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ScienceDirect
Rice Science, 2019, 26(1): 50−59

Effects of Rice-Fish Co-culture on Oxygen Consumption in Intensive Aquaculture Pond

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Abstract: Rice-fish co-culture has gained increasing attention to remediate the negative environmental impacts induced by intensive aquaculture. However, the effect of rice-fish co-culture on oxygen depletion has rarely been investigated. We constructed a rice-fish co-culture system in yellow catfish (*Pelteobagrus fulvidraco*) and freshwater shrimp (*Macrobrachium nipponense*) ponds using a new high-stalk rice variety, and conducted a field experiment to investigate the effect of rice-fish co-culture on water parameters and oxygen consumption. The results showed that rice-fish co-culture reduced the nutrients (total nitrogen, ammonia-N, total phosphorous and potassium) and the dissolved oxygen content in fish and shrimp ponds. However, they showed similar seasonal change of dissolved oxygen in the water of fish and shrimp ponds. Rice-fish co-culture reduced the total amount of oxygen consumption and optimized the oxygen consumption structure in pond. The respiration rates in water and sediment were significantly reduced by 66.1% and 31.7% in the catfish pond, and 64.4% and 38.7% in the shrimp pond, respectively, by additional rice cultivation. Rice-fish co-culture decreased the proportions of respiration in sediment and water, and increased the proportion of fish respiration. These results suggest that rice-fish co-culture is an efficient way to reduce hypoxia in intensive culture pond.

Key words: rice-fish co-culture; oxygen depletion; respiration; pond aquaculture; yellow catfish; freshwater shrimp

Aquaculture was the fastest growing food-producing sector in the world in the last 50 years (Bostock et al, 2010). The total production of global aquaculture accounts for nearly half of the world's fish food supply. Pond culture is an important method of freshwater fish aquaculture particularly in Asian countries. In order to improve fish yields, intensive culture is widely adopted in pond aquaculture. However, intensive culture, characterized by a high stocking density of fish with high materials and energy input, has induced serious negative impacts to the inside or ambient water environment, such as eutrophication and oxygen depletion (Cao et al, 2007; Bosma and Verdegem, 2011). How to reduce these negative effects is a key issue for the sustainable development of pond aquaculture.

The content of dissolved oxygen (DO) is the most critical element of pond water quality, influencing the survival and growth of fish (Glencross, 2009). Inadequate DO reduces the food intake, growth rate, and survival rate of fish. DO in pond water is primarily from the photosynthesis of phytoplankton in water and the gas exchange from atmosphere, and is consumed not only by fish, but also by the respiration of phytoplankton and microbes in water and sediment, which consumes more oxygen (60%–90%) than fish (5%–30%) (Madenjian, 1990; Liu et al, 2005). DO

Received: 24 May 2018; **Accepted:** 7 September 2018
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Peer review under responsibility of China National Rice Research Institute
http://dx.doi.org/10.1016/j.rsci.2018.12.004

produced from natural processes cannot afford the consumption demand of fish, water and sediment. In order to improve DO concentration in water, mechanical aeration has been widely adopted in the past three decades in intensive aquaculture pond (Boyd, 1998). The aeration equipment and energy used by mechanical aeration is a considerable cost in intensive culture (Martinez-Cordova et al, 1997). According to National Bureau of Statistics of China (2017), the electricity used by mechanical aeration in pond aquaculture accounts for 30% of the total electricity consumption of agriculture in China. Therefore, it is necessary to find out an energy-saving way to reduce the oxygen consumption in pond water.

Rice-fish co-culture is a long-term farming system around the world over 2000 years, and has been recognized as a 'globally important agricultural heritage systems' by the Food and Agriculture Organization of the United Nations in 2005 (Hu et al, 2016). Many field studies have been conducted to investigate the effects of rice-fish co-culture on nutrient use efficiency, insect pest controlling, eutrophication, food productivity and economic benefit (Oehme et al, 2007; Li et al, 2008; Xie et al, 2011; Hu et al, 2013; Feng et al, 2016). For example, Xie et al (2011) reported that rice-fish co-culture reduces the pesticide and chemical fertilizer by 68% and 24% than rice mono cropping based on a five-years field study, respectively. Li et al (2008) reported that the N_2O emission, NH_3 volatilization and leakage of NO_3^- are significantly mitigated by rice-fish system. Rice-fish co-culture also improves the water quality, such as reducing nutrient (N and P) content in water (Feng et al, 2016). The improvement of water quality may influence the oxygen production and consumption in pond. However, little study was conducted to investigate the effect of rice-fish system on oxygen consumption in water.

