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Purification Efficiency of Eutrophic Water by Different Aquatic Plant Combinations

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ABSTRACT

Purification efficiency of three combinations of aquatic plants was studied for eutrophic water samples. Combination A was penny grass (*Hydrocotyle vulgaris*), water pack (*Sagittaria sagittifolia*) and water lettuce (*Pistia stratiotes*); combination B was loosestrife (*Lythrum salicaria*), watermifoil (*Myriophyllum verticillatum*) and water lettuce; and combination C was cattail (*Typha orientalis*), water fennel (*Oenanthe stolonifera*) and water lettuce. The control treatment did not contain aquatic plants. The results indicated that the plant combinations had a higher pollutant removal rate than did control. All aquatic plants had higher biomasses in the eutrophic water and performed well in decreasing total phosphorus (TP) and total nitrogen (TN) in eutrophic water. The removal rates of TP and TN in combination A were 83.05% and 67.19%; and correspondingly 88.70% and 67.97% for combination B and 60.45% and 66.41% for combination C. The dissolved oxygen content in the water of each combination showed a downward trend with time, and pH in all treatments remained weakly alkaline. The results suggested that combination B was preferable for purification of eutrophic water and for plant landscaping.

INTRODUCTION

In recent years, discharge of industrial wastewater, agricultural wastewater and domestic sewage has gradually increased caused by increasing rates of urbanization, and increase in fertilizer application and loss. As a result, water eutrophication and water pollution are becoming increasingly serious (Hu et al. 2008). Most lakes and rivers in China, including Taihu Lake (Paerl et al. 2011), have experienced organophosphate pesticide contamination and harmful algal blooms. Compared to the other approach of water remediation, phytoremediation has the advantages of less investment, less energy consumption, less disturbance to environment, and the utilization of plant resources as food and feed (Kramer 2005, Kang 2014). This approach has been effectively applied to the removal of nitrogen (N) and phosphorus (P) from eutrophic water by accumulation and transformation using aquatic plants (Zheng et al. 2013). Aquatic plants reported as removing N and P include reed (*Phragmites communis*) (Xu et al. 2017), cattail (*Typha orientalis*) and canna (*Canna indica*) (Wu et al. 2006, Coleman et al. 2001), calamus (*Acorus calamus*) (Zhou et al. 2007) and water lettuce (*Pistia stratiotes*) (Lu et al. 2010). The effect of the different plants on nutrient absorption and water purification can differ markedly. One kind of plant may have a better removal effect on one nutrient affecting water quality, while the effect on another nutrient is relatively poor. The effect of hornwort (*Ceratophyllum demersum*) on improving the transparency of water is good and fast, but it is poor in absorbing total P (TP) and total N (TN). Watermifoil (*Myriophyllum verticillatum*) is good at absorbing TP and TN, but is not ideal for reducing the chemical oxygen demand and improving dissolved oxygen (DO) (Tong et al. 2003). It is difficult for a single plant to remove all kinds of pollutants. According to the growth characteristics of different plants and their capacity to absorb nutrients, as well as the seasonal differences and the continuity of landscape, and ecological function, combinations of co-locations of plants can have better purification ability all year (Wang et al. 2013). A reasonable combination of plants can produce a better decontamination effect than a single species (Cao et al. 2012, Han et al. 2008). In addition, combinations of aquatic plants can also play a role in shaping the landscape.

Suzhou in China is an important tourist city with a long history. However, some river water bodies in Suzhou city have become polluted during the process of urbanization and the rapid increase of urban population, and their water quality shows a trend of deterioration. The problem of black-odour river is particularly prominent (Jiang & Huang 2012). Therefore, according to the climatic and environmental characteristics of Suzhou, seven aquatic plants (cattail, penny grass, water lettuce, water pack, watermifoil, water fennel, and loosestrife), which grow worldwide and commonly used for bioremediation of wetlands, were selected. The effects of different plant combinations on purification of eutrophied water were studied to provide a theoretical basis for selection of aquatic plants for water purification.

MATERIALS AND METHODS

Plant material: Seedlings of cattail (*T. orientalis*) were collected from the campus pond of Soochow University and water fennel (*Oenanthe javanica*) from the aquatic vegetable base of Suzhou. Penny grass (*Hydrocotyle vulgaris*), water lettuce (*Pistia stratiotes*), water pack (*Sagittaria sagittifolia*), watermifoil (*M. verticillatum*) and loosestrife (*Lythrum salicaria*) were collected from the seedling company (Garden spot of agricultural variety in Suzhou) in April 2016. The collected aquatic plants were pre-cultured in planting boxes containing river sand and tap water.

