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Purification Performance and Production of a Re-circulating Pond Aquaculture System Based on Paddy Field

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Abstract: Developing improved aquaculture systems with a more efficient use of water and less environmental impact is becoming a crying need. A re-circulating aquaculture system consisting of paddy field and fish pond is a new culture mode due to aquaculture combing with agriculture. The present study focused on the purification capacity of the paddy field on nitrogen, phosphorus and organic matter, the fluctuation trend of water quality conditions during the whole rearing process and the culture efficacy of the main culture species of grass carp (Ctenopharyngodon idella). The results were as follows: under a flow rate of 1.4-5.5 m^3/h for the recirculation treatment, the average removal rate of ammonia nitrogen, nitrate nitrogen, total nitrogen, total phosphorus and bio-chemical oxygen demand for the aquaculture effluent amounted to 40.5, 43.5, 31.9, 23.9, 20.7 and 52.4%, respectively, But the dissolved oxygen content in the rice fields increased obviously. During the whole process of fish rearing, the main physicochemical parameters of water quality for the experimental ponds were all maintained at a suitable level for the growth of the grass carp. In addition, there were significant differences ($p<0.05$) in DO, TSS, NH_4^+-N, NO_2^--N, BOD_5 and Chl-*a* between the experimental and control ponds. As far as the yield per unit and survival rate was concerned, the level of the experimental ponds was obviously higher than that of the control, while the feed conversion ratio displayed the opposite trend. Overall, the new aquaculture system realized the double aims of water reuse and the reduction of waste water discharge.

Keywords: Fish pond, grass carp, re-circulating aquaculture system, paddy field

INTRODUCTION

Freshwater pond aquaculture is a popular phenomenon in China and also as an important source of income for farmers. Due to the more and more extensive adoption of intensive culture mode with fresh water, the water quality of culture pond deteriorates easily and hence impacts the yield and quality of aquatic products (Cao *et al*., 2007). At present, the technology summarized for water quality improvement of aquaculture pond mainly includes the integration of physical (Aitcheson *et al*., 2000), chemical (Johnson and Sieburth, 1974) and biological approaches (Redding *et al*., 1997; Panella *et al*., 1999; Lin *et al*., 2002a; Lymbery *et al*., 2006). Physicochemical methods, such as adsorption, sedimentation, neutralization and ion exchange, were normally used for wastewater treatment, but most of the target pollutants did not get efficient removal; the biological methods, for example, plants and beneficial bacteria, literatures were extensively documented on their exploration and utilization for water purification. These organisms were cultivated by their physiological demands for organic matter and nutrients during the metabolic process. Nevertheless, all of the methods above-mentioned possessed the common problem of instability during the practical application. Hence, the research and development of suitable water purification technology for aquaculture effluent treatment gradually become the key contents of scientific research on fisheries.

Paddy field belongs to agricultural wetland that mainly concentrates on the cultivation of paddy rice, which can effectively absorb the nitrogen, phosphorus and other nutrients during the growing process (Jang *et al*., 2012; Xu *et al*., 2012). Fish pond is one of the most important approaches for fish production, but the wastewater from fish pond is responsible for nutrient enrichment in receiving waters. In the present study, as two independent traditional production systems, the paddy filed was integrated into the production of pond aquaculture to form a compound re-circulating

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aquaculture system, realizing the organic combination of agriculture and aquaculture indeed. Investigation was carried out on the purifying capacity of paddy field on fish pond effluent, the variation trend of key water quality parameters during the rearing process and the final culture efficacy. Through the analysis of the investigation, it was expected to realize the double aims of water reuse and the reduction of waste water discharge.

MATERIALS AND METHODS

System design and construction: The present research was carried out in the experimental base of Research Center for Pond Ecological Engineering, Chinese Academy of Fishery Sciences, Jingzhou, Hubei Province, China. The study site (Yao Wan) was located in the urban and rural connecting areas situated in Shashi District, with a subtropical wet monsoon climate and rich in resources of water and heat. The annual average temperature there was 16.1ºC. There were about 230-270 frost-free days every year with an average relative humidity of 80%. The annual rainfall in this area fluctuated in the range of 958-1325 mm with an average annual rainfall of 1028 mm, among of which more than 70% precipitated during the months from May to August.

