5. Production Systems

In categorizing the production systems, it is not possible to completely divorce the purely physical design aspects from the cropping practices. This is because a particular cropping practice may require some specific physical modifications although the converse may not be true. A particular modification does not necessarily limit the cropping practice to be employed. Farmers can always sell their fish as fingerlings if they find it financially advantageous to do so, or conversely grow them to larger size as table fish. Farmers in many areas routinely switch between, or cycle through, rotational and concurrent practices using the same rice field.

This section will describe the two main production systems, concurrent culture – growing the fish together with the rice in the same area - and rotational culture – where the rice and fish are grown at different times. The final part will mention an alternating system that is really a type of rotational culture, but distinct enough to warrant a separate section.

5.1 Concurrent Culture

The growing of fish simultaneously with rice is what comes to mind for most people when rice-fish culture is mentioned. This is often referred in short as “rice-fish” (Yunus et al. 1992; Roger 1996). As mentioned earlier, physical modifications are required to make a rice field “fish-friendly”. The timing in stocking fingerlings is crucial since if stocked too soon after the rice is planted, some fish species are likely to damage the newly planted seedlings (Singh et al. 1980), and if too late there may be a multitude of predator species in the fields.

One constraint of the concurrent system is that the growing period of the fish is limited to that of rice, which is usually 100 to 150 days. Consequently the harvested fish are small, especially if early-yielding rice varieties are used. This can be partly remedied by the use of larger fingerlings, but there is a limit to this since large fish may be able to dislodge the rice seedlings. Another solution is to limit the production to that of large-size fingerlings for sale to farms growing table fish. The increased demand for fingerlings for growout in cages during the late 1970s in Indonesia was one of the catalysts that helped popularize rice-fish farming.

This system is often practiced in rainfed areas and plays an important role in many rice-producing countries, for example in Thailand where rainfed areas constitute 86% of the country’s rice area (Halwart 1998), as well as in the Lao PDR (Funge-Smith 1999) and Cambodia (Guttman 1999; Balzer et al. 2002). The transition from a pure capture system and a capture-based culture system is gradual and has been described as a continuum (Halwart 2003b).

5.1.1 Rice and fish

The stocking and growing of fish in a rice field is basically an extensive aquaculture system that mainly relies on the natural food in the field. On-farm resources and cheap, readily available feedstuff are often provided as supplementary feeds, particularly during the early part of the growing cycle. For the management of the rice crop, compromises are made with respect to the application of fertilizer, which is done judiciously. The use of pesticides is minimized and when applied the water level may be lowered to allow the fish to concentrate in the refuge.

It should be mentioned that the earliest and still most widely practiced system involves the uncontrolled entry of fish and other aquatic organisms into the rice field. Coche (1967) called this method the “captural system of rice-fish culture.” This can only be considered a rice-fish culture system if the fish are prevented from leaving once they have entered the rice field. In this system, the organisms often depend wholly on what feed is available naturally in the field, although it is not uncommon for farmers to provide some type of supplementary feeds.

This system is practiced widely although there are many variations of the basic theme. For example, in the minapadi - literally “fish-rice” system - of Indonesia, the rearing of fish is not one continuous process. It consists of three distinct rearing periods that are synchronized with the rice cultivation. Two different explanations have been given for such a procedure not to subject the fish to very turbid conditions (Ardiwinata 1957) and not to adversely affect rice yields (Koesoemadinata and Costa-Pierce 1992). The
The first and second rearing periods may be considered the nursery periods for growing the fry to fingerling size. The rice field is stocked at the rate of 60 000 fry·ha⁻¹. During the first weeding, the fish stock is confined to the trenches. Before the second weeding, the fingerlings are harvested and sold. In the third growing period, 8-10 cm fingerlings are stocked at the rate of 1 000 to 2 000 fish·ha⁻¹ for the production of food fish.

To have more food available for the fish, the Chinese have introduced the growing of azolla together with the fish and rice. Aside from serving as food for the fish, azolla is also a good nitrogen source for the rice because of its nitrogen-fixing capability (Liu 1995). This system works well in either fields with pits or with rice on the ridges: azolla on the surface of the water and fish within the water column (Yang et al. 1995). The field must have sufficient water and good irrigation and drainage. The proportion of pits and ditch as to the total area depends on the desired yields of rice and fish.

Yang et al. (1995) found that both fish and rice yields varied according to the ridge width or ditch width. Fish yields also vary according to the species cultured and the stage at which they are harvested (Wang et al. 1995). The output of fish was highest using "food fish" followed by carp fry, catfish fry (Clarias gariepinus), and the lowest yield with grass carp. Chen et al. (1995) reported a 70% increase in fish yield with azolla over culture without azolla.6

5.1.2 Rice and fish with livestock

Carrying the concept of integration one step further, livestock rearing may also be integrated with rice-fish systems. This has been tried in many areas but is not as common as the integration of livestock with pond culture.

