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Chapter 2

# Integrated Rice and Aquaculture Farming

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**Abstract**

The burning problems like scarcity of food for ever-growing human population in the present world are addressed by adapting various methods for production of protein, carbohydrate, oils and other food materials. One of the methods to produce high amount of food is integrated farming including rice-aquaculture farming, which produces protein and carbohydrate as major components besides others. Rice-aquaculture farming produces grain (carbohydrate) and animal protein without affecting the quality and quantity of rice yield on the same piece of land and renders additional financial gain besides main crop (rice) like conventional monoculture. The aquatic species grown in the integrated culture are mainly distinct types of fishes, selected crustaceans and other selected species. Profitable rice-aquaculture integrated farming is popular in Asian countries than in Western countries. However, the integrated rice-aquaculture farming has its own limitations. The type of methods, culture species, influencing factors, and pros and cons of rice-aquaculture integrated farming are discussed in the present chapter.

**Keywords:** integrated farming, rice, aquaculture, fishes, crustaceans

## 1. Introduction

Ever-growing human population occupies the available land area in the world by encroachment. This is happening due to drastic increase in population dynamics worldwide. According to US Census Bureau world population estimate, the world's population in 1901 was 1.6 billion; it was 3 billion by 1960, 5 billion by 1987, 6 billion by 1999 and 6.8 billion by 2009 and became approximately 7.9 billion by 2018. Based on the statistics, it is known that one billion population is getting added to the current population by every 9–12 years. Currently, the second highest populated country in the world is India. Based on the recent statistics, India's present population has reached 1.2 billion. Though China is occupying the first place

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in highest population in the world, it is expected that India may become the highest populated country by 2050 as per World Population Data Sheet of 2009.

The size of the population depends on its number and the ratio of available bearable resources. The population size also is contingent on the way resources are used and disseminated between the populations. To meet the demands of forever growing human population, major agricultural fertile lands are getting converted into residential areas. The total available land area in India occupies 2.4% of total land area of the world. Added fertile land area exists in India than any other country except the USA and Canada, which are holding more water area [1]. Because of the availability of more arable land and water, India became an agriculture-based country. From ancient days, major Indian populations live in villages and revolve mostly around agriculture and allied activities. It is well exemplified with the statistics of Indian population since 1947; it is tripled due to improvised and sub-standard conditions in India [2]. However, due to enormous increase in population along with increased poverty, modernization and more effectively globalization and medication, majority of the adjacent villages of small towns and all most all large and moderate villages located around cities were urbanized. Urbanization caused drastic conversion of arable agricultural land into modern housing.

The food scarcity is the predominant factor that influences the growth and economy of the overpopulated country. Supplementation of nutritious food to the forever growing human population in a nation like India or overall worldwide is at most target of governments or World United Nations. Though the agricultural land area is getting reduced due to overpopulation in the world, it is the focus to produce sufficient or more amount of nutritious food to meet the demands of population. The conventional methods of agriculture may not produce or increase the food productivity. Alternative methods are in focus to produce high amount of food by using available agricultural land.

Since ancient days the traditional cultivation methods were contributed for the food and living safety throughout the world. But at the present day, farming is completely linked to high yield by usage of many varieties of pesticides. This type of farming certainly pollutes the environment and drags the farmer into debits due to high investment on crops in the case of crop failures, which ultimately cause suicides of the farmers and their families in developing countries like India. One of the reasons for this is majority of the farmers are focusing only on one crop at time where there is a high degree of uncertainty. Besides this, the usage of excess amounts of pesticides and fertilizers causes imbalance in ecosystem and alters the natural environment, which ultimately influences the flora and fauna of that area, including soil microbiota [3], which may cause drastic change in the livelihood and may also be one of the responsible factors causing severe change in natural cycle and seasons such as reduced rainfall, increase in the temperatures and short or prolonged yearly seasons besides health hazards in the consumers. To overcome the above circumstances, integration of various agricultural enterprises, viz., cropping, animal husbandry, fishery, forestry, etc. has great potentiality in the agricultural economy. The usage of expertise of conventional methods in combination of modern methods is well explained in many studies [4–6].

The conventional methods of agriculture are completely successful and are developed by farmers for different environments which maintain rich biological diversity [4–6]. According to

Csavas [7] the livestock integrated system was started in between fourteenth and seventeenth centuries by growers. The motivation overdue in integrated rice-aquaculture farming (RAF) is to diminish unused matter from several subsystems on the farm. The unused products generated during farming of subsystems were secondhand as contributions to other subsystems to progress the yield and minimize the cost of productivities for the several subsystems [8].

In this series, many methods were coming into picture to produce quality food. Best examples are the terrace farming, zero-acreage farming [9], mixed cropping, mixed farming, integrated farming, etc., which are in practice. The integrated rice-fish co-culture is not a new method of producing food; for centuries, it has been in practice and is designated as globally important agricultural heritage system [10]. Due to the importance of RAF, US Agency for International Development (USAID Mekong ARCC, 2016) encourages farmers in the Asian countries to continue the integrated farming with a refined form [11]. Due to its importance in many Asian countries including India, the present chapter deals with various aspects of integrated RAF.

## 2. Integrated rice-aquaculture farming (RAF)

Integrated culture is not new and exists naturally. The natural ecosystem itself is a big example for integrated culturing where a number of flora and fauna living together in the same area of land. Coming to the natural integrated system in the rice fields, besides fish species coming from outside through water, crabs grow by making burrows within the field. The best well-known natural example for integrated rice and aquatic species (ASp) is rice and freshwater crab culture. The freshwater crab *Oziotelphusa* (*Oziotelphusa*) *senex senex* enormously grow naturally in rice fields in India. Since its natural occurrence in the rice fields, this crab is popularly named as 'Indian rice field crab'. This crab is a good source of protein and is available throughout the year with no cost. The name 'poor man's protein' is also popular for this freshwater rice field crab since most farmers (poor villagers) consume it [12, 13]. Though the farmers do not focus on naturally occurring integrated rice systems like crab within the rice fields for commercial purpose, they understand the importance of more than one culture within the same field. One more thing that the farmers focused on is commercially important species and benefit out of its yield along with the main crop.

The culturing of ASp in the rice fields is originated from the farmers, who were experienced with fish along with prawns, crabs and other invertebrates grown naturally (ASp moves from ponds to rice fields through irrigated water) in the rice fields without adding any ASp seed in the irrigated field. The observation takes the farmers to culture ASp in the rice fields initially without any selection of the ASp. Later farmers are motivated to grow selected ASp with rice by following conventional methods based on the conditions of the local environment. In the ancient days, the farmers tasted the yield of integrated rice-ASp culture. In the beginning, it was called as rice + fish culture [14, 15]; later, it became rice-aquaculture. The uncontrolled entry of outside ASp into the integrated culture field and leaving the cultured ASp to outside the field are problems even today, but capture system of rice-ASp culture was introduced to overcome this problem [16]. In this system, cultured ASp purely depends on the naturally available feed in the field. But in general, farmers supplement feed for growing organism from outside. However, continuum in the transition from pure capture culture to a capture-based production system is gradual and is described by Halwart [17].

Integrated rice and aquatic species culture have lot of scopes and achievements of high productivity in terms of carbohydrate and protein with proper management methods and controlling systems. The selection of culture species plays a crucial role in productivity, besides environmental conditions and proper management at the time of culturing. However, the farmers are in practice to cultivate the integrated rice and aquaculture in many areas of Asian countries and some of the African countries.

### 2.1. Site selection

Certain criteria should be followed while selecting the site (land) for integrated rice-aquaculture. The selected area (place) should have an optimum rainfall of 80 cm in a year; the lands with uniform contour and high water retaining capacity of land are considered for site selection. The site selection for rice cum aquaculture farming is low lying area where water flows easily and is available at any time in needs. The fertile soil rich in organic manure and with high water holding capacity is used for rice fields. In general, soils with medium texture and loam with silty clay are most preferable for RAF [18].

#### *2.1.1. Rice field selection*

The topography and contours of the land will make the difference in preparation of rice field. There are three types of rice fields identified such as:

**a.** *Perimeter-type field*: the field in this type prepared with a moderate elevation and ground sloping on all sides into perimeter trenches which facilitates easy drainage. The middle of the land is the growing area for rice (**Figure 1**).

