

Improving Fishpond Sediment by Aquatic Vegetable Rotation

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Abstract: Continuously intensive fish farming results in pond degradation that needs to be improved. Therefore, the experiment rotating intensive fish culture with two aquatic vegetables lotus (*Nelumbo nucifera*) and water chestnuts (*Eleocharis dulcis*) cultivation is conducted aiming at determining the effect of rotation as a sediment management technique on improving the pond sediment and assessing the food safety risk of the vegetables cultivated in the pond sediment from the aspects of heavy metal. The results showed that after rotation, the content of Total Nitrogen (TN) and Organic Matter (OM) in the upper 10 cm sediment decreased significantly ($p < 0.05$), with TN content reduced 1.05 and 0.74 g/kg; OM content reduced 0.59 and 0.37%, respectively. The contents of Organic-Phosphorus (OP) and Fe/Al-bound Phosphorus (Fe/Al-P) in the sediment decreased significantly ($p < 0.05$), with OP reduced 0.05 and 0.04 g/kg, Fe/Al-P reduced 0.19 and 0.15 g/kg, respectively. The heavy metal contents of As, Pb, Cd, Hg, Cr and Zn except Cu in the pond sediment were under Chinese National II Soil Criterion and the contents of As, Pb, Cd, Hg, Cr, Cu and Zn in edible vegetable rhizomes satisfied Safety Requirements for Non-environmental Pollution Vegetable. Rotation of fish culture with aquatic vegetables cultivation effectively mitigated excessive nutrient load in the sediment while recycled the nutrient in the sediment to produce safe vegetables. It could be considered as a viable sediment quality improving technique.

Keywords: Heavy metal, phosphorous form, pond aquaculture, sediment

INTRODUCTION

In China, freshwater pond aquaculture production accounts for about 70% of the total freshwater aquaculture production and has become the most important aquaculture form. Fishpond sediment receives a large quantity of fertilizers, pellets feed and drugs during the entire period of culture. Excessive accumulation of organic sludge in fishpond sediment impairs sediment quality and can negatively impact water quality which ultimately deteriorates the pond system and lead to culture failure (Thunjai *et al.*, 2004). Meanwhile the sediment in fishponds with continuous intensively culturing of one single species may cause continuous cropping obstacle. Hence, there has been a great concern that problematic intensive fishpond sediment conditions need to be improved.

In practice of pond aquaculture, drying of pond bottom sediment between crops, liming in fishpond, tilling and periodic sediment removal have been used in pond bottom management (Wudtisin and Boyd, 2006). However, removing pond sediment is so expensive that it is commonly done at intervals of decades. At the

same time, the disposal and reuse of the large amount of sludge has been a problem. Moreover, more ponds are occupied year-round in the hope of gaining more profit which means there are no chances to dry and till the sediment. Pond sediment is enriched with organic matter, nitrogen and phosphorus. Alternatively, aquatic macrophytes may utilize abundant nutrients in sediment and result in a different physical and chemical condition in the sediment which may be beneficial to fish culture. Some farmers have changed their ponds from culturing fish to cultivating aquatic vegetables in recent years because some kinds of fish culture are sometimes less profitable than aquatic vegetables cultivation due to the oversupply of fish. Furthermore, the practice of rotating fish with aquatic vegetables may give farmers two crops to market rather than one which is less risky (Yang *et al.*, 2002). Planting lotus in fish ponds could be environmentally and economically effective (Chen and Li, 2007).

The aim of this study was to elucidate nutrient content changes in the sediment by the rotation of intensive fish culture with two popular cash aquatic vegetables lotus (*Nelumbo nucifera*) and water

chestnuts (*Eleocharis dulcis*) cultivation and to assess the food safety risk of the vegetables cultured in the pond sediment from the aspects of heavy metal, which would consequently determine the feasibility of rotation aquatic vegetable in improving the pond sediment.

