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Short communication

Nutrient removal ability and economical benefit of a rice-fish co-culture system in aquaculture pond

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ABSTRACT

Integrated culture of fish with crops has gained increasing attention to remediate the nutrients pollution of aquaculture. However, rice-fish co-culture system has rarely been investigated. In this study, we constructed a rice-fish co-culture system in the pond by using a new high-stalk rice variety, and conducted an on-farm experiment to examine the nutrients removal efficiency and economical benefit of this system. The results showed that this system significantly reduced the nutrients levels in the water and bottom soil in pond comparing with fish monoculture. The contents of total nitrogen (TN), ammonia-N, nitrate-N, nitrite-N, total phosphorus (TP) and orthophosphate (OP) were 70.63%, 60.27%, 54.86%, 71.54%, 85.05% and 78.54% lower in the water of rice-fish co-culture than fish monoculture pond, respectively. And the contents of ammonia-N, TP and OP in the bottom soil were also respectively reduced by 91.14%, 36.99% and 58.57% under rice-fish co-culture system. The total cost was only increased by 2.88%, but the net income was enhanced by 114.48% for rice-fish co-culture than fish monoculture, which was primarily attributed to extensive rice cultivation. These results suggested that rice-fish co-culture in pond was an efficient method to mitigate the eutrophication in an intensive culture pond, and also a potential new way to increase rice production for food security and extra income for fish farmers.

1. Introduction

Pond aquaculture is one of the main contributors to the eutrophication of ambient aquatic environment (Bosma and Verdegem, 2011). Reducing the nutrient loss to aquatic environment is urgent for the sustainable development of pond aquaculture. Phytoremediation has showed great potential in the purification of nutrient-rich aquaculture water for its environmental and economic advantages (Ghaly et al., 2005). A key factor determining the feasibility is the plant used in remediation. A wide varieties of plants, such as reed, algae and crop plants, has been investigated to remediate the effluents of aquaculture by constructed wetland, sequencing batch reactor or hydroponics system in previous studies (Graber and Junge, 2009; Lin et al., 2002; Van Den Hende et al., 2014). Crops are expected to be more suitable for the remediation of large-area pond aquaculture, because the cultivation of crops is beneficial to reuse the redundant nutrients, provide extra food income and reduce remediation cost (Enduta et al., 2011).

Rice is the only cereal crop grown well in flooded soil. So, it has the inherent advantage in the remediation of eutrophic waters (Zhou and Hosomi, 2008). However, previous studies were mostly focused on vegetable or triticeae crops (Graber and Junge, 2009; Snow et al., 2008), but paid little attention to rice. Rice-fish co-culture has been practiced in paddy field over 2000 years in Asian countries (Anita et al., 2014; Islama et al., 2015; Lu and Li, 2006). The results from paddy field have demonstrated that rice-fish co-culture could enhance nutrients use efficiency and reduce nutrients loss to environment because the complementary use between fish and rice (Li et al., 2008a; Oehme et al., 2007; Saikia et al., 2015; Xie et al., 2011). However, this system was rarely conducted in an aquaculture pond, because the rice varieties for paddy field could not grow well in the pond with deep water. Though, some studies have tried to planting rice with floating bed in lakes (Foo, 2000; Song et al., 1996); it was not accepted by fish farmers in a pond aquaculture, because the floating bed inhibited the O_2 exchange from atmosphere into water. Therefore, in order to construct a rice-fish co-culture system in a pond, we developed a new high-stalk rice variety; the height of which is up to 1.85 m (Fig. 1(b)), and can be directly cultivated in the bottom soil and grow well in fish pond.

In this study, an on-farm experiment was conducted to investigate the nutrient removal ability and economical benefit of this rice-fish co-culture system in a yellow catfish culture pond.

