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Simulation Study on Purification Efficiency for Nitrogen in Different Types of Wetlands in Sanjiang Plain, China

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Abstract: The purification law of nitrogen in *Deyeuxia angustifolia*, *Carex lasiocarpa* and *Deyeuxia angustifolia-Carex lasiocarpa* combined wetland systems in the Sanjiang Plain, China was studied by field simulation experiment. The results indicate that the removal rates of TN, NH_4^+-N and NO_3^--N in above three types of wetlands present an obvious logarithm growth trend along with the time. There are evident removal effects for NH_4^+-N and NO_3^--N in water bodies of wetlands after the 30th day of experiment, with the removal rates over 80.0%, but the removal rate of TN is slightly low, being 63.1%–74.3%. NO_3^--N is most quickly removed by the combined wetland, and NH_4^+-N by *Deyeuxia angustifolia* wetland. The removal speeds of TN by the three wetland systems are comparatively slow, of which the *Deyeuxia angustifolia* wetland is the fastest. In consideration of plant growth season, *Deyeuxia angustifolia* wetland has much more practical application value in purifying nitrogen. These results can provide references for the study on the purification function of wetlands and the control of non-point source pollution in Northeast China.

Keywords: wetland; *Deyeuxia angustifolia*; *Carex lasiocarpa*; nitrogen; removal rate; Sanjiang plain

1 Introduction

The non-point source pollution due to chemical fertilizer application has become the main source of nitrogen and phosphorus in surface water body, and also the important reason resulting in water body eutrophication. Wetland is a special ecosystem of land and water interlacing, which has a strong interception effect on land source nutrients, and a huge potential to remove the nutrient elements such as nitrogen and phosphorus (Kadlec, 1999; Lin *et al*., 2002; Steinmann *et al*., 2003; Wu *et al*., 2008; Konnerup *et al*., 2009). The studies on the nutrient purifying effect of constructed wetlands showed that the removal rates of nitrogen and phosphorus could reach over 50% (Koskiaho *et al*., 2003; Mantovi *et al*., 2003), and the removal rate of nitrogen by *Deyeuxia angustifolia* was also high (Xu Hongwei *et al*., 2005). The removal of nitrogen in wastewater by wetlands has gained good effect. There have been many studies on removing nitrogen in wastewater by constructed wetlands (Braskerud, 2002; Mitsch *et al*., 2005; Lu *et al*., 2006; Wagenschein and Rode, 2008; Huang *et al*., 2009). But there were fewer studies on nutrient purifying effect of natural wetlands comparatively (Jansson *et al*., 1998), and it was reported that the interception efficiency of TN in reed wetland was 42% (Yin *et al*., 1995).

The Sanjiang Plain is one of the most typical distribution areas of fresh water wetlands in China. In recent several decades, a large area of marsh wetlands in the Sanjiang Plain have been exploited into farmland, furthermore, the widespread application of chemical fertilizer in agricultural activities has led to the increase of agricultural non-point source pollution. How to bring the purification function of the wetlands in the Sanjiang Plain into full play, to solve the agricultural non-point source pollution problem, is one of the hot points paid attention to by scholars. The present paper studied the purification process and law of nitrogen in the typical wetlands in the Sanjiang Plain through field simulation experiment, and approached nitrogen purification capacity in the typical wetland systems in the study area, so as to provide theoretical basis for solving the non-po-

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int source pollution problem resulting from nitrogen in Northeast China.

2 Materials and Methods

2.1 Experiment equipment

The simulation experiment site is located in the Sanjiang Mire-wetlands Experimental Station, Chinese Academy of Sciences (47°34′30.5″N, 133°29′45.2″E), 55 m above sea level, with an average annual precipitation of 600 mm. The main dominant species are *Deyeuxia angustifolia* and *Carex lasiocarpa* (Liu and Ma, 2000), and the average surface water depths of the *Deyeuxia angustifolia* and *Carex lasiocarpa* wetlands are 5 cm and 30 cm, respectively. The design of the wetland simulation system was mainly based on the natural conditions of the wetland units in the dish-like depression of the experiment site. From the edge to the center of the depression, with the increase of stagnant water depth, *Deyeuxia angustifolia* and *Carex lasiocarpa* wetland units were distributed. The simulation experiment consisted of three types of wetland units, that is, *Deyeuxia angustifolia* wetland, *Carex lasiocarpa* wetland and *Deyeuxia angustifolia-Carex lasiocarpa* combined wetland. The wetland simulation system was consisted of wetland unit, intake system and drainage system (Fig. 1). The wetland unit was placed in PVC experiment pool with length, width and height of 2.50 m × 1.00 m × 0.85 m. The intake system connected the pool with a water pond by intake pipes, and drainage system consisted of two drainage valves for draining water to regulate the water depth in the system.

