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EFFECT OF STUBBLE HEIGHTS AND TREATMENT DURATION TIME ON THE PERFORMANCE OF WATER DROPWORT FLOATING TREATMENT WETLANDS (FTWS)

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Abstract: *Floating treatment wetlands* (FTWs) with Water Dropwort (*Oenanthe javanica*) were established in winter to investigate their potential role in the purification of eutrophicated water, and to identify the effects of different stubble heights of the Water Dropwort on the performance of the FTWs. The results of the experiments demonstrated: The Water Dropwort FTWs were effective in buffering the pH of the experimental water. The Water Dropwort FTWs were efficient in purifying eutrophicated water, with removal rate for *total nitrogen* (TN), *total phosphorus* (TP), *ammonium nitrogen* ($NH_4^+ - N$), and *nitrate nitrogen* ($NO_3^- - N$) at 91.3, 58.0, 94.6, and 95.5% in the 15-day experiment, respectively. No significant difference in the purification effect was found among different stubble heights of Water Dropwort FTWs. Significant differences between the zero control and the FTWs were found for the removal of TP in the first 11 days; and for the removal of $NH_4^+ - N$ in the first 4 days. No significant difference was found between the zero control and the FTWs for $NO_3^- - N$ in the first 4 days, but significant difference was detected after day 4. The optimum treatment duration time for the FTWs with Water Dropwort will depend on the nutrients to be removed. These results will provide basis for further application of the FTWs at large scale, as well as for future studies on the mechanism of nutrient removal process.

Keywords: floating treatment wetland (FTW), nutrients, removal rate, Water Dropwort, *Oenanthe javanica*

Introduction

With the aggravation of fresh water eutrophication worldwide, there is an urgent need to develop a fast, efficient, and cheap technology to solve the eutrophication problems. In ecological engineering, wetlands are often used as a low cost and environmentally friendly way of treating eutrophicated water. All wetlands used for the treatment of wastewater use

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some autotrophic component for the removal of excessive nutrients. The choice of this component depends on the physical and geographical conditions, and on the type of wetland chosen. The wetlands may in principle be of two quite different types, either as *Subsurface Flow Wetlands* (SSFW's) or as wetlands with free water surface. The first type, although being more costly in the construction, is often the only acceptable option in tropical climates where insects that are dependent on free water surfaces during their life cycle act as vectors of various severe diseases such as malaria. In other climates the latter type, as used in our experiment, may be fully acceptable under the given conditions.

The *Floating Treatment Wetlands* (FTWs), a kind of free water surface wetland, are among the best choices for treatment of eutrophicated waters as they are low cost, both in construction and running costs, and energy-efficient in eutrophication control [1]. FTWs reach their aims by taking up excessive nutrients in the free floating plants when grown in the eutrophicated water, and stimulating the biochemical processes in the rhizosphere [2]. In the past 30 years, the FTWs have been tested and applied in laboratories and at pilot scales [3-9]. Characterized by no extra land demand and adaption to a wide range of water depth, FTWs have been widely used in the treatment of domestic wastewater [10], river water [7, 11, 12], lake water [5, 13, 14], agricultural runoff [4, 15], swine sewage [16], rainfall [17], storm water [18] and urban runoff [19].

As the nutrient uptake efficiency is important, much work has been done on the floating plant chosen for the treatment of polluted waters [20, 21], improvement of the purification capability of FTWs [7, 13, 17], and analysis of factors influencing the performance of the FTWs [8, 10, 22-24]. Among studies on FTWs, the purification effect of FTWs on eutrophicated water has been reported from several works [11, 13, 16, 17, 25]. For example, Zhou and Wang [11] studied the Water Dropwort Floating Bed System for the treatment of eutrophicated river water in spring (63 days), and found that the purification effect could be divided into two phases: an actual purification phase (day 0-35) and a decay phase (day 35-63). This indicated that harvesting would be an appropriate and necessary intervention to improve the efficiency of the Water Dropwort treatment system. Li et al [13] constructed a sophisticated floating bed system with freshwater clams and biofilms in addition to the plant structure. This combined system performed better than the other two floating bed systems using only one of the two, *ie* either freshwater clams & the plant structure or biofilms & the plant structure, and the removal efficiencies of integrated ecological floating-bed for total nitrogen, ammonium nitrogen and total phosphorus was 52.7, 33.7 and 54.5%, respectively when the water exchange period was 7 days. Moortel et al [10] studied the influence of temperature and season on physicochemical changes and the removal effect of constructed floating wetland in Drongen, Belgium, and found that the removal rates for *total nitrogen* (TN), *ammonium nitrogen* NH_4^+-N, and *total phosphorus* (TP) were significantly influenced by temperature with the highest removal between 5 and 15°C. Thus, temperature seemed to be the determination factor rather than season. Tanner and Headley [18] conducted a series of patch floating treatment wetlands in an innovative approach to enhance the removal of fine particulates, copper and zinc in urban storm water. It was found that planted FTWs with different species removed the dissolved Cu in the order of 5.6÷7.7 $mg/m^2 \cdot day$ and at total Cu mass loadings of 11.1 $mg/m^2 \cdot d$, and dissolved Zn in the order of 25÷104 $mg/m^2 \cdot day$ at total Zn mass loadings of 350 $mg/m^2 \cdot d$, and decreased approximately 34÷42% of the turbidity within three days. Xian et al [16] studied the effect of three varieties (Dryan, Tachimasari, Waseyutaka) of Perennial Ryegrass *(Lolium perenne* L.)