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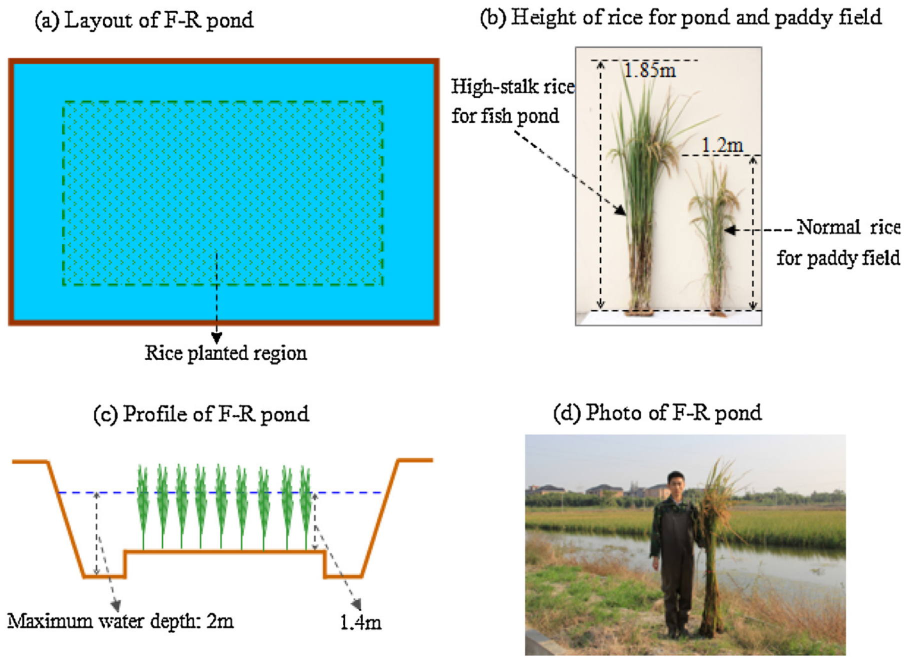

Fig. 1. Layout, profile and photo of F-R.

2. Materials and methods

2.1. Experiment design

This experiment was carried out in a commercial aquaculture farm (120.08° E and 30.49° N) located in Zhejiang province, which is one of the major pond aquaculture regions in South China. Two yellow catfish ponds were selected from the farm. One pond was used for yellow catfish and rice co-culture (F-R), and the other one was for yellow catfish monoculture (F). The area of F-R and F was both 1.5 ha. The shape and profile of pond are shown in Fig. 1. Rice was planted in the center region of pond, occupying nearly 60% of the total area. The region around rice was left for feeding and harvesting yellow catfish. The rice-fish co-culture system tested in this study was characterized by intensive fish culture with extensive rice cultivation in an aquaculture pond, which was contrary to the rice-fish co-culture system conducted in paddy field.

The rice planted in fish pond (namely Yudao No.1) is a new high-stalk rice variety (*Oryza sativa* L.) developed by the hybridization of local rice variety and its high-stalk mutant. The height of this rice can reach up to 1.85 m, which is suitable for being directly planted in fish pond with the water depth below 1.5 m. The water in fish pond was drained off, and pond was empty before planting rice. Rice seeds were manually broadcasted onto the surface of bottom soil at a seed rate of 22.5 kg ha^{-1} on June 11, 2014. Bottom soil was kept moisture but no water flooded after seeding. When the height of rice seedlings reached to 30 cm, the water was added to 20 cm at rice planting region on July 1, 2014. The rice was harvested on November 9, 2014. No chemical fertilizer, pesticide and herbicide were used for rice cultivation.

The fingerlings of yellow catfish were stocked into two ponds on July 10, 2014 at a density of 150 000 fingerlings ha^{-1}. The yellow catfish in two ponds were hand fed commercial formulated feed (35–40% protein and 0.8–1.2% phosphorus) two times per day. The water was added with the height of rice plant increased. The maximum water depth was 1.4 m at rice planting region (Fig. 1). The management methods for fish were similar in two ponds.

2.2. Sampling and analyses

Two ponds were both divided into four sub-plots for water, soil and plant sampling. In each sub-plots, more than five water, soil or plant samples were taken and mixed together to form a composite sample. Water samples were taken at an interval of two weeks from July 2 to November 7. Composite bottom soil samples were taken at a depth of 0–15 cm at the same day after water sampling. Rice plant samples were taken at the mature stage. Rice yield and biomass were recorded at the harvest time.

The concentrations of TN, ammonia-N, nitrate-N, nitrite-N, TP and OP in water samples and ammonia-N, nitrate-N and OP in bottom soil samples were analyzed by using AA3 Auto Analyzer (Bran-lube, GmbH Co., Germany) according to classical colorimetric methods. The content of nitrite-N in bottom soil was not analyzed, because it did not present in detectable amounts. The contents of TN and TP in rice and bottom soil samples were determined by the Kjeldahl and H_2SO_4-H_2O_2 methods, respectively (Lu, 2000).