**b.** *Central pond-type field*: the pond is prepared in the middle of the rice field. This is the easiest way to produce trench for integrated aquaculture and rice production (**Figure 2**).

**c.** *Lateral trench-type field*: trenches were prepared on one or both sides of rice slopes (**Figure 3**).

Besides these three types, there are many types of trenches prepared for integrated rice-aquaculture. Different other types of trenches in the rice field are presented in **Figure 4**. The ideal ratio for making an integrated RAF is explained well, for example if a 1 hectare of land of integrated system is about 125 m × 125 m. In this, 0.67 hectares is the area to be used for rice, i.e. 102.5 m × 102.5 m, whereas 7.5 m × 440 m for four sides of the field which is equal to 0.21 hectares were used for aquaculture (fish, crustacean and other aquatic animal culture). About 0.12 hectares of area, i.e. 3.75 m × 485 m, will be used as embankment area. The other area of about 0.04 hectares is used for planting fruits.

### 2.2. Rice and aquaculture

RAF had been in practice since years due to the constant profits of integrated culture. However, the generally practised rice-aquaculture is categorized into three major types [19],

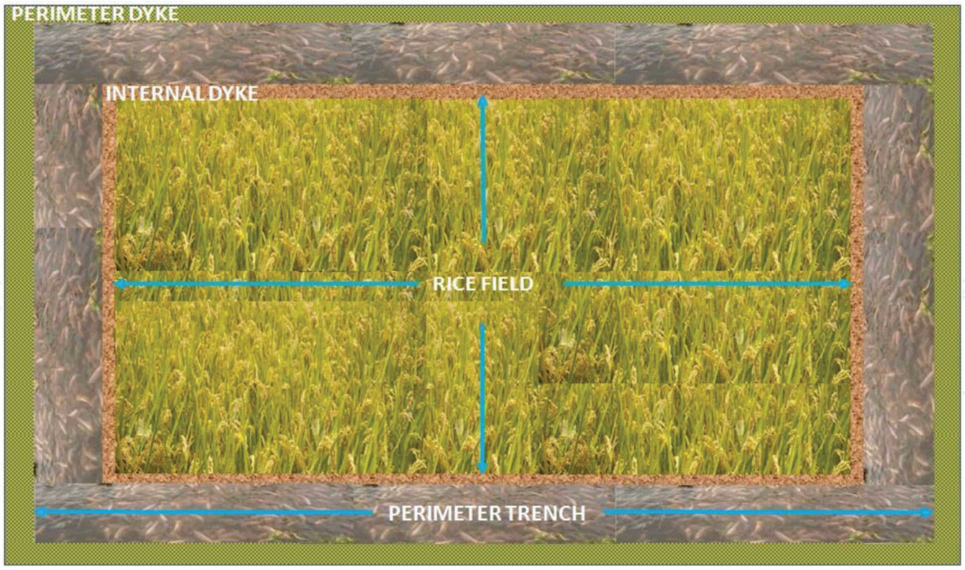


**Figure 1.** Perimeter-type rice field used for rice-aquaculture integrated farming.

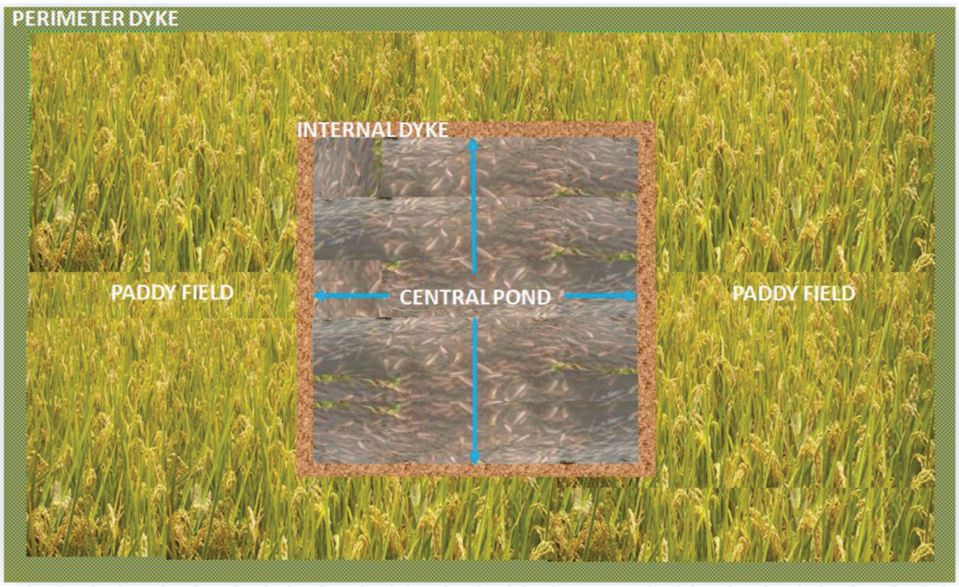


**Figure 2.** Rice field with central pond system for rice-aquaculture farming.

namely, (1) synchronous/combined/simultaneous farming, (2) sequential/rice-aquaculture rotation/alternate farming and (3) relay farming.

*2.2.1. Synchronous/combined/simultaneous farming*

In this type, the rice and aquatic culture species are grown simultaneously in the same field. Both the rice and cultured species are harvested at the same time. The synchronous rice-aquatic farming method has its own importance since it produces aquaculture protein with no additional cost; the cultured aquatic species secretes ammonia for rice growth besides destroying the weeds, tillering, enrichment of minerals (digging activity) and utilization of unused aquatic feed by the crop plant. Due to this the rice yield increases 5–15% than the conventional methods [19].

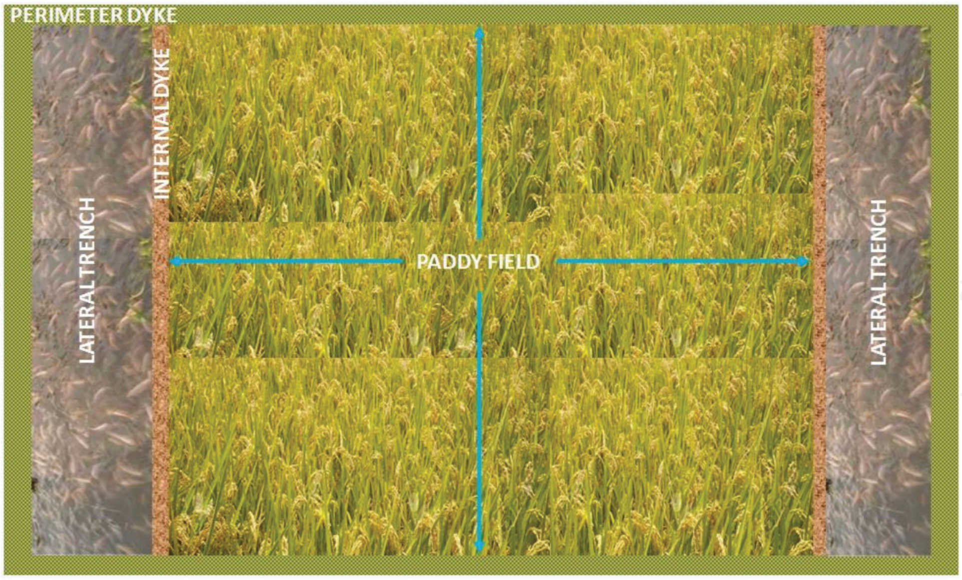


**Figure 3.** Lateral trench-type rice-aquaculture integrated farming.

This method of integrated culture is an old one and is familiar in the Asian countries. Usually in this type, 5 days after transplantation or after proper rooting of rice seedlings, the aquatic culture species seed is released into the trenches/pond (also called as stocking) [19]. The stocking time after transplantation of rice seedlings varies from aquatic cultural species to species. For example, stocking in the case of fry is after 10 days of transplantation, whereas for fingerlings after 3 weeks. The stocking procedure differs with the type of aquatic species growing (fingerlings or fish or prawn or crab or mollusk or any other aquatic species). In simultaneous farming, the rice selected is usually local variety harvested not less than 5 months by using organic manures like stocked cow/buffalo dong or green manure fertilizers without synthetic fertilizers. Moreover, the number of crops produced every year is two in this case. However, the combined rice-aquaculture farming has its own disadvantages such as high activity by predators of aquatic species (piscivore birds) due to less depth in trenches/ponds and restricted usage of herbicides and pesticides which causes harmful effects to growing aquatic species lowers rice yield; there may be 20–60% loss in aquatic species yield due to abrupt change in dissolved oxygen and temperature and limited space availability. Since having drawbacks in simultaneous rice-aquaculture farming, it was modified and established as alternative farming.