floating bed systems on the purification of swine wastewater in 2009, and found that the Perennial Ryegrass constructed floating bed system not only effectively removed *chemical oxygen demand* (COD), TN and TP, but also removed 89÷99% of the veterinary antibiotics in the swine wastewater. However, comparative analyses of the purification progress with time as well as studies of optimal treatment duration time for floating treatment wetlands with given plant species have rarely been carried out for several nutrients at the same time.

As mentioned earlier, the FTW plants play a very significant role in the removal of nutrients [10, 26]. As indicated from the earlier studies [11], the effect of different plant regimes management on nutrients removal still need to be investigated.

In this study, we hypothesize that various stubble heights after cutting may result in different removal efficiencies due to different growth rates of the Water Dropwort. From the results, the best cutting stubble height, *ie* the height giving the optimal nutrients removal can be recommended. If no difference on treatment performance is found, the productivity of plants will become a major factor to be considered for large scale application. We also want to explore the optimum time to re-pump the water into the tank in order to obtain the highest rate, or the shortest time to remove most of the nutrient under our experiment conditions.

Thus, the objectives of this study were: (1) to investigate the removal efficiency of various nutrient species between different stubble heights, (2) to inspect the difference of nutrients removal with and without plants between FTW's with time, (3) to determine the optimum treatment duration time for the Water Dropwort FTW system according to different target removal nutrients.

Materials and methods

Plants

Water Dropwort (*Oenanthe javanica*) was selected as the FTW plants because of its tolerance to freezing temperatures in winter, and its high removal rates for both nitrogen and phosphorus, as identified in Chinese studies [27, 28]. Water Dropwort can grow from October to May next year, and can be cut several times during their life. Therefore it is a perfect species for floating treatment wetland. In this study, Water Dropwort plants of the same breed "Wuxi" were used. The plants with about the same root volume and the same biomass were chosen for our experiment. The plants were pre-cultivated with the water from Taopu River for three weeks (March 13-April 3, 2010) prior to the start of the experiment. Before starting the experiment (April 3, 2010), the experiment plants were cut into 4 different stubble height groups: no cutting, 13 cm, 19 cm, and 25 cm.

Experiment water

Raw water from Taopu River in Shanghai was used in the experiment. The water was classified eutrophicated owing to the excessively high concentration of TN and TP, compared with the China Eutrophication Standard (Table 1). The concentrations of TN and TP were about 20 times and 50 times higher than the levels indicated in the Chinese eutrophication standard, respectively [29].

Table 1

Raw water quality during experimental period in Taopu River, Shanghai [mg/dm^3]

Parameter	Min.	Max.	Mean±SD	Eutrophication standard*
TN	11.512	22.211	16.766±2.409	≥ 0.6
TP	0.495	3.280	1.264±0.764	≥ 0.025
$NH_4^+ - N$	7.940	17.180	11.187±2.876	-
$NO_3^- - N$	0.318	3.713	1.959±0.962	-

"-" not available, *[29]

Experimental design

Site description

The experiments were operated during April 3-17, 2010 at Lijiazhai (121.37°E, 31.23°N), China, along Taopu River, which is connected with Yangtze River via Suzhou River and Huangpu River. The temperature during the experiment was within range between 4.7 and 19.9°C.

