Phosphorus removal from wastewater by five aquatic plants

Xiaoyun Fu [1,a]

[1] College of Forestry Shenyang Agricultural University, 120 Dongling Road, Shenhe District, Shenyang,110161

[a] Fuxiaoyun1230@sina.com

Keywords: Aquatic macrophytes; Total phosphorus, Removal

Abstract. Five aquatic macrophytes, Acorus calamus, Lythrum salicaria, Monochoria korsakowii Alisma orientale and Sagittaria sagittifolia were tested for the relative growth rate (RGR) and abilities of removing total phosphorus (TP) by the manipulative indoor experiment. A nutrient treatment consisted of two levels of phosphorus [low (3 mg L^{-1} N) and high (12 mg L^{-1} N)]of nutrient solution. Result revealed that nutrients had significant affect on the RGR, however the RGR of the species was non-significant. The results showed that TP in wastewater were significantly higher from unvegetated microcosms compared to vegetated. L. salicaria was shown to be best removal effect with the removal rates of 81.7% and 91.1% at low and high concentrations of TP. The order of TP purification capacities was: A. calamus > L. salicaria >M. korsakowii >A.orientale> S. sagittifolia.

Introduction

Eutrophication has become an important indication of serious water pollution in many countries [1]. It is evident that phosphorus is a key factor causing eutrophication[2], because it enhances production in an amplified positive feedback[3]. Nutrient enrichment of aquatic ecosystems can lead to an increase in algae and aquatic plants, loss of component species and loss of ecosystem function[4] and deterioration of public health[5]. Nutrient removal process can be a cost-effective treatment method[6], and recently, various aquatic plants have been proposed to remove P. Hydroponic plants have been widely used in wastewater treatment systems because they can efficiently absorb dissolved compounds in the wastewater as nutrients for plant growth[7,8,9].In all these published constructed wastewater experiments there is a very wide range in treatment efficiency between experiments and many of the experiments failed to meet all governmental standards, especially for total phosphorus [10].In order to discover how to more efficiently construct treatment smaller scale mesocosm and microcosm experiments have been initiated to test the plant species composition[11]

The exchanges of P between water and sediment are highly complex, involving interrelated chemical, biological and physical processes[12].The present study is part of a larger investigation into management options for enhancing biological nutrient removal from wastewater using natural and constructed wetland technology. The objectives of this study were to compare the extent of total phosphorus removal from wastewater by two local plant species Furthermore it can provide a reference for screening accumulators for phytoremediation of contaminated water in the northeast China.

MATERIALS AND METHODS

Experimental set-up. Five aquatic macrophytes, *Acorus calamus*, *Lythrum salicaria*,*Monochoria korsakowii Alisma orientale* and *Sagittaria sagittifolia* were collected from the field. Plants were carefully washed using tap water then distilled water to remove all the debris, then kept for 5 days in clean water to acclimatize. After the adaptation period, the plants were cultivated in 50% Yoshida solution for 1 week. Samples were transplanted to the clear culture buckets (diameter 8 cm, height 15 cm, volume 3.5 L), three plants for each. The nutrient medium was changed into 100% Yoshida solution for 1 week. Then the desired amounts of $NaH_2PO_4 \cdot 2H_2O$ were dissolved in distilled water to achieve the appropriate contamination level: 3mg L^{-1} TN,12 mg L^{-1} TN.

These plants were grown in experimental buckets filled with 3 L of artificial sewage in a greenhouse at a temperature of 23±2˚C.

The experiment was conducted from July 1, 2011 to August 1, 2011. Fifteen clear culture buckets were used to establish three treatments with triple replication. The six treatments included five monocultures (*A. calamus, L. salicaria, M. korsakowii, A.orientale* and *S. sagittifolia*) and no plants (as control).

The microcosms were arranged in three rows and randomly placed. The contaminated water was continuously aerated with an aquarium air pump. Losses in culture volume due to evapotranspiration were countered by addition of deionized water to the original level every other day.

Sampling and analysis. During the course of the experiments, water samples of 250ml were collected every 7 days from each tank. Water samples were collected from water surface of the buckets and kept at 0–4°C until analysis within 24 h. The concentrations of total phosphorus (TP) were measured according to the Standard Methods for the Examination of Water and Wastewater as prescribed by American Public Health Association[13]. Removal of TP was calculated using the following equation:

$$R(\%)=[(C_0-C_t)/ C_0]\times 100 \qquad (1)$$

where C_0 and Ct represent the initial concentration and final concentration, respectively.

After 28 days of incubation, dry weight was determined after drying the plants at 70°C until constant weight. The relative growth rate (RGR) was calculated as the ratio of dry weight difference between dry weight at the end of 28 days of incubation and dry weight at the beginning of the experiment over $[(Wt_{28} – Wt_0):Wt_0]$.

