

# Revisiting Underlying Ecological Principles of Rice-Fish Integrated Farming for Environmental, Economical and Social benefits

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## Abstract

Our goal is to revisit underlying ecological principle of rice-fish farming integration and synthesize information to suggest some pertinent patterns and connections that contribute to understanding of the interactions of abiotic and biotic factors in rice field for productivity enhancement. We synthesized ecological interactions, energy and material flow in absence and presence of bottom feeding omnivore fish to give a clear scenario of food web interactions in rice field. Rice plants, weeds and minute algae can be competitive to each other as they depend on common resources for growth. However, introduction of the fish about two weeks after rice plantation can add new link to the food chain by perturbation and top down control on rice competitors, pests and mobility of nutrients towards rice plant for increased rice field productivity to benefit the farmers economically, environmentally and socially.

In relation to above synthesis, rice-fish integrated field experiments were performed in 4 mid hill districts of Nepal from 2000-2002. The results showed that despite of 3-5% loss of the rice cultivating area due to "trench" as fish hiding place, rice yield increased up to 9% in addition of 529 kg ha<sup>-1</sup> fish from rice-fish integrated farming than cultivating rice alone. In rice-fish system, competitive advantages of rice plants over weeds and micro algae, control on rice pest and increased nutrient supply due to top down, perturbation and nutrient regeneration by fish were the reasons of increased rice yield in treatments than in controls where rice alone was cultivated.

**Key Words:** Ecological principle, Rice-Fish integrated farming, Social benefit

## Introduction

Rice, *Oryza sativa* L., is one of the most dominant crops and major source of livelihood for many poor producers and consumers in Asia (De la Cruz *et al.*, 1992; Rothuis, 1998; Barker and Dawe, 2000). In general, rice require substantial amount of water for farming. Due to abundant water, many fish species prefer the rice field for their reproduction and growth (Li, 1988; Ali, 1992; Fernando, 1993; Little *et al.*, 1996; Halwart, 1998). Such natural aggregation of

fish in rice field might have influenced the idea of rice-fish farming for enhancing productivity.

Rice-fish farming is most advanced in China, producing 377,000 tons of fish from rice field in 1996 (Halwart, 1998). A variety of fish species can be integrated with rice, such as common carp (*Cyprinus carpio*), catfish (*Clarias batrachus*), silver barb (*Puntius gonionotus*), major carps, tilapia, prawn etc. in rice field (Dutta *et al.*, 1986;

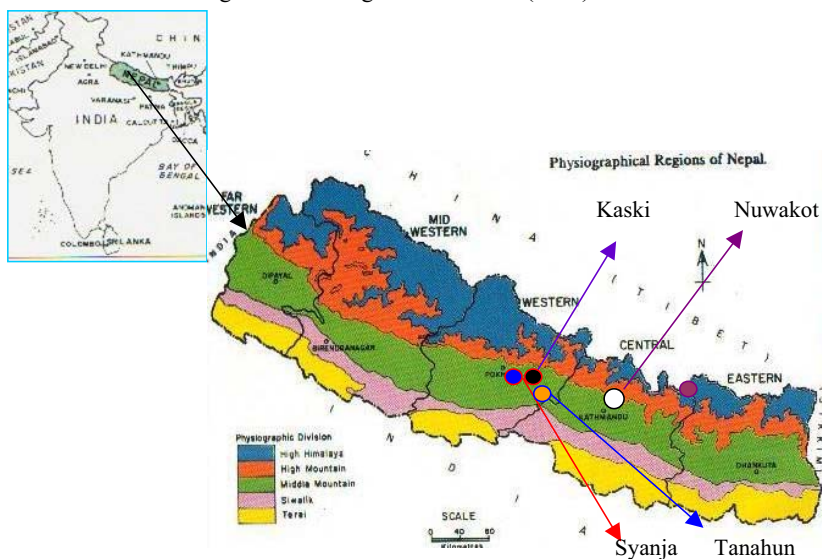


Figure.1. Location of the experimental areas in mid hills of Nepal

Halwart, 1998; Surtida, 2000).

