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Impacts of salinity on degradation of pollutions in hybrid constructed wetlands

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ABSTRACT

To investigate the impact of salinity on the pollution removal performance of constructed wetlands (CWs), four sets of hybrid CWs (HCW) were considered herein. The HCWs were composed of free water surface flow (FWS) and subsurface flow (SSF) CWs that were planted with cattail (*Typha orientalis* Presl.) and reed (*Phragmites communis* Trin.), respectively. After a preliminary experiment of almost seven months with influent fresh wastewater, NaCl was added at concentrations of 5 ppt, 10 ppt, and 20 ppt to simulate the impact of salinity. The removal performance was compared with that of the control CWs, and the impact of salinity on FWS CWs, SSF CWs, and HCWs were investigated. According to the experimental results, the biochemical oxygen demand (BOD) removal ratio in FWS CWs decreased from 70.3% to 58.3% as salinity increased from 0 ppt to 20 ppt, while that in SSF CWs fell significantly from 53.5% to 36.9% as salinity increased to ≧10 ppt. However, hybrid CWs offered more stable BOD removal and ammonia-nitrogen (NH_3-N) removal under salinity impact. Salinity≧10 ppt stimulated the removal performance of NH_3-N in FWS CWs to 19.4% while salinity≦5 ppt had no significant effect. In SSF CWs, a linear relationship was observed between removal loading and salinity, and NH_3-N removal completely ceased at a salinity of 30.6 ppt. All removal ratios of NO_3^--N>94.9% in FWS CWs revealed that salinity had almost no impact because the environment was anaerobic and contained sufficient organic carbon. The TP removal ratio in FWS CWs decreased from 14.7% to 9.2% as salinity increased from 0 ppt to 20 ppt and that in SSF CWs decreased monotonically from 7.2% to −0.2%. The impact period of salinity showed versatile reaction patterns of pollution removals in FWS CWs, SSF CWs, and HCWs. It distributed from 28 days to 186 days, after which the removal performance of CWs was restored.

1. Introduction

Constructed wetlands (CWs) have been used worldwide to treat domestic and industrial wastewater, aquacultural and agricultural effluents, polluted river and landscape water, landfill leachates, and storm water runoff (Carleton et al., 2001; Chyan et al., 2016b; Lin et al., 2015; Nivala et al., 2007; Sun et al., 2005; Torrijos et al., 2016; Trang and Brix, 2014; Zhang et al., 2016). CWs have a minimal need for fossil energy and associated low operational costs (Saeed and Sun, 2012; Zhang et al., 2010). However, the processes by which pollutants are removed in CWs are complex, and the mechanisms include sedimentation, filtration, precipitation, volatilization, adsorption, plant uptake, and various microbial processes. Many investigations of the relations between these processes, affecting factors, and pollution removal performance, have been published in recent years (Vymazal, 2007; Wu et al., 2014). In March 2011, Japan was hit by a tsunami, which caused sea water inundation. Contamination by saltwater was so extensive as to prevent rice production (Chagué-Goff et al., 2012; Mimura et al., 2011). Tidal restoration, rising sea levels and temperatures, reductions in rainfall, anthropogenic disruption of natural drainage routes and storm surges may all increase the salinity (S) of wetlands (Johns et al., 2014; Spalding and Hester, 2007). The effects of saline intrusion into freshwater CWs are important in the management of CWs. The intrusion of salt can potentially have a negative impact on macrophytes and associated microbial communities in CWs (McKee et al., 2016).

High salinity reduces water potential by increasing osmotic stress, reducing nutrient uptake, and exposing tissues to toxic ions.

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High NaCl concentrations have been shown to interfere with cellular processes by altering enzyme activity and interfering with mitosis (Gorham et al., 1985; Janousek and Folger, 2013; Katembe et al., 1998). Macrophyte yield decreases remarkably as surface salinity increases above 5 ppt and the number of species also decreases by as much as 60–70% as salinity increases from zero to 11% seawater. Sodium concentration affects seed germination, biomass, root-shoot ratio, stomatal conductance, evapotranspiration, and photosynthetic rate (Bai et al., 2014; Glaeser et al., 2016; Lin et al., 2016; Smith et al., 2009). By reducing the growth of wetland macrophytes, salinity reduces the ability of some macrophyte species to withstand increases in water depth (Johns et al., 2014). At salinity $\geq$10 ppt, the most species, including those commonly distributed in more saline wetland soils as adults, decline and alter the corresponding germination, therefor shifting plant composition (Espinar et al., 2006; Janousek and Folger, 2013). However, the use of salt-tolerant plants (halophytes) as biofilters to remove pollutants still has potential in wastewater treatment (Brown et al., 1999; Trang and Brix, 2014).