China ranks first in fish aquaculture, contributing nearly 70% of global aquaculture production (Li et al, 2011). The area of rice-fish co-culture grew to 1.49 million hectares in 2015, which is the largest around the world. However, this co-culture system is mostly conducted in paddy field, but rarely conducted in aquaculture pond. The rice varieties for paddy field cannot grow well in the pond with deep water. Therefore, we developed a new high-stalk rice variety with the height up to 1.85 m (Fig. 1-B), which can be directly cultivated in the bottom soil and grow well in fish pond. In this study, we conducted a field experiment to investigate the effects of this new

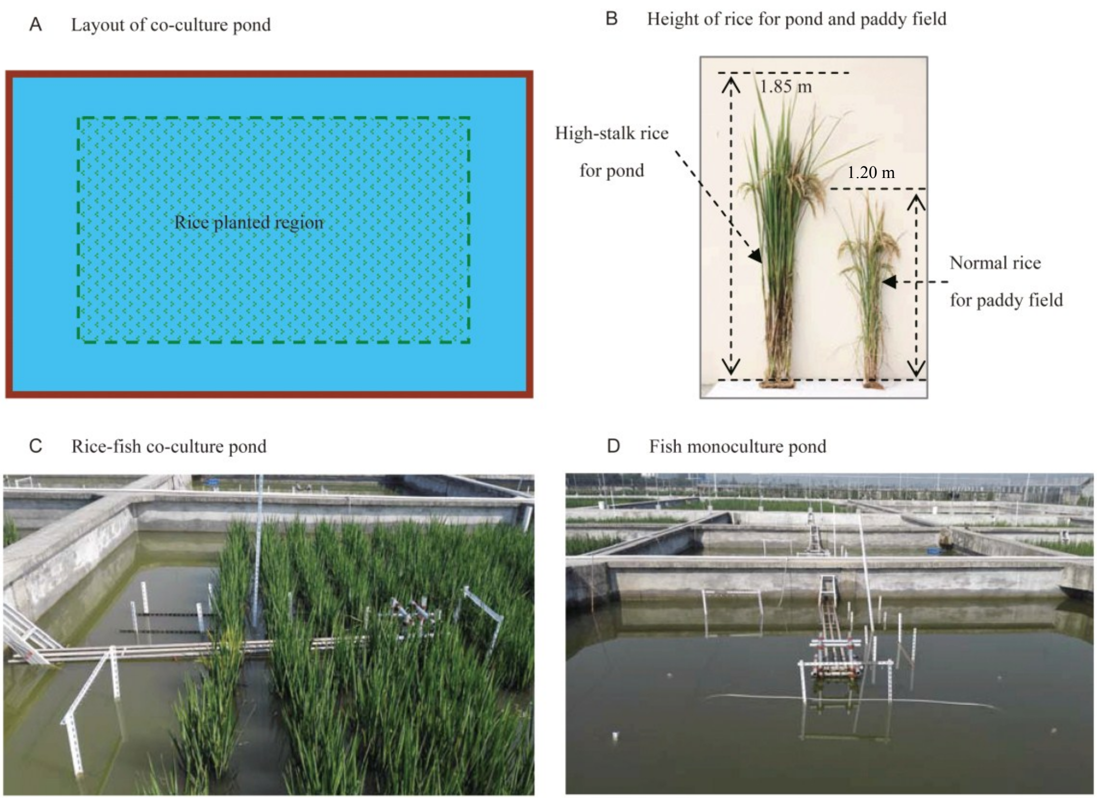

Fig. 1. Layout and photo of experiment ponds.

rice-fish co-culture system on the concentrations of water nutrients in intensive culture pond, seasonal change of DO in pond water, and the main oxygen consumption pathways, including respiration of fish and respirations in water and sediment.

MATERIALS AND METHODS

Experimental design

The experimental site was located at a national experiment farm in Hangzhou City of Zhejiang Province, which is one of the major pond aquaculture regions in South China. Pond aquaculture has been practiced over 20 years in this farm. All the ponds were excavated from the lowland. The fish species included yellow catfish (*Pelteobagrus fulvidraco*), grass carp (*Ctenopharyngodon idellus*), crucian carp (*Carassius auratus*), freshwater shrimp (*Macrobrachium nipponense*), flat fish (*Pampus argenteus*), crab (*Eriocheir sinensis H.Milne-Edwards*) and crayfish (*Procambarus clarkii*). Rice-fish co-culture has been practiced in aquaculture ponds since 2010. This experiment was conducted in 2016.

Four treatments, including yellow catfish-rice co-culture (YC-R), yellow catfish monoculture (YC), freshwater shrimp-rice co-culture (FS-R), freshwater shrimp monoculture (FS), were arranged in 12 experiment plots (three replicates of each). Each plot was 10 m long and 8 m wide. Plots were separated by embankments in the pond that has been used for fish culture over the last 13 years. The profile and images of these plots are shown in Fig. 1. Rice was planted in the central region of the pond, with the area occupying 60% of the total.

The rice planted in the fish pond (namely Yudao 1) is a new rice variety (*Oryza sativa* L.) developed from the hybridization of local rice variety and a high-stalk mutant. This rice variety can reach 1.85 m, allowing it to be planted in fish ponds with a water depth below 1.50 m. Water in the fish pond was drained off before planting rice, and bottom soil was kept moist but not soggy. The rice was sown on the nursery bed on May 20, 2016, and transplanted to the fish pond at a spacing of 0.6 m × 0.6 m on June 20, 2016. The water level was 0.1 m when rice seedlings were transplanted and rose gradually with the growth of rice. The rice was harvested on October 26, 2016. No chemical fertilizer, pesticide and herbicide were used during rice cultivation.

