**In situ** nutrient removal from aquaculture wastewater by aquatic vegetable *Ipomoea aquatica* on floating beds

Wenxiang Li and Zhongjie Li

**ABSTRACT**

Nutrient-rich effluents caused rising concern due to eutrophication of aquatic environment by utilization of a large amount of formula feed. Nutrient removal and water quality were investigated by planting aquatic vegetable on artificial beds in 36-m² concrete fishponds. After treatment of 120 days, 30.6% of total nitrogen (TN) and 18.2% of total phosphorus (TP) were removed from the total input nutrients by 6-m² aquatic vegetable *Ipomoea aquatica*. The concentrations of TN, TP, chemical oxygen demand (COD) and chlorophyll a in planted ponds were significantly lower than those in non-planted ponds (*P* < 0.05). Transparency of water in planted ponds was much higher than that of control ponds. No significant differences in the concentration of total ammonia nitrogen (TAN), nitrate nitrogen (NO$_3^-$-N) and nitrite nitrogen (NO$_2^-$-N) were found between planted and non-planted ponds. These results suggested that planting aquatic vegetable with one-sixth covered area of the fishponds could efficiently remove nutrient and improve water quality.

**Key words** | aquaculture, aquatic vegetable, *Ipomoea aquatica*, nutrient removal

**INTRODUCTION**

Aquaculture effluents with enhanced nutrients caused rising concern due to eutrophication of environment (Carpenter et al. 1998; Ruenglertpanyakul et al. 2004). In China, fishponds with static water and earthen-bottom were mostly open or semi-open farm system. In order to maximize fish production, a great deal of formula feed was applied. But fish culture only retained 20–50% feed nitrogen (N) and 15–65% of feed phosphorus (P) (Schneider et al. 2005). Large amount of uneaten feed and fish feces made water quality bad and turnover of algae was rapid in such ponds dominated by cyanobacteria (Van Rijn 1996). In order to make sure the healthy condition for fish, wastewaters with excessive nutrients was discharged into lakes and rivers without treatment. The point-source pollution of aquaculture effluent promoted the eutrophication of aquatic environment.

Much attention was paid to biological treatments of aquaculture wastewater (Van Rijn 1996; Siddiqui 2003; Troell et al. 2005). In recirculating system, constructed wetland had been investigated as efficient solution to remove nutrients from effluents (Lin et al. 2002; Naylor et al. 2003; Schulz et al. 2003). However, treatment by artificial wetlands outside the culture unit was unfeasible because of high expense in lands and power for small farm holders. Biological treatments within the farming unit, such as planting aquatic macrophytes in fishpond, may be more practicable for pond aquaculture in China.

Aquatic macrophytes can effectively reduce total nitrogen, total phosphorus and chemical oxygen demand (Sooknah & Wilkie 2004). But some aquatic plants may produce the secondary pollution. Aquatic vegetable swamp morning-glory, *Ipomoea aquatica* Forsk, is an important crop in oriental cuisine and animal feed. The vegetable grows well in moist soil or wetland system and has a high yield of 90,000 kg ha$^{-1}$ under the temperature of 25°C (Edie & Ho 1969). The floating bed technology makes it possible...
to plant aquatic vegetable on the water surface of fishpond.
Furthermore, aquaponic–integration of hydroponics with
aquaculture was feasible (Naegel 1977; Quilleré et al. 1995;
Ding et al. 1997; Diver 2006). Based on the above facts, the
feasibility of nutrient removal from water column of
fishponds by planting aquatic vegetable on floating beds
was investigated in the present study.

MATERIALS AND METHODS

Experimental design

The experiment was carried out in six concrete ponds with
area of about 36 m² (11 × 3.3 m; L × W) and depth of
1.0 m under the same field conditions. 25 mandarin fish
Siniperca chuatsi with body length of about 6.0 cm and 100
crucian carp Carassius auratus gibelio with body length of
about 12.0 cm were stocked in each pond. Pelleted feed was
fed at the rate of 1% body weight of the crucian carp per
day. Weight of the crucian carp was estimated according to
sampling every two weeks. Since the mandarin fish was
carnivorous, 1,000 live forage fish silver carp Aristichthys
nobilis was weighed and added to each pond every two
weeks.

Of the 6 concrete ponds, 3 are planted with I. aquatica
on the floating rafts with 20 cm plant spacing and 30 cm row
pitch. Frame of the rafts was made of bamboo. Polyethylene
net with 2 cm mesh was fixed in the frame. Area of the raft
was 6 m² (2 × 3 m; L × W) and covered one sixth of each
pond. The other 3 ponds are as non-planted control.