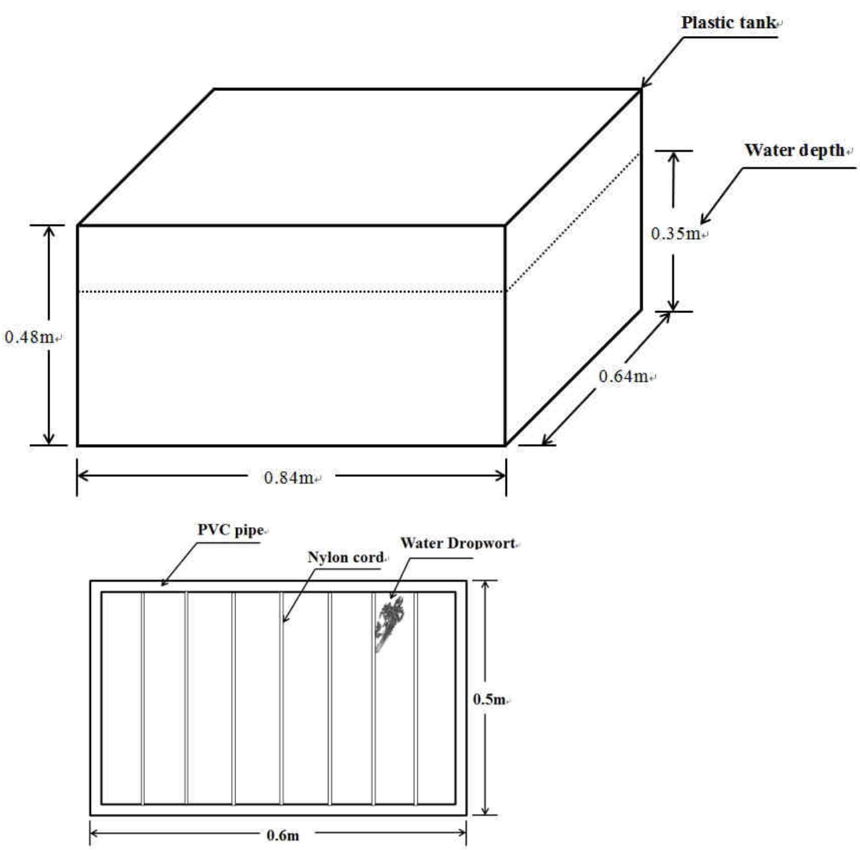

Fig. 1. The water tank and the floating wetland structure

FTW design

The FTW systems, except from the control experiments, were composed of Water Dropwort together with a floating structure to provide buoyancy and support to the plants. The floating structure was made by PVC pipes with a diameter of 33 mm, with sides 0.6 m long, 0.5 m wide and nylon ropes across the frames to fix the plants. The Water Dropwort plants were inserted into the gaps between two pieces of nylon cord. Each piece of floating bed contained 35 pre-cultured Water Dropwort plants. The above system was put into top open plastic tanks with side length of 840 mm, width of 635 mm, and height of 482 mm (Fig. 1).

In all, twenty plastic tanks were arranged in the experiment, four of which contained river water only as zero controls. The other sixteen tanks were covered with plants on the water surface serving as FTWs. The 16 tanks were divided into four treatments containing different stubble heights of the Water Dropwort: no cutting, 13 cm, 19 cm, and 25 cm. Thus, four duplicates were arranged for each treatment.

The plastic tanks were put along the Taopu River near Lijiazhai. Irradiation was enough with mean sunshine 6.73 hour per day, and at the beginning of the experiment, water from the river was pumped into the plastic tanks to depth of 0.35 m, corresponding to approximately 150 dm^3 (L) in each tank. The water was not replaced during the experiment period (April 3-17, 2010).

To approach the natural conditions as closely as possible, changes in water level depth due to evapo-transpiration and rainfall were not taken into consideration.

Water sampling and analyses

Water quality parameters were monitored and samples were collected from each tank every 3 days between 10:00-11:00 am. Each sample (1 dm^3 (L)) was a mixture of five samples collected from five different points (0.2 dm^3 (L) each) - the four corners and the center of the same tank at 0.1 m depth under the water level. All water sample equipment was acid-rinsed (10% HCl) and flushed with distilled water. Water samples were loaded into polythene bottles and transported to the laboratory within 20 minutes. Water quality parameters such as total nitrogen, total phosphorus, ammonia nitrogen and nitrate nitrogen were measured within 1 hour. The experiments lasted from April 3 to April 17.

Before water samples were collected, temperature (Temp), pH value (pH), *oxidation-reduction potential* (ORP), *dissolved oxygen* (DO), *specific conductivity* (SpCond) and chlorophyll *a* were measured with Hydrolab DS5X (Hach Hydromet, USA).

The concentrations of total nitrogen (TN), total phosphorus (TP), ammonia nitrogen $(NH_4^+ - N)$ and nitrate nitrogen $(NO_3^- - N)$ were measured according to standard method for water and wastewater monitoring and analysis in China [30].

Data analyses

The removal efficiency (RE) was calculated according to the following formula:

$$RE\ (\%) = (C_i - C_f) / C_i \cdot 100\%$$

where C_i is the average concentration of initial stage water sample [mg/dm^3], C_f is the average concentration of final stage water samples on finishing the experiments [mg/dm^3] [13].

Data description and statistical analysis were made with SPSS Statistics 18. One-way analysis of variance (ANOVA) was performed using the *least significant difference* (LSD) method.

Results and discussion

The nutrient removal effect of Water Dropwort FTWs

All the Water Dropwort specimens grew well in the two-week experimental period and biomass increased quickly. No plant diseases or insect pests were observed.

Table 2 shows the various removal effects of Water Dropwort FTWs for the different nutrients. The removal rate for nitrogen was higher than 90%, and that for phosphorus was 58%. Compared with the results from Yang [31], in which Water Dropwort was planted in river, we obtained higher removal rate because of our higher ratio between Water Dropwort biomass and water mass than that of Yang's. The removal rate in this study is also higher than that of [27] and [26] which lasted 55 days and 70 days, respectively (Table 3).