The fingerlings of yellow catfish (560 fingerlings/kg) were stocked into co-culture and monoculture ponds at a density of 150 000 fingerlings/hm^2 on July 17, 2016. Freshwater shrimps (6 000 fingerlings/kg) were stocked at a density of 450 000 /hm^2 on July 30, 2016. Yellow catfish and freshwater shrimps were respectively fed commercially formulated feed two times and one time per day. Water was added as the height of rice plants increased. The maximum water depth was 1 m at the rice planting region. The management methods for fish or shrimp were similar in the co-culture and monoculture ponds.

Sampling and analyses

Water parameters were monitored once a week after the transplanted rice was revived. The DO content and pH value of the pond water were measured *in situ* using a handheld analyzer (Mettler Toledo, Seven2 Go pro, Switzerland). Two positions (middle region with rice planted and outside region without rice planted) were sampled at 10 cm below the water depth in each pond. More than five water samples were taken and mixed together to form a composite sample in each pond. The concentrations of total nitrogen (TN), ammonia-N, nitrate-N, nitrite-N, total phosphorous (TP) and dissolved inorganic phosphorous (DIP) in water samples were analyzed using a Skalar San Continuous Flow Analyzer (Skalar Inc., Holland) according to the classical colorimetric methods. Turbidity, total suspended solid (TSS), potassium (K), chemical oxygen demand (COD) and phytoplankton were analyzed using the standard methods (SEPA, 2002).

Water respiration was monitored at sunny days using the classic dark and light bottle method (Vinatea et al, 2010). Net photosynthesis and respiration rate in water were calculated by the change of the DO content in the light and dark bottles during 24 h, respectively. The measurement of respiration in sediment was taken *in situ* using benthic chambers (Morata et al, 2012). The diameter and height of the cylindrical chamber were 30 and 25 cm, respectively. The chamber was manually placed in the bottom soil of pond for 6 h. Water samples were taken from the inside chamber every 2 h using 100 mL syringes through a flexible pipe connected to the chamber. The respiration rate in sediment was calculated from the slope of a linear regression of DO during the incubation period. Respiration rates in water and sediment were measured biweekly before the fish were stocked, and once a week following fish stocking in late July.

Table 1. Primary water parameters of co-culture and monoculture ponds (Mean ± SE, *n* = 3).

Parameter	YC-R	YC	FS-R	FS
pH	7.74 ± 0.03 c	8.08 ± 0.08 b	8.10 ± 0.01 b	8.55 ± 0.12 a
Temperature (ºC)	28.05 ± 0.06 c	28.28 ± 0.06 b	28.25 ± 0.07 bc	28.61 ± 0.11 a
Turbidity (mg/L)	42.46 ± 5.46 b	136.64 ± 40.74 a	28.95 ± 1.80 b	39.86 ± 5.85 b
TSS (mg/L)	418.42 ± 3.50 b	507.11 ± 29.56 a	340.65 ± 18.73 c	345.50 ± 2.28 bc
COD (mg/L)	48.26 ± 6.97 b	87.11 ± 8.57 a	50.96 ± 15.40 b	54.51 ± 9.82 ab
TN (mg/L)	2.26 ± 0.40 b	4.54 ± 0.18 a	0.84 ± 0.06 c	2.70 ± 0.32 b
Ammonia-N (mg/L)	0.31 ± 0.01 b	0.76 ± 0.15 a	0.22 ± 0.02 b	0.34 ± 0.07 b
Nitrate-N (mg/L)	1.43 ± 0.17 a	1.30 ± 0.13 a	0.74 ± 0.08 a	0.84 ± 0.10 a
Nitrite-N (mg/L)	0.30 ± 0.06 a	0.24 ± 0.04 a	0.04 ± 0.01 a	0.04 ± 0.00 a
TP (mg/L)	0.21 ± 0.04 b	0.52 ± 0.08 a	0.27 ± 0.10 b	0.22 ± 0.04 b
DIP (mg/L)	0.014 ± 0.003 a	0.013 ± 0.001 ab	0.007 ± 0.002 ab	0.007 ± 0.001 b
Potassium (mg/L)	3.06 ± 0.61 b	5.13 ± 0.35 a	3.61 ± 0.29 b	4.25 ± 0.34 ab
Phytoplankton (mg/L)	6.64 ± 0.27 b	37.25 ± 13.72 a	8.04 ± 0.78 b	6.32 ± 0.51 b

TSS, Total suspended solid; COD, Chemical oxygen demand; TN, Total nitrogen; TP, Total phosphorous; DIP, Dissolved inorganic phosphorous; YC-R, Yellow catfish-rice co-culture; YC, Yellow catfish monoculture; FS-R, Freshwater shrimp-rice co-culture; FS, Freshwater shrimp monoculture.
Different lowercase letters indicate significant difference at the 0.05 level.

