecology rice-frog	0	100	2 971.5	6 817.5	23.87	1.65	14:1
Organic rice-frog	4	55.5	1 648.5	5 625.0	19.69	2.23	9:1
Green rice-frog	5	44.4	1 318.5	6 750.0	14.18	2.25	6:1
Conventional rice	9	0	0	7 725.0	6.50	1.23	5:1

Source: Cao Linkui and Zhang Huanlin (2016)

TABLE 7.2 Analysis of yield and economic benefits of "frog rice" in 2015

TREATMENT	GRAIN YIELD (kg/ ha)	RICE YIELD (kg/ ha)	RICE PRICE (Yuan/kg)	OUTPUT (104 Yuan/ha)	NET PROFITS (10^4 Yuan /ha)	AREA (ha)
Green frog rice	7 350	4 410	32	14.1	9.6	467
Organic frog rice	7 650	4 667	150	70.0	51.3	20

Source: Cao Linkui and Zhang Huanlin (2016)

The result of a field experiment with different pesticide treatments showed that the rice-frog co-culture system can reduce pesticide use while significantly increasing income and the income / cost ratio (Table 7.1). The output values of green and organic "frog-rice" in the demonstration base of Shanghai Zizaiyuan Agricultural Development Co. Ltd. in 2015 reached 141 000 Yuan per hectare and 700 000 Yuan per hectare, respectively. The output values are much higher than that of conventional paddy field rice (Table 7.2). Reducing or eliminating chemical pesticide and fertilizer inputs can protect the ecological environment of the rice fields by reducing agricultural non-point source pollution, while also ensuring the production of safe and high quality frog rice, which has a higher price. In summary, the integrated rice-frog system significantly improves ecological and economic outcomes.

The extension of the rice-frog system can also have a significant social impact. In early-spring 2015, in Suibin County, Heilongjiang Province, 80 000 pairs of frogs were released in the 13 000 hectares of paddy field in this county. In September, farmers began to catch frogs and sell them to the farmers' cooperative at a price of 8 Yuan per kg. One farmer caught about 125 kg of frog and managed to earn about 1 000 Yuan in one night. The farmers were happy, because they could earn the extra money without any investment. This also reduced the need for and cost of buying pesticides. The investment in frogs was organized by the farmers' cooperative working with a company that sells frogs and high-quality green rice. This relationship of company-cooperative-farmers created a win-win-win situation for all parties (Wu Yukun, 2015).

Integrated rice-frog ecosystems are low-input, high-yield agro-ecosystems. They also reduce energy consumption. The integrated rice-frog co-culture system can be applied in all rice cropping areas in China. Other single or double rice cropping areas around the world can also refer to the relevant technical standards to develop their own integrated rice-frog systems. The integrated rice-frog co-culture is suitable for organic rice production, and has a broad application and marketing potential.

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PHOTO In the next page: Terrace in Yuanyang, Yunnan to show the landscape arrangement

METHOD 8

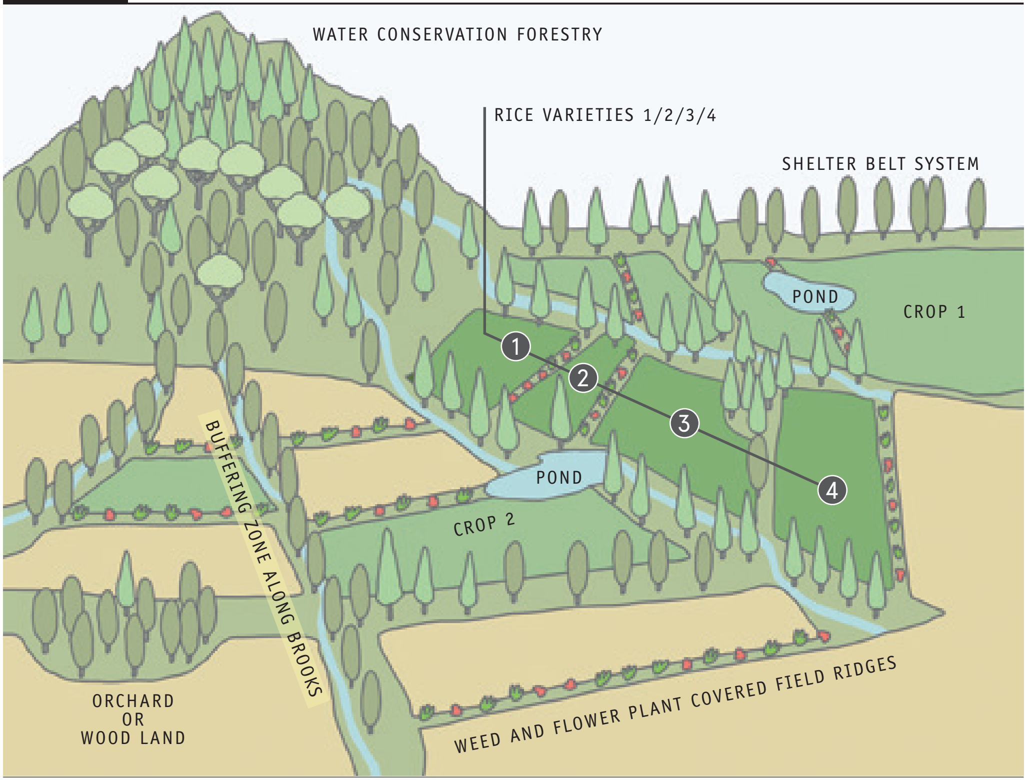
BIODIVERSITY LANDSCAPE ARRANGEMENT FOR RICE PRODUCTION

- METHODS FOR BIODIVERSITY ARRANGEMENT IN A SMALL WATERSHED
- TYPICAL CASES AND BENEFIT ANALYSIS

Biodiversity use in rice production is not only confined to the paddy field, but is also closely related to the landscape environment where the paddy field is located. The influence of the landscape on rice production includes many factors. The distance of the rice field to factory or mining sites will affect the air quality and water quality of the rice field. The distance of the rice field from cities or towns may affect its accessibility to markets and the number of visitors. Mountains and hills within the same watershed may affect the quality and quantity of the water resources of the rice field. The natural vegetation and different habitats surrounding the rice field may by home to many birds, spiders, frogs and other animals that interact with animals in the rice field. Even other crops close to rice field may have an effect on rice production by competing for water resources, reducing food resources for rice pests, or providing plant residues as compost. Therefore, it is important to have a suitable landscape arrangement for sustainable rice production. In this section, the biodiversity landscape arrangement method used in rice production areas is introduced.

A large watershed could cut across several countries or several regions of a country. The landscape arrangement of such a watershed should be the task of development planning of a nation or local government. However, small watersheds usually sit within the management of a rural community such as one or several villages, or even by one or a few farming households. Biodiversity arrangement in this type of small watershed with rice production is feasible and an important aspect for sustainable agriculture development.

FIGURE 8.1 The concept of biodiversity arrangement in a small watershed with rice production



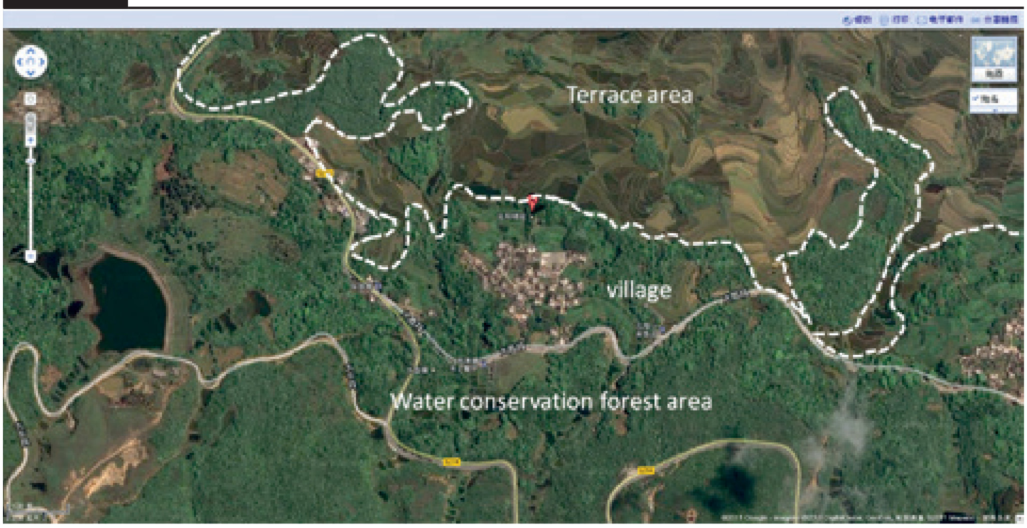
Source: Adapted from Luo Shiming

8.1 METHODS FOR BIODIVERSITY ARRANGEMENT IN A SMALL WATERSHED

Methods for biodiversity arrangement in a small watershed with rice production include managing the proportion of water conservation vegetation to the cropping area, the perennial vegetation on the slopes and around the field, vegetation along streams, biological check dams on the slopes, vegetation arrangements in field ridges, crop diversity arrangements in the watershed, and the diversity of rice varieties in the rice field (Fig. 8.1).

