

Research on Decontamination, Algae Inhibition, and Pollution Resistance of Emergent Plant System in Eutrophic Water

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Abstract

With the development of cities and economic growth, the eutrophication of urban park landscape water has become a hot topic in environmental governance and research at home and abroad. Through the simulation experiment of water pollution, the effect of plant micro system built by aquatic plant on the ability of algae suppression in eutrophic water was studied. The results show that the micro system formed by different types of water plant can be reduced and stabilized the pH value of the rich and enriched water bodies. The pH of *Lythrum salicaria* L. group (Q) and *Iris tectorum* Maxim group (Y) group is the lowest. They are 7.34 and 7.48, which is significantly lower than the plant less group (CK). Different treatments have effectively reduced the nitrogen and phosphorus content in the water body. At the end of the experiment, the total nitrogen content of Y dropped from 9.49 to 3.21 mg•L⁻¹, and the removal rate reached 66.2%; the total phosphorus removal rate of the water body phosphorus of different types of aquatic plants was 59.1%–81.3%, which was significantly higher than that of CK. Among them, the total phosphorus removal rate of Y treatment is the best, and it is significantly different from the CK. At the end of the experiment, chl a content in group Y was the lowest which was 6.6 mg•L⁻¹. It decreased by 37.1% and 54.1% compared to the initial value and CK, respectively. It showed significant differences compared to other treatments ($P < 0.05$). At the same time, the content of proline and malondialdehyde in plants of Y, Q, and *Nelumbo* SP. group(H) significantly increased in eutrophic water, with group Y plants showing the highest increase, with increases of 28.6% and 39.8%, respectively. Different micro-systems formed by different water plants can improve water quality conditions and inhibit the reproduction of algae in the water. Among them, the effect of planting *Iris tectorum* Maxim group is the best.

Background

With the growth of the economy, the discharge of household sewage, industrial wastewater, and agricultural wastewater has been increasing. The eutrophication of urban park landscape water has become a hot topic in environmental governance and research at home and abroad. When the total nitrogen content in the water is greater than 0.3 mg•L⁻¹ and the total phosphorus content is greater than 0.02 mg•L⁻¹, the water is in a eutrophic state [1–2]. Research has shown that there are varying degrees of excessive pollution of TN, NH₄⁺-N, TP, and COD in the water bodies of Chinese parks. This not only leads to economic losses, but also damages the structure and function of the ecosystem, which is not conducive to ecological civilization construction and human health [3]. Therefore, in the construction of water landscape, the effective removal of pollutants from water bodies is an urgent development demand in the field of ecological and environmental science at home and abroad. Compared to traditional physical and chemical remediation technologies, ecological remediation technology has advantages such as simple operation, low cost, ecological friendliness, and strong sustainability. Aquatic plant are the key elements of water ecological restoration, and aquatic plant are an important part of urban water landscape. At the same time, aquatic plant can remove pollutants from the water body or reduce their toxicity through direct adsorption and absorption of pollutants, collaborative microbial decomposition of pollutants and other ways [4–5].

Aquatic plant absorbs organics and nutrients in water through roots, stems, leaves and other tissues and organs in the water environment [6]. Most aquatic plant need to absorb nitrogen, phosphorus and other nutrients throughout the cycle, so the removal efficiency of nitrogen and phosphorus in water is high. In addition, aquatic plant converts other water pollutants into a second substance by absorption and decomposition and accumulate it in the body, which is gradually consumed during its growth process [7]. Aquatic plant can effectively inhibit the proliferation of algae in polluted water. At the same time, aquatic plant can reduce the sunlight required for algal growth, and aquatic plant with large volume can block the sunlight required for algal growth, which restricts algal growth [8]. The rapid propagation of aquatic plant forms a growth zone, in which they play their competitive advantages, accelerate growth and metabolism, and inhibit the growth and metabolism of surrounding algae [9]. However, at present, most water landscape designs consider too much the requirements of garden aesthetics in plant selection, ignoring the purification ability of aquatic plant. For example, Cai Ling and others studied the application of emergent plants and floating leaf plants in the wetland landscape in northern Jiangsu [10]. However, for the research on aquatic plant purifying sewage, there are few kinds of practical plants, and most of the studies select a single type of aquatic plant as materials [11–13], especially for the research on the purification effect of different lifestyle aquatic plant on eutrophic urban river water bodies, there is still less research. Therefore, this study selected six common indigenous aquatic plants and simulated the eutrophic urban river water environment under indoor conditions to analyze the decontamination and pollution resistance capabilities of emergent plants. It revealed their adaptation strategies to pollution stress and their effectiveness in sewage purification in urban rivers, lakes, etc. It is of great significance to improve the stress resistance of emergent plants and expand their application scope.

Materials and Methods

1.1 Test materials

According to the research on the species of aquatic plant growing in the Shichuan River in Fuping County, Shaanxi Province, six common emergent plants were selected as the research objects. They are *Lythrum salicaria* L., *Typha orientalis* Presl, *Thalia dealbata*, *Nelumbo* SP., *Arundo donax* var. *versicolor* Stokes, *Iris tectorum* Maxim.

1.2 Experimental Design

The experiment was conducted in an artificial climate chamber from June to July 2022. The experimental temperature is maintained at 29–32 °C during the day and 20–23 °C at night, with a relative humidity of 75 ± 5%.