Respiration rate of fish was measured using the chamber method reported by Yamamoto (1992). The size of the respiration chamber was 30 cm × 20 cm × 15 cm. The respiration rate of fish was calculated through the changes of DO content in the water of the respiration chamber.

RESULTS

Water parameters

As shown in Table 1, rice-catfish/shrimp co-culture reduced the pH, temperature and COD of water compared with catfish/shrimp monoculture pond. Mean values of turbidity and TSS significantly differed between YC and YC-R. Additional rice cultivation also reduced the water eutrophication in the catfish and shrimp ponds. TN in the water of YC-R and FS-R was significantly reduced by 50.2% and 68.9% compared to that of YC and FS, respectively. Ammonia-N, TP and potassium contents were also significantly reduced by 59.2%, 59.6% and 40.3% in the water of YC-R as compared with YC, respectively.

DO content in water

Seasonal changes of DO content in the water are shown in Fig. 2. DO changes were similar for co-culture ponds and monoculture ponds from July to October. The DO content was, however, significantly higher in the catfish monoculture pond than rice-catfish co-culture pond on selected sampling days (August 1st, August 8th and August 15th).

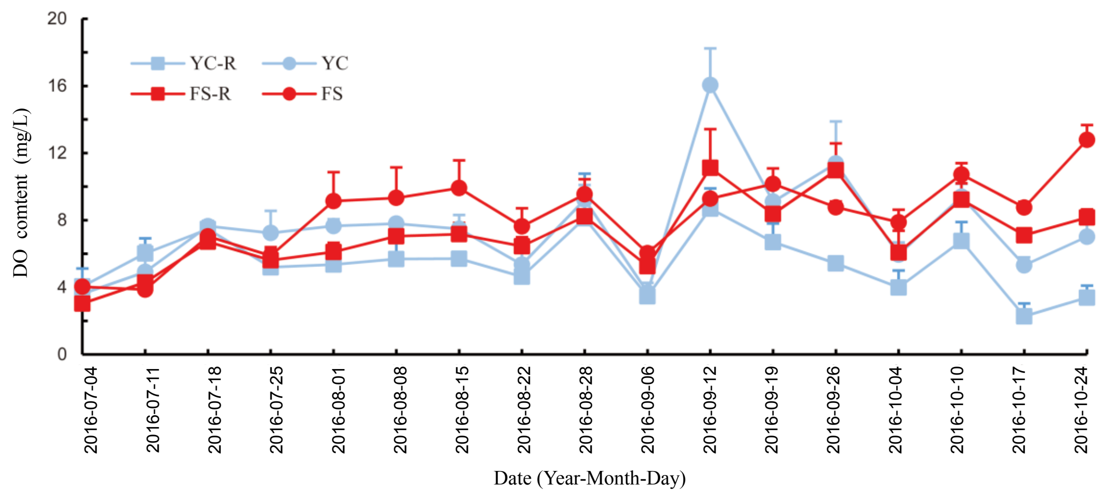

Fig. 2. Change of dissolved oxygen (DO) in the water of co-culture and monoculture ponds (Mean ± SE, *n* = 3).
YC-R, Yellow catfish-rice co-culture; YC, Yellow catfish monoculture; FS-R, Freshwater shrimp-rice co-culture; FS, Freshwater shrimp monoculture.

Net photosynthesis

As shown in Fig. 3, the net photosynthesis rates were lower in the water of the co-culture system than monoculture system in both the catfish and shrimp ponds. Significant reductions in net photosynthesis rate were observed on September 8th, October 5th and October 12th in the rice-catfish co-culture pond compared with catfish monoculture pond. For the rice-shrimp co-culture pond, a significant reduction in net photosynthesis rate was observed during late July and early September. The mean values of net photosynthesis rate were significantly reduced by 67.3% in rice-catfish co-culture ponds and 84.6% in the rice-shrimp co-culture ponds as compared with the catfish and shrimp monoculture ponds, respectively.

Respiration rate of fish and respiration rates in water and sediment

Seasonal changes of respiration rates in water and sediment are illustrated in Fig. 4. The respiration rates in water fluctuated in the range of 0.01–4.38 mg/L for YC-R, 2.56–9.78 mg/L for YC, 0.58–2.24 mg/L for FS-R, and 1.99–8.62 mg/L for FS, respectively (Fig. 4-A). Additional rice cultivation began to reduce water respiration rates from late July in catfish and shrimp ponds. The greatest reduction was observed in late August in both ponds. Average water respiration rates were significantly reduced by 66.1% and 64.4% in YC-R and FS-R than YC and FS, respectively.