Salinity inhibits microbial activities and the degradation of organic matter, slowing the transformation of organic substrates and ultimately resulting in the accumulation of organic matter in the saline soil (Mamilov et al., 2004; Zhao et al., 2017). Biological indices such as soil respiration and microbial biomass decrease as salinity increases, highlighting the detrimental effect of salinity on soil microorganisms. This effect is weakened by adding organic matter (Wichern et al., 2006). Salinity is also the key determinant of *nosZ*-community composition in the environment. Accordingly, the composition of the denitrifying community in wetland soils is reasonably believed to vary with salinity (Piao et al., 2012). Salinity does not regulate denitrification in either sediments or biofilm, suggesting that halotolerant bacteria dominate denitrifier communities (Magalhães et al., 2005). NaCl retards the process of N immobilization, and especially that of NO_3^--N. Both remineralization and nitrification are significantly delayed in the presence of NaCl (Azam and Ifzal, 2006). However, 15 practical salinity units (psu) and at 30 psμ have been found to increase the nitrification rates of sediments in an estuary by 40% and 17%, respectively. A biofilm on a rock almost entirely eliminates the nitrifier activity at 30 psμ (Magalhães et al., 2005). Salinity affects the growth of bacteria, switching the microbial community and the pollution removal efficiency of CW in the treatment of various wastewaters (Lin et al., 2008; Wu et al., 2008).

The suppression of the pollution removal performance of CWs by salinity has been conclusively demonstrated in previous works. However, details of the impact of salinity remain uncertain and must be further investigated. In this work, the pollutant removal performance of hybrid CWs that combine a free water surface flow (FWS) CW and a subsurface flow (SSF) CW was studied to determine the impact of salinity. The corresponding impact periods of individual and hybrid CWs were also determined for further applications.

2. Materials and methods

2.1. Setup of experimental CW models

As shown in Fig. 1, a FWS CW and a SSF CW were combined in a hybrid system with dimensions of 0.69 m long, 0.48 m wide, and 0.66 m high. The water depth was maintained at 0.4 m in both beds. Filled with gravel with diameters of around 30–40 mm, the SSF CW had an initial porosity of approximately 52%. In FWS CW, the bottom soil, approximately 15 cm deep, was used to grow aquatic plants. Local halophytic macrophytes that had been collected from a nearby estuary, cattail (*Typha orientalis* Presl.) and reed (*Phragmites communis* Trin.), were planted in FWS CWs and SSF CWs, respectively. In previous investigations, adult plants of *Typha orientalis* Presl., which were collected from a field, were found to survive at a salinity of 20 ppt. Salinities of up to 17.5 ppt were found not to affect significantly the growth of *Typha orientalis* Presl. (Matoh et al., 1988; Zedler et al., 1990), and 75% of the rhizome-grown reed plants survive 22.5 ppt salinity (Adams and Bate, 1999; Lissner and Schierup, 1997). Four sets of hybrid CW (HCW) systems, HCW-A, HCW-B, HCW-C, and HCW-D, with the same dimensions and arrangements were established to perform experiments with salinities of 0 ppt, 5 ppt, 10 ppt, and 20 ppt, respectively. HCW-A was the control system. The effects of salinity impact on pollution removal performance and the corresponding impact process were investigated by comparing the experimental results obtained using the control system with those obtained using HCWs that were affected by the saline wastewater.

2.2. Model operations and data analysis

To ensure all CW systems were operated in a quasi-steady state, a preliminary program was conducted for almost seven months with fresh wastewater influent. The influent concentrations of the synthetic domestic wastewater were 111 mg l^{-1} for biochemical oxygen demand (BOD), 33.1 mg l^{-1} for ammonia-nitrogen (NH_3-N), 31.2 mg l^{-1} for nitrate-nitrogen (NO_3^--N), and 4.2 mg l^{-1} for total phosphorus (TP). The hydraulic loading (HL) of HCW was 2.0×10^{-1} md^{-1} and the corresponding organic loading was maintained at 2.22×10^{-2} Kg BOD $m^{-2}d^{-1}$. Typical recommended hydraulic loadings in CW designs range from 1.4×10^{-2} md^{-1} to 4.7×10^{-2}

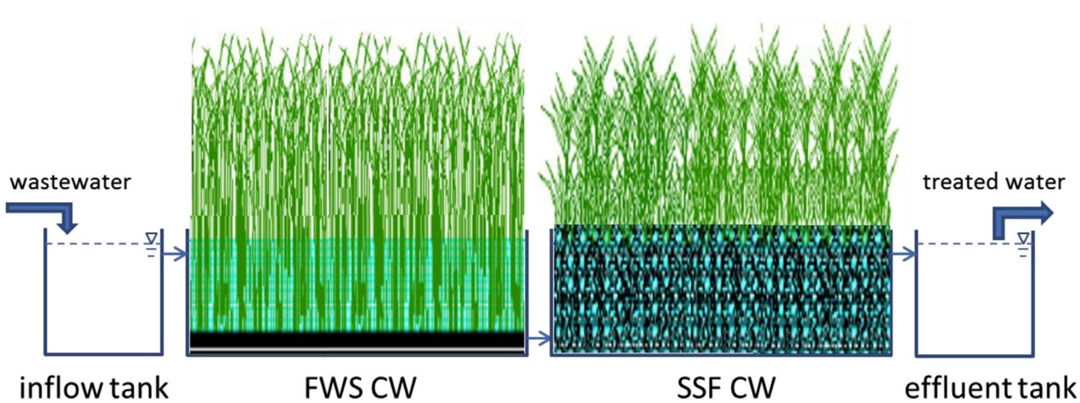

Fig. 1. Layout of hybrid constructed wetland.