This experiment uses a specification of 30 × 50 cm PVC cylindrical experimental box with a water tank divided into 6 groups: *Lythrum salicaria* L. (Q), *Typha orientalis* Presl (X), *Thalia dealbata* (Z), *Nelumbo* SP. (H), *Arundo donax* var. *versicolor* Stokes (L), *Iris tectorum* Maxim(Y). Each group selected one emergent plant, and set up 3 parallel experimental groups and a control group which is without plant planting (CK), totaling 19 experimental groups. Before the experiment begins, fill the bottom mud to the

bottom of the water tank with a filling thickness of 20 ± 0.5 cm. Add tap water to a depth of 22 cm and let it stand for use. Cultivate the plants in clean water for two days. After the growth is stable, select plants with strong growth and relatively consistent growth momentum and transplant them into the water tank; At the same time, lay 2cm crushed stones on the surface to prevent the sediment from floating. After the plant growth is basically stable (about 4 days),

The sampling frequency of water samples in this experiment is: collect water samples every 10 days; A total of 6 water samples were collected. And regularly monitor the decontamination and pollution resistance indicators in the water body.

1.3 Indicator measurement

1.3.1 Algal inhibition indicators

Chlorophyll a exists in all green plants and is the main pigment for photosynthesis, making it an indicator of the photosynthetic capacity of algae. During the experiment, measuring the content of chlorophyll-a in the water can determine the changes in the number of algal cells in the water, and thus compare the algal inhibition effects of these six emergent plants.

Measurement method: Install an acetate fiber filter membrane on the suction filter and pour 100 ml of water sample for suction filtration. Take out the filter membrane containing plankton and dry it in the refrigerator for 6–8 hours. Add a small amount of magnesium carbonate powder and 2–3 ml of 90% acetone to the mortar, mix and grind thoroughly with the filter membrane, and then centrifuge at $4000 \text{ r} \cdot \text{min}^{-1}$ for 10 minutes. Transfer the supernatant into a 10 ml volumetric flask, repeat for 1–2 times, dilute to 10 ml with 90% acetone and shake well. Place the supernatant on a spectrophotometer and use a 1 cm optical path colorimetric dish to read the absorbance of the sample at wavelengths 750 nm, 663 nm, 645 nm, and 630 nm, respectively. Use 90% acetone as the blank absorbance to correct the absorbance of the sample [14]. The calculation formula for chlorophyll a content is as follows:

$$\text{Chlorophyll a (mg} \cdot \text{L}^{-1}) = \frac{[11.64 \times (D_{663} - D_{750}) - 2.16 \times (D_{645} - D_{750}) + 0.10 \times (D_{630} - D_{750})] \times V_1}{V \times c} \quad (1)$$

In Eq. 1, V represents the volume of collected water sample; D is the absorbance at different wavelengths; V1 represents the final constant volume of the extraction solution; C is the range of the colorimetric dish.

1.3.2 Eutrophication related indicators

The pH and dissolved oxygen (DO) of water samples were measured on-site using the SX825 portable measuring instrument produced by Lianhua Technology Company. The Ammonia nitrogen ($\text{NH}_4^+ - \text{N}$) of water samples were measured using salicylic acid spectrophotometry. Nitrate nitrogen ($\text{NO}_3^- - \text{N}$) was measured using hydrazine sulfate reduction method, total nitrogen (TN) was measured using alkaline

potassium persulfate oxidation ultraviolet spectrophotometry, and total phosphorus (TP) was measured using ammonium molybdate spectrophotometry. The specific operation process is referred to the "Water and Wastewater Monitoring and Analysis Method" [15]. At the same time, calculate the removal rate of nitrogen and phosphorus in the water based on the initial and final concentration changes of nitrogen and phosphorus.

1.3.3 Pollution resistance index

(1) Method for the determination of proline (Pro)

Weigh 0.5 g of the leaves to be tested and place them in a large tube and add 5 ml of 3% horizontal salicylic acid solution separately. Extract in a boiling water bath for 10 minutes, cool and then pipette 2 ml of the extraction solution into a stoppered test tube. Add 2 ml of glacial acetic acid and 2 ml of acidic ninhydrin. Heat in a boiling water bath for 30 minutes, cool and add 4 ml of toluene, shake for 30 seconds. After standing for a moment, take the supernatant into a 10 ml centrifuge tube and centrifuge at $3000 \text{ r}\cdot\text{s}^{-1}$ for 5 minutes before taking the supernatant. Using toluene as the blank control, compare the color at the wavelength of 520 nm in the spectrophotometer.

$$\text{Proline content } (\mu\text{g}\cdot\text{g}^{-1}) = \frac{C \cdot V}{a \cdot W} \quad (2)$$

Equation 2: C represents the proline content detected by the standard curve; V is the total volume of the extraction solution (ml); A represents the volume absorbed during measurement (ml); W is the sample mass (g).

(2) Method for the determination of malondialdehyde (MDA)

Weigh 0.2 g of the leaves to be tested, wash, dry, and grind. Add 5 ml of distilled water and transfer to a 10 ml centrifuge tube. Add 5 ml of 0.5% thiobarbituric acid (TBA) solution. After a boiling water bath for 10 minutes, cool and centrifuge. Measure the absorbance values of the supernatant at 450 nm, 532 nm, and 600 nm.

$$\text{Malondialdehyde content}(\text{mol}\cdot\text{g}^{-1}) = 6.452(A_{532}-A_{600})-0.56A_{560} \times 3$$

Equation 3: A is the absorbance.

