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Effect of intermittent operation on contaminant removal and plant growth in vertical flow constructed wetlands: A microcosm experiment

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ABSTRACT

The influences of intermittent operation and different length of drying time on contaminant removal as well as wetland plant growth in vertical flow constructed wetlands (VFCWs) were investigated in this study. Microcosm wetlands planted with *Phragmites australis* were subjected to a 4-month experiment involving different operations (continuously and intermittently flood) and time ratios of flood to drain (F/D) with the hydraulic loading of 0.10 m^3/m^2/batch. It was found that the intermittent operation promoted a lower level of COD and TP removal. The intermittent operation caused more oxidizing conditions in the microcosm wetlands and thus greatly enhanced the removal of ammonium, and the removal efficiency was more than 90%. However, the intermittent operated wetlands had lower TN removal efficiencies the flooding system. With different lengths of drying time, the COD and TP removal were similar. The removal of ammonium was enhanced at a lower level with the prolongation of drying time. Contrarily, the TN removal was lower at F/D = 1:2 (46.86%) than at F/D = 2:1 (56.32%). The detected results of photosynthetic rate of *Phragmites australis* showed that the intermittent operation had no harmful effect on the wetland plant and the plant could grow normally.

1. Introduction

Vertical flow constructed wetlands (VFCWs) have been widely used in recent years for treatment of municipal wastewater, owing to the advantages of good efficiency, low cost and low maintenance. The contaminant removal involves many processes including microbial degradation, plant uptake, sorption, sedimentation, filtration and precipitation [1]. However, the subsurface-flow constructed wetlands, either horizontal or vertical flow, were faced with problems during removal of nitrogen and phosphorus [2]. The main reason for poor N removal, especially ammonium removal, was incomplete nitrification due to the limited oxygen availability in substrates [3]. So the oxidation-reduction condition of the wetland is critical for the removal of nitrogen. Microbial degradation and plant uptake are the dominant processes for the removal of organic compounds and nutrients [4]. Macrophyte is one of the main biological components of wetlands. It can assimilate contaminant directly into their tissues, and also acts as catalysts for purification reactions, increasing environmental diversity in the rhizosphere and promoting a variety of chemical and biological reactions [5]. Therefore, the growth of macrophyte has an important effect on the contaminant removal.

In order to improve the redox conditions and in turn to improve the removal efficiency of VFCWs, the artificial aeration is usually used and has been much studied [6–8]. It can increase biological activities and stimulate nitrification denitrification mechanisms [9]. However, artificial aeration requires energy input and additional cost, and the operation is complex. Actually, the operation of intermittently flood and drain can also improve the redox conditions of the CWs, and this method is of low cost and simple. During the flood drain cycle, thin water films surrounding plant roots and substrate biofilms are exposed to atmospheric oxygen. Diffusion of oxygen through such thin films is rapid, with saturation occurring within a matter of seconds [10]. Many studies on the intermittent operation were carried out in sewage treatment systems such as filtration systems [11,12]. Zhang et al. (2005) found that the nitrogen removal rate was enhanced to 91% by intermittent operation compared to 77.7% realized by the continuous feeding mode in a subsurface wastewater infiltration system [13]. In CWs, this method is usually used to solve the substrates clogging which often occurs to the SSFCWs [14,15], and several literatures have focused on the effect on the contaminant removal in SSFCWs. Li et al. (2008) studied the vertical flow constructed wetlands (VFCWs) and found that the removal rate of COD, TP and TN decreased and the removal rate of ammonium increased by using intermittent operation measures [15].

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Caselles-Osorio and García (2007) evaluated the effect of continuous and intermittent feeding strategies on contaminant removal efficiency of shallow horizontal subsurface-flow constructed wetlands and found that the ammonium removal efficiency in the intermittent fed system was 9–14% higher than in the continuous fed system [16].Tidal wetland and reciprocating constructed wetlands were invented in recent years [10,17,18]. However, the tidal or reciprocating wetlands were termed tidal flow when several flood and drain cycles occur daily to enhance the physical removal of contaminant. The HRT was short and the operation was complex. Several authors have also reported information relating to the time of drainage and filling in wetlands [18,19]. However, the impact on the contaminant removal was not illustrated in detail. So was the impact on the growth of *Phragmites australis*.

The objective of the present investigation was to evaluate 1) the influence of the intermittent operation on urban wastewater contaminant removal efficiency; 2) the relationship between the length of drying time and contaminant removal; and 3) the effect of the intermittent operation on the growth of the wetland plant.