Table 2

The removal efficiency of Water Dropwort FTW within two weeks in April

Parameter	Day 1 [mg/dm^3]	Day 15 [mg/dm^3]	MRM* [mg]	Removal rate [%]
TN	18.315	1.594±0.504	2362.8±226.9	91.3±2.7
TP	0.800	0.336±0.078	65.6±12.7	58.0±9.7
$NH_4^+ - N$	8.370	0.455±0.428		94.6±5.1
$NO_3^- - N$	5.851	0.262±0.319		95.5±5.4

**Mean removal mass* per tank

Table 3

Comparison of nutrients removal rate [%] with other studies in China on Water Dropwort FTW

TN	TP	$NH_4^+ - N$	Detention time	Experiment condition	References
10.63	8.46	13.35	January-April, 2008 (3 months)	River	[31]
50.9	77.1	59.5	May 1-June 24, 2006 (55 days)	Mesocosm	[27]
46.4	88.44		May 24-August 3, 2004 (70 days)	Mesocosm	[25]
91.3	58	94.6	Aril 3-April 17, 2010 (14 days)	Mesocosm	This study

In terms of final nutrients concentration, the results obtained in this experiment were only slightly higher than those of Zhou and Wang (TN: 1.16 mg/dm^3, $NH_4^+ - N$: 0.31 mg/dm^3, $NO_3^- - N$: 0.23 mg/dm^3, TP: 0.16 mg/dm^3), with an experimental period of about 35 days in the purification phase [11].

Variation of the environmental factors during the experiment

Statistical description and figures showing the changes in temperature, pH value, oxidation-reduction potential, dissolved oxygen, specific conductivity and chlorophyll *a* in the water tanks during experiment are presented in Figure 2.

a. Chlorophyll a

The concentration of the chlorophyll *a* in the zero control system was much higher than that in the FTWs (Fig. 2a). Chlorophyll *a* is a composite indicator of phytoplankton biomass in eutrophicated water, and was considered to be an important factor to evaluate the state of eutrophication. In the zero control system, the concentration of the Chlorophyll *a* decreased in the first 4 days, but increased after day 4 which is probably due to an increase in phytoplankton growth under steady water condition. The concentration of the Chlorophyll *a* showed a continuous decrease in the FTWs except for the last 4 days of the 19 cm stubble cutting. In the FTWs, the floating plants assimilated the nutrients in water, and at the same time caused a shading effect on the water body below the plants. Under these conditions the phytoplankton was hampered by the floating plants in its competition for light and nutrients, which caused the decrease of the phytoplankton biomass in the FTWs.

b. Dissolved Oxygen

The FTWs had a lower DO concentration compared with the zero control (Fig. 2b). The DO concentration in the FTWs decreased in the first 4 days and then increased after day 4, which showed a tendency similar with the result of [8], with temperature about 22°C. This is most likely due to an increased consumption of oxygen from nitrifying bacteria together with excretion of oxygen from the plant roots. The DO concentration in zero control increased continuously due to the contribution from photosynthesis of phytoplankton and the natural atmospheric diffusion.

c. pH

The pH values in the zero controls were significantly higher than that in all of the FTWs in our experiment (Fig. 2c). In the zero controls, the initial pH value was higher than 7.0 and increased throughout the experimental period. It is reported [32] that the "carbonate system" which is typically approximated by carbon dioxide, carbonic acid, bicarbonate, carbonate and hydrogen ion, are the most important acid-base relationships in aquatic systems. We assume that the concentration of CO_2 in the zero controls decreased because of the microalgal uptake during photosynthesis, and that the lowering of the concentration of CO_2 induced a shift in carbonate system in an alkaline direction resulting in the observed increase in pH value.

In contrast to the zero controls, the pH of the FTWs was a little bit lower than 7.0 and remained consistent after day 4 in the FTW. It suggested that FTWs can act as a buffer to the pH conditions in the water, *ie* they influence the water environment acidity-base and allows the conditions to remain stable around neutral conditions. The continuous neutral to weak slightly acid condition in the FTW is assumed to be due to the CO_2 buffering of the system from the plant respiration and the lack of phytoplankton photosynthesis, as a plant like Water Dropwort will most likely obtain all its CO_2 from the atmosphere. The effect of acidoids hypothetically released from roots, together with the effect of microbes in the rhizosphere around the roots are other important explanations for the continuous maintenance of stable pH conditions in the FTWs [26, 33]. The lower pH compared with the zero control reflected the better buffer capacity on water alkalinity and acid perspiration of Water Dropwort FTW in our experiment.