PROPORTION OF WATER CONSERVATION VEGETATION AND CROPPING AREA

FIGURE 8.2 Satellite image of Hani terrace in Yuanyan, Yunnan Province



Notice that the terrace area is located in the lower site (upper right) and large forest area (lower left) has been preserved to ensure stable water supply in the watershed

Source: Image from Google Earth, line and character added by Luo Shiming

In a small watershed, water resources are produced within the upper part of the watershed, to be utilized in the lower part to sustain the daily life of the people, and industrial and agricultural production in the area. Sustainable production practices and lifestyles are vital to ensure the balance of water provision and demand. The suitable proportion of water conservation forest within a watershed depends upon the local precipitation, population density, scale of industry and the possibility of alternative water resources. As the rule of thumb, the forest area should be kept within 40–70 percent on the upper part of the watershed. In many cases, the drive to increase agricultural production, timber and economic returns within a short period has greatly reduced or even destroyed the conservation forest before the symptoms of water shortage appeared.

In recent years, climate change around the world has led to an unstable precipitation from year-to-year. Water conservation forests in a watershed provide a buffering mechanism to deal with this climate fluctuation. A good example is in the traditional Hani terrace, Yunnan Province, which has been listed as World Important Agricultural Heritage System by FAO. The farmers in Yuanyan not only created large area of terrace fields in the mountainous area for rice production (up to an altitude of about 2 000 m), they also preserved a large area of natural forest on the upper part of mountains at an altitude of 2 000–4 000 m (Fig. 8.2). Even during the very dry years of 2009 and 2010, when the drought situation was very serious in southwest China, the Hani terrace could still maintain plenty of water to irrigate the rice terraces during the winter period and throughout the production cycle.

WOODLAND AND SHELTER BELT AROUND RICE FIELD

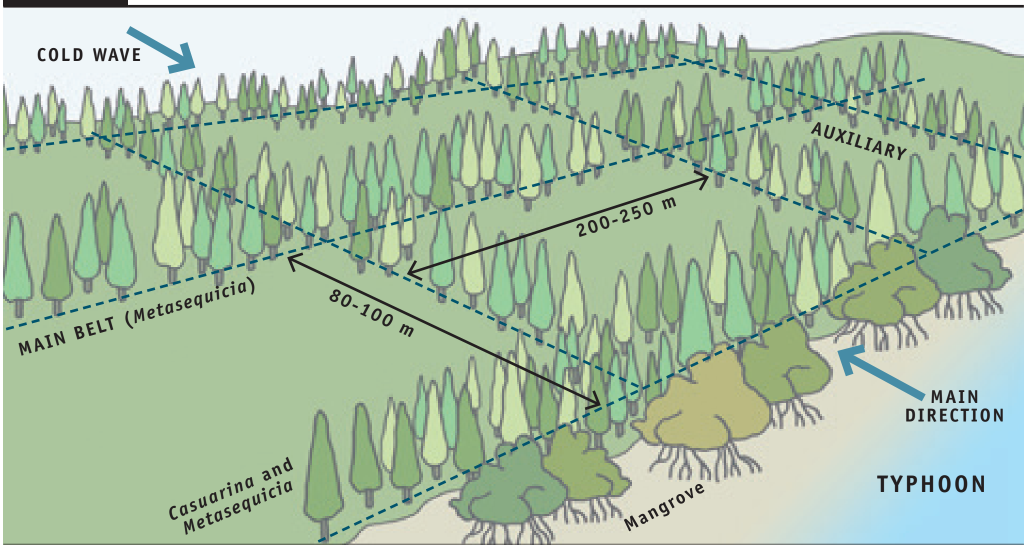
Woodlands and shelter belts around rice fields can provide habitat for wildlife and can stabilize the crop growing environment. Woodland can be arranged around the village, along the walkway and roads, and on transitional and fragmentary pieces of land. A wind break system can be installed along the coastline, and a shelter belt system can be constructed around rice fields. *Casuarina equisetifolia* is usually used for wind breaks in South China because of its characters such as wind resistance, saline alkali tolerance, draught tolerance and rapid growth (Fig. 8.3).

FIGURE 8.3 Shelter belt system using *Casuarina equisetifolia* to protect rice fields in Guangdong Province, China

Source: Luo Shiming

Villages and crop fields behind wind breaks can better withstand the strong winds caused by typhoons. Tree species such as *Casuarina equisetifolia*, *Metasequoia glyptostroboides*, and *Pinus elliottii* are usually used for shelter belt systems in South China because of their adaptation to the high water table and their high resistance to wind. The distance between the main belts of the shelter belt system, which are perpendicular to the main wind direction, should be about 10 times the tree height. The distance between the auxiliary belts can be 2–3 times the distance between main belts (Fig. 8.4). For the best protection result, the density of trees in the main belt should be adjusted to reduce wind speed to about 60–70 percent. A shelter belt system can reduce wind speed in the field and hence reduce the lodging rate of rice and other crops during the invasion of typhoons. Shelter belts can also increase the temperature and humidity during the early-spring and late-autumn periods when cold waves blow from the north.

FIGURE 8.4 Windbreak system along the coast and shelter belt system within fields



Source: Adapted from Luo Shiming

VEGETATION AND ANIMALS ALONG AND INSIDE STREAMS AND PONDS

Vegetation along the banks of streams, rivers, brooks and around ponds, lakes and wetlands can prevent surface pollutants from entering the water system by interception and absorption. They can also provide habitat for wildlife that can control pests in paddy fields. Aquatic plant species, including submerging plants, emergent plants and floating plants inside streams and ponds, can regulate water quality through pollutant detention, nutrition absorption and oxygen generation. Plant species also provide habitat for aquatic animals, and provide energy and nutrition for complicated food webs. Artificial wetlands can be constructed to purify drainage water.

Artificial irrigation and drainage channels can be developed into ecological ditches by introducing aquatic plants for pollution control. Animals such as frogs, eels and loaches that used to occur naturally in the aquatic environment can be re-introduced to these water bodies. They can spread from the water body to the adjacent rice field and prey on rice insect pests.

PLANTS IN THE RICE FIELD RIDGE

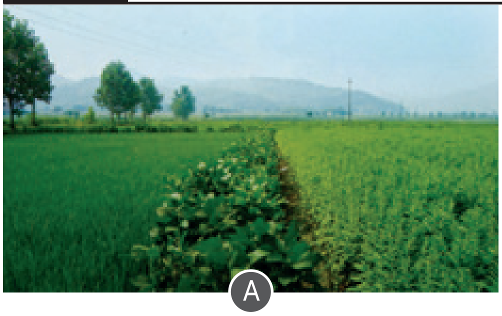
FIGURE 8.5 Flowers in the field ditch attract beneficial insects in Zhejiang Province

Beneficial insects identified by red arrows:
A: *Ranunculus ternatus* Thunb. attracts a bee of *Nomia* sp.
B: Aphid wasp in *Picris hieracioides* plant.
C: *Rosa bracteata* Wendl. attracts a bee.
D: *Lactuca indica* L. attracts bees of *Nomia* sp.

Source: Zhu Zengrong (2012)

Because plants in the field ridge are located close to the rice field, chemical components released from flowers, fruit and leaves of these plants can repel or attract insects and birds away from or towards the adjacent rice field. Research in China (Zhu Zengrong, 2012) indicates that vetiver grass (*Vetiveria zizanioides* L.) can effectively attract adult rice borers, but the rice borer larvae cannot develop normally on the vetiver plant and die at the fourth instar stage. For this reason, it is recommended to grow vetiver grass as trap plant to control rice plant borers. It was also observed that some flowering plants can attract beneficial insects in the rice growing region of Zhejiang Province, China. For example *Ranunculus ternatus* Thunb., *Rosa bracteata* Wendl., and *Lactuca indica* L. can attracted bees of *Nomia* sp. *Picris hieracioides* plants provided habitat for aphid wasps, and honey from sesame flowers can extend the life span of parasitic wasps (Zhu Zengrong, 2012) (Fig. 8.5). Therefore, planting these plant species on the ridge of rice fields can help to control insect pests of rice (Fig. 8.6).