The typical sampling sites with consistent burgeon, good growth and even height of *Deyeuxia angustifolia* and *Carex lasiocarpa* were selected in the experiment site. In order to avoid destroying the integral structure of field original soil, the plants and the grass-root peat layer (0.5 m deep) were taken out together, and the combined wetland consisted of the same size of *Deyeuxia angustifolia* and *Carex lasiocarpa* wetlands. The integral of plants and the grass-root peat layer for different wetland units was transplanted into wetland simulation system, and then placed in the experiment site.

2.2 Simulation experiment methods

On May 15, 2008, the experiment pools were buried into the marsh wetland, which were 30 cm higher than the marsh wetland. In order to simulate the hydrologic gradient characteristics of field dish-like wetland, the surface water depths of *Deyeuxia angustifolia* wetland unit and *Carex lasiocarpa* wetland unit were set to 5 cm and 30 cm, respectively, and the *Deyeuxia angustifolia-Carex lasiocarpa* combined wetland unit was simulated by blocking up 25 cm on the end of *Deyeuxia angustifolia* wetland of the experiment pool. The plants were cultured with the original marsh water without interference. After the plants grew well, the simulation experiment began. On July 1, 2008 the original marsh water in the experiment pools was discharged, NH_4NO_3 solution prepared according to the needed concentrations was poured. The concentrations of TN, NH_4^+-N and NO_3^--N in the pools were 40 mg/L, 20 mg/L and 20 mg/L, respectively.

2.3 Sampling and determination methods

Water samples were collected from all experiment pools in the morning each time on the 4th, 8th, 12th, 16th, 30th day since NH_4NO_3 solution was added into the pools. After sampling, the water in the pools was complemented with deionized water based on the water lev-

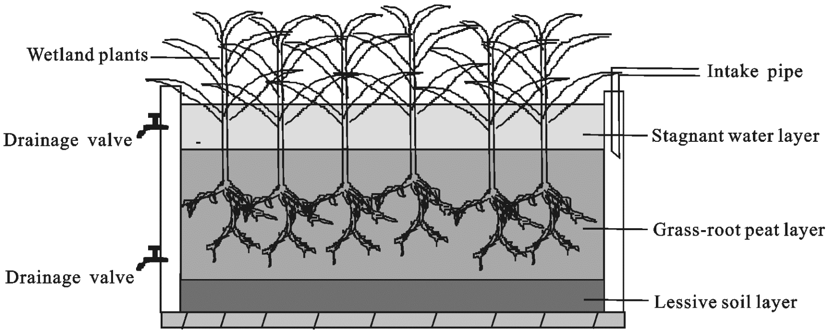

Fig. 1 Wetland simulation system

els and the nitrogen concentration in each pool. All experiments ended on July 30, 2008.

Water samples were analyzed immediately after collection each time in the laboratory of the Sanjiang Mire-wetlands Experimental Station, Chinese Academy of Sciences. TN, NH_4^+-N and NO_3^--N were analysed by the method of peroxide of potassium sulfate-ultraviolet spectro-photometry, Nessler's reagent colorimetric method and phenoldisulfonic acid spectrophotometric method, respectively (Ministry of Environmental Protection of the People's Republic of China, 2002), and determined by ultraviolet visible spectrophotometer (721, Shanghai). The experiment data were analyzed by ORIGIN8.5 and SPSS12.0 statistical software. The removal rate of nitrogen in the water body by wetland was calculated based on the following formula:

$$R_{Ni} = (C_0 \times V_0 - C_i \times V_i)/(C_0 \times V_0) \times 100\%$$

where R_{Ni} is the removal rate of nitrogen in the ith day (%); C_0 is the initial concentration of TN, or NH_4^+-N or NO_3^--N (mg/L); V_0 is the initial water volume (L); C_i is the concentration of TN, or NH_4^+-N or NO_3^--N in the ith day (mg/L); V_i is the water volume in the ith day (L).