### 2.2.2. *Sequential/rice-aquaculture rotation/alternate farming*

Rice-aquaculture rotation is a simple method of farming where aquatic species were grown after harvesting of rice in the flooded fields without removing the rice stubbles. The water levels were shallow in the case of rice, whereas for aquatic species, water depth is raised. In this method more than one ASp were raised [19]. The depth for growing aquatic species in the field is raised well before the transplantation of rice seedlings with a moderate height of external dyke. However, the pesticides used for rice production degrades during interval between harvesting of rice and stocking of aquatic species. The rice stubbles in the water at the bottom of the field facilitate the growth of decomposing microbes which served as food

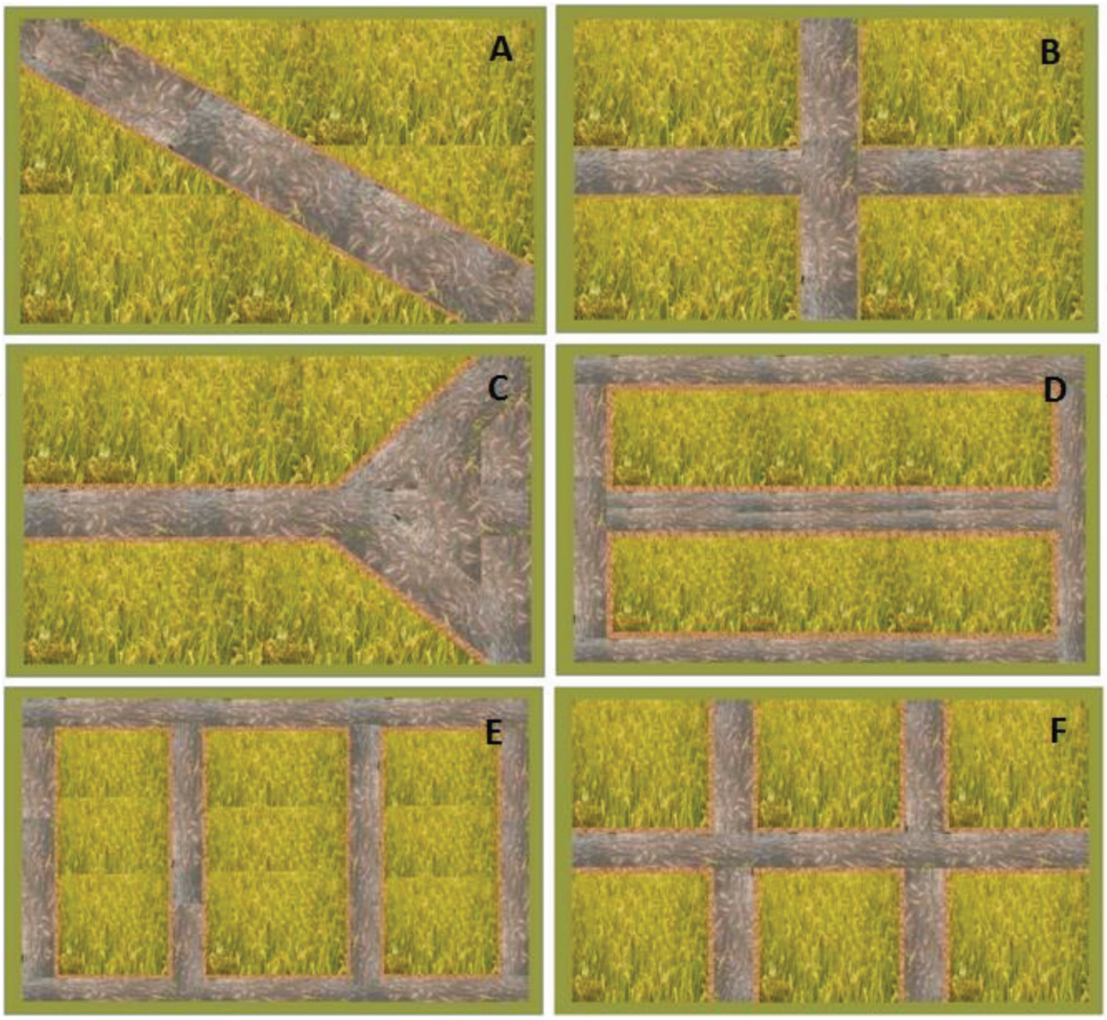


**Figure 4.** Different types of trenches in usage for rice-aquaculture integrated farming. (A) Diagonal trench, (B) crossed trench, (C) Y-shaped trench, (D) peripheral and one central longitudinal trench, (E) two equidistant transverses with peripheral trench and (F) latticed trenches.

for aquatic cultural species. The decomposition of stubbles enriches the water and soil with natural fertilizer utilized by the next cycle of rice where it helps to produce high yield.

The only limitation in alternate farming is about 20–60% loss of ASp due to piscivorous birds like herons and cormorants. Besides this, sequential rice-aquaculture farming has many advantages such as (i) no limitation for depth of water neither in rice cultivation nor in aquatic species culture, (ii) maintenance of adequate water levels provides sufficient dissolved oxygen and water temperature, (iii) rice stubble decomposition facilitates microbial food for aquatic species and fertilizer for the next cycle of rice for improved production, (iv) useful for mono- and polyculture of aquatic species and (v) reduced attack of insect pest on rice fields due to interruption in their life cycle in rotation farming.

*2.2.3. Relay farming*

The name 'relay' itself indicates it is a prolonged farming. The relay farming is a complicated system compared to synchronous and alternative rice-aquaculture farming and is a combination of these two methods [19]. In this farming rice and aquatic species were started like synchronous farming, but the aquatic species are not harvested while rice species are harvested. It means that relay farming requires longer period for aquaculture. During rice harvesting the growing aquatic species were transferred to special ditches/ponds which are connected to channels/pools of the rice field and then restocking them in the rice field after filling up of water for further growth. It means this method requires additional rearing facility for transferring fish at the time of rice harvesting. Relay farming provides high amount of aquatic protein with high yield of rice crop with short duration. The drawback in this method is more investment and labor. The carp and prawn species are the most commonly used to produce protein in relay farming.

### 2.3. Suitable aquatic species

Worldwide integrated farming of aqua with irrigation is becoming popular to produce more yield and makes the farmers economically strong. It is well practised in the rainfed areas mainly in countries producing rice. The 86% of rainfed areas in Thailand produce rice [20] as is the case with Lao PDR [21] and Cambodia [22, 23]. Various types of aquaculture in the rice fields are in practice. The major aquatic species that come under finfish and shellfish are the cultural species used for integration with rice fields. Among finfish and shellfish, the two types of cultures brackish and freshwater species have importance to grow in RAF. But the selection of this species purely depends on the variety of rice growing. It is very particular that only certain rice species are productive in brackish water. The rice varieties of holding salinity tolerance and floating-stem (long-stemmed) were preferred for brackish water RAF. The brackish water effect is tidal on rice species holding salt tolerance and long-stem, since these species have the capacity to withstand even in salt water. Besides rice variety the selection of fish or crustacean cultured also play a role in RAF. The freshwater prawns like *Macrobrachium* species and brackish water prawns like *Penaeus monodon* and other species grow well in the rice fields. Most species of fin fish can grow well in rice fields. However, the farmers have to be careful about the selection of aquatic culture species and the variety of rice for integrated culturing.