Results and Analysis

2.1 Research on the decontamination ability of emergent plants in eutrophic water bodies

2.1.1 The impact of different emergent plants on the pH of water bodies

The pH of the microsystem water formed by six emergent plants showed a fluctuating increase in the early stage and began to decline after July 15th. Among them, the pH of group Q decreases the most significantly, with a pH value of 7.34 at the end of the experiment, showing a neutral state. The second group is the planting Y group, with a pH value of 7.48 at the end of the experiment, which is significantly lower than that of CK. The pH of CK is higher than the initial value at the end of the experiment. It is directly higher than the other experimental groups. From the overall change trend of each treatment in the figure, the fluctuation range of the microsystem water formed by emergent plants is significantly smaller than CK, and the overall performance of the water body is relatively stable (Fig. 1).

2.1.2 Effects of dissolved oxygen (DO) in microsystems created by different emergent plants

Two factor analysis of variance showed that plant material ($F = 28.914$, $P < 0.05$), treatment time ($F = 105.641$, $P < 0.05$), and their interaction ($F = 1.221$, $P < 0.05$) has a significant impact on DO. Except CK group, the DO content in the water shows a stable downward trend, and there are certain fluctuations in the DO content in all other groups of water. At the beginning of the experiment, the DO content of each plant group sharply decreases. As plants grow, the DO in water rapidly increases. At the end of the experiment, the DO concentration in the water of the plant group is higher than that of the CK. The DO concentration in the water of plant microsystems is maintained at $6.91\text{--}8.74\text{ mg}\cdot\text{L}^{-1}$, while the DO concentration in the CK is only $2.74\text{ mg}\cdot\text{L}^{-1}$. Among them, Y group has the highest DO concentration, reaching $8.74\text{ mg}\cdot\text{L}^{-1}$ (Fig. 2).

2.1.3 Changes of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ content in microsystems created by different emergent plants

Under different emergent plants, both $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in eutrophic water have a certain removal effect, and the removal rate is relatively fast (Fig. 3). In the first week of the experiment, the mass concentration of $\text{NH}_4^+\text{-N}$ in the water rapidly decreases, with the removal rates of Y, L, and Z treatments reaching 32.7%, 24.8% and 24.4%, respectively. The removal efficiency of different concentrations of $\text{NH}_4^+\text{-N}$ by planting aquatic plant is significantly higher than that of CK ($p < 0.05$). Moreover, At 21 days of each plant treatment, $\text{NH}_4^+\text{-N}$ shows a decrease with higher efficiency. At the end of the experiment, the final removal rates of $\text{NH}_4^+\text{-N}$ in water by Y, L, and X treatments are 83.8%, 79.8%, and 75.5%, respectively, while the removal rate of the CK is only 10.1%. The removal rates of each treatment are significantly higher than those of CK. The concentration of $\text{NO}_3^-\text{-N}$ in water shows increase-decrease-stabilize. Especially the peak plant growth period (July 1st), $\text{NO}_3^-\text{-N}$ in the water rapidly decreases, and $\text{NO}_3^-\text{-N}$ in different plant treatments decreases to $1.02\text{--}1.46\text{ mg}\cdot\text{L}^{-1}$, with an average $\text{NO}_3^-\text{-N}$ elimination rate of 27.0%. By the end of the experiment, the $\text{NO}_3^-\text{-N}$ levels in Y, X, and L treatments decreased to 68.7%, 64.4%, and 63.2%, respectively. The average removal rate of $\text{NO}_3^-\text{-N}$ reaches 60.5%, significantly higher than that of CK.

2.1.4 Changes in TN and TP content in microsystems created by different emergent plants

In the early stage of the experiment, the TN content in the emergent plant microsystem rapidly decreases due to the strong adsorption and interception effects of rapid sedimentation and plant roots in the early stage; As the experiment progresses, the sedimentation effect weakens and the root system gradually reaches adsorption saturation. Currently, the removal of TN mainly relies on the absorption of plants and the adsorption and degradation of root microorganisms. This process is relatively slow, so the removal rate of TN gradually slows down. At the end of the experiment, the removal efficiency of TN in the plant group is better than that of CK. And the TN content of Y microsystem decreases from 9.49 to $3.21 \text{ mg}\cdot\text{L}^{-1}$, with a removal rate of 66.2% (Fig. 4); The next group is the X and L microsystem, with TN removal rates of 62.9% and 58.3%, respectively. And there is no significant difference in removal rates between the two treatments. The Y shows a rapid decrease in TN on July 15th, mainly due to the rapid tillering and reproduction of plants during this period, which required a large amount of nitrogen absorption, resulting in a rapid decrease in TN concentration. The final average removal rate of TN in the CK is only 8.6%, significantly lower than other experimental groups ($p < 0.05$).

In the early stage of the experiment, the decreasing trend and amount of TP content of different emergent plant microsystems remains basically consistent. At the end of the experiment, the TP removal rate of the plant microsystem water is between 59.1% and 81.3%. It is significantly higher than that of CK, with a removal rate of 37.6%. Based on the comparative analysis of different types of emergent plants, the removal effect of Y treatment on TP in water is superior to other emergent plants, and there is a significant difference compared to CK. Y treatment has a significant removal effect on TP in water, with a removal rate exceeding 80% (Fig. 5). This may be due to the fact that in the early stages of the experiment, different plants are in the early stages of growth and have relatively low demand for phosphorus in the water body; In the later stage of the experiment, plants grow rapidly, and some plants exhibited a large number of tillering phenomena, requiring a large amount of nutrient supplementation, resulting in certain differences in the total phosphorus content in the water.

2.2 Changes in Chlorophyll a Content of Algal Inhibition Indicators in Different Emergent Plant Microsystems

Chlorophyll is an important pigment in the photosynthesis of plants and algae, with chlorophyll a (chl a) being the most important. The concentration of chlorophyll-a of floating algae in the water environment system can reflect the quantity of floating algae, which is an important assessment index in the assessment of water pollution and eutrophication.