3 Results

3.1 Removal effects for inorganic nitrogen by different wetland units

In all wetland units, the final removal rate R_{N30} of TN in *Carex lasiocarpa* wetland is the highest, and then the *Deyeuxia angustifolia* wetland, and the combined wetland unit is the lowest. The removal rate R_{N30} of NO_3^--N shows the same order, but that of NH_4^+-N shows a reverse order (Fig. 2). It can be concluded that all wetland units have obvious removal effect for NH_4^+-N and NO_3^--N in the water bodies, as a whole, and the removal effect for NO_3^--N is better than that for NH_4^+-N in all wetland units (Fig. 2). The R_N for NH_4^+-N in the combined wetland unit is the highest among three wetland units.

3.2 Removal process of inorganic nitrogen by different wetland units

The removal rates of TN in different wetland units present a logarithm growth trend along with the time (Table 1). From Fig. 3, it can be seen that in the earlier period the removal rates of the wetland unites present an increase tread, while those of *Carex lasiocarpa* and combined wetland units are higher, and that of *Deyeuxia angustifolia* wetland unit is lower. Along with the experimental time passing, the removal rates of *Carex lasiocarpa* and combined wetland units increase slowly, but that of *Deyeuxia angustifolia* wetland unit still increases faster, even higher than that of combined wetland unit in the 30th day.

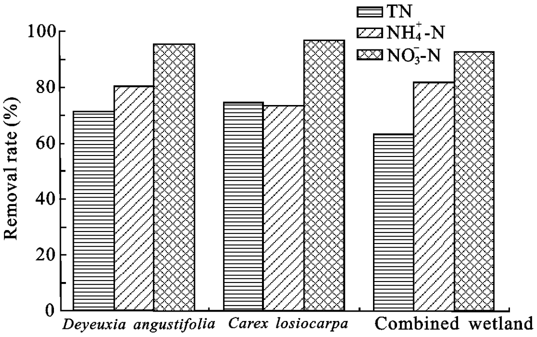

Fig. 2 Removal rates of TN, NH_4^+-N and NO_3^--N in water bodies of different wetland units

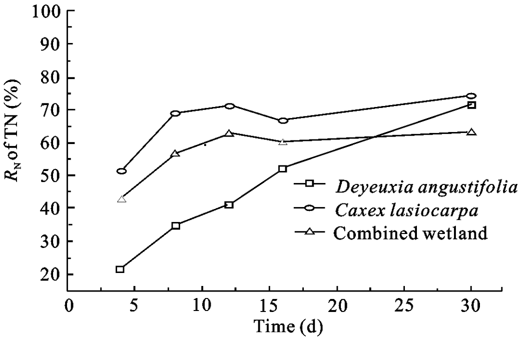

Fig. 3 Removal process of TN in water bodies of different wetland units

As shown in Fig. 4, the removal rates of NH_4^+-N in all wetland units display the trend of first increase and then decrease along with the time. The removal rate of *Carex lasiocarpa* wetland unit fluctuates slightly. The change characteristics of the removal rates of *Deyeuxia angustifolia* and combined wetland units are similar, i.e., the highest values appear in the 16th day, 94.5% and 93.1%, respectively, showing that marsh wetland has a strong capacity to absorb NH_4^+-N in water body.

From Fig. 5, we can see that the removal charateristic of NO_3^--N is similar to that of NH_4^+-N. In the whole experiment period, the removal rates of NO_3^--N in all wetland units present an obvious logarithm growth trend.