Water of treatment and experimental location: The treatment water was collected in the river of the residential area of Che-fang town in Suzhou Industrial Park. The river water was polluted and eutrophic. The pH of treatment water was 8.04 and TN, TP and DO were 2.56, 0.35 and 2.05 $mg \cdot L^{-1}$, respectively. The experimental site was located on the platform of the third floor of Mantis School of Architecture of Soochow University, ensuring that plants were fully exposed to natural light and were not affected by rain.

Experimental method: The experiment period was June-July 2016. The plants were grown in treatment planting boxes, and control planting boxes contained no plants. Before treatment, plants of the same species and size were selected, and the roots washed repeatedly with tap water to avoid introduction of weeds, withered leaves and other substances. River sand was the cultivation substrate. Each planting box measured 50 cm × 38 cm × 25 cm, and 20 L of treatment water was added to every planting box. The plant combinations follow: A included penny grass, water pack and water lettuce; B included loosestrife, watermifoil and water lettuce; C included cattail, water fennel and water lettuce; and D was the blank control (no plants). Every species represented three plants in each combination group, making nine plants in total, with three replicates per treatment.

Water samples were collected weekly from control and treatment planting boxes and analysed for water quality parameters, including TN, TP, pH, DO and plant growth. Evaporative water losses from the container were replaced by adding distilled water to the initial level in each planting box before water samples were collected. During the experiment, any sticks and dry leaves which could change the content of N and P in water, were removed before falling into the water.

Chemical analysis: The physico-chemical characteristics of water in each treatment group were examined periodically to determine any changes of water quality. The pH of water samples was determined using a pH meter FE20 (Mettler-Toledo, Shanghai, China). The DO was determined with the iodometric method, TN content using the alkaline potassium persulfate digestion UV spectrophotometric method (GB 11894-89) and TP with the ammonium molybdate spectrophotometric method (GB 11893-89).

Data processing: The removal rate was calculated using the method of Liu et al. (2011):

$$\text{Removal rate} = (C_0 - C_i)/C_0 \times 100\% \qquad ...(1)$$

Where, C_0 and C_i are pollutant concentrations at the beginning of the experiment and at day i, respectively.

RESULTS AND DISCUSSION

Plant growth and development: The seven species of the plants survived and grew well during the experiment. Plant growth was very vigorous and most increased in height. Among the aquatic plants, the tillering ability of water lettuce was especially strong, and its amount of growth in treatment C was the greatest. Loosestrife had greatest growth height, followed by cattail loosestrife and watermifoil.

TN concentration reduction and removal rate: In general, TN concentration in water decreased with time, including the control (Fig. 1). Introduction of plant groups resulted in higher TN removal rate relative to control during the experiment. The TN concentrations of each combination decreased by varying degrees with treatment time. The average TN concentration in control decreased from 2.56 to 1.16 $mg \cdot L^{-1}$, and the removal rate was 54.69%; and corresponding values for combination A were from 2.56 to 0.84 $mg \cdot L^{-1}$, and 67.19%; for combination B from 2.56 to 0.82 $mg \cdot L^{-1}$, and 67.97%, and for combination C from 2.56 to 0.86 $mg \cdot L^{-1}$, and 66.41%. The TN removal rates of the three combinations were significantly higher than that of the control, and that of combination B was slightly higher than those of combinations A and C.

The TN removal rate varies with plant species and treatment period. In constructed wetlands, TN mean removal percentages of reed, cattail and *Sparganium stoloniferum* were 75.09%, 80.11%, and 71.26%, respectively (Liu et al. 2012). Under high-concentration treatment, the TN removal rate of the mining ecotype (ME) of *Polygonum hydropiper* had a significant advantage compared to the non-mining ecotype (NME) at 15d and 30d, whereas no obvious difference occurred between ME and NME at 45d (Zhang et al. 2007). In our study, TN was significantly removed by the

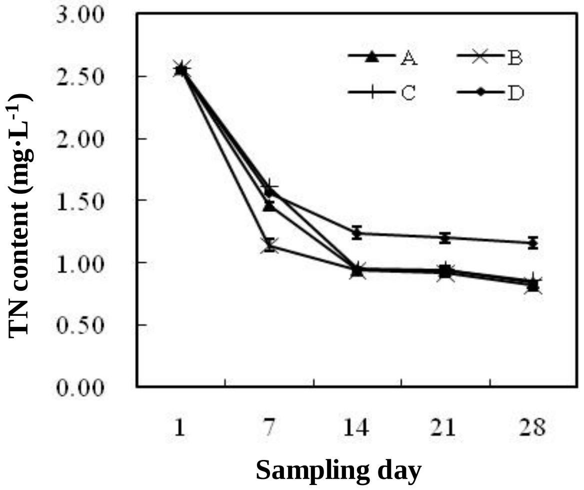

Fig. 1: Effect of the different hydrophyte combinations on TN content of eutrophic water.