Statistical analyses. The results were analyzed statistically by the SPSS (Version 11.0). In all cases, significance was defined by p < 0:05. A two-way ANOVA was used to determine significance of species and nutrient effect on the relative growth rate (RGR). Tukey's LSD was applied to test for significance between treatment means. Linear regressions were performed within each plant species to determine the possible effect of the RGR on phosphorus reduction, but the results were non-significant and therefore we have not included these results.

Results and discussion

The growth of five species. The RGR was analyzed comparatively between nutrient treatments (Fig. 1).A two-way ANOVA (Table 1) showed that nutrients had no significant affect on RGR , however the RGR of the species was non-significantly. *L. salicaria* had the greater RGR at both nutrient levels, and post-hoc analysis determined that the difference was statistically significant in comparison with *A. plantago-aquatica*.

Tab. 1 Two-way ANOVA to determine significance of species and nutrient effect on biomass

Source	Sum-of-squares	df	F-ratio	P
NUTR	0.136	1	8.510	＜0.001
SPECIES	2.347	4	87.448	0.253
NUTR* SPECIES	0.047	9	3.147	0.514
ERROR	1.452	16		

In the table, NUTR refers to nutrient treatment, and SPECIES refers to the plant species treatment. ''df'' is degrees of freedom.

The growth of five species was favorable at the end of experiment (Fig1.). In principle, high nutrient removal efficiencies can be achieved due to the very high growth rates. *M. korsakowii* grew relatively rapidly, which was reflected by the RGR of 0.818. The RGR of *S. sagittifolia* was the lowest (0.039) in the five marophytes.The LSD test has shown statistically significant difference (p<0.05) between *A. calamus, L. salicaria, A.orientale, S. sagittifolia* and *M. korsakowii*. The relative growth rate (RGR) of *A. calamus, L. salicaria, A.orientale,* and *S. sagittifolia* showed no significant difference. Physical and chemical processes associated with the water column and vegetation are primarily responsible for P removal from the overlying water[14].

Most macrophytes species can assimilate P directly through their roots, shoots and leaves[15]. It was inferred that *M. korsakowii* had a greater potential to extract nutrients from wastewater due to the thin and loose root mat that allows water–plant interaction.

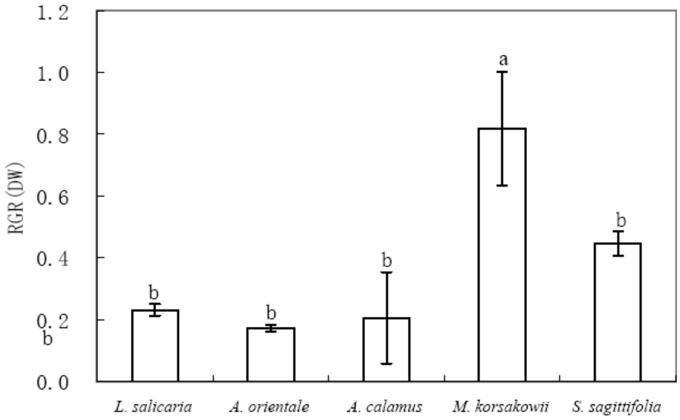

Fig.1. Relative growth rate (RGR) of five aquatic macrophytes in the experiment. Results are means ± standard deviation (n = 3). Means with different letters are significant (P<0.05) according to the LSD test.

P removal from the simulated wastewater. A comparison of total phosphorus by species treatment, and across sampling dates, is shown in Fig. 2 (low nutrients) and Fig. 3 (high nutrient). The 0 sampling date is a pre-treatment baseline measurement. Unvegetated microcosms show significantly higher nitrogen levels at all four post-treatment dates. The two aquatic macrophytes could be effectively used in reducing the TP concentration compared to the control(p<0.01).

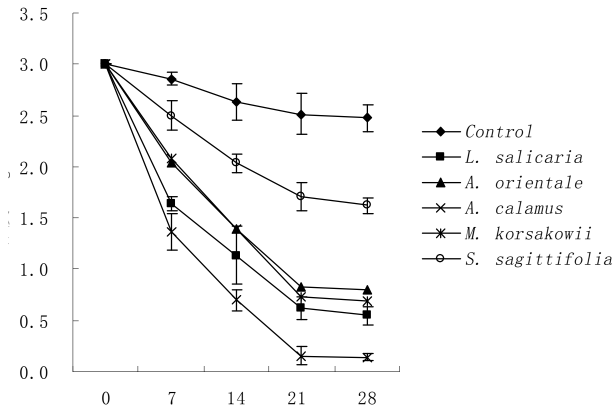

Fig. 2. The mean total phosphorus (mg L^{-1}) in wastewater for low nutrient treatments over the study period. Error bars represent one standard error.