The experiment was conducted from April 1 to November 30. The experimental system mainly consisted of three parts including one paddy field, fish ponds and ecological ditches, among of which the paddy field took up an area of 432 m^2. The paddy field was mainly used to study the efficiency of fertilizer saving via the irrigation with nutrient-rich aquaculture effluent and explore the feasibility of water and nutrient recycling of fish pond with the participation of agricultural wetland and the relative technologies. In order to carry out the purification and reuse experiment on the aquaculture effluent with the combination of water and fertilizer management for farm land and in the meantime considering the organic combination of pond aquaculture and the reconstruction of flooded low-yield farm land under certain conditions, drainage pipes were set up inside the agricultural wetland (bury depth 100 cm). At the end of the drainage pipes, control devices for water discharge were set up. The water percolating through the soil of the wetland firstly flowed into a storage tank that closely approached the drainage pipes. Then, the water in the storage tank was pumped directly into an ecological ditch by a small pump. After flowing through the ditch for re-oxygenation and purification, the water finally flowed into the fish pond for reuse. The configuration of the flow chain (fish pond→ agricultural wetland→ ecological ditch→ fishpond) for water and nutrient utilization was displayed in Fig. 1.

The culture ponds included seven parallel ponds and each one had an area of 600 m^2 and a mean water depth of approximately 1.5 m. Five of the seven were set as the re-circulating ponds (P1→P5) and the remaining as the control. The control ponds corresponded to stagnant water conditions. The re-circulating ponds were connected by culvert pipes across the pond banks. Then, a PVC pipe was erected on the culvert pipe at the inlet end with short sleeves on the top to regulate water level. To avoid fry fish flee hither and thither among the re-circulating ponds, a perforated sleeve was set on the standing pipe. When operating the system, the inner short sleeves were taken out and the upper stratum water rich in DO during the daytime flowed automatically into the bottom of the next pond under head drop. This passive aeration via recirculation could therefore enhance the total stock of DO and improve the environment in the culture ponds (Fig. 2). Before the stocking of the fish, all of the fish ponds were drained, the silt was removed and the bottom of the ponds was disinfected with quicklime.

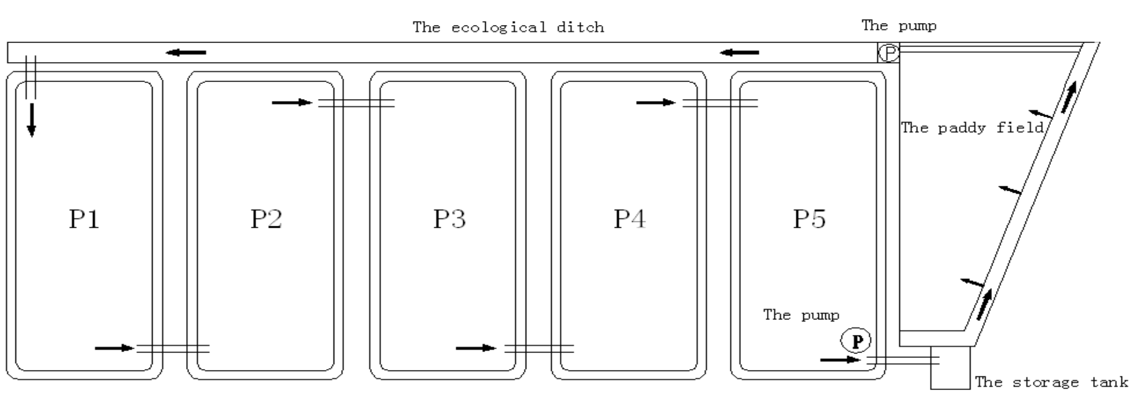

Fig. 1: Diagram of the recalculating grow out system
P1→P5: The five re-circulating ponds; Arrows denote the direction of the water flow

Fig. 2: Snapshots of parts of the re-circulating grow out system

Table 1: Summary of fry stocking in each of the culture ponds over the growing season