Rice and fish are one of the main staple foods for most people of Asia, where food deficiency is one of the crucial issues. On addition, abuses of insecticides have been the problems for sustainable agriculture productivity (Koesoemadinata, 1980; Cagauan and Arce, 1992; Gyawali, 1999; Matteson, 2000).

Rice-fish farming is one of the best options to increase the food production from limited land through ecological agriculture (Jintong, 1996; Sugan *et al.*, 1996; De la Cruz, 1994). This attributes to an environment friendly rice-fish farming for increase productivity by recycling the energy and matter in sustainable manner (Coche, 1967; Xieping *et al.*, 1996; Edwards, 2000).

Here, on the basis of present knowledge, we present a theoretical synthesis and evidences of ecological process: how energy and

matter are mobilized and recycled in rice-fish integration to benefit the rice field productivity.

### Materials and Methods

This study was conducted in farmer's field at Syangja, Kaski, Tanahun and Nuwakot districts of Nepal (Figure 1). In Syangja and Tanahun, experiment on fish stocking density, in Kaski suitable rice cultivar; and in Nuwakot fertilizers and feeding rates on fish production were examined. All the experimental plots ranging from 100-150 m<sup>2</sup> were located at about 600 to 700 m elevation (mid hill region) from the sea level. Slight modification of plots were made according to Figure 2a, where dike were improved to maintain the base 0.5 m, top width 0.3 m and height 0.4 m. Similarly, in each treatment, trench dimension was maintained 0.4-0.5 m

wide and 0.4-0.5 m deep as shelter to fish during emergencies. The area covered by trench was about 3-5% of the experimental rice plots.

At the inlet and outlet, a wire net screen of ¼" mesh mounted on wooden frame was fixed (Figure 2b). Field preparation began by ploughing and harrowing as per farmer's practice. A total dose of inorganic nitrogen, phosphorus and potash at 50.0 kg ha<sup>-1</sup>, 30.0 kg ha<sup>-1</sup> and 30 kg ha<sup>-1</sup> were applied. Out of the total, 50% was used during field preparation as basal dose; remaining 50% was divided into two doses for top dressing at the time of flowering and panicle initiation. Water filling was started after fixing the screens.

For reliability of the rice varieties, seeds were obtained from Agronomy Section of NARC (Nepal Agricultural Research Council) and seedlings were germinated by farmers. A method of straight row planting at 20-25 cm between rows and hills with 3-4 seedlings hills<sup>-1</sup> was followed. Water level was maintained at 8-10 cm in first 30 days and later gradually increases up to 15-20 cm till fish harvest.

#### ***Fish Integration***

Fish used for integration was common carp, *Cyprinus carpio*. Fish were stocked after 10-15 days of rice plantation. In general, feeding at the rate of 2% body weight of stocked fish was started next day after fingerlings stocking, except special care was given according to experimental designs for feeding. The feed ingredients were (i) rice bran 50.0%, (ii) wheat bran 10.0% (iii) oil cake powder 40.0%. These ingredients were mixed and moist balls were prepared which were put everyday at the same place on the base of the trench. The experiment was

continued for about 88-95 days. During this period growth check was performed once in a month by weighing about 1/3 population of stocked fish. Fish were finally harvested 2-weeks prior of rice harvesting.

The inlet and outlet screens were cleaned every day. Dikes were checked and maintained. To measure the growth of rice, random sampling using 1m x 1m quadrat was performed. Tiller from rice plants within the quadrat were counted at an interval of 15-30 days till a nearly constant value was reached. Weeding was carried after 20, 30, 45 and 60<sup>th</sup> day after transplantation. Disease and pest were monitored. Rice yield data were taken by harvesting rice in 1m long and 1m wide bamboos split quadrat.

#### ***Fish density vs. size experiments***

In this study stocking rate of 4000, 5000, and 6000 fingerlings ha<sup>-1</sup> have been considered as low density (LD), medium density (MD) and high density (HD), respectively. Initial average body weight of 5-10 g and 15-20 g fingerling was considered as small size (SS) and large size (LS), respectively. The treatments identified were low density: small size (LD: SS), medium density: large size (LD: LS), medium density: small size (MD: SS), high density: small size (HD: SS), and high density: large size (HD: LS). The rice cultivar used in the experiment was *Sabitri*. In control (C) only rice was planted without trench and fish. All treatments and control were replicated.