Studies were focused on the stability of rice field ecosystem with rice monoculture and rice-aquaculture [10, 24]. A survey by Xie et al. [10], with farmers cultivating rice with or without integrated aquafarming, revealed no difference in the yield of rice between the two farming for a period of 6 years. However, the temporal variation in the yield of rice is influenced by many factors such as year-round and year-to-year changes in climate, pest incidences, rice variety cultivation and the amount of pesticide used until harvesting [25, 26]. The usage of large amount of pesticides is responsible for temporal stability of rice yield in the case of rice monocultures, whereas rice yield stability is partly on the presence of aquatic species in rice-aquaculture farming [10], since fish-aquatic cultural species act as biocontrol agent [27]. In the modern agriculture, the stability of rice yield is maintained through the extensive usage of pesticides and fertilizers [28, 29]. In contrast, the stable yield of rice is highly maintained by exploiting synergies between species to minimize usage of chemicals and is suggesting to the modern agriculture that rice monocultures need to be improved with addition of species for facilitating positive interactions between species and components. The interactions between various components of RAF are presented in **Figure 5**.

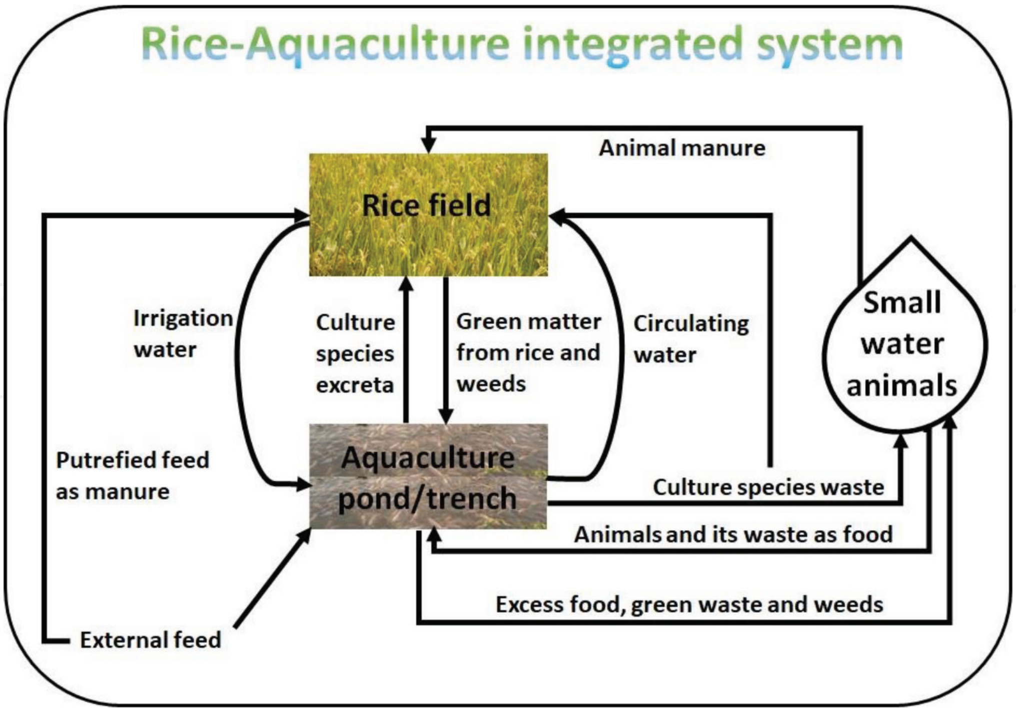


**Figure 5.** Interaction of different components in integrated rice-aquaculture systems.

The type of method for integrated culture mostly depends on local conditions of the culturing area. The climatic and other local conditions, cultured aquatic species and rice varieties, method of culturing, fertilizers used and supplementary feed are the principle factors that influence the quality and quantity of yield [30, 31]. The culture method selection depends on the source of aquatic species (ASp) and its interaction with the growing rice which was well described by Coche [31] seven decades ago.

The integrated rice-aquaculture is a mixed farming, where various rice varieties are grown along with selected aquatic cultural species depending on the local biological and physical factors. However, the selection of one aquatic species or more influences the yield of aquaculture protein. Because of this, the selection of aquatic species plays the most important role for the profit to the farmer and helps to improve the economy of the country. The simple economic benefit of shrimp/prawn, crab and fish with rice cultivation is well defined [32]. Besides profit rice-aquaculture generates the highest employability in rice-prawn culture, followed by rice-crab, rice-shrimp, rice-carp and rice-tilapia.

### *2.3.1. Suitable crustacean types*

There are a number of crustacean species that grow in the rice fields as an integrated culture. The best example to explain this is the freshwater rice field crab that grows naturally in the rice fields of India. Besides crabs, there are other crustacean species like prawns, shrimps, lobsters and crayfishes that can also be grown in the integrated system along with rice with proper management [33], which is in practice in the coastal areas. Since the most profitable crustacean protein in today's world market is from shrimps or prawns, the production of these species is more profitable to the farmers especially the Indian and Asian conditions.

*2.3.1.1. Shrimp/prawn production*

Shrimps are grown in brackish water, whereas prawns grow in freshwater. The shrimp production is done with the fields of holding salty water located in west coast and deltaic areas of eastern India where the salt-resistant rice varieties are grown. Due to limited availability of salt water, only one crop (integrated rice-shrimp farming) is grown mostly in the months of July to September every year. The channels are arranged to control the water supply into the field or pond during harvesting of rice, and the shrimp is protected in the ponds/trenches. At this stage, rice field consists of substantial number of shrimp larvae having less water. The shrimp harvesting in this case is usually done after 3 months of rice harvest. To clearly say the method followed to culture rice and shrimp is through alternative system (semi-intensive monoculture) with few modifications and balanced diet supplied during the culture. The average production rate of shrimp per hectare in this method is 1440 kg. *Penaeus monodon* is the most common species grown in this type of culturing. *Penaeus merguiensis, Penaeus indicus* and *Metapenaeus ensis* are alternative species to grow in this type of system.

The most popular species of freshwater prawn grown in the integrated rice-prawn culture is *Macrobrachium rosenbergii* (*M. rosenbergii*). The monoculture of *M. rosenbergii* in the rice fields is in practice in North Kuttanad, where almost 248 hectares are cultivated integrated rice-prawn culture in a year [34]. Like rice-shrimp farming, the alternative system of culturing is adapted for rice-prawn culture (semi-intensive monoculture). The productivity of prawn monoculture with rice is around 700 kg/hectare. On the other hand, the polyculture of prawn (*M. rosenbergii*) along with fish (*Catla catla*, *Labeo rohita* and *Ctenopharyngodon idella*) in the rice fields is also in practice, where the productivity of prawn is 285 kg/hectare, which has almost two times less production of monoculture of prawn in the integrated system. The yield of *Penaeus monodon* with mixed cultures in the rice fields is about 2135 kg/hectare [35].

*2.3.1.2. Crab production*

More than two decades ago, the role of indigenous technology in the production of rice-crab culture is well described [36]. The crabs *Oziotelphusa senex senex* or *Parathelphusa hydrodromus* are commonly called as ‘freshwater rice field crabs’ since their occurrence is naturally in the rice fields. Besides this *Eriocheir sinensis* (Chinese mitten crab) and *Scylla serrata* (mud crab) are the major crab species used for rice-crab integrated farming. Mitten crab is a famous cultural species of China, whereas the mud crab is the most economic crab identified and grows throughout the world. Both these species grow in saline water and are cultured along with salt-resistant rice species in the case of integrated culture. *Scylla serrata* is popular in Asian continent. This crab culture is picking up in the Indian states such as Kerala, Tamil Nadu, Karnataka, Andhra Pradesh, West Bengal, Maharashtra, Odisha, Gujarat and Union territories. However, the crab culture is influenced by many factors, including environmental, biological, physical as well as socio-economic factors [37, 38].

Crabs depend on naturally available food in the rice fields. Anyhow, supplementation of external feed is needed during fast-growing periods. The management of rice-crab culture is much easier than other RAFs. But the only management aspect that needs to be addressed is regulation of pesticide usage. Since the usage of pesticides is unavoidable for rice yield, it can be managed by selecting less toxic pesticides with a method of spray on rice stems and specific time of spray at which crabs stay in burrows. Proper water management prevents the crab from escaping from rice fields. The average crab protein produced in rice-crab system is approximately 600 kg/hectare. The systematic management of crab culture changes the farmers socioeconomic status than the shrimp/prawn culture alone [39, 40] in addition, these crabs are more eco-friendly and grow easily in polyculture with other species [41, 42]. The only limitation in crab culture is limited availability of wild seed and is overcome by establishing crab hatchery industry to protect natural broodstock for continuous supply of seed [43]. The sequential or synchronous farming is the adaptable system for rice-crab culture, which depends on type of crab species growing.