FIGURE 8.6 **Soybean (A) and sesame (B) planted in the field ridge for pest control**



Sesame has a repelling effect on aphids and its honey is beneficial for parasitic wasps (pest natural enemies).

Source: Zhu Zengrong (2012)

CROP ARRANGEMENT IN RICE PRODUCTION REGIONS

Large rice production regions with only a few rice varieties are more susceptible to the outbreak of rice diseases and insect pests. Alternatively, a mosaic arrangement with different crops and different rice varieties in a watershed will help to control the outbreak of rice pests (Fig. 8.7). Different crops other than rice could reduce the food resources of pests and form a physical barrier to prevent the spread of pests. Those crops may also provide an alternative habitat for natural enemies of the rice pests. Diversified rice varieties with different genetic backgrounds, and differences in stress resistance, quality and taste, provide a number of benefits at the landscape scale. They can help to reduce the risk of large scale outbreaks of certain pests, and can better meet the diversified local market demands for taste and nutrition.

FIGURE 8.7 **An aquatic vegetable *Zizania latifolia* (A) is arranged within rice fields* (B) to form a mosaic crop structure**

* tall plant in the main picture.

Source: Zhu Zengrong (2012)

8.2 TYPICAL CASES AND BENEFIT ANALYSIS

An organic agricultural base is located in Ruiyun village of Putian city, Fujian province, Southeast China. In this agroecological system of rice production, the principles of ecology and ecological economics are applied to effectively manage each phase of rice production. In this process, farmers strive to improve economic returns, while at the same time, protecting and improving the ecological environment of the rice paddy field. The system prohibits the use of synthetic compounds such as fertilizers, pesticides and herbicides, greatly reducing dependence on external inputs, and helping to protect the paddy soil and its quality. The agroecological strategy to protect the environmental safety of paddy fields and enhance agricultural production takes inspiration from the laws of nature, by applying ecological principles. For example, pest control is provided by harnessing and coordinating biodiversity in the paddy field agro-ecosystem, in order to stabilize the system and protect the surrounding environment.

Water purification technology for irrigation

Water purification is a key step to keep irrigation water safe in the system. Maintaining a high quality of irrigation water is essential for good rice production and to ensure food safety. A number of aquatic plants can be used surrounding the paddy fields to purify the irrigation water through phyto-remediation techniques. The ideal plants should be adapted to the local climate, have a powerful purification capacity, long growth duration, a well-developed root system, high disease resistance, and should be tolerant to flooding and easy to manage. By surveying the local hydrology, landforms and climate conditions, it was decided to transplant endemic reeds (*Phragmites communis* Trin.), calamus (*Acorus calamus* L.), and rushes (*Juncus effusus* L.) and other local aquatic plants to build a healthy aquatic plant purification ecosystem located in Ruiyun Village (Fig. 8.8). According to water testing samples from the paddy field after purification by aquatic plants, all determined indexes of the sampled water reached the Chinese national green standards for irrigation water.

FIGURE 8.8 Aquatic plant purification system for the brook running towards the rice field in Ruiyun Village, Fujian Province

Source: Luo Shiming

THE TECHNOLOGY FOR IMPROVING SOIL FERTILITY

The long-term application of chemical fertilizer has been led to many problems such as soil compaction and decreased organic component contents, thereby affecting the health and biodiversity of the soil microbial community. At the same time, if chemical fertilizers are contaminated by heavy metals they may enter the soil and be taken up by the rice plant. In the agroecological rice production process, the use of chemical fertilizers are replaced by interactions between organisms and agronomic measures to maintain and improve soil fertility.

In Ruiyun Village, seeds of Chinese milk vetch (22.5 kg seeds per ha) or rape crop (7.5 kg seeds per ha) were sown in winter (Fig. 8.9). Then, these plants were cut and ploughed into the soil as green manures, using a ploughing machine in March. This method can effectively increase the content of organic matter in the soil. Half a month after rice seedlings were transplanted, 15 kg of loaches per hectare were introduced into the rice field (1 kg was equivalent to 200 – 240 individuals). The activity of mud loaches can accelerate the decomposition of green manure and help to improve soil fertility.

FIGURE 8.9 **The appearance of milk vetch (A) and rape grown (B) in rice fields during the winter period in Ruiyun Village, Fujian Province***

* The winter crops are ready to be ploughed into the soil as green manure

Source: Lin Wenxiong

Optimized planting arrangements for rice cultivar diversity

Large-scale cultivation of rice varieties with almost the same genetic backgrounds, not only reduces the diversity of the rice ecosystem, but also leads to decreased resistance of rice to diseases and pests, increasing the risk of epidemics. To reduce this risk in Ruiyan Village, different rice varieties with genetic backgrounds suitable for the local environmental conditions were screened. Based on the screening results, a mixed cultivation of different rice varieties was implemented to increase the diversity of rice plantations. This cultivation method can effectively prevent the outbreak of rice diseases, in particular rice blast. Results indicated that the mixed cultivation method reduced the rate of rice blast disease by 81.1–98.6 percent. Resistance to lodging also increased and yields increased by 6.5–9.7 percent compared with conventional cultivation using a single cultivar.

For regions where the temperature is sufficient for one crop of rice per year, but insufficient for two, such as in Ruiyun Village and many other places located south of Yangzi River and north of Nanling Mountain, it is highly recommended to develop a ratoon rice system. Ratoon rice has many advantages including short growth period, high daily productivity and good rice quality. It is a seed-saving, labour-saving, water-saving, low-cost and high economic return practice. This ratoon rice system can also prevent attack by rice gall midge and other pests. In Ruiyan Village, the diversity of rice cultivars in a given planting area was continued during the ratoon rice stage (Fig. 8.10). This system allowed farmers to greatly reduce their pesticide application rates in rice fields, while obtaining higher economic and ecological returns. The total rice harvest in a year was 12 750 kg per hectare, of which the grain yield from ratooning rice was 5 250 kg per hectare. This farming practice effectively improved the income of farmers.

FIGURE 8.10 An aerial view of ratoon rice in Ruiyun Village*

* The different rice varieties used in this village can be identified by their colours

Source: Lin Wenxiong

Agroecological pest control

The conventional process of intensification of agricultural production has greatly simplified field ecosystems, leading to an ecological imbalance and higher incidences of disease, pest and weed infections. Paradoxically, the excessive use of pesticides in this model has had an adverse effect on pest control, placing great selective pressure on pests and leading to resistant biotypes that are tolerant to pesticide treatments, and ultimately, more devastating pest outbreaks. Previous studies (IPES-Food, 2016) also suggest that the abuse of pesticides for pest control has decreased biodiversity in field ecosystems by disturbing the natural balance between pests and their natural enemies, disrupting the homeostasis of the agro-ecosystem and reducing its natural pest control functions.

Many studies (Zhu Zengrong, 2012; Luo Shiming, 2009) have shown that the protection of the agro-ecological environment, combined with the re-establishment of biodiversity in the field, is an effective way to control rice pests and diseases. Such an agroecological strategy was implemented in Ruiyun Village, utilising ecological control measures and protecting beneficial organisms including natural enemies in paddy fields. In the Ruiyun Village case study there are two habitats in the rice paddy agro-ecosystem, including the non-rice habitat and the rice habitat. The non-rice habitat provides the main shelter for the natural enemies of rice pests, and plays a central role in promoting and regulating the development of the natural enemy community against the pests.

In the non-rice habitat, both the pests and their natural enemies seek alternative hosts to replenish their nutrition and escape from the adverse environmental conditions. Plants in the non-crop habitats also affect pest activity by releasing allelochemicals to attract beneficial insects. Paddy field ridges are the most common non-crop habitat. Planting soybeans, sesame, chrysanthemum and other crops or plants on the field ridges help to establish and develop the arthropod community including the natural enemies of rice insect pests.