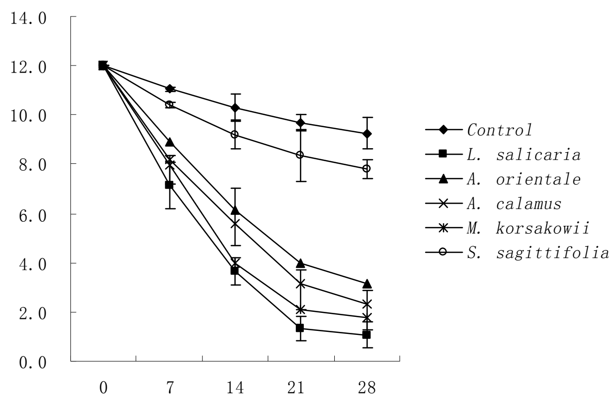

Fig. 3. The mean total phosphorus (mg L^{-1}) in wastewater for high nutrient treatments over the study period. Error bars represent one standard error.

The concentrations of TP had varying degrees decline in the treatment waters and the decline trends were essentially same. It declined rapidly in early 14 days, and became relatively stable after 21 days. The removal effect of *A. calamus* on TP was the best among all tested species; its removal rate was 96.1%, followed by *L. salicaria*(83.4%). *M. korsakowii* and *A. orientale* had stronger ability to remove TP, the removal rates were 79.9% and75.8%.

The TP concentration of *L. salicaria* and *A. plantago-aquatica* declined to a low level after be cultured for 21 days, and tended to level off in the latter 7 days at low nutrient (Fig. 2). In particular, *L. salicaria* had the best removal effect with the removal rates of 81.7% compared to 30.8% in control. At high nutrient(Fig. 3), vegetated microcosms show a general trend to decrease over time. *L. salicaria* had stronger ability to remove TP, the removal rates were 91.1%. Nutrients had no significant affect on *A. plantago-aquatica*, the removal rates were 73.4%(at low nutrient) and 73.7% (at high nutrient), respectively.

Although plant uptake played a significant role in the removal of P, it did not account for all of the P loss from the system, indicating the possibility of biochemical and physico-chemical processes functioning in the system. Studies done by using simulating conditions of “Micro-environment” have limitations. For example, the spatial scale does not generally reflect what occurs in nature, and abiotic conditions may be affected by the experimental conditions. Microcosms however, are extremely useful for controlled mechanistic investigations and have previously been used to test plants’ ability to treat wastewater.

Conclusions

This study demonstrates the importance of macrophytes to reduce nutrient concentrations in the wastewater. Vegetated microcosms had significantly lower total N in their treatment water than unvegetated microcosms. *M. korsakowii and A. plantago-aquatica* were shown to be effective overall at treating TN loaded water and should therefore be considered for the future design of treatment wetlands.

Acknowledgements

This work was supported by the major technology projects: National water pollution control and management (No.2012ZX07202008). We also wish to thank Professor Guangzhu Zhou, for his help in preparing the manuscript.

References

[1] L.J.Sherwood, R.G.Qualls. Environ. Sci. Technol. Vol.35 (2001), p.4126–4131
[2] V.H.Smith, G.D.Tilman, J.C.Nekola. Environ. Pollut. Vol.100(1999), p.179–196
[3] J.L.Garland, L.H.Levine, N.C.Yorio. Hummerick, M.E.,Water Res. Vol.38 (2004), p.1952–1962
[4] R.A. Smith, G.E. Schwartz, R.B. Alexander, Water Resour. Res. Vol.33 (1997),p.2781–2798
[5] C.Forni, J.Chen, L.Tancioni1, M.G.Caiola. Water Res. Vol.35 (2001), p.1592–1598
[6] P.S.Hooda, A.C.Edwards, H.A.Anderson, A.Miller. Sci. Total Environ. Vol.250(2000), p.143–167
[7] A.A.Rababah, N.J.Ashbolt. Water Res. Vol.34(2000), p.825–834
[8] P.R.Adler, S.T.Summerfelt, D.M.Glenn, F.Takeda. Ecol. Eng. Vol.20(2003),p.251–264
[9] M.P.Elless, C.Y.Poynton, C.A.Willms, M.P.Doyle, A.C.Lopez, D.A.Sokkary, B.W.Ferguson. Water Res. Vol.39(2005), p.3863–3872
[10] K.H.Rogers, P.F.Breen, A.J.Chick. Res. J. Water Poll. Control Fed. Vol.63(1991), p.934–941
[11] C.C.Tanner. Ecol. Eng. Vol.7(1996), p.59–83
[12] APHA, Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association, Washington, DC.1998.
[13] D.O.Huett, S.G.Morris, G.Smith and N.Hunt, Water Res. Vol.39 (2005), p.3259–3272.

[14] R.P.Gambrell, W.H.Jr.Patrick. Chemical and microbiological properties of anaerobic soils and sediments. In: Hook, D.D., Crawford, R.M. (Eds.), Plant Life in Anaerobic AnnArbor Science Publishers,AnnArbor, 1978. p.375–423