*2.3.1.3. Crayfish production*

Similar to crabs, crayfishes are the strongest crustaceans that tolerate unfavorable conditions than other species. The most common species used in rice-crayfish integrated system are *Procambarus clarkii* and *Cherax quadricarinatus*. The rice-crayfish culture is common in Southern United States (*Procambarus clarkii*) and in Australia (*Cherax quadricarinatus*). The adult crayfish is used as broodstock to get seed in the ponds. The broodstock is released into field after 1 week of rice seedling implantation. On the other hand, the crayfish seed is also obtained from hatcheries. Besides this the seed also obtained from the rice-crayfish integrated system after harvesting, where the adult crayfish produce juveniles which are used as seed for immediate culture. Unlike other crustaceans rice-crayfish culture is also done with sequential farming. In this system before 2 weeks of harvesting the rice, the water is drained to facilitate crayfish to make burrows [44]. Watering the field after harvesting leads to growth of ratoon crop (occurrence of regrowth from rice stubbles) and facilitates the growth of insects, zooplankton, worms and molluscs, which promotes the direct growth of flushed out crayfish from the burrows [45]. The optimum weight for harvesting crayfish is about 15–60 g. The average yield of crayfish in this system is about 1960 kg/hectare [46].

Many other aquatic species can be integrated with rice culture. The typical integration of aquaculture with rice system followed in Asian countries is presented in **Figure 6**.

### 2.4. Rice-aquaculture farming with livestock

The profit of rice-aquaculture integrated culture created a scope for betterment of social-economic status of farmers. Using this as a concept, the farmers tried to integrate other livestock with RAF. There are many systems evolved in this way and mentioned in **Table 1**. However, the livestock rearing with RAF is in primitive stage and has its own limitations.

### 2.5. Management of rice-aquaculture farming

Individually the rice and aquaculture systems are separate entities but are mostly holding common requirements. Because of commonality in system management, the integrated RAF is prospective and profitable. However this integrated system has conflict in requirements and their management from one system to other. The modified interventions are required to overcome these problems at each and every aspect and step of system management. Besides selection of species (both rice and aquatic species) explained earlier, integrated system requires many other factors to manage and is explained hereunder.

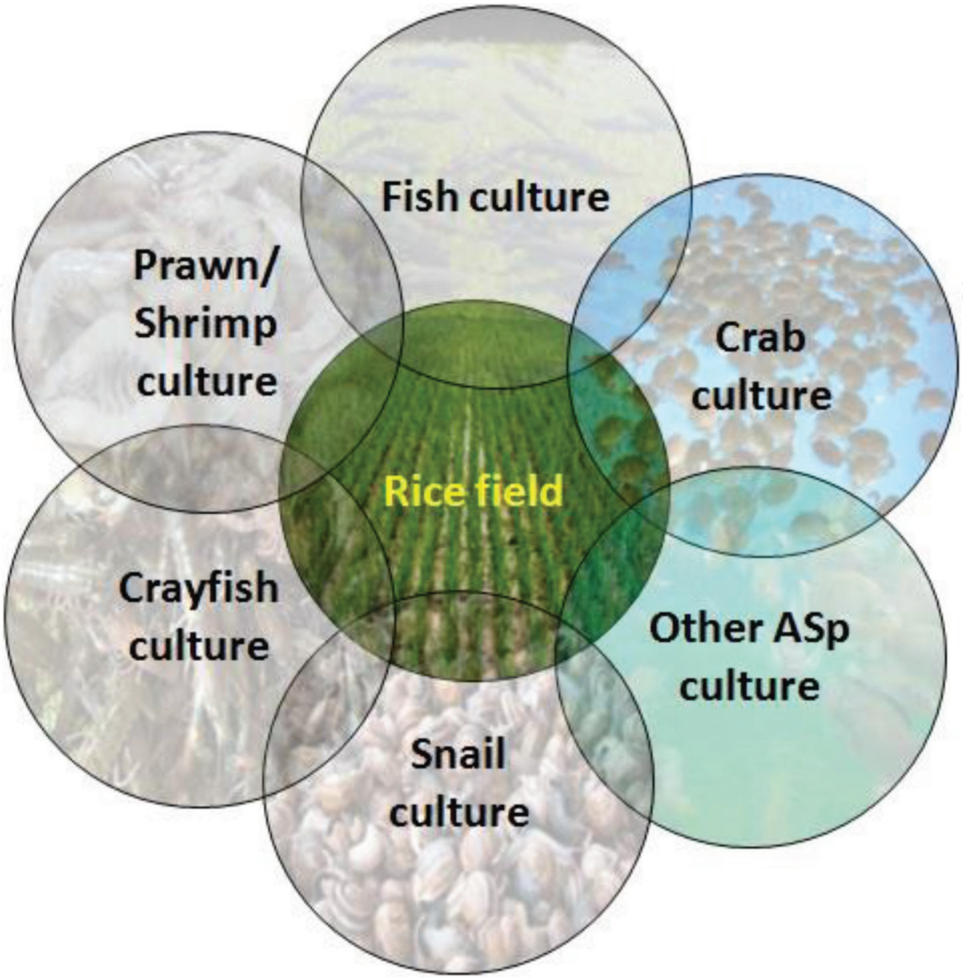


**Figure 6.** Integrated subsystems of traditional rice-aquaculture in Asia.

| S. no. | Livestock integrated with rice-aquaculture system | Product produced from livestock | Reference |
|---|---|---|---|
| 1. | Duck | Eggs and meat | Syamsiah et al. [47] |
| 2. | Golden apple snails | Meat | Halwart [28]; FAO [48] |
| 3. | Cows and buffalos | Milk and meat | Otubusin [49] |
| 4. | Pigs | Meat | Prein [50] |
| 5. | Sheep and goat | Milk and meat | Otubusin [49] |
| 6 | Poultry | Egg and chicken | Otubusin [49], Oladosu et al. [51], Momoh and Norman [52] |

**Table 1.** The livestock integrated systems with rice and/or aquaculture in Asian countries.

### *2.5.1. Water management*

Water plays an important role in any agricultural system. Continuous water supply is badly needed for RAF. The source of water (river, pond, well or bore) is the first parameter one should think of before establishing the integrated system. Uninterrupted water supply required for rice up to its maximum tolerated levels (15–20 cm) is recommended [53, 54] and is good for maximum yield of rice. For the aquatic species, the depth of water in the ponds/trenches should be 65–70 cm and is sufficient to manage cooler and hotter areas for the better growth of aquatic species. Most of the times, crustaceans grow at the bottom whereas fish at the middle and top layers of the water.

*2.5.2. Fertilizers and chemicals*

Organic and inorganic chemicals and fertilizers are essentially required for the growth of both rice and aquatic species. Besides nourishment of rice, external supplementation of reasonable amount of nutrients raised the levels of phyto- and zooplankton, which serve as food for aquatic cultural species. Aquatic species in the rice field enrich the soil fertility, which ultimately reduces the external supplementation of fertilizer and reduces the production cost [55]. This proves that RAF requires less usage of fertilizers than rice alone [56]. Alternatively yield of rice increases by the supplementation of nitrogen fertilizers at the time of land preparation instead of applying at the time of farming [57]. Addition of ammonia during farming causes damage to ASp as it acts as toxicant in the water, whereas no change has been seen with phosphorus fertilizer application in soil and water [56].

Organic fertilizers benefit for the growth of both rice and ASp. Moreover, the additional supplementation of animal manure helps for the better growth of aquatic species at the time of land preparation [58], and in this way, any toxic effects of these manure to the aquatic species are avoided [57]. Nevertheless, integrated rice-aquatic culture farming is good for poor and unfertilized soils where the aquatic culture species play the greatest role in making them fertile [24].

Besides fertilizers and nutrients, the control of pest and fungal diseases of rice is another task for production of higher yield of rice which usage is not at all good for the growth of ASp. In addition to reduced yield, the uncontrolled usage of pesticides and fertilizers declines the biodiversity. Prolonged misuse of pesticides and fertilizers over the years has also halted the development of inland fisheries and aquaculture [59–62].