MATERIALS AND METHODS

Materials: The experiment was conducted in nine 0.6 m² planting chambers (L×W×H = 0.90 m×0.70 m×0.65 m) using a completely randomized design at the Pond Ecological Engineering Research Center of Chinese Academy of Fisheries Sciences, Jingzhou, China, during May-December 2011. There were three treatments in triplicate:

- Lotus cultivation
- Water chestnuts cultivation
- Unplanted control

The chambers were filled with 30 cm deep pond sediment that was dredged in December 2010 from 23 intensive fish culture ponds with 20 years commercial pelleted feed. The chambers then were filled with water to 10 cm deep. Seedlings of the Chinese rhizome variety of lotus and water chestnuts, purchased from a local farm, were transplanted to the chamber respectively at a density of 3 and 9 seedlings per chamber on 8 June 2011. The average leaf length of the transplanted lotus and water chestnuts seedlings were 20 and 15 cm, respectively. After the seedling transplant, water was added to chambers to replace evaporation and water depth was adjusted according to the need of plant growth throughout the rest of the experimental period. Throughout the cultivation period there was no fertilization and no removal of dead plant parts such as dead leaves in all chambers. In control group there was no vegetable cultivation in the sediment. On 8 June 2011 when the plants were transplanted and 22 December 2011 the day the rhizome was harvested, sediment samples were collected from the chambers using self-made core sampler. The upper 10 cm segment of each core was removed and three core segments from each chamber were combined to provide a composite sample for analysis. Samples were transported on ice to the laboratory and were dried naturally in air. Dry sediment samples were then pulverized with a mechanical soil crusher and passed through 0.15 mm mesh sieve.

Before each analysis, samples were homogenized and sub-samples were taken.

Analysis methods: Organic Matter content (OM, reflected by Loss-on-Ignition) was determined by weight loss at 550°C. Total Nitrogen (TN) content was determined by the method of Chen and Wu (2005). Total Phosphorus (TP), Inorganic-Phosphorus (IP), Organic-Phosphorus (OP), Fe/Al-bound Phosphorus (Fe/Al-P) and Ca-bound Phosphorus (Ca-P) in the sediment were measured, using the Standard Measurement and Test (SMT) procedure of phosphorus forms in the freshwater sediments (Ruban *et al.*, 2001). The heavy metal content As, Pb, Cd, Hg, Cr, Cu and Zn in the sediment and vegetable was analyzed by the methods of Ding *et al.* (2007). Data were analyzed statistically by analysis of variance and t-test using SPSS (version 18.0) statistical software package.

RESULTS AND DISCUSSION

Changes of TN and OM content in the sediment: TN and OM content in the sediment after rotation decreased significantly ($p < 0.05$), with TN content reduced 1.05 and 0.74 g/kg, OM content reduced 0.59 and 0.37%. At the same time, TN and OM content in sediment of control also decreased 0.41 g/kg and 0.28% (Table 1). The reason was probably the submerged macrophytes such as *Potamogeton crispus* and periphytic algae were germinated from the propagule in old pond sediment which also utilized the nutrient in the sediment. Removal of organic matter in sediment can reduce soil oxygen demand to lessen the risk of anaerobic zones developing at the soil-water interface. Removal of nitrogen contained in sediment may lessen the likelihood of dense phytoplankton blooms in ponds with heavy feeding. Therefore, the reduction of TN and OM content in the sediment could alleviate excessive nutrient load which could be better for the fish culture in the next year. The results also showed that lotus has much higher utilization of TN and OM from the old pond sediment.