Species	Stocking density (ind./hm^2)	Initial body weight (g/ind.)	Initial biomass (kg)
Grass carp	9000	166.0	89.6
Silver carp	2250	95.00	12.8
Bighead carp	450	224.0	6.00

The number of fish sampled for initial information statistics was 15

The ecological ditches included two parts: one simple ditch (i.e., earth ditch) along one side of the paddy field with a length of 45 m and the other as an enhanced ditch connecting the paddy field and fish pond with a length of 105 m. The cross-section of the ditches was a sort of isosceles trapezoid shape, with bottom width of 0.65, top width of 2.47 and total depth of 0.7 m respectively. The differences between the two sorts of the ditches were that, the earth ditch was constructed along one side of the paddy field in line with local conditions and substituted the paddy field for recirculation when the paddy field endured special periods without the permission of discharge or irrigation. While the enhanced ditch was built up using permeable bricks and the pore of the bricks was filled with gravel. Inside the ditch, a combination planting of Nymphaea alba L, Myriophyllum sp. and Vallisneria natans (Lour.) Hara was achieved to enhance the purifying capacity of the long ecological ditch.

According to the different requirements of water and fertilizer during the growing process of paddy rice, the quantity of water that flowed through the paddy field was controlled in the range of 1.4-5.5 m^3/h. For the whole experiment, sampling of the fish ponds and the influent and the effluent of the paddy field as well as the ditches was done bimonthly. The Indices for water quality analysis included the Total Suspended Solids (TSS), Chlorophyll *a* (*Chl*-*a*), 5-day Biological Oxygen Demand (BOD_5), ammonium nitrogen (NH_4^+-N), Nitrite Nitrogen (NO_2^--N), Nitrate Nitrogen (NO_3^--N) and phosphates. All of the analysis followed the standards procedures released by the State EPA of China (State EPA of China, 2002).

Fish stocking and management: The details for fry stocking in each of the culture ponds are provided in Table 1. Fish stocking adopted the traditional method, i.e., a polyculture strategy. The main culture species was the grass carp (Ctenopharyngodon idella), mixed with a minor quantity of the filter-feeding fish (the silver carp and the bighead carp).

Fish stocking started on April 20 and harvested on November 1 in 2011. During the study, fish were fed to satiation twice daily (*ca*. 8: 00 A.M. and 4: 00 P.M.) by a compound feed with the No. of Q/WTW01 (*ca*. 32 crude protein, 2 crude fat, 3 cellulose, 17 ash and 11% water, respectively). The feed was supplied by Tongwei Feedstuff Co., Ltd. (situated in Wuhan, Hubei Province, China). The daily feed ration was fixed at the range of 3-5% of fish biomass and adjusted slightly according to the variation of weather conditions. All of the fish ponds were equipped with the microspore aerate system that connected to an air compressor (rated power 1.6 kW), which was turned on when the DO of the pond water was lower than 3.0 mg/L. During the rearing process, 15 grass carp in each pond was periodically (for each month) sampled for the measurement of body weight and lengths. At the end of the rearing period, the fish ponds were harvested by complete drainage and all of the fishes were weighted and recorded. Part of the rearing species was randomly sampled for the measurement of fish weight and lengths.

Data analysis: An independent *t*-test was used to compare the differences in water quality parameters between the influent and the effluent of the paddy field and the differences in culture efficacy between the experimental and control ponds. All of the statistical analyses were performed using the SPSS software (SPSS Inc., Chicago, IL, USA; Version 13.0).

RESULTS AND ANALYSIS

Purifying efficiency of the paddy field: The purification efficiency of the paddy field on the effluent from the fish ponds was displayed in Table 2. By the results of statistical analysis, the level of the measured physicochemical parameters (except pH and DO) was significantly lower in the effluent than the influent ($p<0.05$). The removal rate for the various parameters ranged from 20.7 to 52.4%, respectively and the areal

Table 2: The purifying efficiency of the paddy field (n = 17)