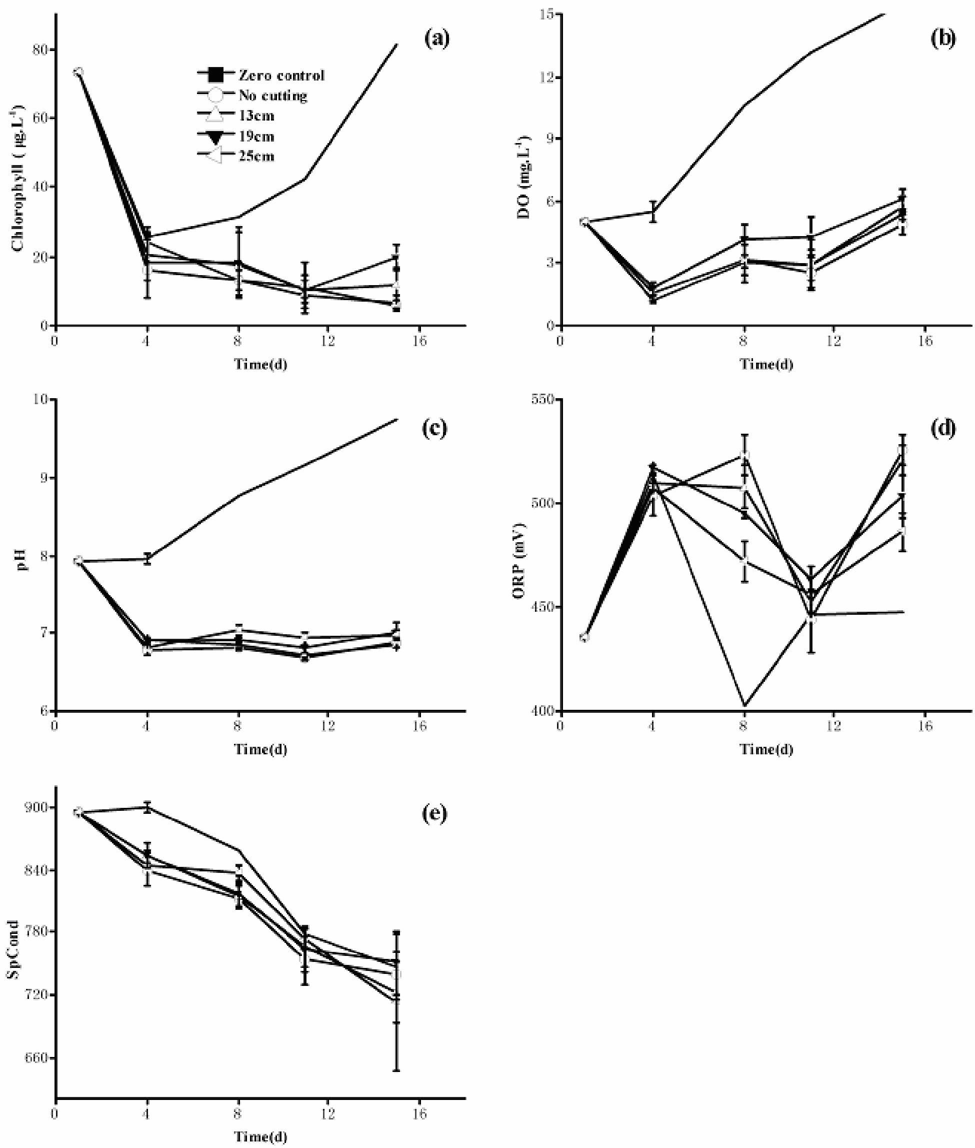

Fig. 2. Changes of DO (a), pH (b), ORP (c), SpCond (d), and Chlorophyll *a* (e) during the experiment under different treatments

It is reported [34] that: (1) when DO concentration in water is over 2 mg/dm^3, only nitrification process occurs; (2) when DO concentration in water is lower than 0.5 mg/dm^3, only denitrification occurs; and (3) when DO concentration in water is between 0.5 and 2 mg/dm^3, both nitrification and denitrification occur at the same time. Likewise, Hao [35] described the optimal conditions of pH: (1) best pH for nitrate bacteria is 5-8; (2) best pH for nitrite bacteria is 7-9; (3) the best pH for denitrification process is 7. The rate of denitrification process is reduced however when the pH is higher or lower than 7. In our experiment, large amount of nitrifying bacteria were detected [36]. In FTWs, the average DO concentration was higher than 2 mg/dm^3; while pH was between 6.5 and 8 all through the experiment. We can conclude that the conditions are favorable for the nitrification process to take place in the FTWs throughout the period of our experiment. The lower DO in the FTWs as compared with the controls may in fact be a result of the consumption of oxygen through nitrification process. In the zero control system the DO concentration was always higher than 5 mg/dm^3. Based on the above criteria, the low DO concentration (< 2 mg/dm^3) in FTW on day 4 could be the result of DO consumption from nitrification at the plant root zone.

d. Redox and conductivity

The FTWs maintain a higher *redox-potential* (ORP) and lower *specific conductivity* (SpCond) than the zero controls (Fig. 2). The decreased SpCond reflected the decrease of metal ions, which is beneficial for the survival of vegetation and microbes. Compared with the zero controls, the FTWs could much better improve the rhizosphere environment by transporting oxygen as a byproduct of photosynthesis to the roots. The higher redox potential (ORP) in planted FTWs reflected a higher oxidation state of the system resulting from this process, which did not occur to the same extent in the zero controls.

Variation of water quality parameters during the experimental period

a. Total Nitrogen

The variations in the water quality parameters and the removal rates during different periods of our experiment are shown in Figure 3 and Table 5. According to Figure 3a TN decreased sharply during day 1-4 and day 11-15, but exhibited a relatively slow decrease during day 4-11, regardless of the cutting treatments and zero control.

b. Total Phosphorus

The FTWs removed most of the TP (Fig. 3b) within the first 11 days, in contrast the concentration decreased from 0.8 to about 0.2 mg/dm^3, while concentrations of TP in the zero controls decreased only 0.2 mg/dm^3 (from 0.8 to 0.6 mg/dm^3) in the same period. The concentration of TP in the FTWs increased after day 11, probably due to the release of phosphorus from decayed plant roots at the end of the experiment [11].

c. Ammonia nitrogen

The removal of $NH_4^+ - N$ was most efficient from day 1 to day 8 with the concentration decreased from about 8 to 1 mg/dm^3. The decrease was not obvious after day 8, where the ammonium concentration seemed to have reached a stable level (Fig. 3c).

