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Removal of nutrients from septic tank effluent with baffle subsurface-flow constructed wetlands

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ABSTRACT

Three new baffle flow constructed wetlands (CWs), namely the baffle horizontal flow CW (Z1), baffle vertical flow CW (Z2) and baffle hybrid flow CW (Z3), along with one traditional horizontal subsurface flow CW (Z4) were designed to test the removal efficiency of nitrogen (N) and phosphorus (P) from the septic tank effluent under varying hydraulic retention times (HRTs). Results showed that the optimal HRT was two days for maximal removal of N and P from the septic tank effluent among the four CWs. At this HRT, the Z1, Z2, Z3 and Z4 CWs removed, respectively, 49.93, 58.50, 46.01 and 44.44% of TN as well as 87.82, 93.23, 95.97 and 91.30% of TP. Our study further revealed that the Z3 CW was the best design for overall removal of N and P from the septic tank effluent due to its hybrid flow directions with better oxygen supply inside the CW system.

1. Introduction

Constructed wetlands (CWs) are increasingly gaining acceptance worldwide for removing contaminants from wastewaters due to their moderate capital cost, low energy consumption, and less maintenance requirement (Vymazal, 2002, 2007). Among several types of CWs, the free water surface, vertical-flow and horizontal subsurface-flow CWs are the most commonly used CWs for wastewater treatments. However, these CWs normally have low nutrient removal efficiency due to their low dissolved oxygen (DO) content in the substrate for nitrification and then denitrification is limited because of insufficient nitrate content (Brix, 1987; Cooper et al., 1996; Cooper and Green, 1995). In recent years, the hybrid CWs have been applied to purify wastewaters in many countries. These CWs combined horizontal and vertical subsurface-flow designs to complement each other for better DO supply in the CW system and are ideal to achieve better nutrient removal efficiency (Vymazal, 2005; Tuncsiper, 2009; Cui et al., 2012). However, the hybrid CWs have some limitations due to their larger land area requirement and lower removal efficiency of P (Zeng et al., 2006). Therefore, the baffle subsurface-flow CWs have been designed in recent years to improve nutrient removal efficiency from wastewaters.

The baffle subsurface-flow CW is a new type of CW and has a better pollutant removal efficiency as compared to the traditional CWs (Tee et al., 2012; Cui et al., 2013). This CW is based on the traditional CW with increasing baffle through the horizontal and vertical directions to make wastewater repeatedly flow through the CWs. Thus, the pollutant removal efficiency is improved (He et al., 2006; Tee et al., 2012). The advantage of the baffle subsurface-flow CW is the use of up and down flows sequentially for improving the nutrient removal. This design enhances the water twists to prolong water pathway by forcing the wastewater to flow up and down. That is, wastewater was forced to passes through the aerobic zone (upper layer) and the anoxic zone (lower layer), and thereby the nitrification and denitrification can be completed alternatively.

The baffle subsurface-flow CW is commonly filled with graded gravels as the growing medium. This material supports the plant growth, but has a very low P sorption capacity (Vymazal, 2010). In recent years, other materials such as furnace steel slag, coal ash (Zhu et al., 2003), and rice husk (Tee et al., 2009, 2012) are used as the growing media with success. Zhu et al. (2003) reported that using the furnace steel slag as a medium, the removal efficiency is 80–89% for total P (TP), while using the coal ash as a medium, the removal efficiency is 70–85% for TP. Their study showed that furnace steel slag and coal ash are the ideal media for filling the CWs. Although the above studies have provided useful insights into

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the applications of the newly designed baffle subsurface-flow CWs, more studies are still needed to estimate their feasibilities.

The aims of this study were to: (1) investigate the removal of N and P from septic tank effluent by using four types of CWs, namely the baffle horizontal flow, baffle vertical flow, baffle hybrid flow, and horizontal subsurface flow (as a control) CWs. These CWs were filled with furnace steel slag and operated at different hydraulic retention times (HRTs); (2) identify the optimal baffle CWs and their operating parameters for maximal removal of N and P from the septic tank effluent; and (3) estimate the removal rate of N and P from the effluent by the aboveground biomass of canna (*Canna indica* L) plant species.