From Fig. 6, chl a content of CK increases compared to the initial concentration at the end of the experiment. In the water of the different emergent plant microsystems, chl a fluctuates significantly in the early stages of the experiment; At the end of the experiment, there is a significant decrease compared to the initial concentration. The Y treatment shows a certain rebound after a sharp decline in the initial stage of the experiment, and then the decline stabilized. Chl a content in treatment Y is the lowest at the end of the experiment ($6.6 \text{ mg}\cdot\text{L}^{-1}$), decreased by 37.1% compared to the initial stage, decreased by 54.1% compared to CK. It reaches a significant difference compared to other experimental

groups ($P < 0.05$). The chl a concentration of CK group shows a slow increase over time, which may be due to the experimental time being summer, strong sunlight, high temperature, and abundant nitrogen and phosphorus content in the water, meeting the conditions for rapid algae growth. Therefore, the concentration of chl a in CK shows a gradual upward trend, resulting in a significantly higher concentration measured at the end of the final experiment than the initial concentration.

2.3 Research on the pollution resistance performance of different emergent plants in eutrophic water

The proline content of Z, Y, and H group in eutrophic water shows a consistent upward trend over time, and the Pro content has increased by 26.4%, 28.6%, and 17.7% compared to the initial value, respectively; However, the Pro content in the bodies of Q and X group shows a decreasing trend, but the plant growth is good. Under sewage conditions, the MDA content of Z, Y, and H group showed a consistent upward trend over time, and the MDA content increased by 38.4%, 39.8%, and 23.9% compared to the initial value, respectively; However, the MDA content in the bodies of Q, X and L group showed a decreasing trend (Table 1).

Table 1
Analysis of pollution resistance of different plants in eutrophic water bodies

Treatment	Pro		MDA	
	0 d	60 d	0 d	60 d
Q	102.34	75.61	0.8125	0.6714
X	148.30	104.55	1.2451	0.9453
Z	29.97	37.89	0.3458	0.4785
Y	95.24	122.52	0.2678	0.3744
L	32.41	33.24	0.3017	0.1151
H	95.21	112.08	0.6528	0.8090

Discussion

Aquatic plant generally has multiple functions such as absorbing nitrogen and water elements in eutrophic water bodies and blocking external nutrients. The roots of aquatic plant can not only inhibit the release of nutrients in sediment, but also remove aquatic plant to take away excessive nutrient loads in water bodies. Some aquatic plant also has inhibitory effects on algae [16–17].

Dissolved oxygen is crucial for the balance of aquatic ecosystems and the growth of aquatic environmental organisms [18]. Wei Jianhua et al. [19] studied the oxygenation technology of polluted water bodies and found that aquatic plant can significantly increase the dissolved oxygen content in water bodies, which is consistent with the results of this study. This study found that under the action of

emergent plant microsystems, the DO content in water significantly increased, with the DO concentration of Iris reaching $8.74 \text{ mg} \cdot \text{L}^{-1}$, significantly higher than the DO concentration of the control group ($2.74 \text{ mg} \cdot \text{L}^{-1}$). It has been found that under different aeration measures, planting plants can effectively remove the ammonium nitrogen content in the eutrophic water head. The NH_4^+ -N removal rate of cattail is 99.9%, and the NH_4^+ -N removal rate of chlorophytum comosum was about 97.0% [20–21]. This is consistent with the results of this study. Planting different plants can efficiently remove ammonium nitrogen and total nitrogen content in eutrophic water bodies, with an NH_3 -N removal rate of 83.8%; The total nitrogen removal rate is 66.2%. The main reason is that after planting plants, nitrogen in water and sediment can be absorbed and degraded through the absorption of plants and the decomposition of symbiotic microorganisms in plant roots, thereby avoiding the harm of secondary release of sediment. Chen Lin et al. [22] found through comprehensive analysis that aquatic plant of different life forms has higher removal rates of total phosphorus, especially the emergent plant *Alisma orientalis*, which can remove up to 99.2% of total phosphorus. This is consistent with the results of this study. Under different emergent plant microsystem environments, the total phosphorus content in the water body was significantly reduced, and the highest removal rate reached 80%.

Aquatic plant can effectively inhibit the proliferation of algae in polluted water. In the process of reproduction and growth, aquatic plant and algae rely on some nutrients in the water body to maintain their own metabolism [23–25]. The results of this study show that different treatments significantly reduce the content of chlorophyll a in the water, of which iris has the best reduction effect, reducing 37.1%, which is consistent with the research results of Chen et al. [26]. The study found that the reduction rate of four different aquatic plant on the concentration of chlorophyll a in the system is 19.1%~72.9%. Mainly because the reduction of ammonia nitrogen and nitrate nitrogen in eutrophic water bodies inhibits the rapid growth and reproduction of algae and plankton in aquatic ecosystems [27–28]; Because in the same water environment, aquatic plant have obvious competitive advantages. The large volume of aquatic plant can block the sunlight required for algae growth, which limits the growth of algae [29]. Aquatic plant can also inhibit the metabolism of algae in water bodies. aquatic plant can reproduce rapidly, inhibit the growth and metabolism of surrounding algae, and damage the growth and reproduction of algae [9]. Some aquatic plant will release some chemical substances to protect themselves during the growth cycle and can also inhibit the metabolic activities of other plankton and algae [30].