Changes of phosphorus forms in the sediment: A large part of the phosphate added to the ponds is stocked in pond soils and can be released under specific conditions. Although some phosphate is necessary for the development of aquatic populations, too large of an

Table 1: Comparisons of the TN and OM content in the sediment before and after rotation

| Item | Treatment | Before rotation | After rotation | Reduction amount |
|-----------|-----------------------------|------------------------|------------------------|------------------|
| TN (g/kg) | Lotus cultivation | 2.41±0.33 ^a | 1.36±0.22 ^b | 1.05±0.35 |
| | ck | 2.40±0.42 ^a | 1.98±0.29 ^b | 0.41±0.47 |
| | Water chestnuts cultivation | 2.46±0.43 ^a | 1.72±0.77 ^b | 0.74±0.38 |
| OM (%) | Lotus cultivation | 7.32±0.33 ^a | 6.73±0.60 ^b | 0.59±0.21 |
| | ck | 7.05±0.42 ^a | 6.77±0.60 ^a | 0.28±0.15 |
| | Water chestnuts cultivation | 7.17±0.43 ^a | 6.8±0.70 ^b | 0.37±0.12 |

Mean values with different superscript letters in the same row were significantly different ($p < 0.05$)

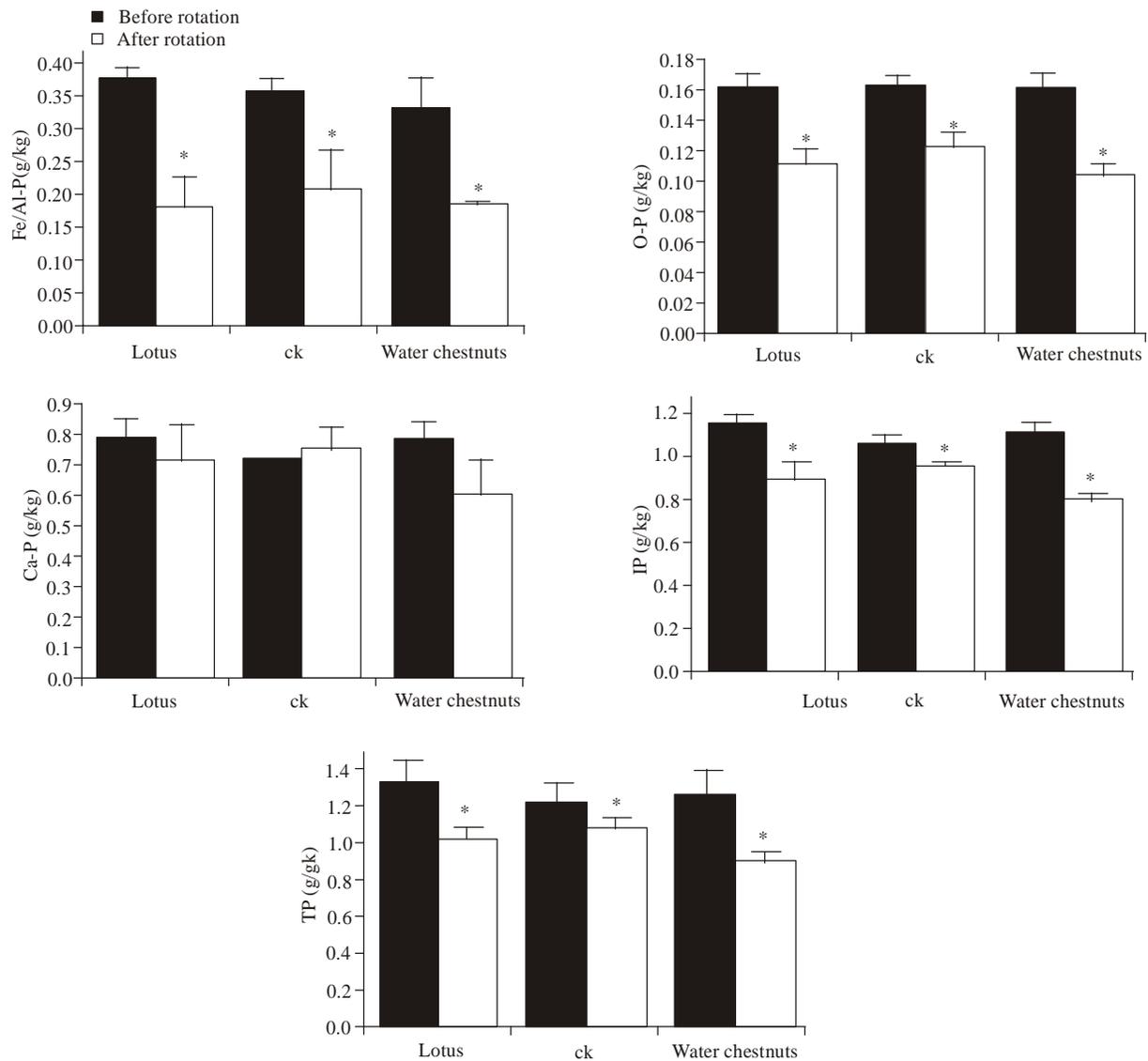


Fig. 1: Phosphorus forms in the sediment before and after rotation

input causes problems (Kassila *et al.*, 2000). Sediment can contribute phosphate to the overlying waters at levels comparable to the external source. However, not all the forms of P are likely to be released from the sediment and thereby increase eutrophication. In order to investigate how the plant cultivation change the bioavailability of phosphorus in the sediment the phosphorus forms were determined. The results are presented in Fig. 1. The concentrations of Fe/Al-P, OP, Ca-P, IP and TP were 0.34~0.38, 0.16, 0.71~0.79, 1.07~1.17 and 1.23~1.34 g/kg, respectively before rotation. And the relative percentages of phosphorus forms of Fe/Al-P, OP, Ca-P and IP, were 26~29, 12, 57~60 and 86~88% of TP, respectively. Therefore, phosphorus originated from fishpond sediment in this study was mainly of Ca-P, which was of detrital origin, whereas anthropogenic origin (Fe/Al-P+OP partly),