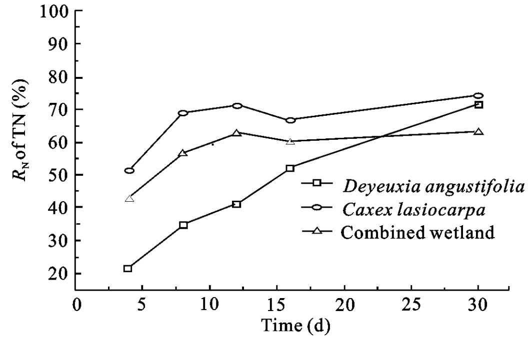

Fig. 4 Removal process of NH_4^+-N in water bodies of different wetland units

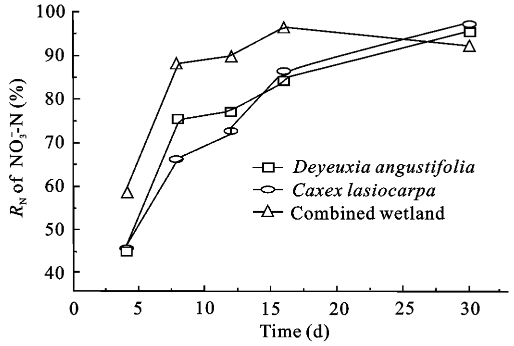

Fig. 5 Removal process of NO_3^--N in water bodies of different wetland units

The removal rate of the combined wetland unit is higher, and presents the trend of first increase and then slight decrease. Through 30 days' experiment, the final removal rates of NO_3^--N in *Deyeuxia angustifolia*, *Carex lasiocarpa* and the combined wetland units reach very high level, 95.2%, 96.9%, 92.6%, respectively.

3.3 Removal model of inorganic nitrogen by different wetland units

As to the removal processes of inorganic nitrogen in *Deyeuxia angustifolia*, *Carex lasiocarpa* and combined wetland units, the removal rates increase fast in the early period of the experiment, and increase slowly and predicted curves become smooth after about 30 days. Furthermore, the removal effects for nitrogen in water bodies present some difference, since wetland units were different. In order to carry out normalized comparison, the correlation equations of the experiment time and the removal rate of nitrogen are given in Table 1.

The removal rate of NH_4^+-N in *Deyeuxia angustifolia*, *Carex lasiocarpa* and combined wetland units for 30 days is 78.4% on an average, and that of NO_3^--N for 30 days is 94.9% on an average. Compared with NH_4^+-N, the removal effect for NO_3^--N by marsh plants is much more obvious. However, whether this removal is caused completely by plant absorption needs further study.

4 Discussion

Compared with previous study results, the removal rate of nitrogen in this study is comparatively higher. Xu Hongwei *et al.* (2005) indicated that the total purification rate of TN in *Deyeuxia angustifolia* simulation system reaches 53%. The study results of Liu and Lu (2001) showed that *Carex lasiocarpa* marsh wetland system could remove about 40% TN within one month. The simulation experiment of Xu Zhiguo *et al.* (2005) indi-

Table 1 Main results about removal experiment of nitrogen in different wetland units

Nitrogen form	Wetland unit	Equation	R	R_N at end of experiment (%)	Calculated time for R_N 100% (d)
TN	*Deyeuxia angustifolia*	$Y = 24.415\ln T - 14.973$	0.9838	71.4	111
	Carex lasiocarpa	$Y = 42.109 + 10.081\ln T$	0.8471	74.3	–
	Combined	$Y = 33.597 + 9.7321\ln T$	0.8766	63.1	–
NH_4^+-N	*Deyeuxia angustifolia*	$Y = 23.385 + 21.169\ln T$	0.8672	84.8	38
	Carex lasiocarpa	$Y = 68.831 + 3.072\ln T$	0.3963	73.3	–
	Combined	$Y = 23.019 + 20.870\ln T$	0.8485	81.9	40
NO_3^--N	*Deyeuxia angustifolia*	$Y = 16.120 + 24.254\ln T$	0.9585	95.2	32
	Carex lasiocarpa	$Y = 10.003 + 26.116\ln T$	0.9910	96.9	32
	Combined	$Y = 42.693 + 17.356\ln T$	0.8325	92.6	28

Note: Y represents the removal rate of different forms of nitrogen; T is time; R_N is removal rate; – denotes the number of days is more than one growth season, so it is not considered cated that the purification of NH_4^+-N in *Carex lasiocarpa* marsh wetland system was obvious, and after 30 days′ experiment, under four different nitrogen gradients, NH_4^+-N contents were reduced 96%, 83%, 69% and 56%, respectively.

In this paper, all experiment units have obvious removal effect for NH_4^+-N and NO_3^--N in the water bodies, as a whole, and the removal effect for NO_3^--N is better than that for NH_4^+-N in all experiment units. The reason may be that on the one hand NH_4^+-N existent form in the wetland system is unstable, so the absorbing effect of plants is not obvious; on the other hand, since the charge and existent forms of NH_4^+-N and NO_3^--N are different, the plants show great differences in absorbing, assimilating and metabolizing. For most plants, absorbing and transporting NO_3^--N is the first step of nitrogen metabolism. Generally, it is considered that absorbing nitrogen by plants is an active process, the obligate transport protein of NO_3^--N exists on cell membrane, the proton driving force produced by means of plasma membrane ATPase hydrolysis transports NO_3^--N into the membrane. Absorption of NH_4^+-N shall be in such a way, that is, first NH_4^+ deprotonation occurs on plasma membrane, and then formed non-protonation NH_3 enters into cells (Li, 2001).