In an attempt to reduce pesticide use, important changes have taken place in strategic approaches to plant protection. Integrated pest management (IPM) methods have brought ecological principles and social scientific perspectives into traditional crop management. These ecology-based pest control methods have resulted in markedly improved rice farming systems, which are not only higher yielding but also more sustainable [63–66]. In addition to this, increased adoption of rice-fish farming, with fish as a natural control agent of pest organisms, provides a promising alternative for further developing ecological sound management strategies of the rice field environment [61, 67–69].

*2.5.3. Nutrition and supplemental feeding of aquatic cultural species*

The rice ecosystem is rich with natural flora and fauna. Naturally the rice ecosystem itself is a rich nutrient supplement for aquatic cultural species. The phytoplanktons and bacteria are the first developers in the rice field and later weeds (macrophyton, benthos and detritus), and zooplankton will develop. All these are directly consumed by the aquatic species. Usually, farmers enrich the natural nutrients of aquatic species by supplementation of fertilizers. An alternative to have natural supplementation in RAF is by raising a fern azolla. Azolla is the best natural feed for fish, but not for crustaceans. Anyhow, this naturally occurring food is not sufficient for growing aquatic culture species. The consumption and utilization of natural field nutrients vary from aquatic culture species to species [24]. So, the external supplementation of nutrients is a must for attaining higher yield of aquatic protein.

The composition of external feed supplemented for crustaceans/other aquatic species is a mix of 40% of animal waste (fish, snail, clam and viscera tRAFh), 25% of plant waste (rice or wheat bran, vegetables, pumpkin, leguminous cakes and sweet potatoes) and 35% of terrestrial gRAFs and/or duck weeds. These materials are made as powder and used for making food pellets. But various types of external feed are in practice in many countries [70–73].

*2.5.4. Temperature and dissolved oxygen*

The fluctuations in the temperature and dissolved oxygen do not have much influence on the yield of rice, but it matters for the production of aquatic protein. In summer, the water temperature for ASp is regulated by rice plant shading during summer [26, 74]. Anyhow the low/moderate temperatures are best suited for good yield of ASp. To maintain adequate temperatures for the better growth of fish, prawn, carb, crayfish, snails and other ASp, high amount of water needs to be maintained continuously in the ponds/trenches/refuges. The only way to maintain temperature in the rice-ASp system is by controlled water system.

The dissolved oxygen is an important factor that affects the survival and growth of ASp, and in extreme conditions, it may lead to death. Unsystematic management of ponds/trenches leads to pollution [75], resulting in reduced dissolved oxygen. Basically the reduced dissolved oxygen changes the physiochemical properties of water, thereby pond/trench ultimately shows effect on growing fish. Most of the times, dissolved oxygen is reduced due to overloading of nutrients in the ponds/trenches and also causes increase in cyanobacterial bloom, which depletes dissolved oxygen and shows poisonous effects on ASp [76]. The increase in photosynthesis in rice due to increased aeration is recorded with the fish movement in the rice field [77, 78].

*2.5.5. Predators and other factors*

The birds are the predators for the ASp in rice-ASp system. Small birds may not cause damage to the system, but the larger ones reduce the ASp production to 20–60%. Aquavorous birds should be controlled by placing certain bird terrorizing signs or holdings in and around the rice-ASp system or making sounds to create panic and foreboding in them.

**2.6. Pros and corns**

**a.** Benefits of rice-aquaculture farming:

1. Usage of available land effectively.
2. Provides employment for village labors than rice alone.
3. One-time investment is good enough for making trenches/ponds/refuges.
4. Not needing of weeding in rice and feeding for Asp ultimately reduces the cost of labor.

5. Aquatic excreta and the waste generated during culturing provide organic fertilization which improves the rice yield up to 15%.

6. Reduced usage of external fertilizers, pesticides and fungicides ultimately provides pollution-free environment, thereby protecting the nature.

7. The additional production of quality aquatic protein for nourishing people suffering from protein malnutrition.

8. The ASp movement and foraging in the rice field increase the dissolved oxygen, thereby increasing photosynthesis and rice production.

9. Rice and aquatic protein produced are hassle-free and organic, which may reduce the occurrence of several diseases caused by polluted environment and food.

10. The external quench may provide place for growing organic onion, sweet potato, bean, ladies finger, tomato, variety of green leaves and other vegetables, which provide additional income to the farmer.

11. The wastelands or land not under usage for cultivation becomes fertile.

12. The wastage of nutrients supplemented for the rice are prevented, since the microalgae, the competitors for nutrients with rice in the field, are controlled by ASp which they swallow as food.

13. The reduction of rice yield up to 50% by the aquatic weeds is controlled by ASp.

14. The ASp fed on insects controls the pest effect on rice and increased yield.

15. The seed of ASp is produced during integrated system and is used for the next cycle of culture.

**b.** Limitations/disadvantages of rice-aquaculture farming:

1. Rice-aquaculture system is restricted only to the areas where surplus water is available.

2. Greater amount of water supply to RAF may increase the water scarcity for human usage and difficulties in getting potable water in the future.

3. Labor required more than rice culture alone.

4. Only specified rice species tolerant of deep water/saline water and low temperatures can adopt this system.

5. Some aquatic species uproot or eat the rice seedlings.

6. The area of rice field is reduced due to ponds/trenches/refuges constructed for ASp.

7. Additional amount of fertilizers and feeding costs more than rice culture alone.

8. The pesticides and herbicides are restricted to use and may reduce the production of rice.

9. Abnormal change in the temperature, low dissolved oxygen, inadequate place and occurrence of birds catching the ASp lead to 20–60% loss in ASp production.

10. Controlling water supply and floods is difficult. Floods may lead to loss of ASp.
11. Most of the cases, only local ASp can be adapted to this system, but not the demand-based ASp culture.
12. Usually the irrigated water that comes from other lands may contain pesticides/herbicides which may drop the production capacity of this system.
13. ASp culture is confined only to the rice growing seasons.

Due to several disadvantages of rice-ASp culture, it has gradually been discarded, and farmers are going for rotational culture. Whatever so, the advantages of this system are more prominent and make the farmers to stand socio-economically especially in developing countries. The governments need to initiate to publicize the importance of rice-ASp integrated farming and its impact on the poverty, society and ultimately country.

## 3. Conclusion

Rice is a main carbohydrate ingredient in the regular diet of approximately 3.5 billion people worldwide, and developing countries are producing more than 90% of the rice in the world [26]. It is suggested that combination of traditional/conventional agriculture and familiar methods such as biotechnology and other modern technologies [79, 80] available may provide high yield by minimizing the usage of pesticides and fertilizers, within the available land area, water and nutrients. Adaptation of new methodologies into traditional RAF may provide chance to meet the global demand for food besides protecting the environment by reducing the pollution.

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## Conflict of interest

Authors declares no conflict of interest.

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## References

[1] Sarah LK, Skoet J, Raney T. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Development. 2016;**87**:16-29

[2] Mathew S. India's demographic transition and economic growth: Implications for China and the balance of power in Asia. IJMRME. 2015;**1**(1):513-516

[3] Chagnon M, Kreutzweiser D, Edward AD, Mitchell Morrissey CA, Noome DA, Van der Suijs JP. Risk of large-scale use of systemic insecticides to ecosystem functioning and services. Environmental Science and Pollution Research. 2015;**22**:119-134

[4] Altieri MA. Linking ecologists and traditional farmers in the search for sustainable agriculture. The Ecological Society of America. 2004;**2**:35-42

[5] Zhu Y, Chen H, Fan J, Wang Y, Li Y, Chen J, Yang S, Hu L, Leung H, Mew TW, Teng PS, Wang Z, Mundt CC. Genetic diversity and disease control in rice. Nature. 2000;**406**:718-722

[6] Altieri MA, Nicholls CI. Biodiversity and Pest Management in Agroecosystems. 2nd ed. New York, USA: The Harworth Press Inc.; 2002. p. 275

[7] Csavas I. Regional review on livestock-fish production systems in Asia. In: Mukherjee TK, Moi PS, Panandam JM, Yang YS, editors. Proceedings of the FAO/IPT Workshop on Integrated Livestock-Fish Production Systems; 16-20 December 1991. Institute of Advance Studies: University of Malaya, Kuala Lumpur, Malaysia; 1992