The most common form of integration is probably the rice-fish-duck farming. The integration of one hundred laying ducks with a one ha rice-fish farm resulted in the production of 17 031 eggs/year in addition to the rice and fish (Syamsiah et al. 1992). It should be noted that ducks are also known to feed on snails, and this combination of biological control agents has been suggested for controlling the various life stages of golden apple snails in rice fields (Halwart 1994a; FAO 1998).

5.1.3 Rice and crustaceans

Crustaceans raised in rice fields range from crabs and crawfish to prawns and shrimp.7 This is being practiced in many coastal areas relying either on natural recruitment or in stocked fields.

In the southern United States, crawfish (Procambarus clarkii) are stocked in their adult stage to serve as broodstock unlike most other aquaculture systems where juveniles are stocked. Reproduction occurs in the rice field and it is the offspring that are harvested. The broodstock are released in the month of June after the rice has reached 10-25 cm and the rice field is already flooded. While the rice is growing, the crawfish reproduce and grow. By August the rice is ready for harvesting. Two weeks before harvesting, the rice field is drained to make harvesting easier. By this time all the crawfish are expected to have completed their burrowing (NAS 1976).

The rice stubble left after harvesting re-grows as a ratoon crop when the field is re-flooded and the new growth is foraged directly by the crawfish (Chien 1978). Loose plant material decomposes and serves as food for zooplankton, insects, worms and molluscs, that make up a large part of the crawfish diet. Although any type of vegetation can serve as forage for crawfish, rice appears to be more widely used. When the field is re-flooded after the rice harvest, the young crawfish are flushed out of their burrows and partial/selective harvesting can start as early as December and proceed through April/May to June/July depending upon the desired cropping pattern. Crawfish are harvested at 15-60 g size by using traps made of plastic or wire screens with ¾ inch mesh and baited with gizzard shad or carp. Lanes between the stands of rice are provided to allow the harvesting boats to move freely.

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6 The system used "fine feed" to feed pigs that produce manure for the rice fields and "beer left-overs" as supplementary feed.
7 The term "prawn" is used for freshwater species and "shrimp" for marine and brackishwater organisms.
Although the river crab or mitten-handed crab (Eriocheir sinensis) has been cultured with rice in China for less than 12 years, there are now almost 100,000 ha devoted to its culture\(^8\) (Wang and Song 1999). The rice field is used either as a nursery for the production of crab juveniles (or “button-crab”); growout for the production of marketable-sized crabs (125 g); or as a fattening area for rearing undersized crabs (50-100 g).

The rice field is modified with a peripheral trench (2-4 m wide, 1 m deep), a cross trench (0.8-1.0 m wide, 0.5-0.8 m deep) and a sump (20-60 m\(^2\), 1 m deep) as a nursery-rearing-harvesting “pond”. In total 15% to 20% of the total area is modified. To prevent crabs from escaping, a wall of smooth material (plastic or corrugated sheet) is installed (Li 1998).

While saltwater is needed for egg hatching and rearing the larvae at the initial stage, at later stages the larvae can develop into crabs in a freshwater or near-freshwater environment. Li (1998) identified the stage stocked in rice fields as zoea that in four months attain “stage V zoea” at 40 to 200 individuals per kg. Wang and Song (1999) found megalopa\(^9\) stocked needed to be slowly acclimated (six to seven days) to near freshwater condition (below 3 ppt) for better survival when stocked in freshwater. It is at this stage that they are either reared into button-crabs or reared directly into adults. For the production of button-crabs, the rice fields are stocked at the rate of 4.5-7.6 kg·ha\(^{-1}\). For growing into marketable crabs, the stocking rate is 75-150 kg·ha\(^{-1}\). These are harvested upon reaching the size of 125 g.

Supplementary feed is given consisting of a mix of trash fish, snail, clam or viscera of animals (40%); vegetables, sweet potatoes, pumpkin, rice or wheat bran, leguminous cakes (25%); and terrestrial grass or duck weeds (35%). The trash fish and other animal protein source are steamed and minced finely during the early stage of growth. The vegetable materials are stewed and are given during the middle stage. At the late stage animal feeds are again given in order to fatten the crabs and develop the gonads that make the crabs even more prized. Pellet feeds are also used in some places.

Good water management is essential and about 20 cm of the water is changed every three days or one-third of the water of the entire field every 10 to 15 days. The dissolved oxygen level is maintained at a level above 4 ppm throughout the culture period. Basal manuring and top-dressing with urea are applied two to three times a year.

The rice crop is harvested at “frost’s descent” and the crabs by October and November when the gonads are ripe. The time of harvest may be advanced if the temperature should abruptly drop since the crabs have a tendency to burrow when the temperature is low. The crabs are concentrated in trenches by irrigating and draining prior to the rice harvest. The crabs are caught when they crawl out of the trenches at night by using bottom trap nets or by draining the water.

