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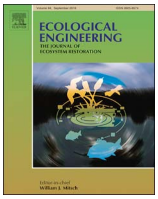

Research paper

Floating ryegrass mat for the treatment of low-pollution wastewater

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ABSTRACT

A floating ryegrass mat was constructed for low-pollution wastewater treatment during a low-temperature season. Plastic tanks were used as containers, and filled with low-pollution wastewater with low or high nitrogen concentrations, and with and without the floating ryegrass mat, creating four treatments in total (Group Low, Control Low, Group High and Control High). The experiment was conducted for 61 days. The results showed that the removal rates of TN, NH_4^+, and NO_3^- were considerably higher in Group Low and Group High than in the controls. The removal rates of TN were 86.8–88.8% in Group Low and 95.0–96.1% in Group High, while the removal rates of NH_4^+ were 91.1–92.5% in Group Low and 97.9–99.1% in Group High. Meanwhile, the COD values were in the range of 5.5–20.9 mg/L in Group Low and 7.0–26.7 mg/L in Group High, which were relatively higher compared to the controls. The higher COD/N ratios in Group Low and Group High might enhance nitrogen removal. Overall, the ratio of plant assimilation to TN input was estimated to be 33.0% and 47.6% in Group Low and Group High, respectively. The ryegrass mat displayed advantages such as easy transport and high seedling survival rate. The constructed floating ryegrass mat effectively reduced nitrogen concentration. Therefore, this technique can be an alternative approach for low-pollution wastewater treatment.

1. Introduction

Agricultural non-point pollution is currently an increasingly serious topic. According to the First National Pollution Source Census in China, the amount of total nitrogen (TN) and total phosphorus (TP) discharge both exceeded 50% of the total amount of agricultural non-point pollution. In previous studies, tail water from wastewater treatment plant (WWTP) and drainage from crop fields were classified as low-pollution wastewater (LPW), as they contained nitrogen, phosphorus, and other nutrients (Duan et al., 2016b). The LPW could cause water contamination, but can be averted if the LPW nutrients were recycled.

Hydrophytes, such as *Canna indica* and *Ipomoea aquatica*, can survive in polluted river water, and have good treatment efficiency for nitrogen and phosphorus (Bu and Xu, 2013; Zhang et al., 2014). However, as the weather gets cold, most of the hydrophytes either die or grow more slowly. Not only is the purification process affected, but the decaying plant residues causes secondary pollution (Wang et al., 1999). Ryegrass is a type of economical feed that can adapt to cold environments (Lindsey et al., 2010). Due to high biomass production rates, ryegrass has been chosen as a ditch plant for domestic wastewater treatment (Abe and Ozaki, 1998).

Ryegrass can be planted on the bottom or along the sides of traditional soil ditches. However, ryegrass cannot grow directly in a cement ditch. Straw mats have been used as a geotextile for ecological restoration and recently for avoiding soil erosion (Luo et al., 2013; Yang et al., 2016). With the advantages of being cost-effective and easy to transport, a straw mat is considered an attractive medium for ryegrass growth in a water-body. However, nutrients may be released when the straw mat has soaked in water for a long time.

In the present study, we establish a floating ryegrass mat (FRM) for LPW treatment. The objectives are as follows:

(a) The effect of N and P reduction in a FRM system receiving LPW of both low and high nitrogen concentrations;
(b) The contribution of ryegrass adsorption for nitrogen removal;
(c) The changes of COD concentration in the water-body during the experiment.

2. Materials and methods

2.1. Establishment of floating ryegrass mat

The straw mat used in this experiment was bought from a local market, and was made of rice straw (physical properties: mean

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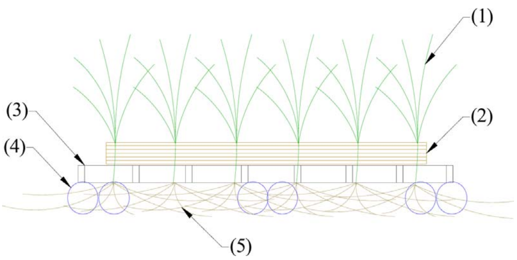

Fig. 1. Cross-section of the FRM. Note: (1) aboveground part of the ryegrass; (2) straw mat; (3) geogrid; (4) floating ball; (5) roots of the ryegrass.

thickness 12 mm, mass per unit area 1714.0 g/m^2). The straw mats were cut into 50.0 × 44.5 cm squares. Approximately 1.2 kg/m^2 of fine soil using a 1 mm sieve was sowed into the straw mat. Then 16 g/m^2 of ryegrass seeds were uniformly added, and finally 0.4 kg/m^2 of fine soil was sowed into the mat again to cover the seed. Clean water was sprayed every day to wet the mat and soil, and a thin plastic film was used to cover the mat to keep in moisture. After germination, the film was removed. When the seedlings grew to a height of 10–15 cm after approximately 20–40 days, the ryegrass mat was ready for the experiment.

The floating bed consisted of a geogrid (4.0 cm × 4.0 cm) and several floating balls. The floating balls were tied to the four corners of the bed, and the ryegrass mat was bound to the top of the geogrid (Fig. 1).

