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Effects of annual harvesting on plants growth and nutrients removal in surface-flow constructed wetlands in northwestern China

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ABSTRACT

The importance of harvest management for the growth and development of plants and nutrients removal in constructed wetlands (CWs) is highly controversial. This study evaluated the effects of annual harvesting on the growth and productivity of local *Phragmites australis* in northwestern China. Growth characteristics such as shoot density, biomass and height were studied using two pilot-scale surface-flow CWs over a two-year operation period. Plants were kept unharvested in one CW for comparative studies with the second CW, which was harvested at the end of the growing season. Each CW of 400 m^2 was operated with a hydraulic loading of 34 m^3/d for the treatment of water from an urban river polluted with municipal and industrial wastewater. The harvested CW recorded a higher shoot density (175 shoots/m^2), biomass (1.4 kg/m^2) and peak height (3.4 m) than the unharvested one (130 shoots/m^2, 1.2 kg/m^2 and 3.2 m). The overall nutrients removals were also slightly higher for the harvested CW (46.0% TN and 38.1% TP) than the unharvested CW (40.6% TN and 29.1% TP). Plants harvesting in the first year improved nutrients removal by plant uptake (41.9 g N/m^2 and 3.7 g P/m^2 versus 37.3 g N/m^2 and 3.2 g P/m^2) as well as in the substrate layer (216.9 g N/m^2 and 8.0 g P/m^2 versus 191.0 g N/m^2 and 5.7 g P/m^2) during the second year. Nonetheless, the increase in nutrients removal by harvesting was minimal.

1. Introduction

Eutrophication of lakes and rivers, which is caused by excessive discharge of nutrients, particularly nitrogen (N) and phosphorus (P) into surface water (Wu et al., 2011), is currently the most widespread environmental water quality problem across the world. Consequently, several appropriate measures are being sought to lower the impacts of nutrient pollution from point sources (Park et al., 1998) and via a variety of pathways (Braskerud, 2002). The use of constructed wetlands (CWs) directly in situ may provide a viable option for improving the water quality of surface waters (Wang et al., 2012). CWs have been widely used to treat various types of wastewater for several decades, due to their simple operation and low implementation costs (Vymazal, 2007).

The presence of macrophytes in free water surface flow (FWS) CWs is one of the most noticeable and significant features for distinguishing CWs from other lagoons (Vymazal, 2013). The macrophytes growing in FWS CWs have several functions in relation to the treatment process such as provision of substrates for the growth of attached bacteria, release of oxygen and exudates, uptake of nutrients, surface insulation and wind velocity reduction (Vymazal, 2013). A large body of evidence indicates that CWs with plants are more efficient compared with unplanted CWs (Borin and Salvato, 2012; Elsaesser et al., 2011; Ibekwe et al., 2007). Nevertheless, the effects of different plant species on CW performance vary considerably (Brisson and Chazarenc, 2009; Iamchaturapatr et al., 2007). On the other hand, the growth and functions of plants can be impacted by several factors such as the climate condition, temperature, plant species and pollutant loadings (Liu et al., 2012).

Due to the importance of plants in CWs, several management strategies have been proposed to improve the plant growth and productivity and the performance of CWs. These proposed strategies include annual harvesting (Toet et al., 2005; Kadlec and Wallace, 2009) and multiple harvesting (Jinadasa et al., 2008; Vymazal et al., 2010). However, the real benefit of plants harvesting for the removal of nutrients or the development of plants biomass remains a highly controversial issue. On one hand, several studies have demonstrated

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that the nutrients uptake by plants can be definitively removed from the wetland by harvesting the aboveground parts of the plants before senescence and decay during the cold season (Vymazal et al., 2010). In addition, it has been demonstrated that harvesting can open up dense vegetated areas to promote the photosynthetic periphyton in the system (Wetzel, 2001). According to Wetzel (2000), both mature and standing dead (withered) plants shade the attached microbial communities, thus, reducing the nutrient retentive capacities of those communities, and also, contribute to short-circuiting of the water flow (Groeneveld and French, 1995). On the other hand, arguments against plant harvesting indicate that the regular harvest of CWs is impractical, does little to improve water treatment, and reduces the readily available carbon source necessary for denitrification (Kadlec and Wallace, 2009). Additionally, some previous studies have pointed out that the withered plants within CWs may have a thermoregulatory effect in winter (Kadlec and Wallace, 2009; Smith et al., 1997). However, studies on this thermoregulatory function, and the competition between the regenerated plants and the withered plants left in the wetland are scarce.