Different emergent plants have certain pollution resistance in eutrophic water bodies. Zhang [31] found through research that the proline and malondialdehyde contents of aquatic landscape plants in sewage do not show a consistent upward trend, but rather some increase and some decrease. This is consistent with the results of this study. The increase in Pro and MDA content of Z, Y, and H group in sewage stress indicates that these three plants exhibit adaptive stress resistance in eutrophic water bodies by adjusting their proline content to adapt to the sewage environment. However, the MDA content in the bodies of *Chrysanthemum*, *Typhae*, and *Phyllostachys* shows a decreasing trend, but the plants are growing well

with more tillers, which may indicate that these two plants are more adapted to the nutrient rich growth environment of eutrophic water bodies.

Conclusion

(1) The pH fluctuation range of the microenvironment formed by the different plant was significantly smaller than that of the non-plant group. The pH performance of the experimental group water is relatively stable.

(2) Different plant groups have significant scavenging effects on $\text{NH}_4^+\text{-N}$, TN, and TP in water. Among them, Iris has the highest clearance rate which is reaching 83.8%, 66.2%, and 80%. And it has a significant difference from CK.

(3) The content of chlorophyll a in different emergent plant microsystems decreased. Iris, Thalia, and Lotus produced certain pollution-resistant that adapted well to adversity.

Based on comprehensive analysis, the microsystems formed by different emergent plants can improve water quality conditions and inhibit the reproduction of algae in the water. Iris, Thalia and lotus have strong pollution resistance, among which iris cultivation has the best water quality improvement, algae inhibition ability, and pollution resistance.

Declarations

Data availability

All data generated or analyzed during this study are included in this published article. Six common emergent plants (*Lythrum salicaria* L., *Typha orientalis* Presl, *Thalia dealbata*, *Nelumbo* SP., *Arundo donax* var. *versicolor* Stokes, *Iris tectorum* Maxim) were purchased from Shaanxi Fuping County Seeding Industry Co., Ltd. The material source complies with relevant institutional, national, and international guidelines and legislation. The experimental land is provided by Shaanxi Land Engineering Construction Group. We have obtained the permission from the landowner.

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Competing interests

The author(s) declare no competing interests.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

