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Short Communication

Effects of intermittent aeration on pollutants removal in subsurface wastewater infiltration system

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HIGHLIGHTS

- Intermittent aeration achieved high removal of COD, TP, NH_4^+-N and TN.
- Intermittent aeration created aerobic conditions in upper matrix.
- Microbial populations, NR and NIR activities increased in intermittent aeration.
- Intermittent aeration provided an appealing option for SWISs.

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ABSTRACT

In this study, the pollutant removal performances in two pilot-scale subsurface wastewater infiltration systems (SWISs) with and without intermittent aeration were investigated. Matrix oxidation reduction potential (ORP) results showed that intermittent aeration well developed aerobic conditions in upper matrix and anoxic or anaerobic conditions in the subsequent sections, which resulted in high NH_4^+-N and TN removal. Moreover, intermittent aeration increased removal rates of COD and TP. Microbial populations and enzyme activities analysis proved that intermittent aeration not only obviously boosted the growth and reproduction of bacteria, fungus, actinomyces, nitrifying bacteria and denitrifying bacteria, but also successfully increased nitrate reductase (NR) and nitrite reductase (NIR) in the depth of 80 and 110 cm. The results suggest that the intermittent aeration could be a widespread research and application strategy for achieving the high removal performance in SWISs.

1. Introduction

Subsurface wastewater infiltration systems (SWISs) are currently a well-accepted friendly ecological process for decentralized wastewater treatment (Li et al., 2011). Satisfactory organic removal performances can be achieved and nitrogen removal efficiency varies greatly with wastewater quality, environmental conditions and operating conditions in SWISs (Wang et al., 2010). Many studies have shown that the insufficient supply of oxygen is the major cause of limited nitrogen removal in land treatment systems (Zhang et al., 2005; Fan et al., 2013). Nowadays, treatment wetlands with active aeration have gained attention because they are capable of improving the removal of organic carbon, nitrogen and pathogens (Dong et al., 2012). However, the artificial aeration in most studies is performed in continuous mode (Maltais-Landry et al., 2009), which always leads to contradiction between the removal of NH_4^+-N and TN because of the lacking in favorable (i.e. alternate aerobic/anaerobic) conditions for nitrification and denitrification. Recent study report enhanced nitrogen removal by the use of intermittent artificial aeration in wetlands (Fan et al., 2013). However, so far no studies investigate on the application of intermittent aeration in a SWIS. Unfortunately, the characteristics of microbial populations and enzyme activities involved in pollutants removal are not clear about this system (Li et al., 2011). This paper focuses on a pilot-scale experiment consisting of two SWISs treating decentralized domestic wastewater. Pollutants removal was evaluated in a side-by-side comparison of a non-aerated and an intermittently aerated SWIS in order to assess the effect of intermittent aeration. Matrix oxidation reduction potential (ORP) level, main microbial populations and enzyme activities involved in pollutants removal were also studied.

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2. Methods

2.1. System description and operation

Two microcosm SWISs made from clear plexiglass (120 cm in length and 50 cm internal diameter) were performed in parallel in a greenhouse environment, which were operated under different conditions. Sampling ports were installed at 50, 80 and 110 cm from the top of the SWIS to test microbial quantity and enzyme activities involved in pollutants removal process. Pt electrodes coupled with calomel electrodes were buried in advance in the depth of 50, 80 and 110 cm to monitor ORP of pilot systems. The 10 cm of deep gravel (10–20 mm, diameter) was prepared at the bottom to support infiltration system and evenly distribute the treated water. Wastewater was continuously fed into each SWIS at a hydraulic loading of 0.06 $m^3/(m^2\,d)$ from a feed tank through a rubber hose with flow rate control valves. Distributing pipe was installed in the depth of 50 cm below the surface. The treated wastewater was collected at the bottom of the column near the outlet. Each infiltration system filled with the same matrix made of 80% brown soil and 20% cinder in weight ratio.

System A (SA) was composed without aerated units. System B (SB) was installed with aeration units which consisted of air compressors, air tubes and micro-bubble diffusers at a height of 40 cm, which had four aerated/non-aerated cycles (A/N) every day. In each A/N cycle, the system was firstly subject to aeration for one hour with an airflow rate of 2 L/min, and then has five hours interval without aeration. The aeration would begin at 0 AM, 6 AM, 12 PM, and 6 PM, respectively.

The experiment began in May and lasted for more than three months in 2014. During the experimental period, temperature was 22 ± 2 °C. Wastewater from Shenyang Normal University Campus was used. The wastewater quality indexes were pH 6.7–7.5, COD 185.3–262.4 mg/L, TN 33.9–46.7 mg/L, TP 4.6–8.3 mg/L, NH_4^+-N 30.3–44.6 mg/L.