#### ***Feeding and fertilization experiment at Nuwakot***

The stocking rate of fish was 6000 fingerlings ha<sup>-1</sup> with an average size of 5-10 g in all treatments. The feeding rate examined were 0%, 2%, 4% of the total body weight of stocked fish. The rice variety used was

*Janaki*. All the treatments and control were replicated. In control and treatment, the dose of inorganic fertilizer (In) was same as described earlier, while organic (Or) fertilizer (farm yard manure) was used at the rate of 7000 kg ha<sup>-1</sup>, with a basal dose used was at 3000 kg ha<sup>-1</sup>. The remaining dose was used for top dressing (four times) at 15 days interval after rice plantation.

#### **Rice cultivar experiment at Kaski**

In this experiment *Mansuli* (M), *Sabitri* (S) and *Radha-4* (R) rice cultivars were tested for their performance in combination with fish. With all rice cultivars, controls were without fish, while two: (i) organic and (ii) inorganic fertilizers treatments possessed 5-10 g body weight individual fish at the density of 6000 ha<sup>-1</sup>. All controls and treatments were replicated.

#### **Result and Discussion**

Our results agreed with the findings of previous studies, where it has been shown that productivity of rice field increased by integrated farming of rice and fish together in the same field (Arce and De la Cruz, 1978; Middendrop and Verreth, 1986; Dewan, 1992; Torres *et al.*, 1992; Xu and Yixian, 1992; Cagauan, 1994; Dasu and Jiangu, 1996). It is known that interrelationship between abiotic and biotic factors play vital role on final product of food chain and has direct impact on net output of ecosystem. The primary source of energy accumulation in plants is through absorbing solar energy, CO<sub>2</sub>, nutrients for photosynthesis.

The abiotic and biotic components of rice fields are shown in Figure 3 as described in many previous studies (Jintong, 1996; Sugen *et al.*, 1996). Here, pests are rice enemies, weeds and micro algae are competitors for

resources; and nutrients may assume in immobile state (Figure 3A) comparing to where a bottom feeding omnivore, common carp is present (Figure 3B). Thus, if the fish with bottom feeding capabilities are introduced, they add new link to the food chain by top down control and bioperturbation on rice competitors, pests, parasites and on mobility of the nutrients towards the rice plant (Figure 3B).

Rice-fish integration is one of the best examples of commensalisms, where both rice and fish are benefited for increased productivity of rice field. In this relation fish has the advantage for shelter and feeding, while rice has the privilege for luxurious nutrient up take, pest reduction, and competitive advantages over weeds and micro flora (minute algae). This cumulatively results in funneling of energy and matter of rice field ecosystem towards fish and rice production to benefit the farmers.

During the study period, water temperature in all experimental plots ranged from 27±2 to 40±2°C in Tanahun and Syangja, 21±2 to 33±2°C at Nuwakot and 27±2 to 36.6±2°C at Kaski districts. Some of other experiences gained in rice-fish experiments are as follows:

#### **I. Rice varieties and yield in rice-fish farming**

Rice varieties such as, *Janaki*, *Mansuli*, *Sabitri* and *Radha-4* were successfully grown with fish in the same rice field. In general, dwarf rice cultivars resistant to high water level are suitable for rice fish integration in addition to those of the deep water, tall and semi-wild rice cultivars (Mukhopadhyay *et al.*, 1992).