Thus, the regrowth of plants can exhibit marked differences in different plants management practices. Therefore, for the purpose of maximizing the contribution of plants to nutrients removal, an appropriate method for managing the plants needs to be adopted, and require further research. According to Batty and Younger (2004), nutrients uptake and growth rates are higher in young vegetation stands. More particularly, it is important to determine the management strategy that does not adversely affect the regeneration of plants or their capacity to uptake nutrients. Besides, research on the effect of plant management on the growth and development of plants and nutrients removal in large-scale CWs under the climatic conditions of northwestern China are rare, especially during the startup period of the CW operation. Furthermore, the uncertainty of the performance of FWS CWs with the presence or absence of the withered plants over the winter period, and their thermoregulatory effects, in northwestern China, where temperature varies widely, requires research attention. In this study, the growth characteristics of local *Phragmites australis* in northwest China were evaluated under an annual harvest management scheme. The specific objectives were to: (1) assess the growth characteristics and nutrients accumulation in the local *P. australis* under the condition of annual harvesting; (2) evaluate the effects of plants harvesting on the overall performance of the wetland; and (3) analyze the impact of standing withered plants on the performance of FWS CW for treating polluted river water during the cold season.

2. Materials and methods

2.1. Description of the pilot wetlands

The pilot-scale CW system was constructed on the eastern bank near the confluence of an urban river to the Weihe River (the largest tributary of the Yellow River) in Xi'an, northwestern China (34°22′54″N, 108°51′05″E). The area has a sub-humid continental monsoon climate, which is cold and lacks rainfall during the winter. The average monthly temperature reaches a maximum of 26.3 °C in July and a minimum of −1.3 °C in January, with an average annual precipitation of 750 mm. The two FWS CWs used for this study were the second stage of a pilot-scale hybrid CW system, the design of which was described by Zheng et al. (2014). The two CWs were identical (40 m length, 10 m width, 0.6 m height), and were filled with sand to a depth of 0.35 m. The water depth was controlled at 0.4 m. After passing through the first stage of treatment (a subsurface flow CW) the highly polluted river water flowed into the FWS CWs continuously. At this stage, the river water contained low concentrations of organic pollutants, but the concentrations of nutrients (N and P) were still high. The inflow rate to each CW was 34 m^3/d, on average, which corresponds to an average HRT of 1.8 d and a surface loading of 0.085 m/d.

2.2. Plants harvesting scheme

Young *P. australis* (common reeds) were obtained from the field near the riverbank. Plants of similar size (20–30 cm in height) were selected and washed with tap water in order to remove soils and dead tissues from their roots. They were then planted in the CWs at

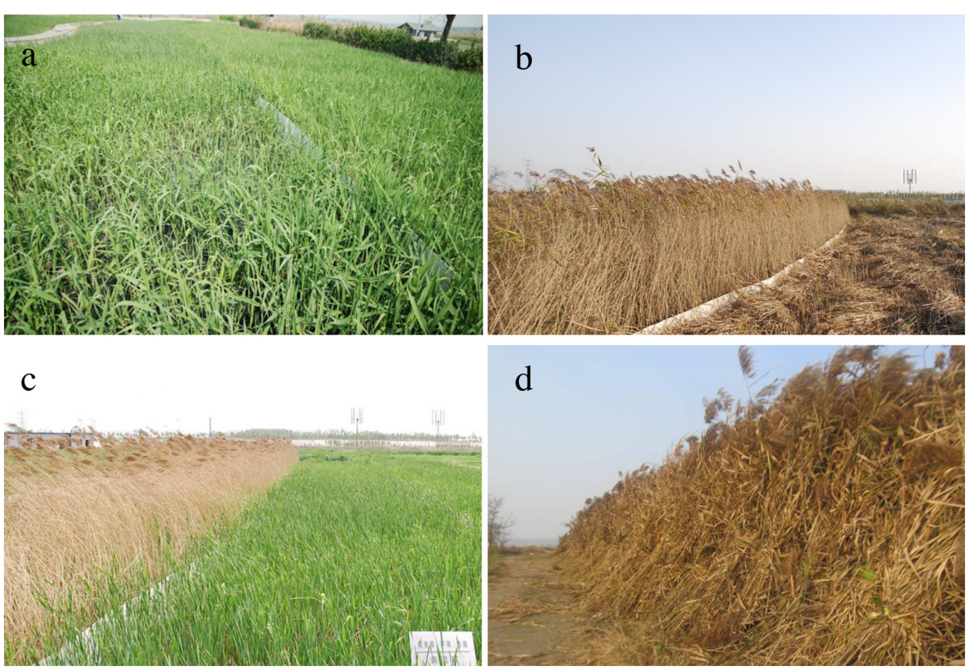

Fig. 1. Overview of the free water surface flow constructed wetlands with different plant harvesting schemes (a) before harvesting, (b) harvesting system, (c) regrowth after harvesting, (d) harvested plants.