In this case study, field management practices that were adopted included the use of a mixed trapping plantation with vetiver grass (Fig. 8.11), coreopsis plants (Fig. 8.12), and soybean, planted together on the ridge. Insect-attracting plants such as vetiver grass produce volatile compounds. These allelochemicals play an important role in the trophic level interactions between plant-insect-natural enemies. The volatile compounds from the host plant have a strong attractiveness to pests, which aggregate on the plants. They can influence insect behaviour including chemotaxis, mating and oviposition. In this way, they can disturb the life cycle of insect pests and reduce the damage caused to rice plants. Vetiver grass in the field ridge can induce rice stem borers to lay a large number of eggs on the plants. The active ingredients of vetiver grass poison the larvae of stem borers, preventing them from completing their normal life cycle. Meanwhile, nectar plants such as cosmoses and legumes provide a more suitable microenvironment, including food and alternative host or prey resources for natural enemy insects. In particular, nectar plants can increase the diversity and fitness of natural enemies.

FIGURE 8.11 **Vetiver grass (*Vetiveria zizanioides*) (left) is planted next to the rice field (right) in Ruiyun Village to attract and trap the rice borer**

Source: Lin Wenxiong

FIGURE 8.12 Coreopsis planted on the ridge of a rice field to attract beneficial insects in Ruiyun Village

Source: Lin Wenxiong

FIGURE 8.13 A bird's eye view of constructed wetlands within a rice field in Ruiyun Village*

* The wetlands have become a local biodiversity centre

Source: Lin Wenxiong


© Lin Wenxiong

It has also been important to make full use of the unexploited grassland and marshes around paddy fields. Small-scale wetland ecosystem (Fig. 8.13) have been re-established around the rice fields by introducing frogs. As outlined in the discussion on the rice-frog co-cultivation system, frogs and other aquatic animals can effectively control rice pests. Local suitable herbaceous grass species have also been re-introduced into the wetlands. Through investigation, it has been discovered that the artificial wetland can provide sufficient and stable habitat for small mammals, birds and the natural enemies of insect pests such as ground beetles, spiders, rove beetles, etc. The abundant herbaceous plants in the artificial wetland can provide plenty of food to attract parasitic wasps and bumblebees to forage and multiply. Moreover, wetlands can also act as a temporary shelter for natural enemies of pests to move from the rice field during the gap period between rice crops, thereby preserving the diversity of natural enemies.

Benefit analysis

For Ruiyun Village, the use of agroecological method used in rice cultivation has increased the economic, ecological and environmental benefits.

Environment benefits: The diversity of the rice paddy agro-ecosystem was significantly improved. An investigation of weed species in the paddy field ridge and artificial wetland found that there were 42 weed species in the organic rice field, while only 6 weed species surrounding the traditional rice fields. The diversified primary producers (plants) in ecosystem benefits the diversity of other organisms along the food chain trophic layers such as those rely on plants and those rely on other animals. Likewise, the numbers of frogs, spiders and earthworms in the ecological agriculture farmland were significantly higher than that of the traditional farmland.

In 2015, an outbreak of banded sclerotial blight occurred in the traditional rice planting area. However, the demonstration site for agroecological rice production showed effective prevention and control over the outbreak and spread of pests and diseases without application of any pesticides (Fig. 8.14). The agroecological method could effectively improve soil fertility and quality. The organic matter content, total nitrogen content and total potassium content in the agroecology field increased by 69, 75 and 29.9 percent, respectively. The content of heavy metals including cadmium, arsenic, and lead was reduced by 40.4, 22.3 and 36.5 percent, respectively. Rice quality in the ecological agriculture production mode was significantly improved and met the national green food standards.

Socio-ecological benefits: Local farmers have an increased awareness and exposure to concepts of ecological agriculture through technical training. This growing agroecological movement resulted in the gradual change of farming practices from an unsustainable approach to more sustainable agroecological methods. This new approach has not only improved the surrounding environment, but also motivated people to participate in and further promote the agroecological movement in their rice production, sale and consumption activities. These type of practices applied in rice production have also been extended to the production of vegetables, fruits, and Chinese herbal medicinal plants. Agroecology has significantly improved the agro-environment and living conditions of the residents in the area.

Socio-economic benefits: Organic cultivation methods have produced good quality rice, which meets the standard of green food production, and is able to reach a higher value in markets than the traditional mode of production. Farmers' income from rice increased to 6 300 Yuan per hectare. Such good economic returns have aroused the enthusiasm of local farmers to expand agroecological rice production and increase efforts to restore biodiversity in the whole watershed.

FIGURE 8.14 The effect of different rice production methods on the appearance of rice in 2015

A: organic rice field with heathy rice plants.
B: traditional chemical method for rice production with serious pest damage.

Source: Lin Wenxiong

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PHOTO Rice-arrow head inter-cropping in Guangdong, China

THE 10 ELEMENTS OF AGROECOLOGY AND PRACTICAL EXAMPLES OF RICE PRODUCTION IN CHINA

> **INTRODUCTION**

> **THE 10 ELEMENTS APPLIED TO RICE AGROECOLOGICAL SYSTEMS**

9.1. INTRODUCTION

Agroecology addresses the challenges of sustainable and fair food systems by applying ecological concepts and principles to the design, development and maintenance of agro-food systems while taking into consideration the social and economic dimensions of those systems. Agroecology in China is based on the combination of the rich traditional agricultural knowledge with modern science and technology and is organized around three major aspects (Luo, 2016):

- **Sustainable landscape arrangement:** it focuses on the organization at watershed scale, including the spatial arrangement of forestry, farmland, fishponds, crop, livestock and non-agricultural species and the combination of different practices to ecologically minimize the degradation of ecosystems and preserve and restore their ecological functions.
- **Circular design of agro-ecosystems:** the aim is to reduce waste and nutrient, energy and material losses from agro-ecosystems. The design addresses five major cycles: crops residues, animal waste, household organic waste, waste from factories and carbon released to the atmosphere. It also refers to the efficient use of renewable sources of energy such as biogas or solar energy.
- **Biodiversity arrangement:** diversification is the cornerstone of efficient utilization of resources and control of pests, diseases and weeds based on the principles of ecology. Diversification includes different crop varieties, intercropping, rotation, crop and animal co-culture and spatial and temporal arrangement of various biological elements.

A framework of 10 Elements of Agroecology emanated from the FAO regional seminars. The 10 Elements are aligned with the Chinese principles among others (Figure 9.1). These 10 elements[1] cut across the environmental, social and economic aspects of sustainability. They are derived from the scientific work of authors such as Altieri (2002), Gliessman (2007) and Tittonell (2015), and reflect the outcomes of the global and regional processes facilitated by FAO on agroecology[2], including the contributions of governments, researchers, civil society and the private sector. The different elements can be identified in various configurations across a range of agroecological initiatives, practices, policies and programmes, depending on the local socio-ecological context. This section provides an overview to the 10 elements of agroecology, as illustrated by the practices and case studies of agroecological rice systems in China that are described in the previous chapters.

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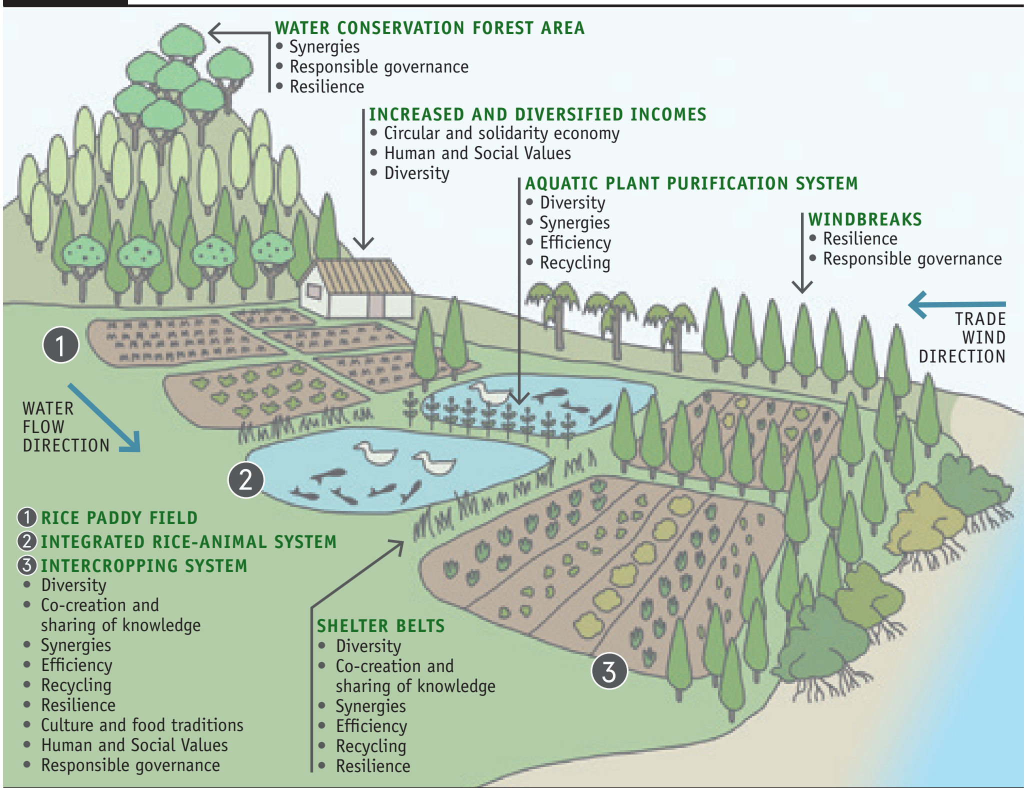
[1] More info: http://www.fao.org/agroecology/knowledge/10-elements/