2.2. Sampling and analytical methods

Water samples were taken from influent and effluent to analyze the transformation of organics, phosphorus and nitrogen in two systems. COD, TN, NH_4^+-N, NO_3^--N, NO_2^--N and TP of the water samples were analyzed according to the standard methods (APHA, 2003). Matrix samples were collected from sampling ports after the experiments. All samples were taken to the laboratory and analyzed immediately. The results were repeated for three times.

The number of bacteria, fungus and actinomyces were determined by plate counts (Pan et al., 2013). The nitrifying and denitrifying bacteria were counted using the most probable number (MPN) calculation (Li et al., 2011). Urease activity, Nitrate reductase (NR) activity and Nitrite reductase (NIR) activity in the matrix was measured according to the method of Li et al. (2011).

3. Results and discussion

3.1. ORP profile in an aerated/non-aerated cycle and treatment performance in two SWISs

Soil ORP has been widely used instead of the dissolved oxygen (DO) concentrations to indicate soil aeration conditions. Different redox conditions are easily distinguished through the ORP profile of a system. Fig. 1(a) shows the ORP profile in an aerated/non-aerated cycle. The difference was distinct between the SWISs with intermittent aeration and without aeration. In SA, the average ORP were −48.6, −173.4 and −256.8 mV in the depth of 50, 80 and 110 cm, respectively, which indicating that the non-aerated system was under anoxic or anaerobic condition. In the vertical direction, previous work has suggested that the ORP decreased with depth (Zhang et al., 2005). Previous studies by Zhang et al. (2005) showed that the oxygen from air diffused to the matrix was limited and the prevailing conditions in the SWISs were anoxic or anaerobic below distributing pipe. As for the average ORP changed in SB, a similar tendency was observed for all depth, i.e. matrix ORP increased in aerated period, but decreased slowly in non-aerated period. The average ORP could be more than 181 mV during aeration and as high as 103 mV when supplementary aeration was turned off in the depth of 50 cm. However, in the depth of 80 and 110 cm, the average ORP was −48.3 and −165.7 mV during aeration, and was −104.6 and −218.8 mV without aeration. In contrast, aerobic condition was effectively developed in the depth of 50 cm and anoxic or anaerobic condition was not changed in the depth of 80 and 110 cm within SB by intermittent aeration. High aeration-induced ORP values may be reduced by the decomposition of nutrients and organic matters, which may explain the decreasing tendency in non-aerated period.

In a SWIS, organic matters were absorbed by the soil, then broken down by aerobic and anaerobic microbial processes, and mineralized as a source of energy or assimilated into biomass (Li et al., 2011). The aerobic heterotrophic bacteria played an important role in the aerobic degradation of organic matters. Domestic wastewater was richer in dissolved organic matters and disadvantageous aerobic and anaerobic environment always limited its degradation (Fan et al., 2013). Fig. 1(b) shows the COD concentrations and removal rates in the long-term experiment. The average COD effluent concentration was 19.3 mg/L, with the average removal rate 91.4% in SB and declined to 39.9 mg/L in SA. The average removal rate of COD was 81.8% in SA, with a remarkable decrease by 9.6% compared with that of SB. The intermittent aeration strategy in SB obviously improved the removal of COD, which was in accordance with other studies (Fan et al., 2013; Ong et al., 2010). Ong et al. (2010) reported that sufficient oxygen supply would greatly elevate the performance of aerobic biochemical oxidation. The intermittent aerobic conditions in SB enhanced the growth of aerobic microbes and thus facilitated aerobic removal of organic matters.

Physical sedimentation, chemical adsorption were the main ways of phosphorus removal in SWISs, which could complete instantaneously (Brooks et al., 2000). TP concentrations in effluent were all steadily under 0.45 mg/L in two systems, reflecting the effectiveness of SWISs in removing TP (Wang et al., 2010) (Fig. 1(c)). In SB, the average TP removal rate (95.9%) was a few higher than non-aerated SA (93.8%). The intermittent aeration strategy enhanced the removal of TP, which was in accordance with other study (Zhong et al., 2014). However, the improvement of artificial aeration on TP removal was limited (Dong et al., 2012). Brooks et al. (2000) revealed the positive correlation between phosphorus removal rate and the matrix area. In this study, intermittent aeration enhanced contact between phosphorus and matrix, which was beneficial to physical sedimentation and chemical adsorption of phosphorus removal.

In a SWIS, nitrification coupled with denitrification was the major removal process through the mechanisms as follows (Zhang et al., 2005):

$$NH_4^+ + 2O_2 \xrightarrow{\text{Nitrifying bacteria}} NO_3^- + 2H^+ + H_2O - 351\ \text{kJ}$$

$$6NO_3^- + 5CH_3OH \xrightarrow{\text{Denitrifying bacteria}} 5CO_2 + 7H_2O + 6OH^- + 3N_2 - 3276.6\ \text{kJ}$$

The above equations revealed that complete TN elimination relied first on complete nitrification, which is an aerobic chemo-autotrophic microbial process. Most conventional SWISs