The experiment covered for 120 days from 18 July to 14
November in 2006. Natural water from lake was sup-
plemented when water level of fishponds decreased 5.0 cm.
Aquaculture wastewater was never discharged, and aeration
was supplied for 1 hour at 6:00 am every morning.

Sampling and analysis

Water temperature was recorded at 7:00 am and 5:00 pm
every day. Water samples were collected at 11:00 am every
two weeks. Water transparency was measured by sechi disc
method. Concentration of DO and value of alkalinity (pH)
were measured by portable apparatus (YSI, 550A; HANNA,
HI 98127). Sampled water was collected and taken to lab to
determine chlorophyll a (Chl a), total nitrogen (TN), total
ammonia nitrogen (TAN), nitrate nitrogen (NO₃⁻-N), nitrite
nitrogen (NO₂⁻-N), total phosphorus (TP) and chemical
oxygen demand (COD) according to Standard Methods
(1998). Water samples were filtered through GF/C filters.
The filtrates were collected for analysis of chlorophyll a by
acetone extraction. Amount of TAN, NO₃⁻-N, NO₂⁻-N in
filtered samples was determined by photometry methods. At
the end of the experiment, all fish and the sediment were
collected and weighed. Contents of TN and TP in pelleted
feed, fish, vegetable and sediment were measured according
to methods by Huang et al. (1999).

Statistical analysis

The nutrient flows of TN and TP were analyzed using mass
balances. Total nutrient inputs consisted of initial planted
vegetable, experiment fish (including mandarin fish, crucian
carp and forage fish), formula feed, and influent water. Total
nutrient outputs comprised of harvested vegetable and fish,
effluent, and sediment. Percentage nutrient removal due to
vegetable assimilation was calculated based on the differ-
ence of nutrients in harvested and initial vegetable divided
by total input nutrients.

Significant differences in fish production and water
quality at the same day between planted and control ponds
were tested by Student’s t-test. Statistics were performed
with the STATISTICS6.0 software package (Statsoft, Inc.,
Tulsa, Oklahoma).

RESULTS

Water temperature and growth of the vegetable

The average water temperature during the experiment was
24.4°C, and the temperature fluctuations ranged from 13.5
to 35.5°C. Mean water temperature in every day was less
than 25°C since September.

Before September, the vegetable I. aquatica did not
grow well, with some yellow green leaves becoming necrotic
around the margin. However, the plant exhibited good
conditions with dark green leaves and extensive root system
since September. When the experiment was finished, the biomass of the root under water surface was about one fifth of the plant. High transparency was observed in planted ponds, whereas control ponds were covered by blue-green algae.

**Harvested fish and vegetable and nutrient reduction**

Mean weight of the formulated feed, stocked forage fish, harvested crucian carp, mandarin fish and vegetable, and their content of P and N were listed in Table 1. There was no significant difference in fish production between planted and control ponds ($P < 0.05$). Average fresh weight of the vegetable was $141.5 \pm 20.8$ kg, and the productivity was $195.8$ g m$^{-2}$ per day.

Budget balance of total nitrogen and total phosphorus was given in Table 2. Removal nutrients of TN and TP by vegetable were $271.1 \pm 60.0$ g and $49.6 \pm 17.2$ g, respectively. Percentage nutrient removal of TN and TP were 30.6% and 18.2%, respectively. About 34.2% TN and 34.3% TP were removed by harvested fish. Nutrient retentions of TN and TP in sediment of the planted ponds were 31.7% and 37.3%, and in control ponds were 37.4% and 50.7%, respectively.

**Variation of water quality**

Concentrations of TN, TP and COD increased in plant and control ponds as feed residue and fish excreta accumulated. But the concentrations of TN, TP and COD in planted ponds were significantly lower than that of control ponds on 27 July and 14 November ($P < 0.05$). Concentrations of TAN, NO$_2$-N tended to increase, NO$_3$-N almost kept constant except for a sudden evaluation due to continuous raining before sampling. However, there were no significant differences between planted and control ponds ($P > 0.05$; Figure 1A–F).

On the last two sampling time, concentrations of Chl a and DO in planted ponds were significantly lower than that of control ponds ($P < 0.05$), and the inversed result was observed in water transparency. Value of pH in planted ponds was significantly lower than that of control ponds from August on ($P < 0.05$; Figure 1G–J).