[8] Edwards P, Kaewpaitoon K, McCoy EW, Chantachaeng C. Pilot scale crop/livestock/fish integrated farm. AIT Research Report 184. Bagkok, Thailand. 1986. p. 131

[9] Thomaier S, Specht K, Henckel D, Dierich A, Siebert R, Freisinger UB, Sawicka M. Farming in and on urban buildings: Present practice and specific novelties of zero acreage farming (ZFarming). Renewable Agriculture and Food Systems. 2014;**30**:43-54

[10] Xie J, Hu L, Tang JJ, Wu X, Li N, Yuan Y, Yang H, Zhang J, Luo S, Chen X. Ecological mechanisms underlying the sustainability of the agricultural heritage rice–fish coculture system. PNAS. 2011;**108**:E1381-E1387

[11] USAID Mekong Adaptation and Resilience to Climate Change (USAID Mekong ARCC): Development of Rice-Shrimp Farming in Kekong River Delta, Vietnam. 2016. http://mekongarcc.net/sites/default/files/rice-shrimp_report_amdi_final_eng_format_approved.pdf

[12] Ramachandra RP. Isolation and Characterization of Eyestalk Peptide Hormones Regulating Molting and Reproduction in the Crab *Oziotelphusa senex senex* [Thesis]. Tirupati: Sri Venkateswara University; 2005

[13] Kishori B. Involvement of Opioid Peptides in Regulating Carbohydrate Metabolism and Reproduction in the Fresh Water Crab, *Oziotelphusa senex senex* [Thesis]. Tirupati: Sri Venkateswara University; 2003

[14] Yunus M, Hardjamulia A, Syamsiah I, Suriapermana S. Evaluation of rice-fish production systems in Indonesia. In: De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR,

Bimbao MP, editors. Rice-fish Research and Development in Asia. Proceedings of the ICLARM Conference. Vol. 24. 1992. pp. 131-138, 457

[15] Roger PA. Biology and Management of the Floodwater Ecosystem in Rice Fields. Los Banos, Laguna, Philippines: International Rice Research Institute; 1996. p. 250

[16] Coche AG. Fish culture in rice fields a world-wide synthesis. Hydrobiologia. 1967;**30**:1-44

[17] Halwart M. Ricefield fisheries and rice-based aquaculture—Underestimated and undervalued resources. In: FAO Inland Water Resources and Aquaculture Service. Review of the State of World Fishery Resources: Inland Fisheries. FAO Fisheries Circular No. 942, Rev. 1. Rome: FAO; 2003. pp. 36-47, 60

[18] Halwart M, Gupta MV. Culture of Fish in Rice Fields. FAO and The World Fish Center; 2004

[19] CIFRI Technology. Paddy Cum Fish Culture. West Bengal, India: Central Inland Fisheries Research Institute, Barrackpore; 1984

[20] Halwart M. Trends in rice-fish farming. FAO Aquaculture Newsletter. 1998;**18**:3-11

[21] Funge-Smith SJ. Small-scale rural aquaculture in the a Lao PDR FAO Aquaculture Newsletter. 1999; Nos. 22 and 23

[22] Guttman H. Rice field fisheries—A resource for Cambodia. Naga, The ICLARM Quarterly. 1999;**22**:11-15

[23] Balzer T, Balzer P, Pon S. Traditional use and availability of aquatic biodiversity in rice-based ecosystems—I. Kampong Thom Province, Kingdom of Cambodia. In: Halwart M, Bartley D, editors. FAO Inland Water Resources and Aquaculture Service. Rome: FAO; 2002. CD ROM ISBN 92-5-104820-7

[24] Tilman D, Hill J, Lehman C. Carbon-negative biofuels from low-input high diversity grassland biomass. Science. 2006;**314**:1598-1600

[25] Thomas MB. Ecological approaches and the development of "truly integrated" pest management. PNSA. USA.1999;**96**:5944-5951

[26] Frei M, Klaus BK. Integrated rice-fish culture: Coupled production saves resources. Natural Resources Forum. 2005;**29**:135-143

[27] Halwart M. Fish as Biological Control Agents in Rice: The Potential of common Carp *Cyprinus carpio* l. and Nile tilapia *Oreochromis niloticus* (L) [Thesis]. Germany: University of Hohenheim, Hohenheim; 1994

[28] Omer A, Pascual U, Russell NP. Biodiversity conservation and productivity in intensive agricultural systems. Journal of Agricultural Economics. 2007;**58**:308-329

[29] Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. Agricultural sustainability and intensive production practices. Nature. 2002;**418**:671-677

[30] Schuster WH. Fish culture in conjunction with rice cultivation. World Crops. 1955;**7**:11-14 67-70

[31] Yang Y, Zhang H-c, Xiao-jun HU, Qi-gen DAI, Zhang Y-j. Characteristics of growth and yield formation of rice in rice-fish farming system. Agricultural Sciences in China. 2006;**5**(2):103-110

[32] Salam MA, Ross LG, Beveridge MCM. A comparison of development opportunities for crab and shrimp aquaculture in South-western Bangladesh, using GIS modelling. Aquaculture. 2003;**220**:477-494

[33] Anonymous. Algicide for direct-seeded rice. IRRI Reporter. 1971;**2**(71):2-3

[34] Nair RR. Integrated fish farming in kuttanad: Problems and prospects. In: Proceedings of the Seminar on Integrated Fish Farming in Upper and Northern Kuttanad. 1994. pp. 1-8

[35] Ghosh A. Rice-fish farming development in India: Past, present and future. In: De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP, editors. Rice-fish Research and Development in Asia. Proceedings of the ICLARM Conference. Vol. 24. 1992. pp. 27-43, 457

[36] Rajasekaran B, Whiteford MB. Rice-crab production in South India: The role of indigenous knowledge in designing food security policies. Food Policy. 1993;**18**:237-247

[37] Largo D, Ohno B, Ohno M, Critchley AT. Constructing an Artificial Seaweed Bed. Japan International Cooperation Agency (JICA): Seaweed Cultivation and Marine Ranching. Kanagawa International Fisheries Training Center; 1993. pp. 113-130

[38] Kingzet B, Salmon R, Canessa R. First nation's Shellfish Aquaculture Regional Business Strategy. BC Central and Northern Coast. Aboriginal Relations and Economic Measures, Land and Water British Columbia. 2002

[39] Cholik F, Hanafi A. A review of the status of the mud crab (Scylla spp.) fishery and culture in Indonesia. The mud crab. In: Angell CA, editor. A Report on the Seminar Convened in Surat Thani, Thailand; November 5-8, 1991; Bay of Bengal Programme, Madras, India. 1992. pp. 13-27

[40] Overton JL, Macintosh DJ. Mud Crab Culture: Prospects for the Small-scale Asian Farmer. Vol. 5. Malaysia: INFOFISH International. FAO Publication; 1997. pp. 26-32

[41] Chong LP. The culture and fattening of mud crabs. Info Fish International. 1993;**3**(May/June):46-49

[42] Chandrasekaran VS, Perumal P. The mud crab, *Scylla serrata* a species for culture and export. Seafood Export Journal. 1993;**25**:15-19

[43] Salam MA, Ross LG. Optimising site selection for development of shrimp (*Penaeus monodon*) and mud crab (*Scylla serrata*) culture in South-western Bangladesh. In: Proceedings of the GIS 2000 Conference; Toronto, Canada. 2000

[44] NAS. Making aquatic weeds useful: Some perspectives for developing countries. Report of an Ad Hoc Panel of the Advisory Committee on Technology Innovation, Board of Science and Technology for International Development, Commission on International Relations. Washington D.C.: National Academy of Sciences; 1976. p. 175

[45] Chien YH. Double Cropping Rice Oryza Sativa and Crawfish *Procambarus clarkii* (Girard) [M.S. thesis]. Baton Rouge LA, USA: Louisiana State University and Agricultural and Mechanical College; 1978. 85 p

[46] de la Bretonne LW Jr, Romaire RP. Crawfish Production: Harvesting, Marketing and Economics. Southern Regional Aquaculture Center Publication. SRAC No. 242; 1990. p. 4. http://www.aces.edu/dept/fisheries/aquaculture/pdf/242fs.pdf