The giant freshwater prawn (Macrobrachium rosenbergii), as well as another prawn species (M. nipponensis), grow together with rice in China. The physical preparations are the same as for river crabs in terms of providing trenches, sumps and screens; so are pre-stocking preparations up to the liming stage (Li 1988). Thereafter, submerged aquatic plants are planted in the trenches to cover one-half to one-third of the water surface.

For M. rosenbergii, the stocking rate is 3 pieces per m\(^2\) of 1.5 cm sized juveniles.\(^{10}\) The M. nipponensis on the other hand may be stocked as 4-6 cm size brooders at 3.0-3.8 kg ha\(^{-1}\) and allowed to breed, or as juveniles at 23-30 pieces per m\(^2\). The feed consists of soybean milk and fish gruel for the early stages (seven to eight days after stocking the fry) and pelleted feeds or a mixed diet of wheat bran or rice bran and some animal protein source thereafter. The M. rosenbergii is fed a higher protein diet.

M. rosenbergii is harvested before the temperature drops too low. Harvest for M. nipponensis can start on a selective basis by late November or early December. The undersized animals are left to grow for the total harvest by May or June before the rice planting season.

In coastal rice fields encroached by saltwater, it is common for saltwater shrimps to enter the rice fields with the floodwater and grow among the rice plants. In the Mekong Delta area in Vietnam

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\(^8\) This includes pens and cages set in lakes, ponds, and rice fields.
\(^9\) Megalopa is the last larval stage of crabs before they metamorphose into fully-formed juvenile crabs. It is the most likely the more accurate designation of the crab larvae when stocked in the rice fields.
\(^{10}\) This rather low stocking rate is due to the aggressive behavior of the prawn.
some farmers have been successful in growing shrimp together with a traditional tall rice crop in a brackishwater environment. Supplementary feeding results in higher yields even when the feed consists of nothing more than “rice bran, broken rice and rotten animals” (Mai et al. 1992).

5.1.4 Concurrent but compartmentalized culture

Rice culture and fish culture both require water and in some circumstances the rice and fish are cultured side by side sharing the water. One advantage of this set-up is that fish rearing becomes independent from rice, making it possible to optimize the conditions for both rice and fish. However, the synergistic effect of rice and fish on each other is no longer present. Generally there is only a one-way influence from fish to rice in the form of nutrient-enriched water.

In the rice culture zone of Senegal, environmental changes have forced the rice farmers to diversify and integrate fish culture in their farming operations (Diallo 1998). Owing to two decades of drought, the foreshore mangrove areas have expanded resulting in the salinization of surface and ground water. To protect their rice fields against the infl ow of saltwater, farmers built fishponds along the foreshore area to produce fish. The fishponds range from 500 to 5,000 m² (30 cm deep with 1 m deep peripheral canal).

During the first rain, the gates of the rice fields and fishponds are opened to allow the rainwater to wash away any salt that may have accumulated. Then the gates are closed and the rainwater and surface runoff are collected for both the rice planting and fish growing operations. After the rice has been planted from mid-August to mid-September, the seaward gates are opened during the spring tides. Coastal fish attracted by the flow of freshwater come into the ponds and are trapped. No attempt is made to control the species and the number of fish that enter. The rice fields and fishponds are fertilized with cattle and pig manure and ash. The fish are fed rice bran, millet bran and sometimes termites.

The fish are harvested either when the rice is about to mature or just after the rice has been harvested from December to January, when the fish have been growing from 120 to 150 days. Harvesting is done during low tide by draining the pond with a basket locally known in Senegal as etolum placed at the end of the drainpipe.

5.2 Rotational Culture

5.2.1 Fish as a second crop

In Hubei and Fujian provinces, China, raising fish during the fallow period or as a winter crop is practiced to make use of the rice field when it otherwise would not be used (Ni and Wang 1995). Elsewhere in China it does not seem to be as widely practiced as concurrent culture. In Indonesia, particularly West Java, the art of rotating fish with rice has been developed to a greater degree and can be traced back to 1862 or earlier.

The Indonesians call raising fish as a second crop palawija or “fallow-season crop.” Instead of growing another rice crop or soybeans or maize after one rice crop, some Indonesian farmers grow fish. The only physical modification required is the raising of the dike to hold water. Without the rice, the entire rice field can be operated and managed just like a regular fishpond. The production of two or three crops of fingerlings instead of one crop of table fish is done by some farmers in Indonesia to avoid problems of poaching or fish mortality due to infestation by predators such as snakes, birds and water insects (Koesomadinata and Costa-Pierce 1992).