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Figures

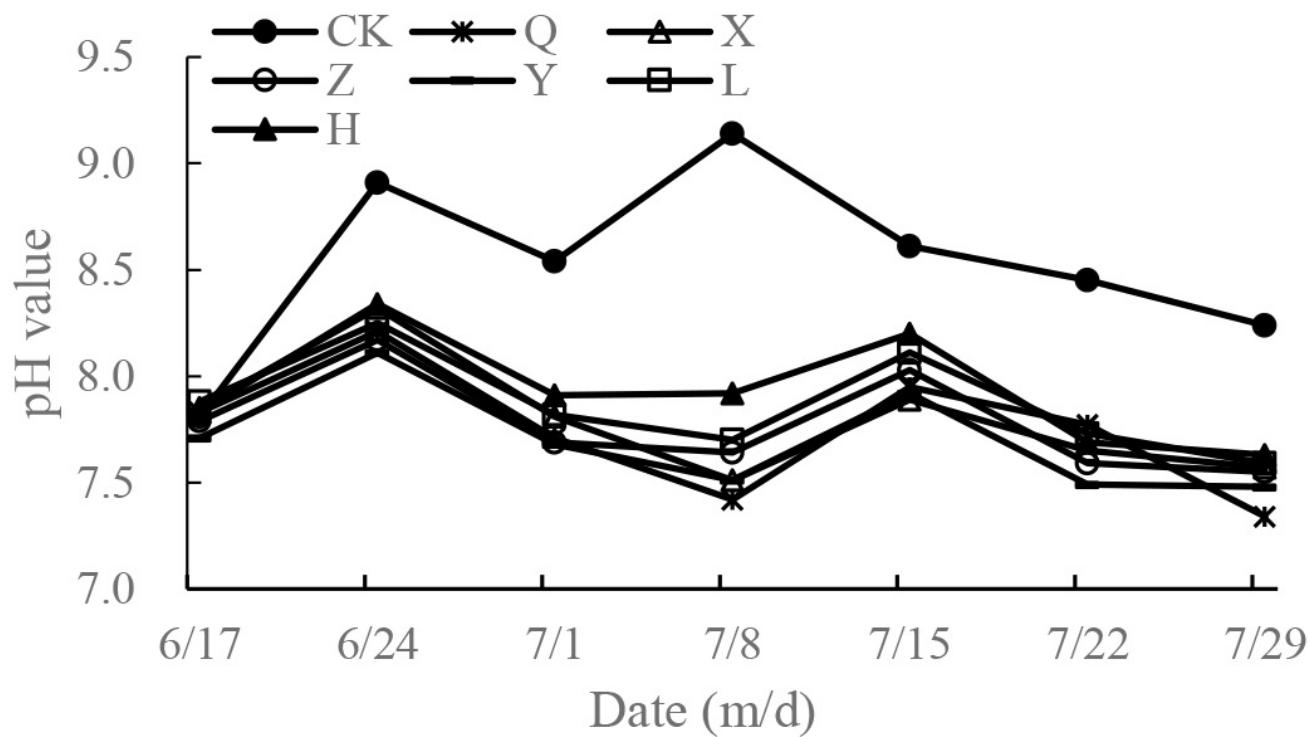


Figure 1

Changes in pH value of microsystem water by different emergent plants

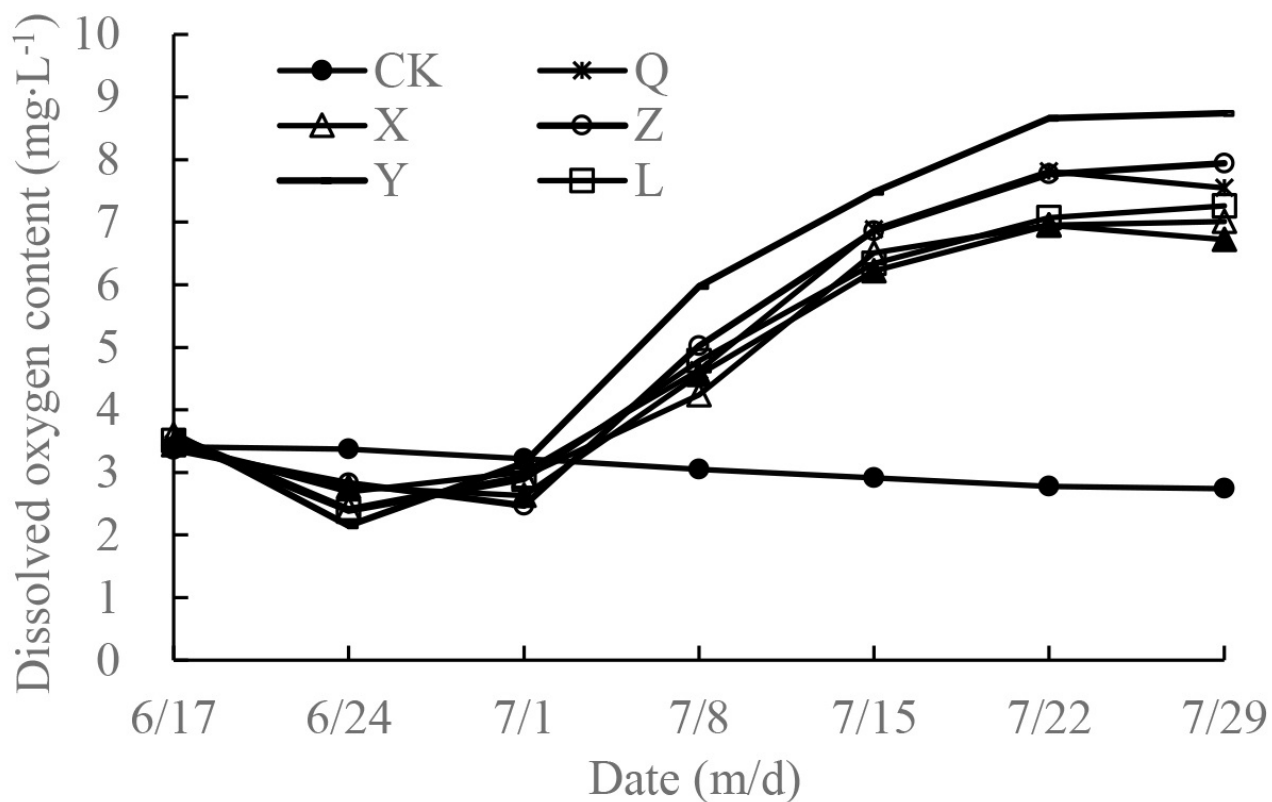


Figure 2

Changes of dissolved oxygen in microsystems water by different emergent plants

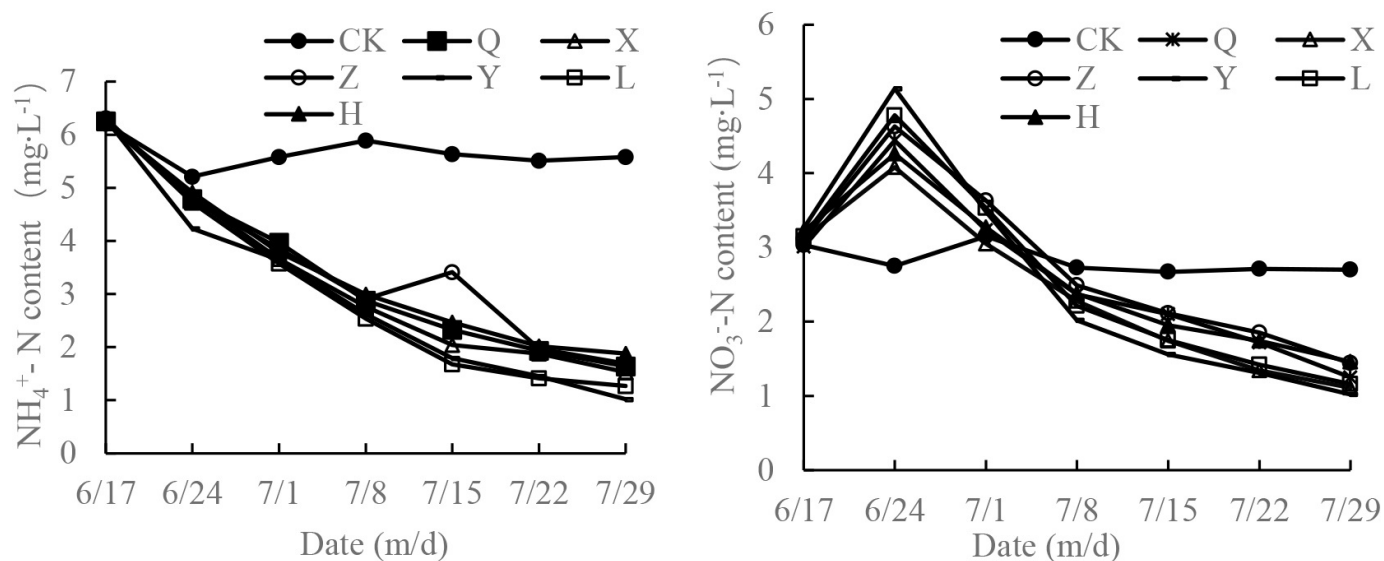


Figure 3

Changes in $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ content under different treatments