**DISCUSSION**

**Percentage nutrient removal**

During the growth period of 120 days of *I. aquatica*, fresh weight of the vegetable increased about 140.0 kg, and the percentage nutrient removal of TN and TP were 30.6% and 18.2%, respectively. The nutrient retention consisted with other researches treated by plants. About 28% of nitrogen supplied was recovered from the hydroponic tomatoes in the artificial productive ecosystem (*Quilléré et al. 1995*). Nutrient retention of TN and TP in the macrophyte duckweed was rather low with 15% and 17%, respectively (*Schneider et al. 2005*). Despite the percentage of nutrient removal was unknown in the treatment of aquaculture wastewater by constructed wetlands, the efficiency of nutrient removal (the ratio of nutrient concentration in the effluent vs in the influent) was much higher. 95% to 98% total inorganic nitrogen and 32% to 71% TP were removed under different hydraulic loading using a construct wetlands system (*Lin et al. 2002*). Total kjeldahl nitrogen

<table>
<thead>
<tr>
<th>Mean weight (kg)</th>
<th>Control ponds</th>
<th>P content (%)</th>
<th>N content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formulated feed</td>
<td>8.18</td>
<td>8.18</td>
<td>1.79</td>
</tr>
<tr>
<td>Stocked forage fish</td>
<td>16.21</td>
<td>16.21</td>
<td>0.64</td>
</tr>
<tr>
<td>Harvested crucian carp</td>
<td>4.47</td>
<td>3.71</td>
<td>0.45</td>
</tr>
<tr>
<td>Harvested mandarin fish</td>
<td>7.53</td>
<td>7.96</td>
<td>0.90</td>
</tr>
<tr>
<td>Harvested vegetable</td>
<td>141.50</td>
<td>–</td>
<td>0.0387</td>
</tr>
<tr>
<td>Sediment (dry matter)</td>
<td>8.45</td>
<td>8.59</td>
<td>1.22† 1.69†</td>
</tr>
</tbody>
</table>

*Represents P and N content of sediment in planted ponds.
†Represents P and N content of sediment in control ponds.
was reduced by 91.7%, and TP by 98.5% in 31-day growth of water hyacinth *Eichhornia crassipes* (Sooknah & Wilkie 2004). The high removal efficiency may reside in the percolation of substrate with high affinity in created wetlands (Naylor et al. 2003).

Considerable nutrient was generally deposited in the sediment, about 29% N and 51% P accumulated in the sediments in the integrated agriculture-aquaculture farms (Nhan et al. 2008). In semi-intensive fishponds, nutrient accumulation in pond sediments accounted for about 66–70% N and 35–86% P of the total food input (Edwards 1993; Green & Boyd 1995). In our experiment, 31.7% TN and 37.5% TP were retained in the sediment in planted ponds, and 37.4% TN and 50.7% TP in control ponds. The retention of TN and TP in the sediment was compatible with the reports of those authors.

### Variation of nutrient

Since the high percentage nutrient removal due to the vegetable assimilation, concentrations of TN, TP and COD in planted ponds were significant lower than in control ponds on the last month of the experiment. The significant decreases of content of nutrient and organic matter in planted ponds were due to the growth of the vegetable on the last month of the experiment. Nitrogen and organic matter removal were correlated with the presence and biomass of plants (Naylor et al. 2003). Usually, plant productivity was greatly affected by temperature. Nutrient removal was highest during the growing season and lowest in the cold months (Spieles & Mitsch 2000; Picard et al. 2005). On the other hand, growth of plant was dependent on nutrient content that was relatively low in fish farm effluent (Naylor et al. 2003; Ruenglertpanyakul et al. 2004). In the present study, *I. aquatica* grew slowly when water temperature was above 25°C and concentration of nutrients was relatively low before September. However, when water temperature was below 25°C and concentrations of TN, TP and COD increased a high level on September, the vegetable was in good condition and developed rapidly. Therefore, concentrations of TN, TP and COD declined sharply in planted ponds due to decomposition of much more organic matter in planted ponds and absorption of much nutrient by the plant. The results suggested that the vegetable *I. aquatica* had much high efficiency of nutrient removal when water temperature was below 25°C and nutrient concentration in aquaculture wastewater reached a high level.