Lightfoot *et al.* (1992) described that all interaction between rice and fish are not positive, for example early stocking of

Fig 2 a

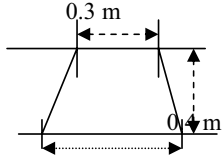


Fig 2 b

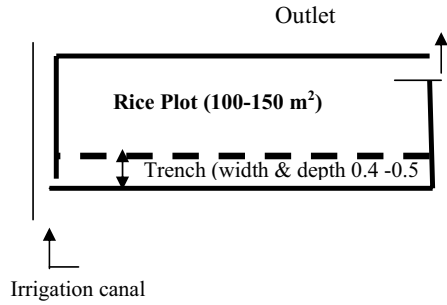


Figure 2. (a) Dimension of the rice field dike for rice fish integration (b) field sketch of rice field for rice-fish integration used in the experiments.

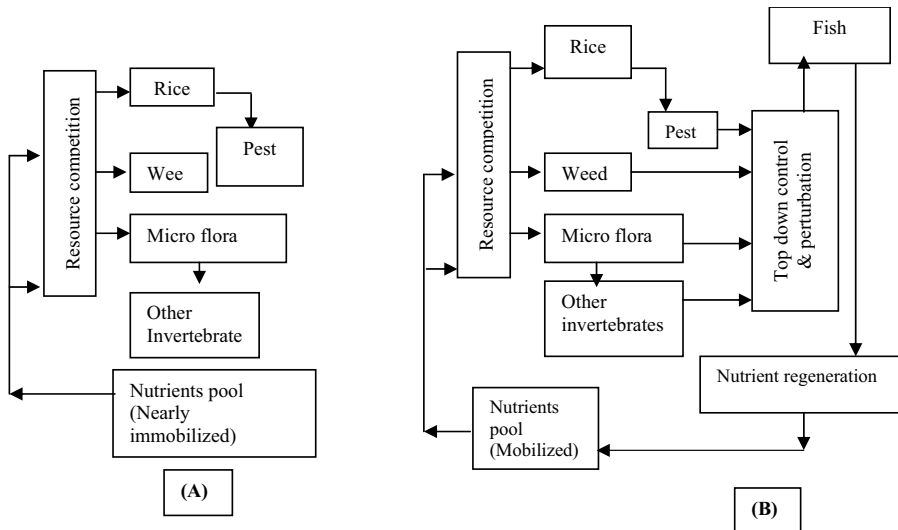


Figure 3. Schematic representation of ecological components in conventional (A), and rice-fish integrated rice field (B) and pathways of material flow.

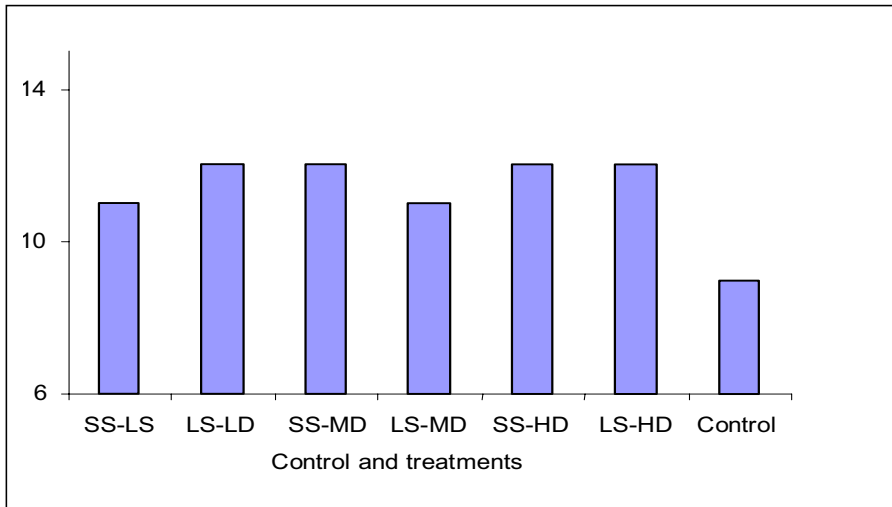


Figure 4. Number of tillers in rice plant in treatment where rice and fish were integrated and in control plots where rice was cultivated alone in Syangja.