Rice cultivation also mitigated the O_2 consumption of respiration in sediment (Fig. 4-B). The mean

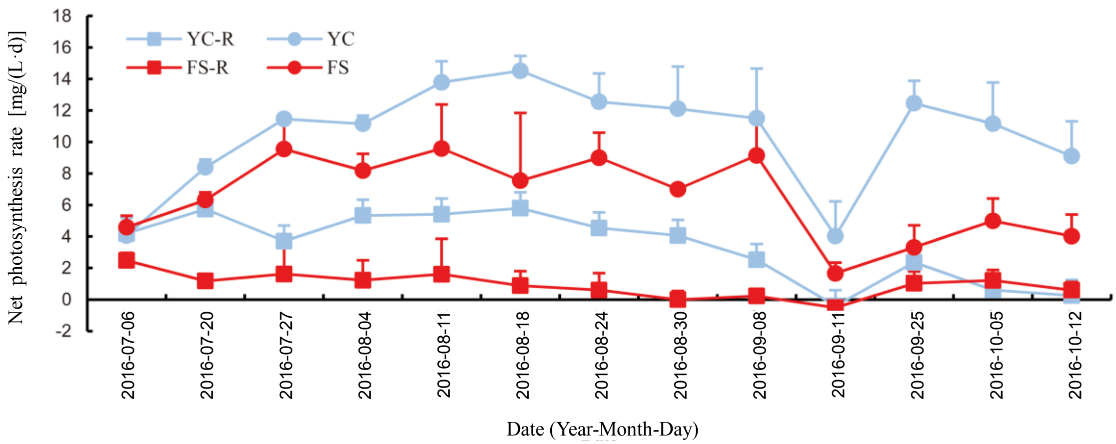

Fig. 3. Changes of net photosynthesis rate in the water of co-culture and monoculture ponds (Mean ± SE, *n* = 3).

YC-R, Yellow catfish-rice co-culture; YC, Yellow catfish monoculture; FS-R, Freshwater shrimp-rice co-culture; FS, Freshwater shrimp monoculture.

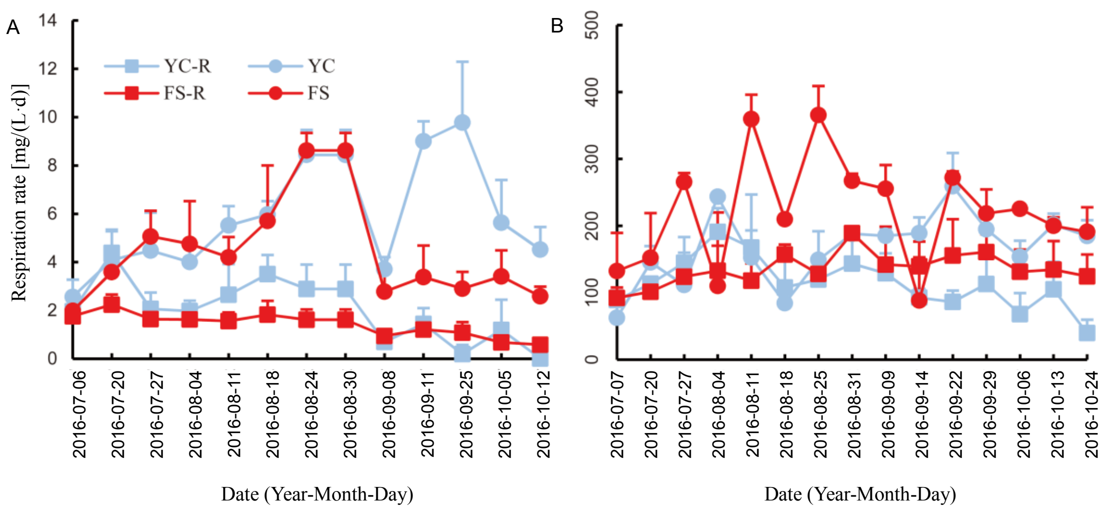

Fig. 4. Changes of respiration rates in water (A) and sediment (B) of co-culture and monoculture ponds (Mean ± SE, *n* = 3).

YC-R, Yellow catfish-rice co-culture; YC, Yellow catfish monoculture; FS-R, Freshwater shrimp-rice co-culture; FS, Freshwater shrimp monoculture.

respiration rates in sediment were 114.09 and 167.04 mg/L for YC-R and FS-R, which were significantly reduced by 31.7% and 38.7% compared with YC and FS, respectively.

The respiration rates of catfish and shrimp per unit weight decreased with increased weight of the catfish and shrimp, both in the co-culture and monoculture ponds (Fig. 5). Rice-catfish co-culture significantly reduced the catfish respiration rate on August 18. However, the seasonal average values of respiration rates of catfish and shrimp showed no significantly difference between the co-culture and monoculture ponds.

Oxygen consumption proportion

As shown in Fig. 6, rice cultivation not only reduced the total amount of O_2 consumption, but also optimized the pattern of O_2 consumption. The total amount of O_2 consumption was significantly lower in YC-R and FS-R than in YC and FS, particularly in September and October. The O_2 consumptions of respiration in water and sediment decreased from 140.2 (July) to 40.5 g (October) and from 148.9 to 91.4 g in YC-R, respectively. While the O_2 consumptions of respiration in water and sediment increased from 210.5 to 388.3 g and from 137.0 to 231.7 g, respectively. The largest proportion of O_2 in water was consumed by fish respiration (63.9%), followed by respirations in sediment (25.0%) and water (11.1%) in YC-R co-culture pond. In YC monoculture pond, respiration in water was the dominant O_2 consumption pathway, which occupied 43.6% of the total O_2 consumption. Fish respiration only consumed 30.4% of the O_2 in pond water. Similar results were observed in the shrimp pond. Respirations in water and sediment only occupied 53.8% of the total O_2 consumption in FS-R co-culture pond, however, 75.2% of the total O_2 consumption in the FS monoculture pond.