2.2. Experimental design

Plastic tanks (internal dimensions of 74.8 cm in length × 52.0 cm in width × 48.5 cm in height) containing FRMs were used for the treatment of LPW. Simulated LPWs of low or high nitrogen concentrations were used as the experiment water. Ammonium chloride and sodium nitrate were added to ensure the total nitrogen concentration was 5 and 15 mg/L for the low and high treatments, respectively (with the NH_4^+/NO_3^- ratio of 1.5). Monopotassium phosphate, potassium sulphate, magnesium sulphate and calcium chloride were added to the water at the following concentrations: 1 mg/L PO_4^{3-}, 0.0004 mol/L Ca^{2+}, 0.0006 mol/L, and 0.0002 mol/L for both K^+ and Mg^{2+}.

The tanks were filled with 145 L of LPW at low or high nitrogen concentrations, and with and without a floating bed, for a total of four treatments (Group Low, Control Low, Group High and Control High). Each treatment had three replicates. The experiment lasted from January 18, 2016, to March 18, 2016, (61 days). The experiment water was changed once in the middle of the experiment.

2.3. Sampling and analysis

Water samples were collected every 7 days at 9:00 a.m. TN, TP, NH_4^+-N, and NO_3^--N were analysed using flow injection analysis with a Skalar San + + System (Skalar Co., The Netherlands). Chemical oxygen demand was measured using a COD analyser (DR1010 COD, *HACH*, China). Chlorophyll-a (Chl-a) in the water was measured by an ethanol-non-grinding method (Yang et al., 2011). Air temperature and water temperature were recorded every 30 min by a temperature recorder (RC-30B, *Elitech*, China). Water pH, dissolved oxygen (DO), and electrical conductivity (EC) were monitored on-site prior to water sampling.

Plant height, root length and SPAD values were measured before the mid-experiment water exchange and at the end of the experiment. The plant height and root length were measured with a ruler. The SPAD value was determined by SPAD-502, a chlorophyll meter produced in Japan. At the end of the experiment, plant samples were collected and separated into their aboveground and underground components, washed with deionized water, and later dried in an oven at 65 °C to a constant weight. After grinding, subsamples were digested using the sulphuric acid-hydrogen peroxide (H_2SO_4-H_2O_2) method. The N concentration was then determined via the Kjeldahl method (AOAC, 2005; Lu, 2000), and the P concentration was analysed using the vanadium molybdate yellow colorimetric method (Okalebo et al., 2002; Lu, 2000). N and P accumulations were determined by multiplying the N or P concentration by the dry sample weight.

After plant harvesting, plant root samples of each mat were collected and washed carefully. Then a digital scanner (V700 photo, EPSON, Japan) was used to store the complete image of the root system to a computer. After that, root analysing software (WinRHIZO Pro) was used to analyse total root length, surface area, volume and average diameter.

2.4. Statistical analysis

The plant growth status and tissue nutrient concentration were compared using independent samples T-tests between Group Low or High, and the controls (SPSS 13.0).

3. Results

3.1. Physical-chemical parameter variations

The average air temperature and water temperature changed over time and ranged from 4.1 to 19.1 °C and 6.0 to 14.5 °C (Fig. 2a). The pH values of Group Low and Group High decreased gradually during the experiment, but increased overall with a sudden drop after water exchanging in the controls (Fig. 2b). Similar trends were observed in DO variations (Fig. 2c). The initial EC value was lower in Group Low than in Group High, and they both declined before and after the water exchange (Fig. 2d). In contrast, the EC values in Control Low and Control High decreased gradually.

3.2. Removal of pollutants

Changes in the concentrations of TN, NH_4^+, NO_3^-, TP, COD, and Chl-a in each treatment group are shown in Fig. 3. The TN concentrations of Group Low and Group High decreased rapidly before and after water exchanging, and the removal rates of TN were 88.8% and 86.8% in Group Low, and 96.1% and 95.0% in Group High. In contrast, the TN concentrations of the controls changed slightly, and the removal rates of TN were 10.5% and 51.3% in Control Low, and 9.4% and 36.7% in Control High. The NH_4^+ concentration trends were similar to that of TN, with the removal rates of 92.5% and 91.1% in Group Low and 99.1% and 97.9% in Group High, respectively, before and after water exchanging. Similarly, the NO_3^- concentrations of Group Low and Group High declined sharply before and after the water exchange, and the removal rates were higher than 90%. The TP concentrations of Group Low and Group High declined rapidly before water exchanging, and the removal rates of TP were 84.6% and 83.0%, respectively. However, TP concentration decreased at first and then increased in every group during the second phase of the experiment. The COD concentrations were relatively higher in Group Low and Group High compared to the controls, especially in the first phase of the experiment. The COD values ranged from 5.5–20.9 mg/L and 7.0–26.7 mg/L in Group Low and Group High, respectively. The Chl-a concentration was low in each group during water exchanging; however, the values in the controls increased significantly at harvest.

3.3. Changes of COD/N ratio

Changes of the COD/N ratio (N was expressed as TN concentration) are shown in Fig. 4. The COD/N ratios were higher in Group Low than Group High during the first 20 days, and then increased rapidly after 15 days. In contrast, the COD/N ratios of the controls were no more