[47] Syamsiah I, Suriapermana S, Fagi AM. Research on rice-fish culture: Past experiences and future research program. In: De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP, editors. Rice-fish Research and Development in Asia. Proceedings of the ICLARM Conference. Vol. 24. 1992. pp. 287-293, 457

[48] FAO. Fish-Farming in Vietnamese Rice Fields Fights Golden Apple Snail Pest. News & Highlights. 1998. FAO Web Page: http://www.fao.org/NEWS/1998/980410-e.htm

[49] Otubusin SO. A proposed integrated livestock-rice-poultry cum fish culture in enclosure system. In: Proceedings of the Fifth Annual Conference of the Fisheries Society of Nigeria. Ilorin: Fish; pp. 319-326

[50] Prein M. Integration of aquaculture into crop-animal systems in Asia. Agricultural Systems. 2002;**71**:127-146

[51] Qladosu GA, Ayinla OA, Onuoha GC, Needom JG. Performance of *Clarias gariepinus* in polyculture with *Oreochromis niloticus* under the integrated broiler chicken fish farming. NIOMR Tech. Pap. No. 65. 1990. p. 22

[52] Momoh EJJ, Norman JE. Integration of fish with poultry and rice production. In: Olapada JO, Senessie SMB, editors. Sustainable Integrated Pond-based Aquaculture with Rice and Poultry Production Economic, Social and Environmental Assessment. 1st ed. Njala University Press. pp. 77-88

[53] Rosario WR. Rice-fish culture. In: Philippines (BFAR) Freshwater Aquaculture Extension Training Manual. Technology. Vol. III. Quezon City, Philippines: USAID-Bureau of Fisheries and Aquatic Resources; 1984. pp. 189-206, 248

[54] Koesoemadinata S, Costa-Pierce BA. Development of rice-fish farming in Indonesia: Past, present and future. In De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP, editors. Rice-fish Research and Development in Asia. Proceedings of the ICLARM Conference. Vol. 24. 1992. pp. 45-62, 457

[55] Wu L. Methods of rice-fish culture and their ecological efficiency. In: MacKay KT, editor. Rice-fish Culture in China. Ottawa, Canada: International Development Research Centre (IDRC); 1995. pp. 91-96, 276

[56] Li X, Huaixun W, Yontai Z. Economic and ecological benefits of rice-fish culture. In: MacKay KT, editor. Rice-fish Culture in China. Ottawa, Canada: International Development Research Centre (IDRC); 1995. pp. 129-138, 276

[57] Singh VP, Early AC, Wickham TH. Rice agronomy in relation to fish culture. In: Pullin RSV, Shehadeh ZH, editors. In: Proceedings of the ICLARMSEARCA Conference on Integrated Agriculture-Aquaculture Farming Systems; Manila, Philippines. 1979. pp. 15-34, 258

[58] Sevilleja RC, Cagauan AG, Lopez EA, de la Cruz CR, van Dam AA. Component technology research in rice-fish systems in the Philippines. In De la Cruz CR, Lightfoot C, CostaPierce BA, Carangal VR, Bimbao MP, editors. Rice-fish Research and Development in Asia. Proceedings of the ICLARM Conference. vol. 24. 1992. pp. 373-384, 457

[59] Moulton TP. More rice and less fish: Some problems of the "green revolution". Australian Natural History. 1973;**17**:322-327

[60] Cagauan AG, Arce RG. Overview of pesticide use in rice-fish farming in Southeast Asia. In: De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP, editors. Rice-fish Research and Development in Asia. Proceedings of the ICLARM Conference. Vol. 24. 1992. pp. 217-234, 457

[61] Halwarth M. Fish as biocontrol agents in rice. The potential of common carp *Cyprinus carpio* and Nile tilapia *Oreochromis niloticus*. Tropical Agroecology, Vol. 8. Weikersheim: Hoenheim University; 1995

[62] Abdullah AR, Bajet CM, Matin MA, Nhan DD, Sulaiman AH. Ecotoxicology of pesticides in the tropical paddy field ecosystem. Environmental Toxicology Chemistry. 1997;**16**:59-70

[63] Stone R. Researchers score victory over pesticide-and pests-in Asia. Science. 1992; **256**:1272-1273

[64] Settle WH, Ariawan H, Astuti ET, Cahyana W, Hakim AL, Hindayana D, Lestari AS, Sartanto P. Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. Ecology. 1996;**77**:1975-1988

[65] Noda T, Loc NT, Van Du P. Rice pest management in the Mekong Delta. In: Xuan VT, Matsui S, editors. Development of Farming Systems in the Mekong Delta of Vietnam. Ho Chi Minh: JIRCAS, CTU & CLRRI, Ho Chi Minh Publishing House; 1998. pp. 271-287

[66] Huan NH, Mai V, Escalada MM, Heong KL. Changes in rice farmer's pest management in the Mekong Delta, Vietnam. Crop Protection. 1999;**18**:557-563

[67] Cagauan AG. Overview of the potential roles of pisciculture on pest and disease control and nutrient management in rice fields. In: Symoens JJ, Micha JC, editors. The Management of Integrated Freshwater Agro-Piscicultural Ecosystem in Tropical Areas. Brussels: Royal Academy of Overseas Science; 1995. pp. 203-244

[68] Dela Cruz CR. Role of fish in enhancing rice field ecology and integrated pest management. In: Proceedings of the ICLARM Conference. Manila: International Center for Living Aquatic Resources Management; 1994

[69] Gesa Horstkotte-Wesseler. Socioeconomics of rice-aquaculture and IPM in the Philippines: Synergies, potential and problems. ICLARM Tech. Rep. 1999.57,225. ISBN: 971-802-004-7

[70] Gupta MV, Abdul Mazid M, Islam Md S, Rahman M, Hussain MG. Integration of aquaculture into the farming systems of the flood-prone ecosystems of Bangladesh: An evaluation of adoption and impact. ICLARM Tech. Rep. 1999. 56. p. 32

[71] He QH, Sheng HQ, Xu GH. The use of supplementary feeds for semi-intensive fish culture practices in reservoirs in China. In: Mathias JA, Charles AT, Hu BT, editors. Integrated Fish Farming. Proc. Workshop on Integrated Fish Farming; 11-15 Oct. 1994 Wuxi, Jiangsu Prov. P.R. China: CRC Press; 1998. pp. 307-324, 420

[72] Darvin LC. Status of rice fields as hatcheries/nurseries for tilapia in the Philippines. In: De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP, editors. Rice-fish Research and Development in Asia. Proceedings of the ICLARM Conference. Vol. 24. 1992. pp. 145-150, 457

[73] Chikafumbwa FJK. Use of terrestrial plants in aquaculture in Malawi. In: Pullin RSV, Lazard J, Legendre M, Amon Kothias JB, Pauly D, editors. The Third International Symposium on Tilapia in Aquaculture. Proceedings of the ICLARM Conference. Vol. 41. 1996. pp. 175-182, 575

[74] Wahab MA, Kunda M, Azim ME, Dewan S, Thilsted SH. Evaluation of freshwater prawn-small fish culture concurrently with rice in Bangladesh. Aquaculture Research. 2008;**39**: 1524-1532

[75] Asala G. Principles of Integrated Aquaculture. In: Olatunde AA. In Lake Kaiinji. In: Ayeni JSO, editor. Helmited Guinea Fowl (NMGP). 1994

[76] Pearl HW, Tucker CS. Ecology of blue-green algae in aquaculture ponds l. World Aquaculture Society. 1995;**26**:130-135

[77] Kunda M, Azim ME, Wahab MA, Dewan S, Roos N, Thilsted SH. Potential of mixed culture of freshwater prawn (*Macrobrachium rosenbergii*) and self recruiting small species mola (*Amblypharyngodon mola*) in rotational rice-fish/ prawn culture systems in Bangladesh. Aquaculture Research. 2008;**39**:506-517

[78] Mustow SE. The effects of shading on phytoplankton photosynthesis in rice-fish fields in Bangladesh. Agriculture. Ecosystems and Environment. 2002;**90**:89-96

[79] Gebbers R, Adamchuk VI. Precision agriculture and food security. Science. 2010;**327**: 828-831

[80] Tester M, Langridge P. Breeding technologies to increase crop production in a changing world. Science. 2010;**327**:818-822