Correlation between respiration rates and water parameters

As shown in Table 2, the respiration rate in water of the catfish pond significantly correlated with pH, turbidity, TSS, COD and nutrients (TN, TP and K). Unlike the fish pond, the respiration rate in water of the shrimp pond showed no significant correlation with turbidity, TSS and TP. The respiration rates in sediment of the catfish pond also displayed a significant correlation with more water parameters than that of shrimp pond.

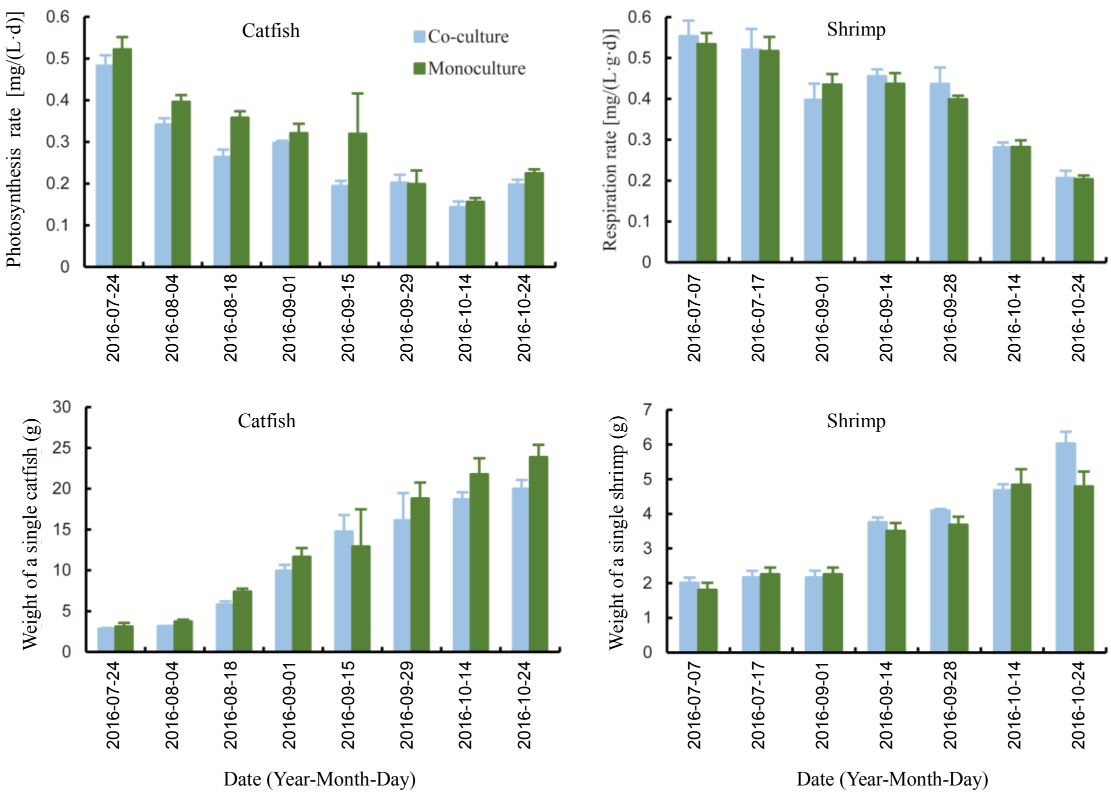

Fig. 5. Changes of the respiration rates and weight of catfish and shrimp in the co-culture and monoculture ponds (Mean ± SE, *n* = 3).