3. Results

3.1. Nutrients contents in the water

The concentrations of nitrogen and phosphorus were significantly lower in the water of F-R than F, especially from August 15 to December 7 (Fig. 2), which was the primary rice growing stage (jointing, heading and grouting) of high nutrients demand. The mean levels of different forms of nitrogen and phosphorus were 70.63% (TN), 60.27% (ammonia-N), 54.86% (nitrate-N), 71.54% (nitrite-N), 85.05% (TP) and 78.54% (OP) lower in the water of F-R than F during rice growing season, respectively. At most sampling dates, the levels of TN and TP in the water of F were higher than the worst level of environmental quality standards for surface water in China (Grade V, 2.0 and 0.4 mg L^{-1} for TN and TP, respectively). While for F-R, TN and TP contents were lower than the recommended level of surface water (Grade III, 1.0 and 0.2 mg L^{-1} for mg L^{-1} for TN and TP, respectively).

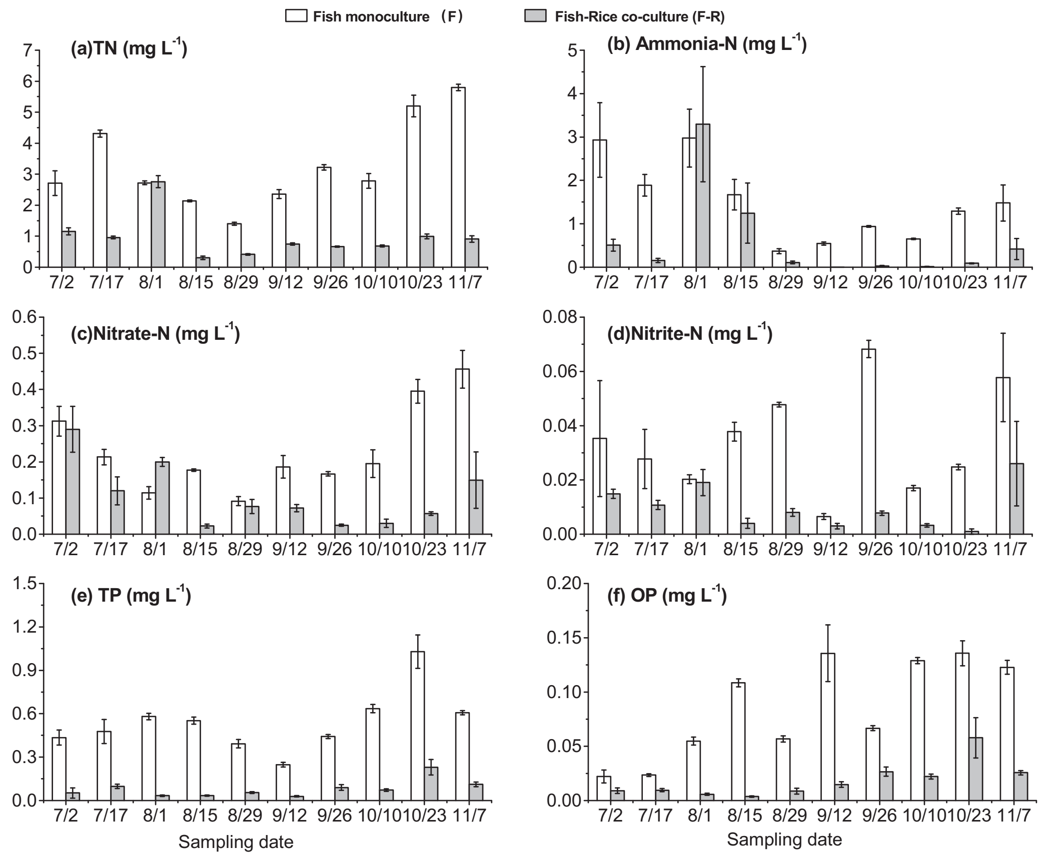

Fig. 2. Concentrations of nitrogen and phosphorus in the water of F and F-R.