[2] The first International Symposium on Agroecology for Food Security and Nutrition was held in Rome in September 2014. Since then, regional meetings have taken place in 2015: Brasilia, Brazil (June); Bangkok, Thailand (November); Dakar, Senegal (November); and 2016: Kunming, China (September); La Paz, Bolivia (September); Budapest, Hungary (November); Dakar, Senegal (December). In total, an estimated 1350 participants from at least 162 countries attended the international and regional meetings.

FIGURE 9.1 Multiple interaction among components in a watershed ecosystem producing rice in South China



Source: adapted from Luo Shiming

9.2. THE 10 ELEMENTS APPLIED TO RICE AGROECOLOGICAL SYSTEMS

DIVERSITY: Diversification is key to agroecological transitions to ensure food security and nutrition while conserving, protecting and enhancing natural resources

One of the most fundamental aspects of agroecological systems is diversification, which refers to the preservation and use of biodiversity at different spatial and temporal scales, from intercropping different varieties of the same crop to spatially arranging forest, farmland and urban land-use. A growing body of research and field experiences shows how increased diversity in agro-food systems reduces the risk of crop failure and dampens several shocks such as droughts, pests or climatic fluctuations.

PHOTO Terrace in Yuanyang, Yunan

In addition, a diversified system can improve crop yields, reduce the need for external inputs (like fertilizers and pesticides) and deliver higher incomes for farmers.

All those positive aspects of diversification is highlighted in the previous chapters:

» ***Intercropping.*** The spatial and temporal combination of same crop varieties or different species is highlighted in Methods 1 (“Intercropping of two rice varieties”) and 2 (“Rice intercropping with lotus”). In both cases, the benefits of increased diversity in the system include a very significant pest reduction (including rice blast, rice plant hoppers, leaf rollers and sheath blight), an important reduction on pesticide use and reduced need for chemical fertilizers. All those benefits happened while rice yields increased, total system output (in the rice-lotus system) augmented and economic output of the systems were higher than in their monoculture counterpart.

» ***Rotations.*** Integration of different crops at different moments in time constitutes the focus of Methods 3 (“Rice-rice-milk vetch rotation system”) and 4 (“Rice-rice-Azolla rotation system”). The integration of milk vetch (Astragalus sinicus) and Azolla sp. into rice cultivation reduce the need for chemical fertilization, increase the yield of rice and the economic output of the system. In the long run, those systems help to rebuild the soil organic matter content, the soil available nitrogen and soil microbial biomass. In addition, both the milk vetch and the Azolla can be used as feed for animal species, increasing the functional diversity of the systems.

» ***Animal integration.*** Another aspect of system diversification is the integration of crops and animal species, as seen in Methods 5 (“Rice-duck co-culture”), 6 (“Rice-fish co-culture”) and 7 (“Integrated rice-frog co-culture”). A more detailed description of the benefits is given under the “Synergies” section, given the nature of crop-animal interaction.

» ***Landscape diversity.*** The arrangement of diverse land-uses and its benefits are covered in Method 8 ("Biodiversity landscape arrangement for rice production"). As the chapter discusses, arranging and managing biodiversity for rice production is not confined within the paddy field, but goes further into the surrounding landscape. An adequate spatial disposition of woodlands, rice fields and other crop farms and urban areas is crucial for the ecological functions of the systems, including water provision, pest regulation and soil preservation. Other important aspects such as diverse food provisioning ("Culture and food traditions") or eco-tourism ("Circular and solidarity economy") are mentioned in the corresponding elements.

Diversity can be achieved in different ways in a food system, such as spatial and temporal diversity addressed in intercropping systems. Spatial diversity refers to more than one species and/or varieties are utilized at the same time, while temporal diversity refers to different species are used in different points in time or during different seasons. To ensure production and an appropriate land use, landscape approaches must be based on a wide range of diversity. Those approaches take into consideration both food production and the territorial dimension of diversity, while ensuring multiple ecosystem services by adopting agroecological approaches. Multiple studies and research have shown that diverse farming system have less crop damage, similar or increased yields, higher productivity and greater yield stability compared to monocultures (Frison *et al.*, 2011; Altieri *et al.*, 2015). Additionally, diverse cropping systems also lead to more diverse diets (Altieri 1999; Frison *et al.*, 2011). Modern mono-cropping farming systems appear to be highly vulnerable to the effects of a changing climate (Altieri *et al.*, 2015). On the other hand, diverse farming systems have the potential to mitigate climate change and increase resilience. In the case of climate change mitigation, for instance, trees and shrubs in agroforestry systems have demonstrated to sequester significant amounts of carbon in above- and below-ground biomass and in the soil (Jose and Bardhan, 2012; Chauhan, 2015).

CO-CREATION AND SHARING OF KNOWLEDGE: Agricultural innovations respond better to local challenges when they are co-created through participatory processes

Agroecology is knowledge-intensive. It requires the development of ecologic literacy and decision-making within the farming communities. The complementary combination of traditional knowledge and the advances in ecological research is a complex process that functions best when farmers have a real participation and say in it. Thus, horizontal knowledge co-creation, its sharing and protection are fundamental pieces of the agroecological transition of food systems. Formal and non-formal education plays a key role in the co-creation, promotion and innovation of agroecological body of knowledge.

The role of knowledge in agroecological systems is highlighted in some of the previous chapters:

» ***Methods inspired in traditional knowledge.*** Methods 5 ("Rice-duck co-culture system") and 6 ("Rice-fish co-culture system") are two examples of agroecological systems inspired and guided by traditional practices and knowledge. Both systems have a long history within Chinese agriculture and they deliver important benefits both to the environment and to the farmers. Current ecological knowledge allows a deeper understanding of the intricate relationships that occur in those valuable, traditional systems.

» ***Methods resulting from farmer experimentation.*** A singular case of innovation is described in Method 2 ("Rice intercropping with lotus"). The lotus farmers of Litang Town (Guangxi Region) started experimenting with rice-lotus intercropping as potential solution to avoid purchasing rice in the market. After several years of trial and error, they succeeded in establishing a system that provide them with lotus and rice. This innovation, which was entirely the result of their own experimentation and local knowledge of their fields, highlights the potential of shared, horizontal processes in agroecological innovation and development.

Kosaka and Shirahada (2013) called attention to the necessity of innovative and integrated solutions for achieving sustainability at different levels (social, economic an environmental). They argued that without a horizontal integration of different levels and sources of knowledge, the solutions will always be less innovative as fewer aspects and backgrounds are taking into consideration. Also, according to Laccarino (2003) traditional knowledge systems adopt a more holistic approach and do not separate observations into different disciplines as normally the scientific knowledge does. Furthermore, traditional knowledge systems do not analyze results based on a cause-effect approach, as in science, but rather as a holistic and integrated system (Freeman, 1992).

SYNERGIES: Building synergies enhances key functions across food systems, supporting production and multiple ecosystem services

A direct effect of diverse systems is the increased range of interactions between its components, including plants, soil organisms, animals and humans. That creates new relationships that simply could not exist in more simplified settings. By assembling crops, animals, trees and other factors in a particular spatial and/or temporal manner, the agro-ecosystem can develop and build its own capacity to enhance soil fertility, to naturally regulate pest occurrence and to improve crop productivity. A key aspect of this element is the focus on how diverse components of an agro-ecosystem, from individuals to entire landscapes, are organized in order to promote beneficial interactions and minimize detrimental effects.