2. Materials and methods

2.1. Constructed wetland system

A schematic diagram showing a plane view of the four different types of CWs used in this study was shown in Fig. 1. They are horizontal baffle flow (Z1), vertical baffle flow (Z2), hybrid baffle flow (Z3) and horizontal subsurface flow (Z4). The first three cells were further divided into five compartments for different water flow paths. A pool was built into four concrete cells and each cell represents one type of the CW. Each cell was 2 m in length, 1 m in width, and 0.75 m in height and was divided into five compartments (Fig. 1). For the horizontal baffle flow (Z1) CW, the baffles were 0.9 m in length and 0.75 m in height. Therefore, the wastewater can only flow horizontally, but not vertically through the bottom of the compartments due to the baffle separation. For the vertical baffle flow CW (Z2), the first and third baffles were 1 m in length and 0.6 m in height, whereas the second and fourth baffles were 1 m in length and 0.65 m in height. Additionally, there were five holes each with a diameter of 0.05 m along the baffle width at an interval of 0.2 m for the second and fourth baffles. The wastewater entered into the first compartment vertically and overflowed (or spilled) into the second compartment. It then flowed from the second compartment to the third compartment through the baffle holes at the bottom. The wastewater flow path from the third compartment into the fourth compartment was the same as that from the first compartment into the second compartment, while the wastewater flow path from the fourth compartment into the fifth compartment was the same as that from the second compartment into the third compartment. For the hybrid baffle flow (Z3) CW, it had both the Z1 and Z2 CW designs and the wastewater flow path was a combination of the Z1 and Z2 CWs.

Table 1
The compositions of wastewater used for the experiment (mg/L).

Index	Variation range	Average
TN	52.46–234.12	145.20 (6.27)[a]
TP	3.31–50.05	12.72 (1.12)
BOD_5	11.12–214.32	84.78 (7.05)
COD	65.89–793.70	233.59 (18.78)
NH_4^+-N	34.65–240.66	137.93 (6.73)
pH	6.64–8.20	7.68 (0.071)

[a] Values in the parentheses were standard errors (S.E.).

Each cell (or CW) was first filled with 10-cm limestone with a particle diameter of 4 cm at the bottom, and then with 4-cm gravel with a diameter of 1–2 cm as the supporting layer. For the first three baffled subsurface flow CWs (i.e., Z1, Z2, and Z3), the first compartment was filled 25% cinder, 25% rubble, and then 50% blast furnace slag, and the rest of the four compartments for the first three CWs (or cells) were filled with 55 cm thick blast furnace slag above the gravel layer. For the control CW (Z4) (or the conventional horizontal subsurface flow CW), all of the compartments were filled with 55 cm thick blast furnace slag above the gravel layer. Finally, a layer of 3 cm fine sand was spread on the top of the four cells.

The four CWs were planted with yellow flower canna (*C. indica* L), and the average cultivation density of each compartment was three strains. Canna is a perennial herbaceous flower, up to 1 m tall.

2.2. Constructed wetland operation

The four CWs were operated for 24 months from March 2005 to March 2007, with three different hydraulic retention times (HRTs) of 1, 2, and 3d. These HRT schedules made the CWs dried and rewetted. Effluent was added to the CWs at a set rate according to different HRTs. Occasionally, the effluent was discharged at a faster rate when the wetland bed needed for recovery. The plants were harvested each quarter to analyze water, total N (TN), and TP contents. The removal efficiency of TN, TP, and ammonia nitrogen (NH_4^+-N) with varying HRTs by the four CWs was estimated to determine the optimum HRTs.

The wastewater (or effluent) was obtained from the septic tank

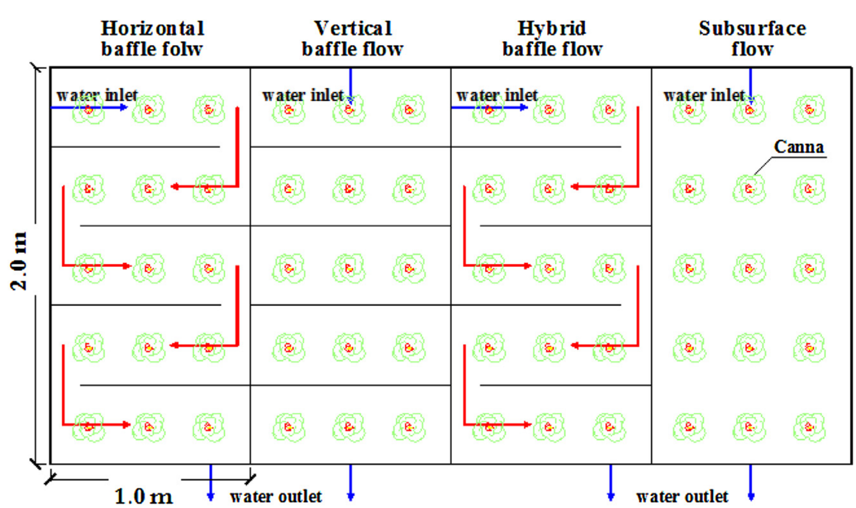

Fig. 1. A schematic diagram showing four different types of constructed wetlands, including horizontal baffle flow (Z1), vertical baffle flow (Z2), hybrid baffle flow (Z3), and subsurface flow (Z4) constructed wetlands.