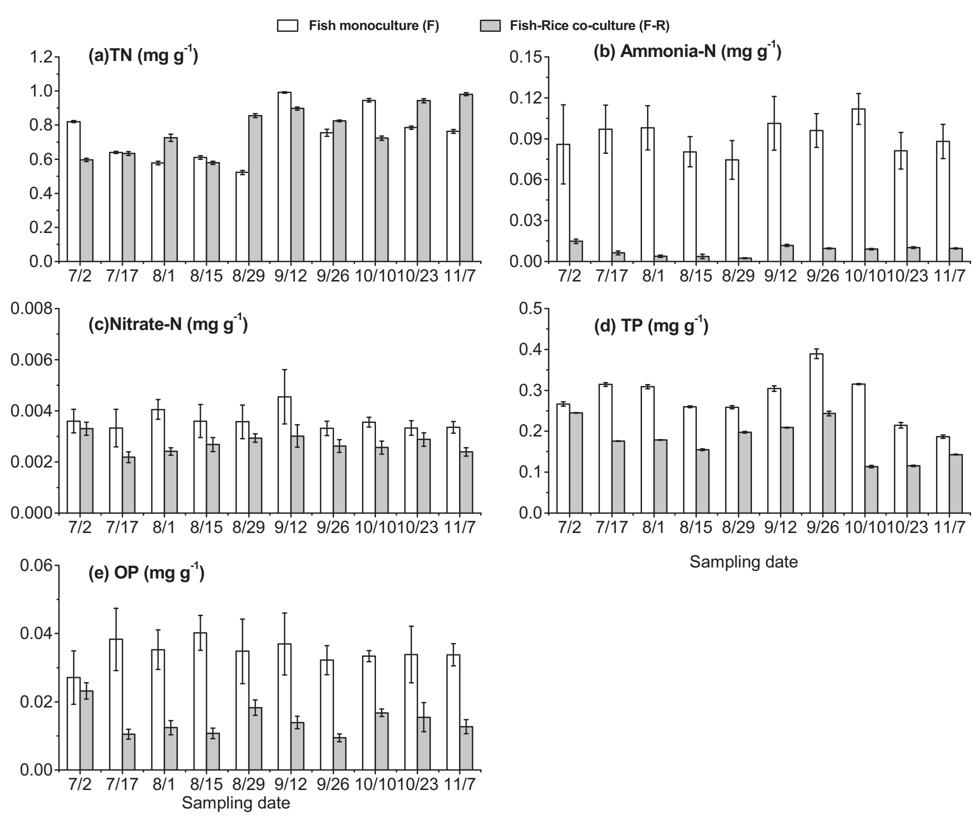

Fig. 3. Concentrations of nitrogen and phosphorus in the bottom soil of F and F-R.

Table 1
Economical costs and benefits of F and F-R.

		F (US$ ha^{-1})	F-R (US$ ha^{-1})
Costs	Land rent	2286.6	2286.6
	Fingerlings	1600.6	1600.6
	Rice seed	–	102.9
	Fish feed	12118.9	12118.9
	Labor for fish culture	457.3	457.3
	Labor for rice production	–	1372.0
	Electricity for watering	137.2	91.5
	Electricity for pond aeration	548.8	45.7
	Fish medicine	686.0	274.4
	Total	17835.4	18349.8
Income	Fish	22982.5	23849.1
	Rice	–	3324.2
Net income		5147.1	8823.5

3.2. Nutrients contents in the bottom soil

The content of TN in the bottom soil did not show consistent differences between F and F-R (Fig. 3(a)). The content of TN was significantly lower in the bottom soil of F-R than F on July 2, September 12 and October 10, but significantly higher on August 1, August 29, October 23 and December 7. However, the content of ammonia-N in the bottom soil was significantly reduced by F-R (Fig. 3(b)). The mean level of ammonia-N was 91.14% lower in the soil of F-R than F. The content of nitrate-N was also lower in the soil of F-R (Fig. 3(c)); but the difference was not significant except on August 1, October 10, and December 7. Regard to phosphorus, the contents of TP and OP were both significantly reduced by F-R (Fig. 3(d) and (e)). The mean levels of TP and OP were 36.99% and 58.57% lower in the soil of F-R than F, respectively.

3.3. Economical analysis

The total cost of F-R was 2.88% higher than that of F, which was mainly attributed to the additional costs of rice seed and labor for rice production (Table 1). However, thanks to the improvement of water quality, the other costs, such as electricity used for watering and pond aeration and the fish medicine, were lower for F-R than F. The fish yield of F-R was 16.29 t ha^{-1}, which was 3.77% higher than that of F (15.70 t ha^{-1}). And the rice yield of F-R was 4.84 t ha^{-1}. With increasing consideration of food safety, the price was nearly two times higher for rice produced from F-R (1.52 US$ kg^{-1}) than normal paddy field (0.61–0.91 US$ kg^{-1}), because no pesticide and herbicide were used for rice cultivated in F-R. The net income of F-R was 114.48% higher than that of F.