The concentration of $NH_4^+ - N$ in the zero controls decreased slowly (Fig. 3c) owing to the shortage of the co-substrate, oxygen, and microbes related to nitrification. In the zero control, very little or no $NH_4^+ - N$ was transformed into $NO_3^- - N$. It has been reported that at pH values higher than 8.0, $NH_4^+ - N$ volatilization is enhanced; when pH value is lower than 7.5, it can be ignored [37]. In our experiment, the pH in the zero control system was higher than 7.8 throughout, and it is likely that most of the $NH_4^+ - N$ was removed through the ammonia volatilization under these conditions although temperature may limit the overall rate of this process.

In the FTWs, the concentration of $NH_4^+ - N$ decreased rapidly during the first 4 days (from about 8 to about 2 mg/dm^3). It might be caused by two reasons: (1) uptake of the plant. During our experiment, the Water Dropwort grew well because of the suitable temperature and sufficient light; and (2) the intensive nitrification with DO concentration over 2 mg/dm^3, resulting in high amount of $NH_4^+ - N$ being transformed into $NO_3^- - N$ [36, 38].

d. Nitrate nitrogen

The concentration of $NO_3^- - N$ in different period of our experiment is presented in Figure 3d. The decrease of $NO_3^- - N$ mainly occurred after day 11, with a total removal rate of 92.6% (Table 5). In consistence with the declination of TN, the FTWs removed most of the $NO_3^- - N$ in the last 4 days. In the first 4 days, unlike the change of TP and $NH_4^+ - N$, the removal rate was only 13.5%.

Table 4 showed the changes of TN, TP, $NH_4^+ - N$ and $NO_3^- - N$ at different phases of the experiment. In the first 11 days, the removal rate for TP and $NH_4^+ - N$ in FTW was much higher than that in zero control which reflected that the FTW removed the most TP and $NH_4^+ - N$ of the water in the first 11 days. No significant difference was found for the removal rate of TP in the zero control all through the experiment. The higher removal rate either in FTW or in zero control at last 4 days (from day 11 to day 15) showed that the removal of TN and $NO_3^- - N$ took place at the last period of experiment.

Table 4

The removal rate [%] for the zero control and the FTW during different period in our experiment

Parameter	Nutrients	Day 1 - Day 4	Day 4 - Day 11	Day 11 - Day 15
Zero control	TN	34.1±16.4	35.8*	76.8*
	TP	24.4±2.5	18.1*	26.0*
	$NH_4^+ - N$	20.8±6.0	19.5*	59.8*
	$NO_3^- - N$	15.3±6.1	-	85.4*
FTW	TN	25.7±16.9	11.1±23.9	83.0±7.2
	TP	60.9±11.1	68.5±24.7	–868.9±1256.6
	$NH_4^+ - N$	67.2±19.0	83.3±6.7	6.1±90.9
	$NO_3^- - N$	13.5±13.4	18.8±17.1	92.6±7.1

*Short of duplicate data, "-" Data are missing

From day 1 to day 4, in the FTWs, the concentration of TN and $NH_4^+ - N$ decreased about 7 and 6 mg/dm^3, respectively (Fig. 3). From Day 11 to day 15, the concentration of TN and $NO_3^- - N$ decreased about 9 and 4 mg/dm^3, respectively. Therefore, concerning TN removed, $NH_4^+ - N$ removal contributed the major part during day 1 to day 4, while $NO_3^- - N$ removal contributed an important part during day 11 to day 15 in our experiment.

It is likely that the first period was dominated by transformation of ammonium to nitrate nitrogen and later on by denitrification and nitrate uptake into the plants in the FTWs. Sun et al [39] used *Canna* sp. in FTWs in various seasons for the removal of nitrogen from eutrophicated water. In spring, a period of only 2 days out of the 5-day experiment was sufficient to remove 100% of the $NH_4^+ - N$. In autumn, due to the degeneration of Canna and low temperature, it took 4 days out of the 5-day experiment time to remove 100% of $NH_4^+ - N$. Similar results were found for the removal of TP (Table 5), where the FTWs removed 70% of TP in the first 4 days. Zhang et al [27] obtained result consistent with the present study for TP removal, where FTW performed well in the first 3 days after domestic sewage was pumped into the system.