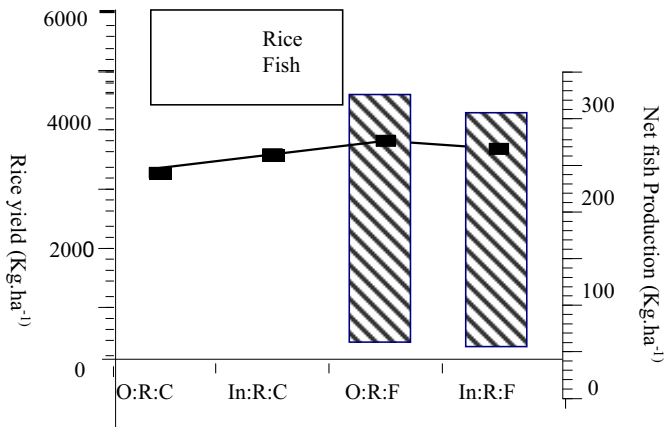


Figure 5. Rice yield and fish production with Radha-4 rice cultivars where, Or: organic manure, In: Inorganic fertilizers, R: Radha-4 rice and C: control

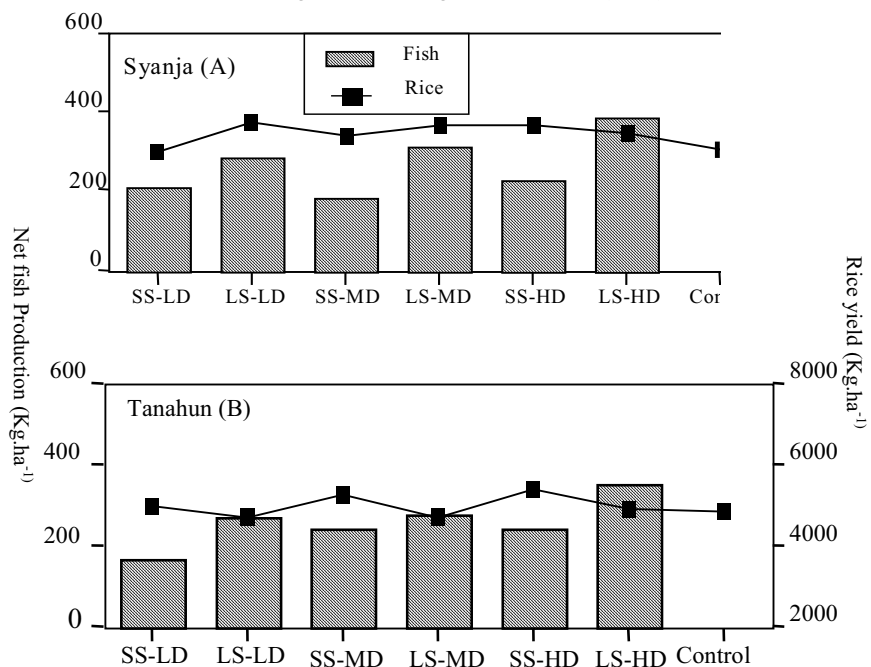


Figure 6. Rice yield and fish production in different treatments of rice-fish integration experiments at (A) Syangja and (B) Tanahun.

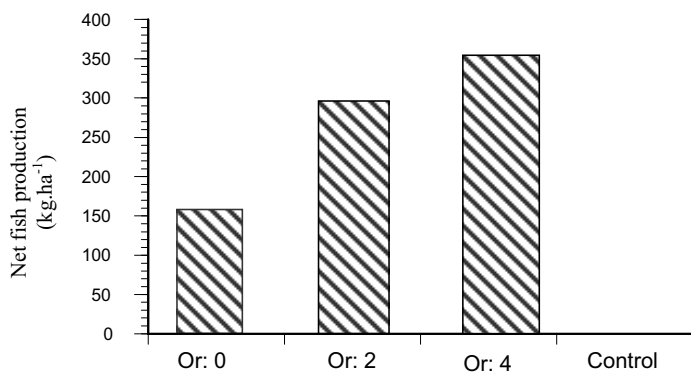


Figure 7. Fish production in treatments with feed and without feeding, rice-fish integration experiments at Nuwakot. The symbols: Or depicts organic, respectively with 0, 2 and 4% body weight of feeding rates.