Although TN content was reduced, concentration of TAN elevated during the experiment, and there was no significant difference between planted and control ponds. Compared with the floating plant duckweed

| Table 2 | Nutrient balance of total phosphorus (TP) and total nitrogen (TN) in planted and control ponds. Experiment fish was comprised of mandarin fish, crucian carp and forage fish in nutrient inputs, and harvested fish consisted of mandarin fish and crucian carp. Error represents the differences between input and output nutrients divided by input nutrients |
|---------|-------|-------|-------|-------|-------|-------|
|         | TP    |       | TN    |       |       |       |
|         | Planted ponds | Mean ± SD (g) | Control ponds | Mean ± SD (g) | Planted ponds | Mean ± SD (g) | Control ponds | Mean ± SD (g) |
| Nutrient inputs | 272.24 ± 1.25 | 269.67 ± 0.95 | 886.93 ± 7.43 | 876.05 ± 1.29 |
| Influent water | 3.04 ± 0.37 | 2.46 ± 0.8 | 28.72 ± 3.48 | 31.26 ± 1.92 |
| Planted vegetable | 1.50 ± 0.88 | 1.50 ± 0.88 | 1.50 ± 0.88 | 1.50 ± 0.88 |
| Experiment fish | 120.95 ± 0.85 | 120.46 ± 0.24 | 426.55 ± 2.6 | 425.15 ± 0.65 |
| Formula feed | 146.75 | 146.75 | 419.63 | 419.63 |
| Nutrient outputs | 251.49 ± 6.33 | 260.37 ± 4.25 | 925.45 ± 51.06 | 780.95 ± 110.32 |
| Effluent water | 5.22 ± 2.98 | 27.49 ± 6.27 | 57.62 ± 10.06 | 190.26 ± 17.59 |
| Harvested vegetable | 51.13 ± 16.37 | 283.12 ± 56.32 | |
| Harvested fish | 93.51 ± 12.18 | 96.10 ± 11.83 | 303.27 ± 39.01 | 292.86 ± 34.35 |
| Sediment | 101.63 ± 1.64 | 136.79 ± 14.3 | 281.44 ± 66.05 | 327.83 ± 46.72 |
| Error (%) | 7.62 | 3.45 | 4.32 | 7.43 |
Figure 1: Mean ($\pm$ SD) concentrations of total ammonia nitrogen (TAN, A), nitrate nitrogen (NO$_3^-$-N, B), nitrite nitrogen (NO$_2^-$-N, C), total nitrogen (TN, D), total phosphorus (TP, E), chemical oxygen demand (COD, F), chlorophyll a (Chl a, G), dissolved oxygen (DO, H), and water transparency (Transparency, I) and value of alkalinity (pH, J) in planted and control ponds. Asterisk (*) represents significant difference between planted and control ponds at the same day ($P < 0.05$).
Lemna perpusilla that could efficiently remove ammonia (Ruenglertpanyakul et al. 2004), assimilation of TAN of the vegetable I. aquatica was limited in the present study.

Changes of water quality

The growth of the vegetable also induced changes of water quality, such as Chl a, DO and pH. Concentration of Chl a and DO in planted ponds was significantly lower than in control ponds on last month of the experiment. The low content of Chl a was responsible for inhibition of algae growth by the vegetable and the low concentration of TN and TP in aquaculture wastewater. Low DO concentration could be explained by high respiration rate of vegetable roots and reduced oxygen diffusion into water column from the atmosphere due to rapid growth of the vegetable (Moorhead & Reddy 1988). At the same time, roots of the vegetable exhaled CO2, which lead to low value of pH. Therefore, aeration and quicklime should be applied to improve DO and alkalinity in the integrated aquaculture system.

Covered area of the vegetable

1 ha fishpond would require 1.2 ha of wetlands to remove 80% of ammonium from effluent of aquaculture according to estimation of Lin et al. (2002). Schwartz & Boyd (1995) estimated wetland area of 0.7–2.7 times pond area for treatment of wastewater in catfish aquaculture. The rice with 20% coverage rate had the largest specific removal rate (rate/biomass) of TN and TP in eutrophic water (Song et al. 1998). The specific removal rate was highest at 25% stocking density of duckweed (Ruenglertpanyakul et al. 2004). In the present farming system, vegetable with one-sixth covered area of the fishponds efficiently removed nutrient and improve water quality. Larger covered area of plant may have higher efficiency of nutrient removal, but the growth of plant could be limited by the low concentration of nutrient. Furthermore, more plant consumed more oxygen at night and prevented oxygen in the atmosphere from entering into water column, which was dangerous for the farming fish.

CONCLUSION

Our results showed that planting aquatic vegetable I. aquatica on floating rafts could efficiently retain nutrient, improve water quality, and inhibit bursting-out of water bloom in aquaculture ponds. However, assimilation of TAN of the vegetable was limited. The vegetable should be transplanted on the floating beds when water temperature was below 25°C and concentration of nutrient increased a high level. Purified water quality can support higher stock density of farming fish. The integrated aquaculture system also can supply vegetable production and save water. Furthermore, treatment by vegetable can reduce the point-source pollution of aquaculture effluent.

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