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Nitrogen removal along the treatment cells of a free-water surface constructed wetland in subtropical Taiwan

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ABSTRACT

The Daniaopi free-water surface constructed wetland (DNCW), which treats municipal wastewater and nitrogen removal, was compared between the warm and cool seasons in northern Taiwan from March 2009 to August 2010. The results showed that the nitrogen removal in terms of area removal rates (ARRs) were significantly positively regressed with the area loading rates (ALRs) for ammonia nitrogen (NH_3-N), nitrite and nitrate nitrogen (NO_X), particulate organic nitrogen (Org-N), and total nitrogen (TN). The ARR of NH_3-N was 1.69 N g m^{-2} d^{-1} during the warm season and 1.51 N g m^{-2} d^{-1} during the cool season, whereas the concentration removal efficiency (CRE) was approximately 85% for both seasons. The ARR of TN was 1.77 N g m^{-2} d^{-1} during the warm season and 1.32 N g m^{-2} d^{-1} during the cool season. The CRE of TN of 67% during the warm season was higher than the CRE of TN of 46% during the cool season. The CRE of TN was lower than that of NH_3-N, particularly during the cool season, due to the increase in NO_X-N and Org-N in the treatment cells. However, the ARR of NH_3-N and TN were not significantly different between the cool and warm seasons. Our results show that mass loading was a major factor in the nitrogen removal. Atmospheric gains (precipitation minus evapotranspiration) appear to cause an increase in water flow, thereby reducing the loading rate, which reduces the nitrogen removal rate.

1. Introduction

Nitrogen loading in aquatic and terrestrial ecosystems has increased substantially throughout the world due to rapid urbanization and population growth over the past 150 years (Holland et al., 1999; Goolsby et al., 2000; Whitehead and Crossman, 2012). It has altered regional and global nitrogen biogeochemical cycles (Galloway et al., 2004; Jia et al., 2012) and caused extensive eutrophication with hypoxia and anoxia, water toxicity, methemoglobinemia, habitat degradation, food-web structure alteration, and the subsequent loss or reduction of biodiversity (Gerardi, 2002; Camargo and Alonso, 2006; Howarth, 2008; Dunne et al., 2013).

Constructed wetlands (CWs) are man-made wetlands that imitate natural wetlands and function as a type of wastewater treatment facility to remove pollutants (Kadlec and Wallace, 2008). They have been demonstrated to be an effective bioreactor in nutrient removal for treating various types of wastewater for more than 40 years (Vymazal, 2011). CWs have advantages over conventional wastewater treatment facilities because they are easily constructed, have low energy consumption, low operational and maintenance costs, and provide habitats for an extensive diversity of plants and animals (Mitsch and Jøgensen, 2003; Kadlec and Wallace, 2008; Hsu et al., 2011).

The complex processes of nitrogen transformation in CWs include NH_3 volatilization, nitrification, denitrification, nitrogen fixation, plant and microbial uptake, mineralization, nitrate-ammonification, anaerobic ammonia oxidation (ANAMMOX), fragmentation, sorption, desorption, burial, and leaching (Kadlec and Knight, 1996; Green et al., 1998; Vymazal, 2007; Lee et al., 2009). Nitrification and denitrification are the major mechanisms for nitrogen removal in CWs, which may remove 60–90% of the total nitrogen removed (Lin et al., 2002; Faulwetter et al., 2009; Dong and Reddy, 2012). Nitrification and denitrification are generally confined to microbial processes. These processes frequently correlate with temperature and exhibit significant reduction with decreasing temperature (Atlas and Bartha, 1998). The optimal temperature for nitrifying bacteria ranges from 28 to 36 °C, but decreases where

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water temperatures are less than 10 °C and is inhibited below 5 °C (Cookson et al., 2002 Xie et al., 2003). The maximum denitrification rates occurred between 60 and 75 °C and denitrification rates were also suppressed at temperatures below 5 °C (Burchell et al., 2007). Ammonia removal efficacy was limited during the winter months (Vymazal, 2011; Garfí et al., 2012). In addition to the temperature effect, nitrification and denitrification rates are further influenced by pH, available carbon and nitrogen, oxidation–reduction conditions (redox potential), dissolved oxygen, and the microbial community (Vymazal, 2007; Kadlec and Wallace, 2008; Lee et al., 2009; Ding et al., 2012).