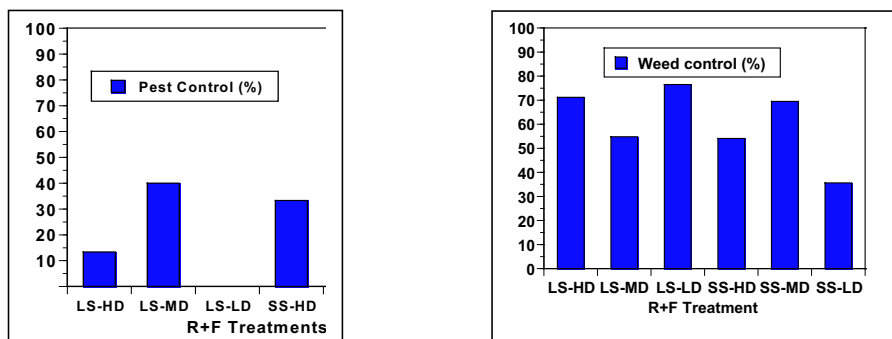


Figure 8: (A) Abundance of pest (hoppers) occurred in different rice-fish treatments in comparison to control (100%). (B) Weed abundance in different rice-fish treatments in comparison to control (100%)

fish can uproot the rice seedling etc. He also mentioned that a definite conclusion why fish integration increase rice yield could not be clear (Lightfoot *et al.*, 2000). One of the reasons might be healthy and well-grown rice tiller in rice-fish integration than cultivating rice alone. We found higher tiller in treatments than in control where only rice was grown (Figure 4). This suggests that higher tiller number supported higher rice yield in treatment than in control. In 0.05 ha area there could be nearly 2500 rice plants suggesting that tiller numbers can indeed bring substantial difference on rice yield.

In our study, up to 9% of higher rice yield was occurred in rice-fish integration than in control. The rice yield in control was 3.37, while 3.67 Mt.ha<sup>-1</sup> in treatment with *Radha-4* cultivars (Figure 5). *Mansuli* and *Sabitri* also showed similar trends. Our present results of rice yield closely resemble with the national rice productivity of these varieties. The average production rate of *Radha-4* is reported to be 3.2 Mt ha<sup>-1</sup> (Krishi Diary, 2003). However, there are exceptions where

rice yield was negligibly low in rice-fish integrated farming than cultivating rice alone in some treatments (Figure 6B). We assume that such unsubstantial results will not affect our main conclusion that average yield of the rice increases with rice fish integration than farming rice alone.

Rice-fish interaction could indeed increase the rice yield, despite of fact that 3-5% of total rice field was used for trench as fish refuse, where rice was not planted. Rothuis (1998) found no difference in rice yield between rice-fish and rice monoculture, based on the seeded rice area. Since, 11-16% area was lost due to trenches and dikes in his experiments; it clear that despite of the reduced cultivated area there was no change in yield suggesting that fish integration has indeed increased the rice yield. He also noted that the height of the rice plants in rice-fish integrated plots were relatively higher than in rice monoculture plots (Rothuis, 1998).

In fact, there are several positive effects of fish integration in rice yield. Fish regenerate nutrients such as nitrogen and phosphorus for



increase soil fertility; and predate over rice pest. Browsing and movement of fish in rice field during food search causes high turbidity, which prohibits photosynthesis and growth of under water weeds (Caguan, 1994; Shugen *et al.*, 1996). Contrastingly, rice plant above the water can harvest abundant light and nutrient from under water.

### **II. Appropriate fish stocking density and size**

In experiment with fish stocking density and size, higher fish production occurred with increasing stocking size and fish density. The highest fish yield (529 kg.ha<sup>-1</sup>, corresponding of 339 kg.ha<sup>-1</sup> net production) was achieved where 6000 fingerlings of 20 g size (LS: HD treatment) were stocked in Syangja (Figure 6). In China, highest yield (834 kg ha<sup>-1</sup>) achieved, when 9000 common carp ha<sup>-1</sup> fry were stocked, however, in that experiment the largest fish harvested was 70.8 g (Guanghui *et al.*, 1996). We harvested about 90 g size of common carp in most treatments. The discrimination in harvested body weight might reflect the management, growing periods, stocking size, density etc. (Banghuai and Qianlong, 1996; Xieping *et al.*, 1996).