Synergies arising from increased biodiversity in rice production are highlighted in:

» ***Intercropping.*** Method 1 ("Intercropping of two rice varieties") describes how the combination of two different varieties of rice creates new, beneficial dynamics in the system. Changes in the microclimate in the paddy field creates a less suitable environment for the rice blast, reducing its impact and spread. Also, physical characteristics caused by the rice varieties' different heights help containing the spread of a particular pathogen.

» ***Rotations.*** The importance of synergies in crop rotations is mentioned in Methods 3 ("Rice-rice-milk vetch rotation system") and 4 ("Rice-rice-*Azolla* rotation system"). In addition to increased diversity, the rotation of rice and other species can bring beneficial effects, exemplified in those cases by the potential use of both the milk vetch and the *Azolla* as animal feed or, in the case of the milk vetch, to sustain honey production as bees feed on the flowers.

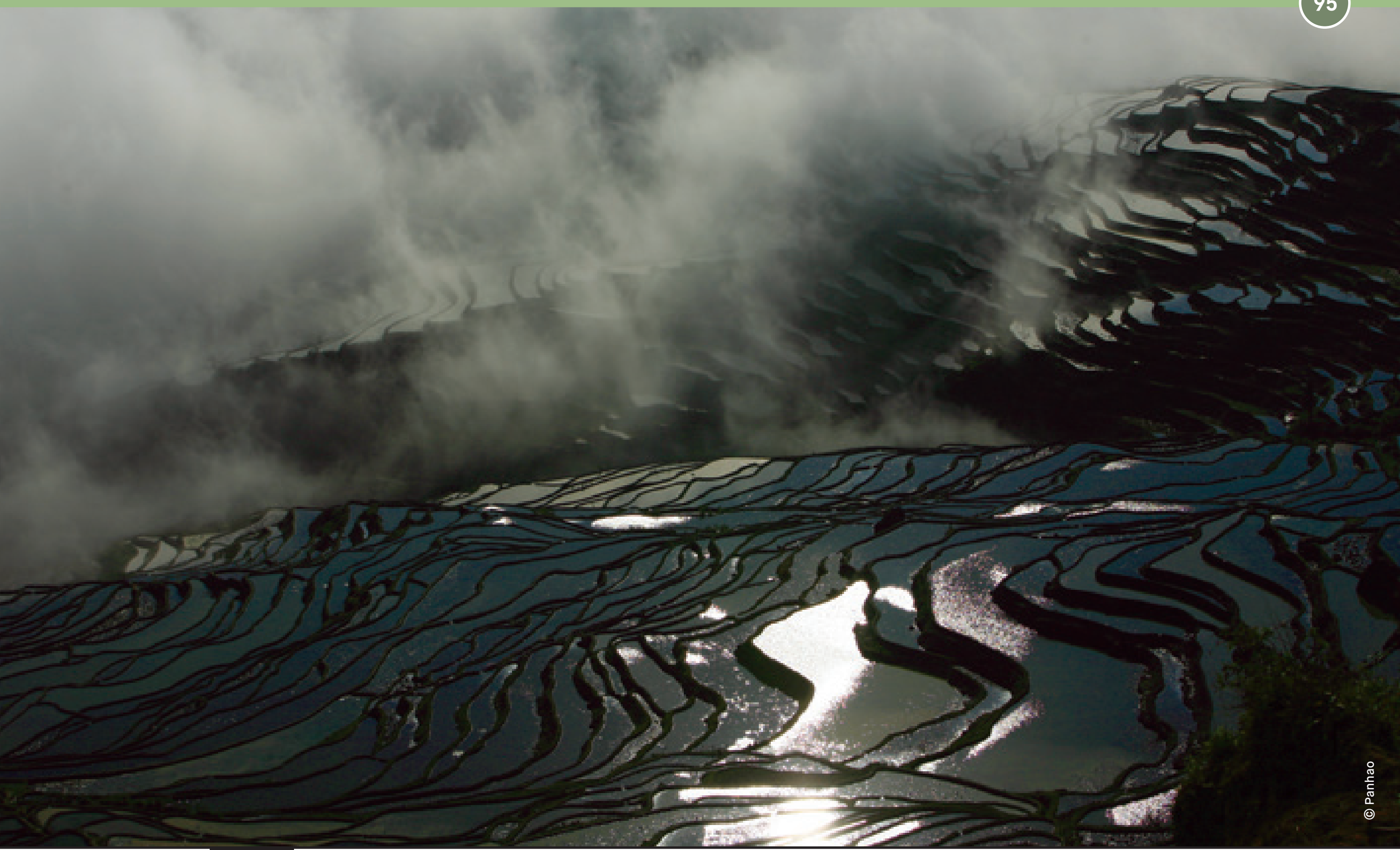


PHOTO Terrace in Yuanyang, Yunan

- ***Animal integration.*** Integrating animals into rice production generates a wide range of beneficial synergies that are not present in monoculture fields, as shown by Methods 5 ("Rice-duck co-culture"), 6 ("Rice-fish co-culture") and 7 ("Integrated rice-frog co-culture"). In all cases, integrated systems see the spread, occurrence and severity of pests significantly reduced due to the different animal species feeding on the pest organisms or interfering with their activities. Another beneficial aspect of integration is the greater efficiency of the system, as they provide higher and more diverse outputs (carbohydrates from the rice and quality protein from the animal species) without needing to reclaim additional land. That is closely related to yet other positive aspects: increased yields and economic output, improved nutrition and reduced need for fertilizers and pesticides.

Synergies can be addressed in food system in different ways. Numerous research has been conducted to study synergies within rice integrated systems with fish, ducks and/or azolla. Integrated rice systems maintain or increase productivity and rice yields and improve diet diversity compared to rice monocropping (Cagauan *et al.*, 2000; Hossain *et al.*, 2005; Cheng *et al.*, 2015; Xie *et al.*, 2011). Less chemical nitrogenous fertilizers are needed to obtain the same yields as rice monocultures (Cagauan *et al.*, 2000; Xie *et al.*, 2011; Hu *et al.*, 2016). This can be explained by the release of unconsumed nitrogen in fish feed in the system (Xie *et al.*, 2011). Also the movement of fish and ducks in the rice field enhances aeration of the water, increasing the availability of

PHOTO Landscape of rice, mulberry and forestry

nutrients (Berg *et al.*, 2012), and aeration of the soil, which prevents buildup of harmful gases in the rhizosphere (Hossain *et al.* 2005). In addition, feces of ducks provide the essential nutrients for the rice crop and increases soil health (Cagauan *et al.*, 2000; Fan, 2012). In the context of climate change mitigation and adaptation, rice provides shade to the fish and regulates the temperature of the water during warm seasons (Frei and Becker, 2005; Xie *et al.*, 2011), which could increase the resilience of the system. In addition, Tilman *et al.* (2002) stressed that rice paddy systems are one of the main agricultural contributors to greenhouse gas emissions through high levels of emissions of methane. Rice-duck integrated agriculture has shown to reduce both nitrous oxide as well as methane emissions from the paddy field (Huang *et al.*, 2005; Li *et al.*, 2009).

EFFICIENCY: Innovative agroecological practices produce more using less external resources

Improving the use of natural resources within agro-ecosystems reduces or eliminates the need for external inputs and the extent of the negative aspects of their use such as nutrient leakages that cause severe pollution. Additionally, this reduces production costs. Numerous agricultural technologies and practices have been developed to address efficiency as a result of much conventional agricultural research. This may be a first step in a transition to agroecological systems, particularly when used to enhance biological processes.

Several examples of how improved efficiency is beneficial for different aspects of rice production are given in the previous chapters and are highlighted here:

- ***Efficiency and reduced/eliminate external inputs.*** All Methods covered in this book report significant reductions or the complete elimination of the need for external inputs of chemical fertilizers and pesticides. Although the specifics vary among systems, the fundamental idea of enhancing biological processes allows a better use the system's natural resources: biological nitrogen fixation, natural pest predation or proper temporal species arrangement are some mechanisms by which pesticides and fertilizers are less needed to maintain agricultural production. This, in turn, has other environmental and socio-economic benefits, such as reduced nonpoint source pollution, liberation of economic resources due to decreased need for external purchases and safer and healthier food. Also can improve the profitability of the system.
- ***Efficient use of natural resources.*** Methods 5, 6 and 7 are interesting examples of efficiency in natural resources use. Thanks to the integration of crops and animals, different outputs (in that case, cereals and animal protein) are generated within the same area, eliminating the need for additional agricultural land when compared to systems providing the same outputs separately. These systems also make a more efficient use of other natural resources as water, once with the same amount of aquatic animal protein and crops can be produced.