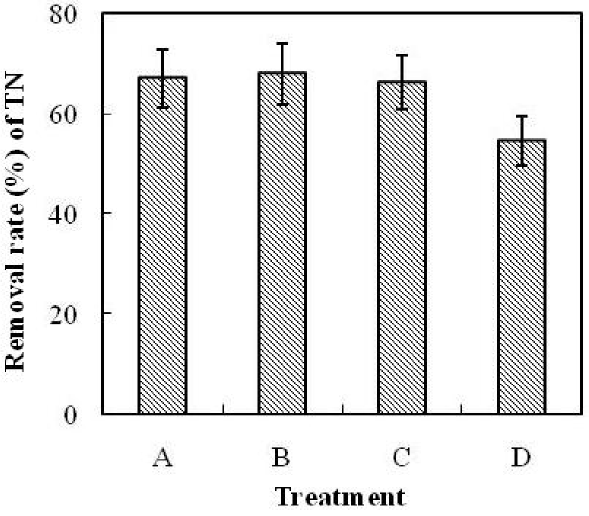

Fig. 2: Removal rate of TN by different hydrophyte combinations.

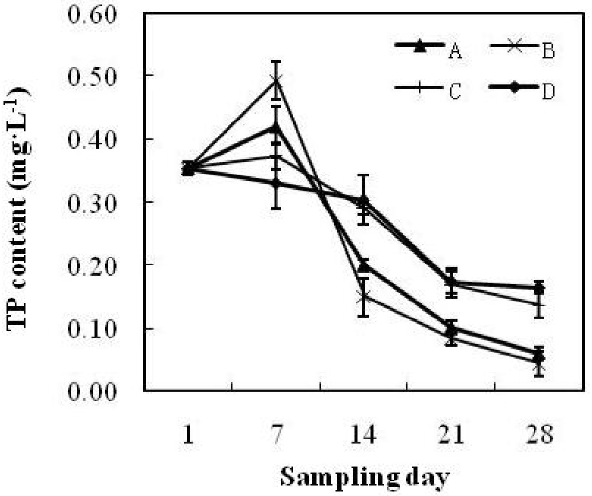

Fig. 3: Effect of different hydrophyte combinations on TP content of eutrophic water.

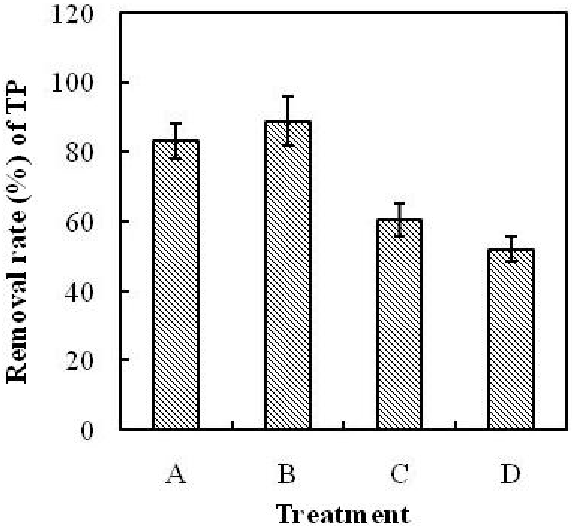

Fig. 4: Removal rate of TP by different hydrophyte combinations.

plants of combination B at 28d (Fig. 2), and the removal rate of TN in control was 54.69%.

TP concentration reduction and removal rate: The TP concentration of each combination decreased by varying degrees with treatment time (Figs. 3 and 4). After 28d of treatment, the TP removal rates of different plant combinations were compared and analysed. The average concentration of TP in the control decreased from 0.35 to 0.17 mg·L^{-1}, and the removal rate was 51.98%; and corresponding values for combination A were from 0.35 to 0.06 mg·L^{-1}, and 83.05%; for combination B from 0.35 to 0.04 mg·L^{-1}, and 88.70%; and for combination C from 0.35 to 0.14 mg·L^{-1}, and 60.45%. The TP removal rate of combination B was highest of all combinations, being slightly higher than that of combination A.