Parameter	Concentrations in CW/mg/L Influent	Effluent	Mean removal rates/%	Mean removal capacity/g/m^2/d
DO/mg/L	3.64±2.50^a	7.65±3.90^b		
TN	4.13±1.60^a	2.81±0.67^b	31.9	0.47
NH_4^+-N	1.32±0.45^a	0.79±0.41^b	40.5	0.10
NO_3^--N	0.27±0.24^a	0.15±0.23^b	43.5	0.08
TP	0.64±0.31^a	0.49±0.20^b	23.9	0.08
PO_4^{3-}-P	0.31±0.54^a	0.25±0.53^a	20.7	0.03
BOD_5	9.12±2.30^a	4.34±3.20^b	52.4	1.22

Different letter superscripts between columns indicate significant differences ($p<0.05$); pH is 7.26 for influent and 7.15 for effluent

Table 3: Comparison of the measured water quality parameters between the experimental and control ponds (Mean±S.D., n = 17)

Parameters	Experimental pond	Control pond
Temperature/°C	25.7±5.3^a	25.6±4.9^a
Transparency/cm	28.5±13.8^a	31.0±5.6^a
DO/mg/L	3.64±1.5^a	3.65±1.9^a
pH	7.28±0.26^a	7.17±0.31^a
BOD_5/mg/L	7.2±2.0^a	11.0±2.2^b
TSS/mg/L	28.6±8.6^a	35.9±23.1^b
Chl-*a* /mg/L	28.2±9.7^a	47.4±31.2^b
NH_4^+-N/mg/L	1.36±0.29^a	1.83±0.43^b
NO_2^--N/mg/L	0.03±0.02^a	0.04±0.03^a
NO_3^--N/mg/L	0.30±0.16^a	0.27±0.35^a
TN/mg/L	3.87±0.82^a	4.22±1.28^b
TP/mg/L	0.68±0.12^a	0.72±0.27^a
PO_4^{3-}-P/mg/L	0.33±0.01^a	0.34±0.02^a

Different letter superscripts between columns indicate significant differences ($p<0.05$)

Table 4: The culture efficacy of the rearing objects in the experimental and control ponds (Mean±S.D., n = 15)

Item	Experimental pond	Control pond
Initial body weight/g		
Grass carp	166.0±31.00	166.0±31.0
Final body weight/g		
Grass carp	1433.5±83.4	1360.0±75.5
Grass carp	97.2	90.6
Grass carp	6.57±0.62	6.19±0.50
Gross yield/kg	3761.6	1330.1
Total weight gain/kg	3672.0	1240.5
Feed consumption/kg	5397.8	2493.4
Feed Conversion Ratio (FCR)	1.4700	2.0100

***:** Food Conversion Ratio (FCR) = Total feed consumption/Total weight gain

removal rate fluctuated in the range of 0.03-1.22 g/m^2/d. The paddy fields displayed relatively high removal efficiency for NO_3^--N (43.5%) and NH_4^+-N (40.5%); the pH difference between the influent and effluent is indistinctive, but the DO content increased obviously from 3.64 mg/L of the influent to 7.65 mg/L of the effluent. The level of DO, BOD_5 and NH_4^+-N of the effluent from the paddy field met the standards of water quality for fishing areas released by the country in 1989 (GB11607-89). Hence, the paddy field could effectively purify the effluent from aquaculture ponds.

Characteristics of water quality in the fish ponds: The characteristics of the measured physicochemical parameters in the experimental and control ponds were listed in Table 3.

The average contents of the BOD_5, TSS, Chl-*a*, NH_4^+-N, TN and TP in the experimental ponds were 7.2, 28.6, 28.2, 1.36, 3.87 and 0.68 mg/L, respectively, while in the control ponds there were 11.0 for BOD_5, 35.9 for TSS, 47.4 for Chl-*a*, 1.83 for NH_4^+-N, 4.22 for TN and 0.72 mg/L for TP, respectively. By the statistical results, the levels of the measured physicochemical parameters in the experimental ponds were significantly ($p<0.05$) lower than those in the control except the indices of water temperature, transparency, DO, pH, NO_2^--N, NO_3^--N and phosphates. The above results demonstrated that the recirculation treatment via the paddy field improved the water quality of the fish ponds dramatically that was beneficial for the rearing objects.