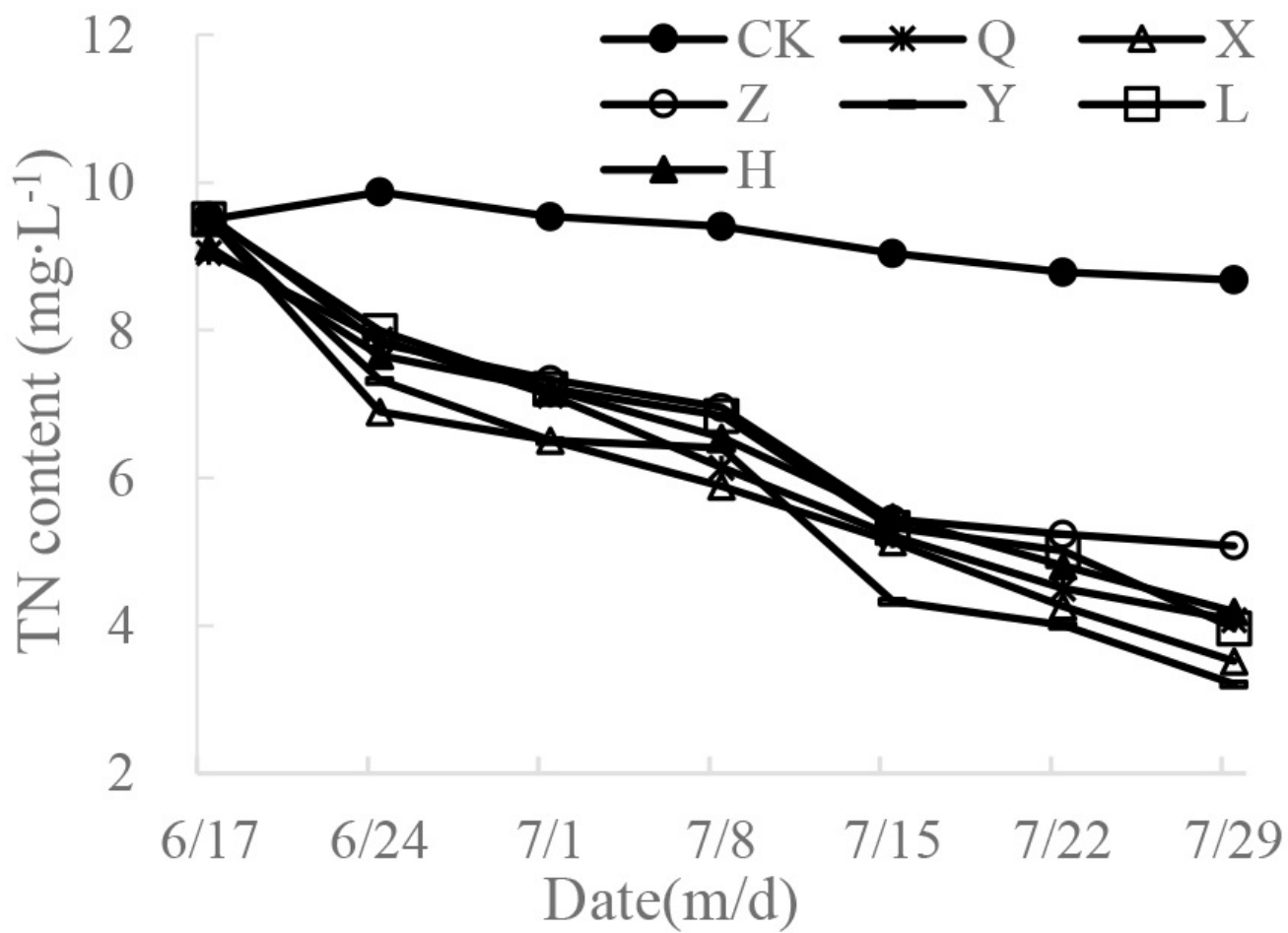


Figure 4

Changes of TN content in the water

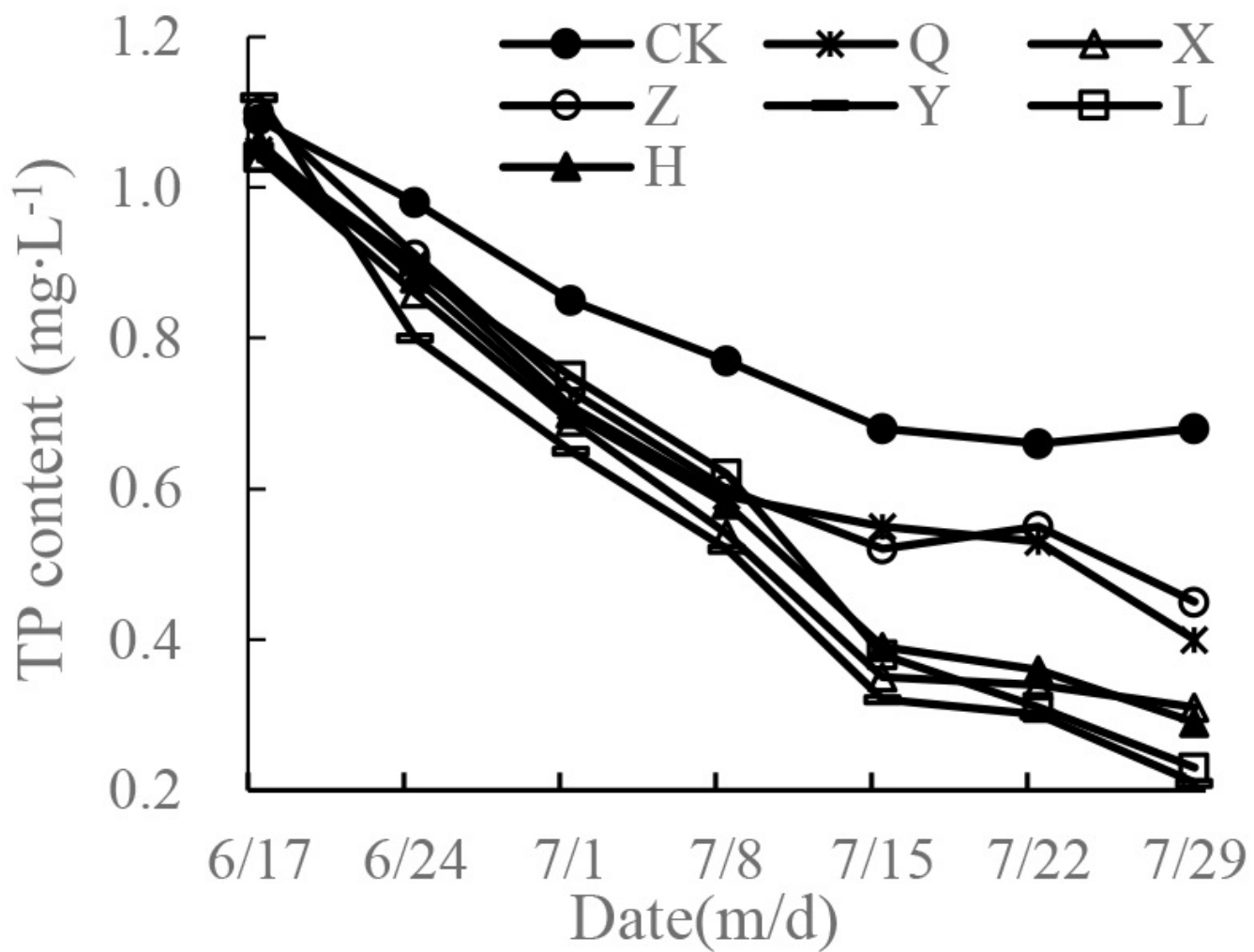


Figure 5