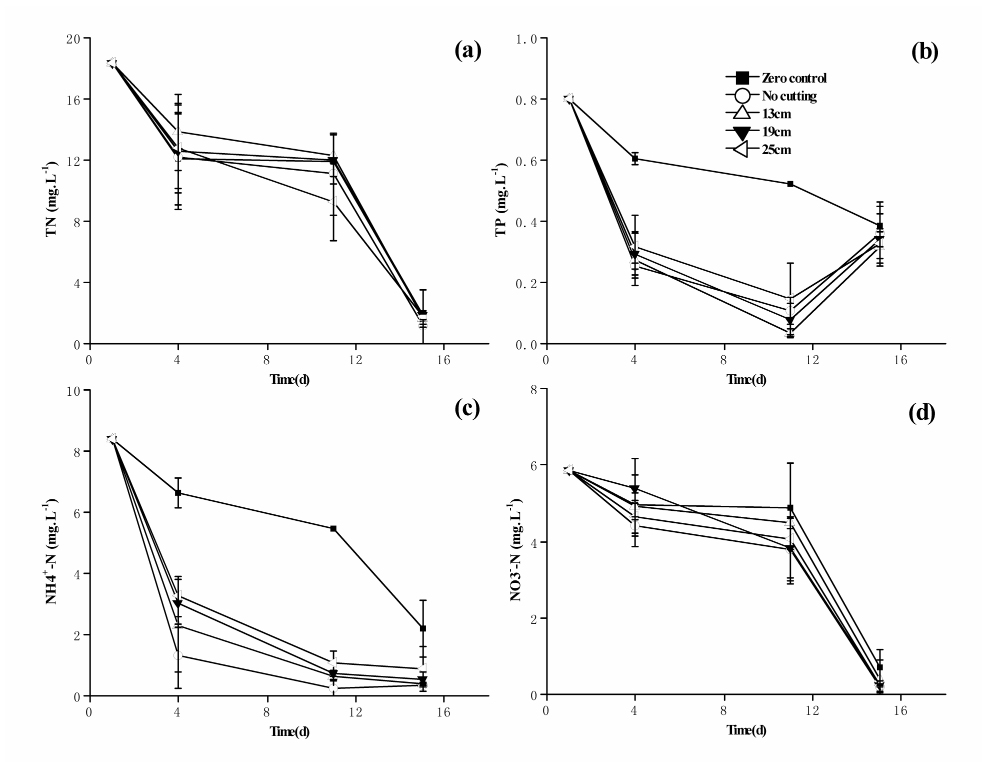

Fig. 3. Changes of TN (a), TP (b), $NH_4^+ - N$ (c) and $NO_3^- - N$ (d) concentration during the experiment

The statistical difference between Zero Control and the FTWs during different periods of our experiment

An ANOVA analysis of the nutrients removal was carried out for the different periods of the experiment to test whether there were significant differences 1) among the different cutting treatments of Water Dropwort FTWs, and 2) between the FTWs and the zero controls. Results with significant differences are listed in Table 5.

In the first 4 days, a significant difference was found between the zero controls and the FTWs in removing TP and $NH_4^+ - N$ at $P < 0.01$ level. No significant differences were found among the various stubble heights after cutting in the FTWs. Also, no significant difference was found among the FTW treatments for TN, TP, and $NO_3^- - N$ removal (Table 5). For the removal of $NH_4^+ - N$, significant difference was found between the 25 and 19 cm stubble heights, as well as the no cutting treatments (Table 6).

During the first 11 days, similar result for TP was found as that in the first 4 days (Table 5): there was significant difference between the zero control and the FTW. No significant difference was found between the zero controls and the FTWs, or among the different treatments for Water Dropwort in the FTW for $NH_4^+ - N$ removal. For $NO_3^- - N$, significant difference was found between the zero control and the FTW except for the 13 cm cutting treatment. No significant difference was detected among the FTW treatments for $NO_3^- - N$, TN and TP.

For the whole period of 15 days, significant difference was detected only for $NO_3^- - N$ between the zero controls and the FTWs (Table 5). No significant difference was detected among the FTW treatments for TN, TP, $NH_4^+ - N$ and $NO_3^- - N$.

Table 5

ANOVA analysis results between the FTWs and the zero control in our experiment

Parameter	**Treating**	**Treating**	**Day 1 - Day 4**	**Day 1 - Day 11**	**Day 1 - Day 15**
			MD	**MD**	**MD**
TP	Zero control	No cutting	–48.00715***	–16.98611**	
		13 cm	–44.65069***	–15.55622**	
		19 cm	–44.81159***	–15.61424**	
		25 cm	–35.63864**	–14.44367**	
$NH_4^+ - N$	Zero control	No cutting	–718.94881***		
		13 cm	–557.79491***		
		19 cm	–633.06106***		
		25 cm	–329.63175**		
$NO_3^- - N$	Zero control	No cutting		–254.78731*	–192.04355**
		13 cm		–163.63241	–180.16694*
		19 cm		–245.58511**	–232.81777**
		25 cm		–231.50623**	–255.03718***

*P < 0.05, **P < 0.01, ***P < 0.001, MD: *Mean Difference*

Table 6

ANOVA analysis results among different treatments for Water Dropwort FTWs

Parameter	**Treating**	**Treating**	**Day 1 - Day 4**	**Day 1 - Day 11**	**Day 1 - Day 15**
			MD	**MD**	**MD**
$NH_4^+ - N$	25cm	Zero control	329.63175**		
		No cutting	–389.31706**		
		13 cm	–228.16316		
		19 cm	–303.42931*		

*P < 0.05, **P < 0.01, MD: *Mean Difference*

No significant difference was detected among the FTW treatments for TN, TP, NH_4^+-N and NO_3^--N. Therefore, cutting treatments for the plants in FTW had no significant different effect on the removal of TN, TP, NH_4^+-N and NO_3^--N in our experiment. Therefore, biomass productivity will become the main factor to be concerned during large scale application of this technique.