Culture efficacy: By the results displayed in Table 4, the average survival rates of the grass carp in the experimental and control ponds were 97.2 and 90.6%, respectively. The final average body weight of the grass carp in the experimental and control ponds were 1433.5 and 1360.0 g, respectively, indicating the weight level of the experimental ponds was obviously higher than that of the control ponds. For the Specific Growth Rate (SGR) of the grass carp, they were 6.57% in the experimental ponds and 6.19% in the control ponds indicating obvious differentiation in the growth of the grass carp between the two sorts of the rearing ponds. The total gross yield in the experimental and control ponds were 1.25 and 1.10 kg/m^2, respectively, while the Feed Conversion Ratios (FCR) were 1.47 for the experimental ponds and 2.01 for the control ones. Hereby, conclusions could be reached that the culture efficacy of the experimental ponds was obviously higher than that of the control ponds.

CONCLUSION AND DISCUSSION

In order to treat the harmful substances rapidly and sustain a good water quality condition for a fish pond, waste water treatment unit usually needs a short hydraulic residence time to ensure a high percentage ratio of water recycling in a pond re-circulating aquaculture system. Redding *et al*. (1997) reported on the use of emergent macrophytes for the treatment of aquaculture waste water; under the hydraulic loading rate of 12 m/day, the removal rate of the system could reach 10.7% for NH_4^+-N (0.53 g/m^2/d), 15.4% for NO_3^--N (2.16 g/m^2/d) and 8.63% for PO_4^{3-}-P (0.32 g/m^2/d). Panella *et al*. (1999) designed a pilot-scale compound aquaculture system mainly consisting of wetland and intensive culture ponds; under the hydraulic residence time of 2.8-3.0 days, the average removal rate for the various pollutants of the waste water could amount to 33% for BOD_5 (0.69 g/m^2/d), 14% for SS (0.46 g/m^2/d), 41% for NH_4^+-N (0.015 g/m^2/d), 27% for NO_3^--N (0.419 g/m^2/d) and 58% for PO_4^{3-}-P (0.015 g/m^2/d).

In the present case, the paddy field was utilized to treat the effluent from the fish ponds. As a result, better purification efficiency towards the various pollutants including NH_4^+-N, NO_3^--N and BOD_5 was achieved. Nevertheless, the system showed uneven removal efficiency for the various parameters. The reasons explained for the differences in the treatment performance of the wetland system towards various waste waters could be documented extensively. For example, by the results of Vymazal (2002, 2005, 2011) and Lin *et al*. (2002a, 2002b, 2003, 2005) the differences could be attributed to the differentiation in the operating conditions of the wetland system. This may include the hydraulic loading rate, the pollutant concentration of the influent or the pollutant loading rate (i.e., the product of hydraulic loading rate and pollutant concentration).

In this study, the areal removal rate of TN was fairly low, only being 0.47 g/m^2/d. The reason explained for this could possibly be attributed to the low pollutant loading rate of TN for the system. Under the condition with low pollutant loading, the absorption by plants and the nitrification and denitrification activities induced by microbes constitute the main fraction of nitrogen removal. In comparison to many previous researches, this case study displayed higher treatment performance for BOD_5, indicating the organic suspended solids had been well decomposed or degraded by microbes and plants in the wetland system. According to the results, the removal efficiency for PO_4^{3-}-P (20.0%, 0.003 g/m^2/d) was lower than the values (31.9%, 0.23 g/m^2/d) reported by Tanner *et al*. (1995). This was partly due to that the removal rate of PO_4^{3-}-P in constructed wetland generally increased with the increase of pollutant loading rate till reaching the maximum and thereafter decreased with the increase of pollutant loading (Kadlec and Knight, 1996). For the present case, the low removal rate of PO_4^{3-}-P was mainly related to the low pollutant loading rate.

RASs have been developed to respond to the increasing environmental regulations in countries with limited access to land and water. For the present research, paddy fields as water purification unit also obtained the rice output of 7400 kg/ha, the integration of paddy field into pond aquaculture forming a RAS can possibly become a new promising culture mode in China in catering to the current theme of healthy culture advocated by the government. Although the present study demonstrated that the new constructed culture mode was good for fish production, but the mechanisms functioned within the system was still unclear. Therefore, further studies on the problems should be proceeding at a more detailed level.

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