Raising fish, in this case common carp as palawija, was described in detail by Ardiniwata (1957). The rice field is flooded with the rice stubble, either trodden down or cut off and stacked together with loose rice-straw, before or after the first flooding. Within two or three days the water becomes putrid due to the decomposition of plant materials and is released and replaced with new water. Water depth is maintained between 30-80 cm.

Carp fingerlings are stocked at a density that is based on the magnitude of the rice harvest and the size of the fingerlings. The rule of thumb is to stock from 500 to 700 fingerlings (5-8 cm long) for one tonne of padi (unhusked rice) harvested. Sometimes large fingerlings (100 g) are also stocked at the rate of 10% of the main stock. These larger fish keep the soil surface loose by their activities. Alternatively, 10-day old carp fry may be stocked at the rate of 100,000 fry·ha⁻¹ for growing into fingerlings. This practice often results in high mortality but is apparently resorted to only if no other area is available as a nursery.

 Marketable fish are harvested in 40 to 60 days, fingerlings after only 4 weeks. There is enough time
for a second, third or even fourth crop of fish prior to the next rice planting season, depending on the availability of water. The stocking density is increased by 25% during the second fish cycle but then reduced since there is a risk of running out of water before the fish have reached marketable size. In Indonesia, a short growing period is possible since the local preference is for small fish averaging 125-200 g (Costa-Pierce 1992). Table fish are harvested by draining the field, forcing the fish into trenches where they are picked by hand. The field is left to dry for two days, repairs made and rice straw turned over and the field is ready once again for another crop of fish. To harvest fingerlings, a temporary drainpipe covered with a fine meshed screen is installed and then the water level is carefully lowered until it is only in the trenches. Fingerlings left in puddles on the trench floor are gathered first, and when only a little water is left, the fingerlings concentrated at the screened outlet are carefully scooped out and placed in holding vessels for distribution.

Another Indonesian system is called penyelang or “intermediate crop” where farmers who double-crop rice with an adequate water supply year-round find it possible to raise fish in between the two rice crops. Since the seedbeds occupy only a very small portion of the rice field, the farmers can use the rest of the rice fields for growing fish during a period of 1-1½ months sufficient to produce fingerlings. Some farmers let fish breeders use their rice fields during this period (Koesoemadinata and Costa-Pierce 1992). The whole rice field can be operated as a fishpond and with the widespread use of the high-yielding varieties (HYVs) that make possible four to five crops of rice in two years, the penyelang is reported to be more popular than the palawija described earlier.

The fields are stocked after they have been tilled and made ready for the next rice crop and are already clean and free from rice stubble (Ardiwinata 1957). This makes them suitable for rearing carp fry and are sought after by fish breeders. The same stocking density is used as in palawija (100 000 fry·ha⁻¹). Fingerlings are harvested after only one month. If used for growing marketable fish, the stocking is 1 000 fish·ha⁻¹ (8-11 cm). As long as trenches are provided, whether peripheral or otherwise, the fish may remain during the plowing and harrowing process.

5.2.2 Crustaceans as a second crop

Along the western coast of India the low-lying coastal rice lands are left fallow after one crop of salt-tolerant rice (Pillay 1990). The dikes are raised after the rice is harvested (in September) and tidal water is allowed to inundate the field carrying with it shrimp larvae and fry. This natural stocking process continues for two to three months with every spring tide. Lamps are installed over the inlet to attract the shrimp larvae and conical bag nets installed at the sluice gates to prevent the trapped shrimps from getting out. Selective harvesting may start as early as December allowing of the earliest shrimps to enter. Regular harvesting thins the stock resulting in better growth rate for the remaining stock. With such uncontrolled stocking, several species are harvested but mainly of Penaeus indicus, Macrobrachium rosenbergii and Palaemon styliferus.

This system of shrimp culture is an old practice in India, but lately due to the high value of shrimps farmers are devoting greater attention to managing the shrimp stock through better water management and fertilization. Many farmers now no longer leave the stocking to chance preferring instead to stock at a controlled density using hatchery-produced postlarvae, particularly of P. monodon.

5.3 Alternating Culture System

Another alternative is an alternating system since rice takes from 105 to 125 days to mature depending on the variety, but fish can be marketable as fingerlings in as short as 30 to 45 days. Fish therefore can also be a good “time-filler” crop. By alternating between rice-fish and fish-only farming, rice fields can be productive throughout the year and higher incomes can be realized. A farmer may practice two rice crops and then a fish-only crop, or two rice-fish crops followed by a fish-only crop, with the latter becoming more popular in parts of Indonesia (Koesoemadinata and Costa-Pierce 1992). Ironically enough, even if rice is the main crop, fish are raised year-round in the rice field rather than rice. In a survey in West Java, farmers who practiced two rice-fish crops followed by a fish-only system had a net return to input of 173% per year as against 127% for those practicing a rice-rice-fish system and 115% for those practicing rice-rice-fallow system (Yunus et al. 1992).