Nitrogen inputs contribute to emissions of nitrous oxide, about 280 times more powerful greenhouse gas than CO_2 (Tilman *et al.*, 2002). Therefore, in the context of climate change, an increase in nutrient use efficiency and a reduction of nitrogenous fertilizers use are crucial to reduce nitrous oxide emissions (Scialabba and Müller-Lindenlauf, 2010).

In addition, improved water use efficiency can increase the resilience of farming systems to (severe) drought and reduced rainfall (Power, 2010). In a legume intercropping system with a cereal crop such as maize, the legume crop fixes nitrogen from the air while the cereal uses soil nitrogen. Thus, the legume effectively increases the soil nitrogen content when it is incorporated into the soil. Another example of increased efficiency through intercropping techniques occurs when using crop varieties with different rooting depths or different sowing times. This avoids competition over resources and plants are able to use a larger soil volume with nutrients and water at different depths, including the use of residual soil nitrogen (Hauggaard-Nielsen and Jensen, 2005; Li *et al.*, 2007; Kremen and Miles, 2012; Gaba *et al.*, 2015).

RECYCLING: more recycling means agricultural production with lower economic and environmental costs

The enhancement of nutrient flow and cycling within the system through biological means is a key element of agroecology. Above- and below-ground biodiversity drive the biogeochemical processes that recycle nutrients in the soil profile and facilitating its availability. Recycling occurs at multiple spatial scales, and it can be augmented both at farm and landscape levels through different practices, from intercropping different species in the same field to integrating crops and livestock. In addition, recycling presents important social and economic aspects.

Examples of nutrient recycling and its benefits to the agro-ecosystems have been discussed in previous chapters:

» ***Recycling of nutrients, biomass and energy.*** Methods 3 ("Rice-rice-milk vetch rotation system"), 4 ("Rice-rice-Azolla rotation system"), 5 ("Rice-duck co-culture system") and 6 ("Rice-fish co-culture system") depict how biodiversity enhances recycling within the agro-ecosystems. Rotation systems incorporate nutrients into the system that are cycled back into the crops, greatly reducing the need for external fertilizers. Co-culture practices, on the other hand, foster nutrient and biomass recycling due to increased trophic interactions between rice plants, insects, animal species and soil microbiota.

» ***Recycling and circular design.*** The element of recycling is closely linked to the circular design principle of Chinese agroecology, as both aim at reusing nutrients, energy and biomass within the system based on biological processes.

Recycling of crop residues (such as straw) and green manure by incorporation or retaining them in the field after harvest has shown positive effects on soil quality such as nitrogen content, soil organic matter and soil organic carbon contents, recycling of nutrients and soil moisture retention (Dolan *et al.*, 2006; Dahlin, 2011; Turmel *et al.*, 2015). According to Altieri *et al.* (2015) "soil organic matter (SOM) and its management are at the heart of creating healthy soils with an active biological activity and good physical and chemical characteristics". For instance, an increase in soil organic matter has a positive effect on arbuscular mycorrhizal (AM) fungi, which is a beneficial soil microorganisms essential for plant productivity and soil health (e.g. for nutrient transfer, AM fungi increases nutrient uptake) (Gianinazzi *et al.*, 2010; Altieri *et al.*, 2015).

RESILIENCE: Enhanced resilience of people, communities and ecosystems is key to sustainable food and agricultural systems

Natural ecosystems have the ability to self-regulate and resist in front of external pressures. Resilient systems have a greater capacity to recover from disturbances including extreme weather events such as drought, floods or hurricanes, and to resist pest and disease attack. Rather than focusing on controlling single pest, agroecology aims at facilitating and enhancing a complex community of organisms that reduce the severity and occurrence of pest outbreaks to a managing level. The question of resilience and its role in regulating external pressures including pest occurrence and severity has been described in previous chapters:

» ***Agroecological pest control.*** Several Methods described previously – 1 ("Intercropping of two rice varieties"), 2 ("Rice intercropping with louts"), 5 ("Rice-duck co-culture system"), 6 ("Rice-fish co-culture system"), 7 ("Integrated rice-frog co-culture system") and 8 ("Biodiversity landscape arrangement for rice") point out how increasing the diversity of the system with the appropriate species and their combination can greatly reduce or virtually eliminate the occurrence of common rice pests and diseases such as rice blast, sheath blight or apple snails.

PHOTO Diversified rice and vegetable

- » ***Agroecological methods to increase soil health.*** Methods 3 ("Rice-rice-milk vetch rotation system") and 4 ("Rice-rice-Azolla rotation system") describe how soil health can be restored and enhanced using biodiversity. In both cases, the use of nitrogen fixating species and their incorporation into the soil profile foster soil microbiota biomass and activity and increase the organic matter content.

An example of balanced system is System of Rice Intensification (SRI). SRI is a set of soil, plant, water and nutrient practices that aims at improving production while reducing water and agrochemical inputs and competition between plants (Uphoff and Randriamiharisoa, 2002; Abraham *et al.*, 2014). Thus, the system improves productivity of land, labor and water (Uphoff and Randriamiharisoa, 2002). This allows resource-poor farmers (even with infertile soils) to produce more compared to the conventional system (Stoop *et al.*, 2002). Since water use is reduced under SRI, weed control becomes especially important (Satyanarayana *et al.*, 2007; Krupnik *et al.*, 2012). The combination of practices within SRI increases nutrient uptake by plants (Uphoff and Randriamiharisoa, 2002) and SRI has the potential to decrease methane emissions, although nitrous oxide emissions could increase (Uphoff and Randriamiharisoa, 2002; Jain *et al.*, 2014).

HUMAN AND SOCIAL VALUE: Protecting and improving rural livelihoods, equity and social well-being is essential for sustainable food and agricultural systems

Human and social values must play a critical role in determining our food systems. Yet too often they are neglected. Agroecology emphasizes the importance of those values such as the local, empirical knowledge of farmers and their communities, who are at the core of food production; the importance of a healthy diet and environment to ensure the well-being of local communities and the crucial role of women and youth in developing, maintaining and managing rural and agricultural communities.

PHOTO Lanscape for rice and plum

Some examples of the aforementioned social and human dimensions are discussed in previous chapters:

- ***Health benefits to humans and nature.*** All Methods described in the book have a positive impact in both human and natural health as a result of the reduced use or elimination of chemical fertilizers and pesticides and their substitution for biologically based processes.
- ***Nutrition benefits.*** In addition to other beneficial aspects described in previous sections, there are clear nutritional benefits from food produced in diverse and safe environments: the diet is richer in nutrients and does not pose a risk to human health due to the presence of toxic substances.
- ***Socio-ecological resilience and social cohesion.*** Another advantage of agroecological systems compared with simplified approaches is their higher resilience, exemplified by the resistance to drought of the Hani terrace system described in Method 8 ("Biodiversity landscape arrangement for rice production"). This sort of resilience does not only allow to keep food supply, but helps ensuring the maintenance of local livelihoods and strengthens social cohesion in the face of external pressures.
- ***Women and youth in agriculture.*** Another important aspect of agroecological systems is the focus on the role of women youth in the development and maintenance of agro-ecosystems. Several Methods described in this book can help achieving this goal thanks to the revitalization of rural communities through increasing and diversified incomes (Methods 1, "Intercropping of two rice varieties"; 3, "Rice-rice-milk vetch rotation system"; 5, "Rice-

duck co-culture system"; 6, "Rice-fish co-culture system"; 7, "Integrated rice-frog co-culture system" and 8, "Biodiversity landscape arrangement for rice production"), the expansion of local economy based on eco-tourism (Methods 3, "Rice-rice- milk vetch rotation system" and 8, "Biodiversity landscape arrangement for rice") and the extension of agroecological practices to vegetables, fruits and medicinal plants production (Method 8, "Biodiversity landscape arrangement for rice").