Since significant difference was found between the zero controls and the FTWs for most of the target nutrients, it indicated that FTWs have extra removal capacity as compared with the self-purification of open water. When no significant difference was found between the zero controls and the FTWs, it means that the time could be used as a criterion when to renew the treated water or plants.

Based on the ANOVA analysis results from our experiment, the following detention time is recommended: (1) If the target nutrient is TP, the best treatment duration for Water Dropwort FTW is 11 days. (2) If the target nutrient is NH_4^+-N, the best treatment duration for Water Dropwort FTW is 4 days. (3) If the target nutrient is NO_3^--N, the best treatment duration for Water Dropwort FTW should be 15 days, or longer. Our conclusion about detention time is similar with that from Zheng et al [40] who concluded that short treatment duration is benefit for the removal of TN and TP, while long treatment duration is benefit for the removal of NO_3^--N.

There are several questions that need to be discussed: (1) Cutting method. The cutting method which allows retaining part of leaves could be better for nutrient removal, as indicated by lack of nitrification in the 13 cm treatment. (2) Relatively shorter intervals between water samples collected and measured are recommended in a short experimental time like ours (15 days). It seemed we had missed some of the key turning point by sampling every two days. (3) Adoption stage of the FTW plant in mid-growth season. It is impossible to plant mid-growth season vegetables like what we did in practical application. However, the purpose of our study is to determine the best detention time for maximum nutrients removal in a short time. Mid-growth season plants will provide stable condition for nutrients removal.

For real world application, all treatment systems will necessarily be flow through systems. In order to understand the water treatment process, the system was designed as a stagnant water system, so that external disturbance such as various hydraulic conditions of the eutrophicated water could be avoided.

Conclusions

The results of our experiment indicate that the Water Dropwort FTWs can play a significant role in improving water quality of eutrophicated water. The FTWs are effective in buffering the variance of pH to maintain a neutral to weakly acid water environment. The removal rate for TN, TP, NH_4^+-N, and NO_3^--N was 91.3, 58.0, 94.6 and 95.5% respectively in our 15-day experiment. Cutting the Water Dropwort at different stubble heights did not affect the removal efficiency in our experiment. The presence of plants clearly affected the transformation in particular of nitrogen. The concentration reduction of TP and NH_4^+-N mainly took place in the first 11 days. The decrease of TN concentration after day 11 was mainly due to removal of NO_3^--N in our experiment. The best detention time that eutrophication water was treated varied according to different target removal nutrients.

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WPŁYW CZASU I WYSOKOŚCI ŚCIERNISKA NA PROCES OCZYSZCZANIA ŚCIEKÓW Z WYKORZYSTANIEM RUCHOMYCH MOKRADEŁ

Abstrakt: Badano proces oczyszczania wód z wykorzystaniem ruchomych mokradeł (FTW) obsadzonych *Oenanthe javanica*. Celem prowadzonych w zimie badań była ocena ich potencjalnej roli w oczyszczaniu wód zeutrofizowanych oraz określenie wpływu różnych wysokości ściernisk roślinnych na wydajność procesu. Wyniki eksperymentów wykazały, że systemy FTW skutecznie buforowały pH badanej wody. Za pomocą FTW ze zeutrofizowanej wody usunięto azot ogólny (TN), fosfor ogólny (TP), azot amonowy ($NH_4^+ - N$) i azot azotanowy ($NO_3^- - N$) odpowiednio w ilościach: 91,3, 58,0, 94,6 i 95,5%, w czasie trwania 15-dniowego eksperymentu. Nie wykazano istotnych różnic w efekcie oczyszczania przy stosowaniu różnych wysokości ściernisk roślinnych. Stwierdzono wpływ czasu prowadzenia eksperymentu na usuwanie TP, którego usunięto najwięcej w pierwszych 11 dniach, a $NH_4^+ - N$ w ciągu pierwszych 4 dni trwania procesu. Nie stwierdzono istotnej różnicy między kontrolą i FTW dla $NO_3^- - N$ w ciągu pierwszych kilku dni, ale znacząca różnica pojawiła się po 4 dniu. Optymalny czas trwania procesu z wykorzystaniem FTW zależy od składników odżywczych, które mają być usunięte. Opisane wyniki stanowią podstawę zarówno do rozwinięcia zastosowania FTW na dużą skalę, jak i dla przyszłych badań nad mechanizmem procesu usuwania składników odżywczych.

Słowa kluczowe: oczyszczanie ruchomymi mokradłami, FTW, składniki odżywcze, szybkość usuwania, *Oenanthe javanica*