accounted for less than 40%. The results were in agreement with the previous results in morocco's fishpond in which Ca-P phosphate represented major part 86 to 91% TP and OP represented a small part between 0.87 and 5% (Kassila *et al.*, 2000). Compared to phosphorus forms content in many lakes there was much higher content of Ca-P in the fishpond sediment (Jin *et al.*, 2008). The reason is probably the frequently and large quantity use of lime in order to disinfect the pond.

After planting for a whole growing season the contents of OP and Fe/Al-P in the surface sediment were decreased significantly ($p < 0.05$), with O-P form phosphorus content reduced 0.05 and 0.04 g/kg, Fe/Al-P form phosphorus content reduced 0.19 and 0.15 g/kg while there was also some reduction in the control for the same reason of the submerged plant and periphytic

Table 2: Heavy metal content in the sediment and plant rhizome

| Heavy metal content (mg/kg) | As | Pb | Cd | Hg | Cr | Cu | Zn |
|--|-------|-------|-------|-------|--------|------|-------|
| Sediment before planting | 5.780 | 4.130 | 0.130 | 0.194 | 111.01 | 57.4 | 146.9 |
| Chinese national soil criterion (GB15618-1995) | 30.00 | 50.00 | 0.300 | 0.250 | 150.00 | 50.0 | 200.0 |
| Safety requirements for non-environmental pollution vegetable (GB18406.1-2001) | 0.500 | 0.200 | 0.050 | 0.010 | 0.5000 | 10.0 | 20.00 |
| Lotus rhizome | 0.160 | ND | 0.005 | 0.009 | 0.4400 | 0.38 | 2.940 |
| Water chestnuts rhizome | 0.170 | ND | 0.002 | 0.009 | 0.4500 | 1.97 | 9.170 |

mg/kg dry weight for sediment and mg/kg fresh weight for plant

algae growth. Fe/Al-P and OP are likely to be released at the sediment-water interface in case of anoxia and could diffuse into the water column, thus increasing the risk of eutrophication. The results indicated that aquatic vegetable cultivation mainly used the OP form and Fe/Al-P form which is the potentially releasable P in sediment. Thus, removal of OP and Fe/Al-P phosphorus present in sediment by rotation may lessen the likelihood of dense phytoplankton blooms and make a better management against eutrophication in ponds with heavy feeding.