Various examples of the importance of human and social value within food systems can be found in literature. For example, Asrat (1996) reported on the ability of farmers from Ethiopia to manage soil and water in uniquely adapted ways to the different crops and labor demand patterns and to physical conditions found in the agro-ecological/altitudinal zones of the highlands. Leclerc *et al*. (2013) described how indigenous people from Kenia are able to use their traditional knowledge to take decisions to adapt their cropping calendar in the context of climate change. Olson (2001) explored the role of local ecological knowledge on crayfish, concluding that local users have substantial knowledge of resource and ecosystem dynamics. These experiences show that farmers and communities possess locally adapted knowledge linked to nature, based on the co-evolution of the people and the environment they inhabit (Marten, 2001). To promote human and social values within food system it is necessary to understand that farmers play a critical role in determining those very food systems. In this way, placing farmers in the center of the decision making process is essential to support the provision of ecosystem services. Asrat (1996) also calls the attention to the fact that some top-down approaches jeopardize fundamental (and fragile) natural resources.

CULTURE AND FOOD TRADITIONS: By supporting healthy, diversified and culturally appropriate diets, agroecology contributes to food security and nutrition while maintaining the health of ecosystems

Agriculture is a core part of the cultural heritage of humankind. Food and food traditions play a central role in society. However, this importance, our current food systems have, in many cases, disconnected food production, culinary habits and alimentary traditions. This has contributed to a situation where malnutrition and obesity coexist in a world that produces enough food to feed its entire population but fails in making it accessible to those in most need. Agroecology aims at re-connecting tradition and modern food habits, bringing them together in a way that promotes healthy food production and consumption, while ensuring that local food traditions are respected.

Examples of that re-connection can be found in previous chapters:

» ***Traditional integrated systems.*** The integration of rice and other animal species, like the systems described in Methods 5 ("Rice-duck co-culture system"), 6 ("Rice-fish co-culture system") and 7 ("Integrated rice-frog co-culture system"), is an example of how traditional food systems address nutritional needs while becoming a distinct cultural aspect of local communities. Those systems, besides the ecological benefits mentioned before, have clear nutritional benefits compared to rice monocultures. Ducks, fishes and frogs constitute a high quality protein and fat sources that complement the carbohydrates of the rice, helping the local communities to have a balanced, rich and nutritious diet. In addition, diversified rice-animal systems provide the basis for many traditional dishes, thus preserving the local culinary culture.

» ***Preservation of cultural and agricultural systems.*** One important initiative for the dynamic preservation of traditional cultural heritage, the Globally Important Agricultural Heritage Systems (GIAHS) is mentioned in Method 8 ("Biodiversity landscape arrangement for rice"). The traditional Hani terrace system in Yunnan Province is also one of the Globally Important Agricultural Heritage System. It provides an example of the dynamic interactions and mutual shaping between environmental conditions, food systems, traditional knowledge and how the local communities have adapted the three dimensions during generations. Method 6 ("Rice-fish co-culture system") in Zhejiang Province is also one of the Globally Important Agricultural Heritage Systems (GIAHS) site recognized by FAO with rich traditional rice-fish culture.

Ecosystem services can benefit from culture and food traditions, as the latter promotes biodiversity, food production and different cultural services (Daniel *et al*. 2013). As omnivores, diversity is part of the mindset of the human being, as the human brain favors the sensation for diversity while eating (Pollan, 2006). He explored these needs for diversity in our food as well as the consequences in a modern society where food culture is diminishing. Nowadays, we are facing overweight and obesity levels that are considered an epidemic by the World Health Organization (WHO, N.D.). Such situation can be linked to the absence of strong culture and food traditions (Roux, 2007). By promoting short value chains, agroecology can rebuild and strengthen the link between farmers and consumers. A consumer that knows the origin and the people behind the food he or she is eating, is a citizen with a better level of awareness on the social and ecological impacts of the food (Tallontire, *et al*. 2001).

RESPONSIBLE GOVERNANCE: Sustainable food and agriculture requires responsible and effective governance mechanisms at different scales – from local to national to global

Transparent, accountable and inclusive governance mechanisms are necessary to create an enabling environment that supports producers to transform their systems following agroecological concepts and practices. Successful examples include school feeding and public procurement programmes, market regulations allowing for branding of differentiated agroecological produce, and subsidies and incentives for ecosystem services. Agriculture uses about 70 percent of the world's water withdrawals, which are often inefficient and threatening to surface and groundwater reservoirs. In contrast, agroecology promotes a fair, efficient and sustainable use of water resources. On the other hand, ensuring land tenure is fundamental to maintaining functional and sustainable food systems. Agroecology defends fair access to land and respects the customary use of it. Finally, the vision of agroecology on land governance is that of a landscape approach, discussing land tenure issues within the communities.

Some examples of land and natural resources governance are mentioned in the book:

- ***Water purification.*** All Methods described in the book have a significant impact in the use of water resources, particularly in improving water quality and reducing or completely eliminating the use of toxic compounds.
- ***Landscape arrangement and natural resources governance.*** Method 8 (“Biodiversity landscape arrangement for rice production”) highlights the importance of landscape approach when deciding the governance and land and water resources use and the balance between agricultural and other uses.

CIRCULAR AND SOLIDARITY ECONOMY: Circular and solidarity economies that reconnect producers and consumers provide innovative solutions for living within our planetary boundaries while ensuring the social foundation for inclusive and sustainable development

In order to sustain livelihoods, ensure food security and well-being, incomes (both monetary and non-monetary) need to be fair and sufficient. Agroecology promotes local economies by putting in place a multidimensional approach for goods and services provision that takes ecological, social and economic dimensions into account. Circular and solidarity economy seeks fair, sustainable markets dictated by local needs, resources and capabilities. A key aspect for this strategy is to strengthen short food circuits with reduced intermediaries, facilitating increased incomes for food producers while maintaining an affordable price for consumers.

There are several examples of circular and solidarity economy and its benefits throughout the book:

- ***Increased incomes for producers.*** Methods 1 (“Intercropping of two rice varieties”), 3 (“Rice-rice-milk vetch rotation system”), 5 (“Rice-duck co-culture system”), 6 (“Rice-fish co-culture system”), 7 (“Integrated rice-frog co-culture system”) and 8 (“Biodiversity landscape arrangement for rice production”) describe how agroecological practices can result in better incomes for farmers. In some cases, this income increase is partially caused by cost savings from using less chemical fertilizers or pesticides. In other cases, new income is generated by the additional outputs of the system: higher yields and/or additional sources of income like fish, ducks or frogs. In some cases, the increase in incomes is remarkable: up to 10 times higher than rice monocultures.
- ***Certification.*** The transition from rice monocultures to more diverse systems open the opportunity to harvest additional economic benefits for the farmers under organic and other certification systems. As depicted in Methods 6 (“Rice-fish co-culture systems”) and 7 (“Integrated rice-frog co-culture systems”), identifiable brands of fish, frog or rice can be sold at higher market prices, increasing farmers’ income and helping to ensure their livelihoods.

» ***Agro- and eco-tourism.*** Methods 3 ("Rice-rice-milk vetch rotation system") and 8 ("Biodiversity landscape arrangement for rice") highlights the importance of landscape arrangement for rice production while, at the same time, its potential to boost agro- and eco-tourism. A diverse and healthy ecosystem can attract visitors thanks to its natural, aesthetic and cultural values, increasing and diversifying the sources of income for the local economy. The GIAHS sites of rice-fish in Zhejiang Province and rice terrace system in Yunnan Province are also tourist hot spots today in China.

Circular and solidarity economy can be supported in different ways. Community Supported Agriculture (CSA) was developed in the 1980s and it has been used in many countries as a tool to support agroecology (Volz *et al.*, 2016). CSA is a community-based organization of producers and consumers who support each other and share responsibilities. The consumers agree to provide up-front support for the local farmers, while the farmers agree to provide a sufficient quantity and quality of food to meet the needs and expectations of the consumers (Lamb, 1994; Freedman and King, 2016). Another action that has been used to promote and support agroecology is the Participatory Guarantee System (PGS). PGSs are local quality assurance systems, and certify producers based on active participation of stakeholders. PGS are built upon trust, social network and knowledge exchange (IFOAM, 2009). It is an important alternate for organic certification and re-creates bond among producers and consumers, creating a transparent and trustful market (Kirchner, 2015).

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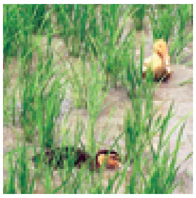

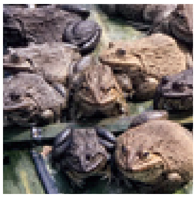

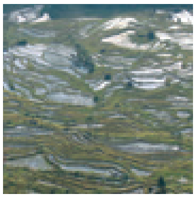

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