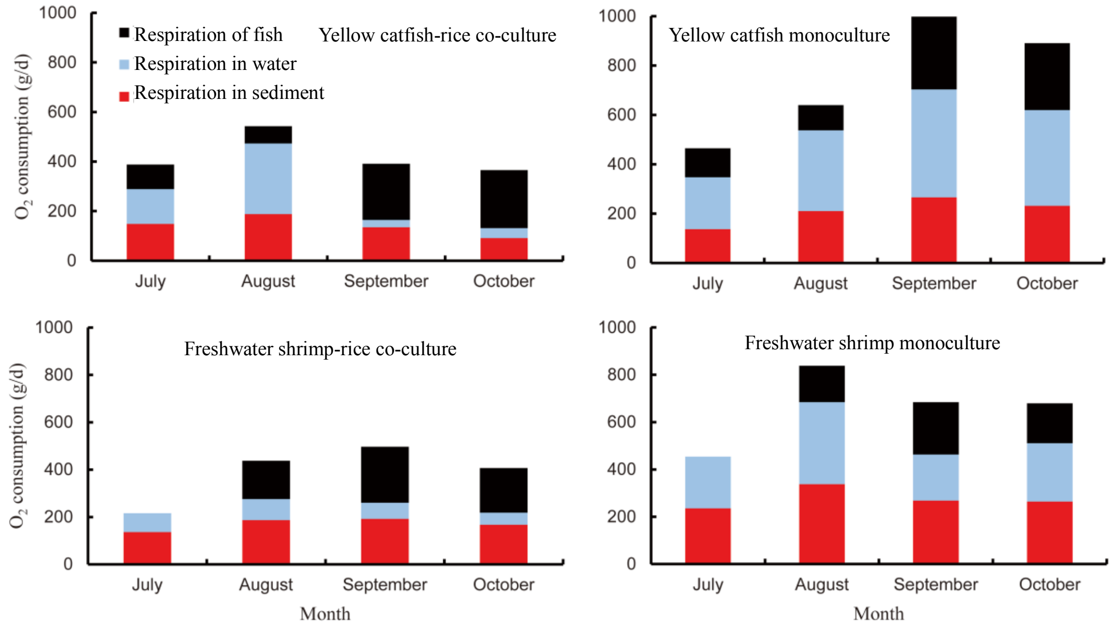

Fig. 6. Proportion of three O_2 consumption pathways in the co-culture and monoculture ponds.

DISCUSSION

Effects of rice-fish co-culture on water parameters

The changes of water parameters revealed that rice-fish co-culture in aquaculture pond improved the water quality (Table 1). Rice-fish co-culture significantly reduces the water temperature of aquaculture pond, reducing damage to fish by high temperature (such as higher metabolism, respiration and oxygen demand of fish, and lower solubility of dissolved oxygen and more toxic substances in water) in intensive aquaculture ponds during the summer (Siikavuopio et al, 2012). The cooling effect of rice was primarily attributed to the shading of rice leaves in the co-culture pond. COD was reduced by 44.6% and 6.5% by rice cultivation in the catfish and shrimp ponds, respectively (Table 1). The removal efficiency of this new rice-fish co-culture system on COD is comparable with the aquaponics systems, in which vegetable and triticeae crops are used to restore aquaculture wastewater (Snow et al, 2008). Rice cultivation also significantly reduced eutrophication in the pond water particularly in the yellow catfish pond. The contents of TN, TP and K were reduced by 50.2%, 59.6% and 40.4% through rice cultivation in the yellow catfish pond, respectively. The restoration efficiency was lower than that of the aquaponics systems (Ghaly et al, 2005; Snow et al, 2008; Graber and Junge, 2009). This was most likely

Table 2. Pearson correlation coefficient between the respiration rate and water parameters.

Parameter	Respiration in water		Respiration in sediment	
	Catfish pond	Shrimp pond	Catfish pond	Shrimp pond
pH	0.483*	0.474*	0.542*	0.396*
Temperature	0.107	0.364	0.171	0.252
Turbidity	0.731*	0.221	0.400*	-0.238
TSS	0.431*	-0.205	0.511*	0.311
COD	0.726*	0.295	0.467*	0.175
TN	0.617*	0.839*	0.471*	0.743*
Ammonia-N	0.220	0.273	0.372*	0.070
Nitrate-N	-0.160	0.462*	-0.098	0.589*
Nitrite-N	0.082	0.158	0.111	-0.101
TP	0.819*	-0.050	0.646*	-0.116
DIP	-0.155	-0.084	-0.258	-0.186
Potassioum	0.748*	0.807*	0.547*	0.633*

TSS, Total suspended solid; COD, Chemical oxygen demand; TN, Total nitrogen; TP, Total phosphorous; DIP, Dissolved inorganic phosphorous.
* indicate significant correlation at the 0.05 level.

due to the cultivation density of rice in the fish pond being lower than that of vegetable and triticeae crops in the aquaponics systems.

Effects of rice-fish co-culture on DO in pond water

Rice cultivation did not significantly influence the DO in pond water (Fig. 2). This was due to the fact that rice had either positive or negative effects on the DO. Gas exchanges from the atmosphere and the photosynthesis of phytoplankton are two main sources of DO in pond water. O_2 saturation content in water negatively correlates with water temperature (Culberson and Piedrahita, 1996). Rice cultivation significantly reduced the water temperature (Table 1), thus increasing the oxygen saturation content in the pond water. Additionally, the waving of rice plants causing by the wind may promote the diffusion of the O_2 from surface water into deep water (Foster-Martinez and Variano, 2016). Thus, rice cultivation could promote the O_2 diffusion from the atmosphere to water. Conversely, rice cultivation significantly reduced the levels of phytoplankton in the pond through the competition for nutrients (Table 1). The significant reduction of nutrients (N, P and K) in water limited the growth of phytoplankton in rice-fish co-culture pond. Additionally, the shading of rice leaves decreases the available light for the photosynthesis of phytoplankton (Mohanty et al, 2009). Thus, rice cultivation reduced the photosynthesis of phytoplankton in pond water.