Heavy metal content in the sediment and plant rhizome:

Heavy metal may accumulate in the bottom sediment, have adverse effect on the aquatic animal and cause potential risk to the environment. Many researches had been done on the N, P accumulating and agricultural reuse ability of the pond sediment; nevertheless little research had done on the hazard of accumulation effect of heavy metal in the sediment and edible part of vegetables. As can be seen from Table 2, the heavy metal contents of total As, Pb, Cd, Hg, Cr and Zn in the pond sediment were under Chinese National || Soil Criterion. However the content of Cu in the sediment was 57.4 mg/kg, which was slightly higher than 50 mg/kg in the Criterion. And the Hg, Cr and Zn content exceeded half of limit concentration in the Criterion. The relatively high content of Cu, Hg, Cr and Zn may be due to the drug use of CuSO₄, Hg(NO₃)₂, K₂Cr₂O₇ and ZnSO₄ especially before fish drug use was not strictly regulated. Another source of heavy metal is the pellet feed that did not eaten by fish and settled in the sediment. The heavy metal contents of As, Pb, Cd, Hg, Cr, Cu and Zn in edible parts of the aquatic vegetables rhizome satisfied Safety Qualification for Agricultural Product-Safety Requirements for Non-environmental Pollution Vegetable (GB18406.1-2001). The content of Hg which was 0.009 mg/kg in both plants and content of Cr which were 0.44 and 0.45 mg/kg in the two plant rhizome were very close to the limit value of the requirement. Although the content of Cu in the sediment exceeded Chinese National II Soil Criterion the Cu content in the plant rhizome were under the limit value. Heavy metal pollution and potential toxicity cannot be ignored. In the study of growing Pakchoi cabbage in mixed Wu Han Donghu Lake sediment soils the content of Zn was very near to the vegetable criterion, Zn was the limited factor for the fertilizing utility of the sediment (Li *et al.*, 2009). In the present study the pollution of heavy metal

was not critical. Hg, Cr and Cu are the limiting factor for the agricultural utility of fishpond sediment. However, the extent of heavy metal pollution is different due to the different background of the sediment and later input including feed, drug and disinfectant. Moreover different plant has different ability in accumulating different kinds and forms of heavy metal. It is essential to analyze the heavy metal content in the sediment prior to vegetable cultivation and in edible part of vegetable before entering market when planting aquatic vegetable in old pond sediment.

Although there was not any fertilization in the sediment, lotus and water chestnuts growth performance was normal. The extrapolated lotus and water chestnuts rhizome production from the 0.6 m² chambers for 6 month cultivation reached 29181 and 26846 kg/hm² in the present experiment. The yield of lotus was much higher than that of lotus planted in an old pond (17415 kg/hm²) which was also not fertilized (Zheng *et al.*, 2011) meanwhile the yield of water chestnuts was decreased for about 10% than that planted in the field with no fertilization (29700 kg/hm²) (Peng *et al.*, 2009). The high yield of lotus indicates that the nutrient content in the pond sediment could be sufficient or exceeded the amount required for lotus, nevertheless the nutrient may not be enough for water chestnuts growth which demonstrate that lotus is more suitable rotating fish culture with no fertilization.

CONCLUSION

The results of the present study demonstrated that rotation fish culture with aquatic vegetables cultivation effectively mitigated excessive nutrient load in the sediment to favorable levels meanwhile recycled the nutrient in the sediment to produce profitable vegetables. The aquatic vegetables cultured in the fishpond sediment satisfied safety requirements from the aspects of heavy metal. Aquatic vegetable rotation could be considered as a viable management option in improving the sediment quality within ponds. This kind of rotation which integrated intensive aquaculture and agriculture would ensure long-term sustainability of both farming and consequently could make contributions to regional sustainable development.

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