4. Discussion

The results of this study showed that rice-fish co-culture in fish pond could significantly reduce the nutrients levels by 36.99%–91.14% in the water and bottom soil comparing with fish monoculture, and greatly decreased the risk of nutrients pollution caused by pond aquaculture. Comparing with previous studies, it was still hardly to decide whether the nutrients removal efficiency of rice is better or not than vegetable and triticeae crops examined in previous studies (Enduta et al., 2011; Ghaly et al., 2005; Graber and Junge, 2009; Snow et al., 2008) based on current data. Because the system designs, crop growth duration and nutrients levels in water were different in these studies. Thus, further work is needed to compare the efficiency of these crops at the same experiment condition.

Similar as the other integrated culture systems, the uptake and assimilation directly by rice plants was an important way to remove the nutrients in the water and bottom soil (Graber and Junge, 2009). However, the nutrients accumulated in rice (nitrogen: 78.1 ± 11.8 kg ha^{-1}, phosphorus: 23.0 ± 4.1 kg ha^{-1}) were lower than other crops reported in previous studies (Graber and Junge, 2009; Snow et al., 2008). Therefore, rice may also play an important indirect role in the mitigation of nutrients levels. For example, rice plants may promote the sedimentation of uneaten feed and fish faeces by decreasing the fluctuation of water in fish pond and inhibit the release of nutrients from these matters (Li et al., 2008b). This was a possible reason to explain why the content of TN was significantly higher in the bottom soil of YC-R than YC (Fig. 3(a)) at some sampling dates. Additionally, rice plants may raise the emission of gaseous nitrogen (*e.g.* N_2O and NH_3) from bottom soil and water to atmosphere through aerenchyma formation (Hayashi et al., 2008; Yan et al., 2000).

The total productivity and the net income were two important factors influencing the feasibility of a rice-fish system. The rice yield of the rice-fish system in this study (4.84 t ha^{-1}) was close to that of previous rice-fish systems (2.6–4.84 t ha^{-1}) (Berg, 2002; Ofori et al., 2005; Oehme et al., 2007; Mohanty et al., 2009); while the fish yields were far higher in this study (16.29 t ha^{-1}) than these previous studies (0.201–6.96 t ha^{-1}). And the net income per hectare was 8–17 times higher in this study (8823.5 US$ ha^{-1}) than previous studies (463.8–1233.8 US$). The higher productivity and net income of this study mainly attributed to the new structure of rice-fish system. The rice-fish system in this study was characterized by intensive fish culture with extensive rice cultivation in an aquaculture pond. While the structure of previous rice-fish systems was commonly intensive rice production with extensive fish aquaculture conducted in paddy field. Shallow water depth in paddy field limited the fish yield and net income.

Rice is the most important staple food in China and other rice cultivation countries in Asian. Due to the limited arable land and water resource, there is a great demand of rice to feed the increasing population in these countries (Van Nguyen and Ferrero, 2006). The yield of the high-stalk rice variety in this study (4.84 t ha^{-1}) was respectively higher than the yield of deepwater rice (2.60–3.25 t ha^{-1}) reported by Mohanty et al. (2009) and the mean yield of word rice production in 2013 (4.49 t ha^{-1}) (FAOSTAT, 2014). Furthermore, economical benefit is an important factor determining the feasibility of a rice-fish co-culture system (Ali and Mateo, 2007; Mridha et al., 2014; Rashed 2008). The results of this study showed that the net return of this new rice-fish co-culture system was nearly two times higher than that of conventional fish monoculture system (Table 1). This new system has been widely accepted by fish farmers in Zhejiang and Jiangsu provinces of China. The area of global culture pond was 110 832 km^2 (nearly 6.7% of world rice planting area), which were primarily located in Asian countries, including China, India, and Bangladesh (Verdegem and Bosma, 2009). Thus, rice-fish co-culture in pond is a potential new sustainable way to increase the rice planting area and production in Asian countries.

5. Conclusions

The results of this study showed that the rice-fish co-culture in fish pond by using a new high-stalk rice variety significantly reduced the contents of nitrogen and phosphorus in the water and bottom soil comparing with fish monoculture. The net income was higher for rice-fish co-culture than fish monoculture. These results indicated that rice-fish co-culture in pond was not only an efficient system to remediate the eutrophication of pond aquaculture, but also a potential way to increase rice production and economical benefits for fish farmers.

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