Effects of rice-fish co-culture on respiration rate of fish and respiration rates in water and sediment

In traditional intensive culture pond, the oxygen in water is mostly consumed by the unwanted pathways (respirations in water and sediment). Rice cultivation significantly reduced the rates and proportions of respiration in water and sediment both in the catfish and shrimp ponds (Fig. 4), which benefits to reduce the hypoxia in intensive pond and reduce the mechanical aeration. Our previous study showed that the mechanical aeration is reduced by 91.8% in rice-fish co-culture pond than fish monoculture pond (Feng et al, 2016). The Pearson correlation efficient showed that respiration in water of yellow catfish pond was significantly correlated with pH, turbidity, TSS, COD and nutrients (TN, TP and K) (Table 2). We can deduce two possible pathways as to how rice affected respiration in water based on this evidence. Firstly, the competition for nutrients and light between rice and phytoplankton inhibited the growth of phytoplankton in rice-fish co-culture pond. pH is also an important factor that influences the growth and succession of phytoplankton. Hansen (2002) reported that the growth rates of three species of phytoplankton negatively correlate with water pH in the range of 7.00–9.60. Rice-fish co-culture reduced the water pH from 8.08 to 7.74, which may promote the growth of phytoplankton. However, this effect may be weaker than the competition for nutrients and light, as the total levels of phytoplankton were lower in the rice-fish co-culture ponds than the fish monoculture ponds (Table 1). Secondly, the significant correlations between respiration in water and turbidity, TSS and COD indicated that the decomposition of suspended organic matters by microbes was an important source of respiration in water of the yellow catfish pond (Vinatea et al, 2010). Rice-fish co-culture significantly reduced turbidity and TSS by the adsorption of suspended organic matters through the stems and roots of the rice plants in water (Ghaly et al, 2005; Sun et al, 2018), which may inhibit the decomposition of suspended organic matters, thus reducing respiration in water. Unlike the catfish pond, the respiration rates in water of the shrimp pond showed no significant correlation with turbidity and TSS (Table 2). This was due to the lower levels of feed in the shrimp pond than yellow catfish pond. Organic matter produced from the excretion and residual feed may also be lower in the shrimp pond than the catfish pond. Thus, the decomposition of suspended organic matter may contribute little to the water respiration in the shrimp pond.

Rice can transfer O_2 from the atmosphere to root zones in pond mud through aerenchyma (Armstrong, 1971; Colmer et al, 2006). Rice also affects O_2 diffusion at the sediment-water interface. Previous study reported that rice cultivation can slow the decrease of the O_2 concentration around the sediment-water interface, and increase the O_2 penetration depth (Qin et al, 2016). These effects can improve the anaerobic condition in pond mud and benefit to decrease the respiration in sediment. Additionally, rice cultivation can inhibit the resuspension of surface sediment (Horppila and Nurminen, 2001), and reduce the decomposition of organic matters in the surface sediment, thus reducing the respiration rate in sediment.

Fish respiration is influenced by fish weight and environmental factors, such as oxygen content, water temperature and pollutants (Fernandes et al, 2007). The respiration rates of catfish and shrimp showed a significant correlation with body weight. This is consistent with previous studies (Jobling, 1982; van Rooij and Videler, 1996). However, rice cultivation did not affect the growth rates and weight of catfish and shrimp in the intensive aquaculture ponds. Thus, the effect of rice on fish respiration may be attributed to its effect on environmental factors. Rice cultivation significantly reduced the temperature and pollutants (such as ammonia-N and COD). However, significant reduction in fish respiration rate only observed on August 18 in yellow catfish pond, possibly due to the reduction in water temperature caused by the shading of rice leaves in hot summer (van der Lingen, 1995). However, the seasonal mean respiration rates were not significantly affected by the improved water quality, either in the catfish or shrimp ponds. Whereas, the proportion of fish respiration increased due to the reduction of the proportion of respiration in water and sediment.

CONCLUSIONS

This study investigated the effects of rice-fish co-culture on the water parameters and O_2 consumption in two intensive culture ponds (yellow catfish and freshwater shrimp). The results showed that rice-fish co-culture significantly reduced the contents of TN, ammonia-N and TP in the water of catfish and shrimp ponds. The effects of rice on the mitigation of water nutrients were weaker in the shrimp pond than in the catfish pond. The seasonal changes of DO were not influenced by additional rice cultivation both in the catfish and shrimp ponds. Rice cultivation significantly mitigated the respiration rates in water and sediment both in the catfish and shrimp ponds, but did not affect the respiration rates of catfish and shrimp. The proportions of respiration in water and sediment were also reduced through extensive rice cultivation. These results provide references for the future application of rice-fish co-culture in intensive aquaculture.

ACKNOWLEDGEMENTS

This work was supported by the Natural Science Foundation of China (Grant No. 31400379), Natural Science Foundation of Zhejiang Province of China (Grant No. LY15C030002) and Innovation Program of Chinese Academy of Agricultural Sciences.

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(Managing Editor: LI Guan)