In these experiments rice yield ranged from 4.6 to 5.7 Mt ha<sup>-1</sup> in treatments and 4.7 to 5.1 Mt ha<sup>-1</sup> in controls. The average productivity of *Sabitri* in Nepal is 4.5 Mt ha<sup>-1</sup> (Krishi Diary, 2003). Since, all the plots were irrigated and well managed, therefore slight higher production than the national average values should be considered legitimate.

### **III. Fish production with feeding to fish in rice-fish farming**

Generally, rice yield depends on various factors such as seed quality, water level, nutrient concentration, soil texture, management, variety and diseases etc (Pokharel, 1997; Witcombe *et*

*al.*, 2002). Fish growth and production in rice field also depends on food availability, space, size of fish, predation, and mortality etc. At Nuwakot, the net fish production was 354 kg ha<sup>-1</sup>, with a total production of 514 kg ha<sup>-1</sup> in treatment with organic manure where 4% of feed was supplied (Figure 7). Almost similar results was obtained with inorganic fertilizers and feeding treatments. These results are within the range reported in many studies in various countries (Halwart, 1998; Rothuis, 1998; Jintong, 1996).

Common carp can be grown without supplementary feed in rice field by allowing them to access the whole rice field as their grazing ground (Figure 7). It is therefore essential to raise the water level in rice field. Sometimes fish may be restricted to the trench due to low water level. In such case, if fish cannot access the main parts of the rice field for grazing, affectivity of fish for weed and pest control will be questionable, resulting in poor production of rice and fish.

### **IV. Fish as IPM tools in rice field**

Many studies showed that fish in rice fields could be a part of the integrated pest management tool (Caguan, 1994; Xieping *et al.*, 1996; De la Cruz *et al.*, 1992; De la Cruz, 1994). Our study showed that in general, number of hoppers visited in rice-fish integrated plot was lower than in control (Figure 8A). Weeds may play the role of secondary host for many harmful pests because, high water table maintained in the rice field could destroy the egg and larval stages of pest. Thus, the rice-fish integration can reduce pest in rice field.

### **V. Role of fish for weed control**

Abundance of weeds in rice field substantially decreased, where fish were

integrated (Figure 8B). One of the main reasons of weed infestation in rice field is due to insufficient water level and abundance nutrient resource. Usually, weed starts to infest after 4-5 weeks of rice plantation depending on availability of light and nutrients. The removal of weeds is necessary part of the rice field management for obtaining substantial yield. In general, weeds are uprooted at least three times in a season. But, in rice-fish integrated rice field weeds are not needed to remove so often because fish can consume and destroy some weeds.

#### **VI. Role of fish for bioturbation**

In water-sediment interface mostly a thin layer of organic matter is deposited, which contains high nutrient concentration and low dissolved oxygen than the water upper lying (Brönmark and Hansson, 1998). Usually small organisms, which can sustain low oxygen level, inhabit this layer. The activities of small animals can oxygenate the underlying water, thus changes the water quality. This process is known as bioperturbation (Brönmark and Hansson, 1998). If bottom feeder fish are introduced in such a system, their activities in search of food substantially increase dissolved oxygen. These are known to accelerate microorganisms' activities by which usable nutrients are regenerated. Perturbation by fish in rice field is therefore considered as one of the seasons for increasing rice productivity in rice-fish integrated farming.

#### **Conclusion**

Several studies showed that rice fish integration could be one of the best ecological methods to enhance productivity. The use of fish in rice field could substantially reduce abuse of insecticides on rice field. As a biological control agent of weed, insect, snail, and other diseases in rice

field, integration of fish could be one of the attractive and safest alternatives over pesticides. Therefore, focus on wider scale adoption of rice-fish farming for ecological, economical, and social benefits should be emphasized in all rice growing countries.

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