Changes of TP content in the water

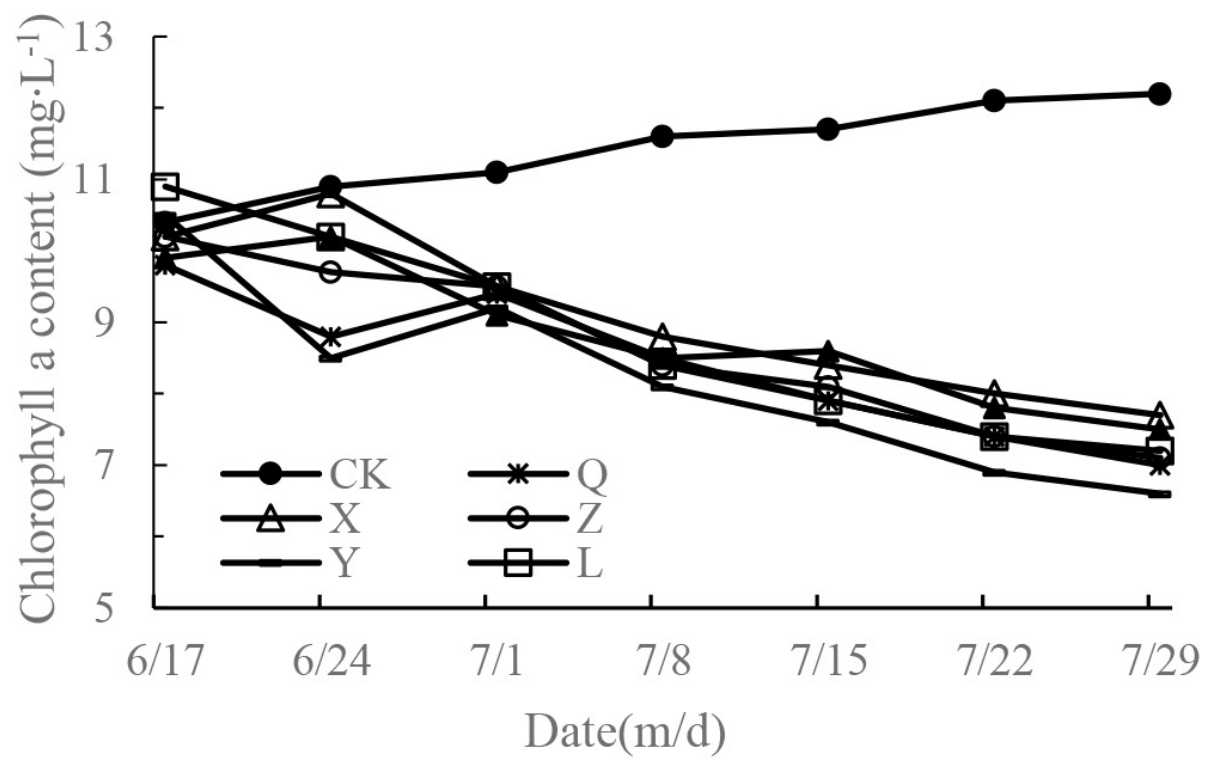


Figure 6

Changes in chlorophyll a concentration in different emergent plant