The shifts of TP residues in water showed a similar trend for all treatments. After 28d of bioremediation, combination B showed only 0.04 mg·L^{-1} TP (Fig. 3). The key mechanisms of TP elimination from wastewater are physico-chemical processes, such as adsorption of phosphate by plants and their derivatives or remnants, and fixation of phosphate by iron in substrates (Del et al. 2003). During a 7-d wastewater retention, the average TP removal rate for *Phragmites australis* was 96.5% (Liu et al. 2011). After 8 weeks, 89.4% of TP was removed at initial coverages of 80% by *Spirodela oligorrhiza* (Xu et al. 2011). In our study,

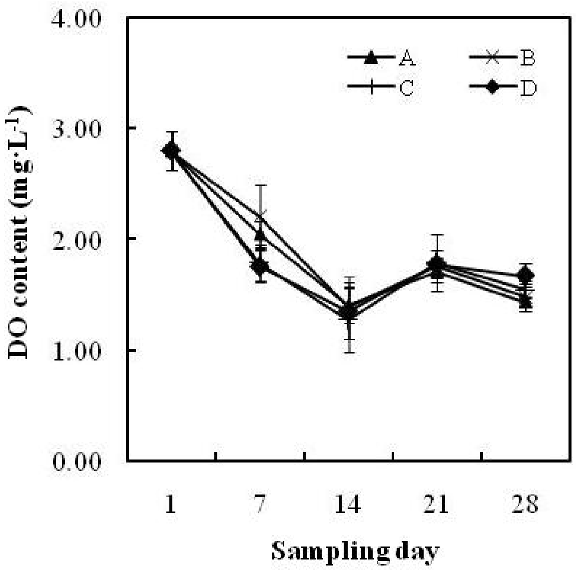

Fig. 5: Effect of different hydrophyte combinations on dissolved oxygen (DO) content of eutrophic water.

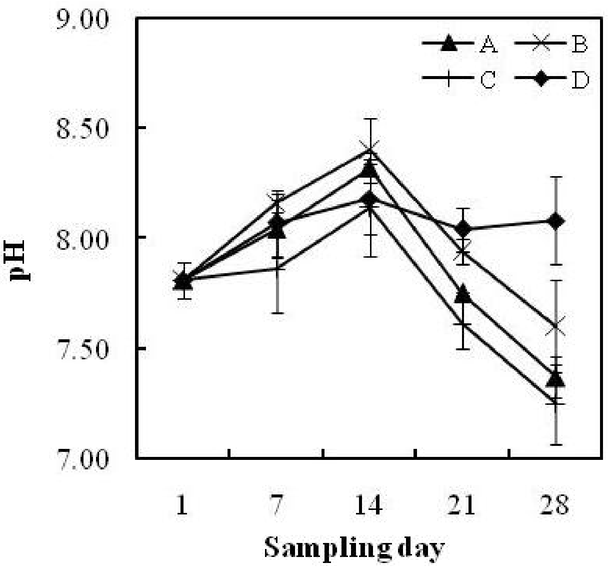

Fig. 6 Effect of different hydrophyte combinations on pH of eutrophic water.

the plants of group B removed 88.70% of TP at 28d.

Changes in DO and pH: The DO contents in water of each combination showed a downward trend with time. The DO of the control group showed the smallest change, from 2.80 to 1.68 mg·L^{-1} (Fig. 5), and that of combination A decreased the most, from 2.80 to 1.44 mg·L^{-1}. The decrease of DO content of combination B was less, with a decrease from 2.80 to 1.48 mg·L^{-1}; and that of combination C was slightly less decrease than for A and B, from 2.80 to 1.55 mg·L^{-1}, representing a decrease of 1.25 mg·L^{-1}.

There were also differences in pH changes among the treatments (Fig. 6). The pH of combination A decreased from 7.81 to 7.37, that of combination B from 7.81 to 7.60; and that of combination C from 7.81 to 7.25, but pH of combination D (control) increased slightly. The pH in all the treatments remained slightly alkaline during the experiment.

CONCLUSION

The combination tests showed that an appropriate combination of aquatic plants could improve the purification effect on TN and TP. Among the four treatments, the removal rate of TN and TP was best for combination B (loosestrife, watermifoil and water lettuce), with removal rates of 88.70% and 67.97%, respectively. The corresponding removal rates for combination A (penny grass, water pack and water lettuce) were 83.05% and 67.19%; and those for combination C were 60.45% and 66.41%. For TN and TP removal, B was the best combination of aquatic plants. The combination of B which included an emergent aquatic plant (loosestrife), a floating plant (water lettuce) and a submerged plant (watermifoil) has a good landscape effect, the flowers of loosestrife are highly ornamental, and the shape of watermifoil is attractive, and their combination showed good absorption of TN and TP.

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