2. Materials and methods

2.1. Microcosm wetland system

Nine duplicate wetlands were constructed using circular barrel-type polyethylene containers, each one of which had a surface area 0.24 m^2 and depth 65 cm (Fig. 1). The microcosm wetlands consisted of three successive layers of the following substrates: a 5-cm bottom layer of 4–5 cm diameter washed river gravel, which served as the drainage layer; a 40-cm main layer of 1–3 cm diameter washed gravel for the microcosms. Finally, a 15-cm layer of washed sand was added at the top, facilitating dispersion of applied wastewater and the growth of plants. An effluent outlet was set at the bottom of each container. A valve was placed at the interface of sand layer and gravel layer to control the water level. One vertical, perforated PVC pipe (65 cm in length and 3 cm in diameter) was inserted into the substrate in the middle of each wetland system to enable measurements of various physical and chemical parameters. All the microcosms were planted with *P. australis* in March 2009 and placed outdoors in the Baihua Park in Jinan, China. The *P. australis* was transplanted from the same place and had no difference. After planting, the microcosms were kept flooded for about one and a half months until the macrophyte was well established.

2.2. Experimental procedure

In May 2009, the microcosms established were fed with wastewater. For health and safety reasons, synthetic wastewater was used in this study by mixing (in tap water) the following different components: 312 mg/L sucrose, 188 mg/L $(NH_4)_2SO_4$, 17.5 mg/L KH_2PO_4, 10 mg/L $MgSO_4$, 10 mg/L $FeSO_4$, and 10 mg/L $CaCl_2$. Nitrate came from the tap water. Table 1 shows the composition of the influent. The C:N:P ratio was about 85:10:1. Sequencing fill-and-draw batch mode was used for influent mode. The synthetic wastewater was prepared prior to each feeding. At about 8:00 am on the first day of each cycle, the wastewater was pumped into the microcosms within 10 min until the water overflowed from the water level control valve. The wetlands were fed every three days. The water depth was kept about 45 cm. And the hydraulic load (HL) was about 0.10 m^3/m^2/batch.

To determine the influence of intermittent operation on microcosm wetlands performance, three systems with different stage fractions were used: F/D = 1:2 subject to one day flooding and two days drying; F/D = 2:1 subject to two days flooding and one day drying; F/D = 3:0 subject to flood during the whole hydraulic retention time of 3 days. Effluent was discharged from the outlet on the bottom of the microcosms. The entire experimental process was illustrated in Fig 1. Each system was conducted in triplicate with three treatment cells.

After running for about two months, the effluent concentrations of the microcosm wetlands became stable. From July 2009 on, influent and effluent of the microcosms were sampled to evaluate their transformation and treatment performance. Meanwhile, the photosynthetic rate of *P. australis* was tested. The whole experiment lasted for four months, from July to the end of October, which was the growth period of *P. australis*.

2.3. Water sample and analysis

The influent was sampled before the wastewater was pumped into the microcosms. And the effluent samples were taken from the outlet before the water was drained from each unit at about 7:30 am. A certain amount of tap water was added into the wetlands to make up the lost water caused by evapotranspiration. The application was carried out several hours before collecting the samples to make sure the water was fully mixed. In addition, water samples were collected daily to evaluate the transformation of contaminant. The samples were taken to the laboratory and analyzed immediately for organic matter (COD), ammonium, nitrate, nitrite, total nitrogen (TN) and total phosphorus(TP) using the methods as described in APHA-AWWA-WPCF [20]. Water temperature, pH values, dissolved oxygen (DO) measurements were obtained by monitoring the water within the vertical perforated pipe in situ and were taken at the midpoint of the water depth. DO was measured using a DO meter (HQ 30d 53LED™, HACH, USA) and pH was measured using a pH meter (LIDA 220, China). The measurements were conducted four times a month.

2.4. Determination of net photosynthetic rate and plant height

The net photosynthetic rate of *P. australis* was analyzed using portable photosynthesis measurer (Li-6000, Li-COR, USA). The experiment was conducted twice in August and October and measurements were taken between 9:00 and 11:00 am on a sunny day. Each measurement was repeated three times.

The height of *P. australis* was measured every ten days since the microcosms were fed with wastewater in May.

2.5. Statistical analysis

All statistical tests were performed with the statistical program SPSS 11.0 (SPSS Inc., Chicago, USA). The tables and figures show the results of averaged data obtained from the triplicate microcosms of each system. In order to evaluate the effect of different operations on the removal rate of contaminant, independent-sample *T* test was used. And spearman correlation was used to analyze correlations of the different nitrogen forms. For all tests, differences were considered as significant only if $p < 0.05$.

3. Results and discussion

3.1. Effect of intermittent operation on the wetland performance

The microcosm wetlands performance was compared between the intermittent operated systems (F/D = 1:2 and 2:1) and the flooding system (F/D = 3:0) in this study. The pH values measured at the perforated pipe changed slightly during one cycle of 3 days in the three systems (Fig. 2a). During the three days, the pH values changed little and maintained around 6.96–7.27. And throughout the whole experimental period, the pH values in the intermittent operated systems were 7.22 (±0.33), 7.23 (±0.29) respectively, for F/D = 1:2 and 2:1 systems, which were slightly higher than the value of 7.18 (±0.30) in the flooding system and no significant difference between the three systems was found. The temporal changes of DO in