Taiwan is situated in a tropical/subtropical zone that experiences a year-round warm climate. The past 30-year (1980–2010) records show that the annual mean precipitation is about 2400 mm with ample rainfall evenly distributed throughout the year in northern Taiwan (http://www.cwb.gov.tw/V7/climate/monthlyMean/Taiwan_tx.htm). The annual mean temperature is about 23.0 °C; the maximum is registered in July (29.6 °C) and the minimum in January (16.1 °C). The warm climate may enable aquatic microbes and plants to remove nutrients in the CW operation. CWs were introduced to Taiwan in the middle 1990s. The first full-scale CW was constructed in 2001, and approximately 82 full-scale CWs were installed by 2006. CWs have been considered to be an attractive method for solving water pollution problems in Taiwan (Lin et al., 2002; Jing et al., 2008). Climate has been shown to affect the performance of nitrogen removal in CWs (Kadlec and Wallace, 2008; Garfí et al., 2012; Vymazal, 2011). Although numerous studies (e.g., Moshiri, 1993; Vymazal and Kröpfelová, 2008) of CWs for wastewater treatment have focused on the temperate region, few tropical and subtropical CWs have been investigated for their effectiveness (Nahlik and Mitsch, 2006). As such, the effects of season and temperature in nutrient removal remain uncertain in tropical and subtropical CWs due to the lack of cold winter temperatures. For the CWs that have been constructed in Taiwan, the treatment performance of a few CWs have been investigated, including the Bamboo Creek CW of Tainan City (Lo, 2006) and the Erh-Ren River CW in southern Taiwan (Jing and Lin, 2004). These studies showed high efficiencies for removing biological oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (NH_3-N), and total phosphorus (TP) (Jing et. al., 2008). For example, Jing and Lin (2004) showed the mass removal rate of ammonia decreased exponentially with increasing temperature in the Erh-Ren River CW. However, the authors deemed that the effect of seasonal temperature change on the ammonia removal is uncertain.

The Daniaopi constructed wetland (DNCW) is a free-water surface (FWS) CW that is situated in the riparian zone of the Da-Han Creek, which is a tributary in the Dan-Shuei River in northern Taiwan (Fig. 1). It was constructed in 2006 with five sequentially arranged treatment cells (Table 1). This study was intended to reveal the mechanisms of nutrient nitrogen removal in the subtropical CW. Our objectives were as follows: (1) to examine the removal efficiencies of nutrient nitrogen for the treatment cells of the DNCW; (2) to determine the seasonal effect on the nitrogen removal efficiencies in this subtropical zone; and (3) to determine potential influencing factors.

2. Materials and methods

2.1. Study site

The DNCW receives municipal wastewater that flows in the stormwater drainage system from the Tucheng and Banquio districts of New Taipei City in northern Taiwan. The wastewater was pumped into the CW at an average flow rate of 7700 m^3 day^{-1}. The remaining wastewater was discharged via the Dai-An Canal into the nearby Dan-Han Creek (Fig. 1).

The DNCW included five treatment cells (DN-1 to DN-5) with a total area of 9.3 ha and a hydraulic retention time (HRT) of 89 h (3.7 days). The pump station was located between DN-2 and DN-3 (Fig. 1). The treatment cells (see Table 1 for the configurations) were sequentially arranged as follows: DN-1 for sedimentation; DN-2 for

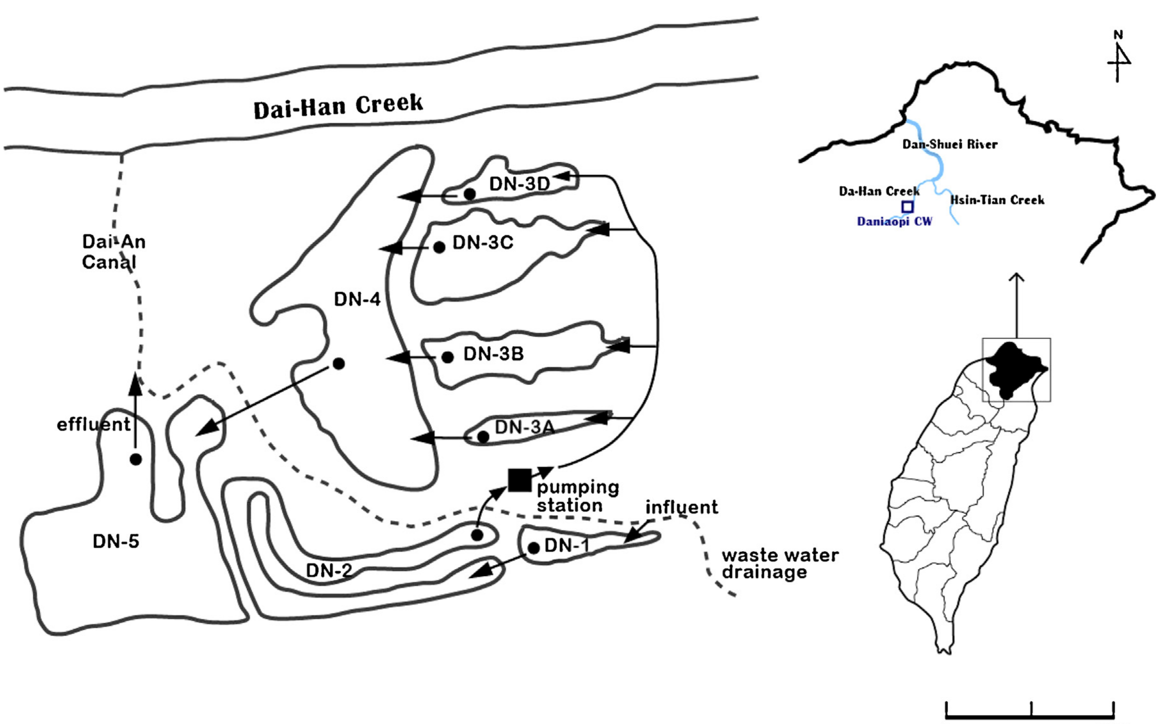

Fig. 1. The study site and treatment cell configurations of the Daniaopi constructed wetland in northern Taiwan.