The removal rates of TN and NO_3^--N in different wetland units are *Carex lasiocarpa* wetland unit > *Deyeuxia angustifolia* wetland unit > the combined wetland unit. The reason may be that *Carex lasiocarpa* wetland system has a thick peat layer, loose soil is favorable for moisture penetration, and peat adsorption and decomposition intensify purification effect. *Deyeuxia angustifolia* peat layer is relatively thin, and hard and dense soil is not favorable for moisture penetration, thus weakening the filtration effect of the whole system.

The removal rate of NH_4^+-N in the combined wetland unit is the highest among three wetland units. The removal of NH_4^+-N is mainly influenced by oxygen content in wetland soil. Radial oxygen loss from root of wetland plants is the main source of oxygen of wetland soil. *Deyeuxia angustifolia*-*Carex lasiocarpa* combined wetland unit is favorable for producing high oxygen enrichment status, and high oxygen enrichment rate is more favorable for the removal of NH_4^+-N (Kaldlec, 1999; Stottmeister *et al*., 2003).

The adsorbing and desorbing processes of different nitrogen forms by plants in soil are fast at the earlier period, and slow at the later period. Under the condition of initial high nitrogen concentration, the physiological function of plants is improved, therefore, on the one hand, plant root system activity is raised, thus accelerating root border environment change, which conduces to the activities of various microbes such as nitrifying and denitrifying bacteria to accelerate nitrogen removal; on the other hand, the photosynthetic capacity of plant leaves is improved, thus quickening plant oneself metabolic process, and promoting the absorption and utilization of inorganic nitrogen in plants. Under the condition of low nitrogen concentration, the removal of nitrogen in wetlands may be mainly through such physical and chemical processes as adsorption, coprecipitation, ammonia volatilization and nitrification (Blanke *et al*., 1996; Claussen and Lenz, 1999).

In consideration of field condition, one growth season of *Deyeuxia angustifolia* and *Carex lasiocarpa* is about 180 days. Therefore when the removal time for 100% removal of nitrogen is more than plant growth season (Table 1), we do not consider it due to lack of observed data. Under simulation conditions, within one growth season of plants, the removal effects for TN, NH_4^+-N, NO_3^--N in *Deyeuxia angustifolia* wetland unit are good. The removal times of NH_4^+-N and NO_3^--N are similar in the three wetland unites, but the removal time of TN and NH_4^+-N in some wetland units exceeds the growth season of plants. Among three types of wetland units, *Deyeuxia angustifolia* wetland unit is more significant for nitrogen removal in practice.

5 Conclusions

Deyeuxia angustifolia, *Carex lasiocarpa* and *Deyeuxia angustifolia*-*Carex lasiocarpa* combined wetland systems in the Sanjiang Plain have remarkable purification effect of nitrogen. Among different wetland units, the final removal rate of TN is 63.1%–74.3%, that of NH_4^+-N is 73.3%–81.9%, and that of NO_3^--N is 92.6%–96.9%. The removal rate of NO_3^--N is the highest at the end of simulation experiment. There is not great difference in the removal rates of different nitrogen forms in these three wetland units.

In the light of fitting equation, the removal speeds of NH_4^+-N and NO_3^--N are faster among three nitrogen forms. Under simulation conditions, NH_4^+-N and NO_3^--N in water bodies can be basically removed completely in about 30–40 days, but the removal speed of TN is comparatively slower. In consideration of the growth season of plants, *Deyeuxia angustifolia* wetland unit is more suitable for the removal of nitrogen in water bodies than *Carex lasiocarpa* and combined wetland units.

For preventing water body from potential eutrophication caused by farmland back water in the Sanjiang Plain effectively, the existing canal patterns should be changed; the hydraulic connection between farmland and wetlands should be communicated; wastewater should be filtered and purified through wetlands before entering rivers and lakes; and the rehabilitation and reconstruction of wetlands should be carried out in a planned way.

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