International Biodeterioration & Biodegradation 112 (2016) 80–87

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Seasonal applicability of three vegetation constructed floating treatment wetlands for nutrient removal and harvesting strategy in urban stormwater retention ponds

Zhigang Ge [a, b, c], Cuimin Feng [a], Xianping Wang [d], Jibiao Zhang [c, *]

[a] Key Laboratory of Urban Stormwater System and Water Environment (Beijing University of Civil Engineering and Architecture), Ministry of Education, Beijing 100044, PR China
[b] College of Biological, Chemical Science and Engineering, Jiaxing University, Jiaxing 314001, PR China
[c] Department of Environmental Science and Engineering, Fudan University, Shanghai 200433, PR China
[d] Jiaxing Planning & Research Institute Co., LTD, Jiaxing 314001, PR China

A R T I C L E I N F O

Article history:
Received 9 April 2016
Received in revised form
7 May 2016
Accepted 7 May 2016
Available online 13 May 2016

Keywords:
Urban stormwater runoff
Floating bed
Nutrient removal
Harvesting strategy
Seasonal applicability

A B S T R A C T

Three floating treatment wetlands (FTWs), which consist of emergent macrophytes, were constructed and planted to investigate the influence of seasonal change on contaminant removal and harvesting strategy. The investigation was carried out by treating simulated urban stormwater runoff sewage through selected aquatic plants in Jiaxing, Yangtze River Delta, China. Samples collected from the influent and effluent water of three FTWs planted with *Canna indica*, *Thalia dealbata*, and *Lythrum salicaria*, respectively, were analyzed for contaminant concentration in different batches. Results demonstrated that *T. dealbata* outperformed *C. indica* and *L. salicaria* in nutrient removal. The FTWs of *T. dealbata* achieved average removal efficiencies (AREs) of 71.17% ± 2.01% for chemical oxygen demand (COD), 69.96% ± 2.11% for total nitrogen (TN), and 82.40% ± 2.34% for total phosphorus (TP) in nine stages. The COD and TN concentrations in effluent water were under 20 and 1.5 mg L^{-1} for 20 weeks. Based on the analyses of accumulated nutrient removal in vegetation over time, the strategy of harvesting the aboveground tissues of *T. dealbata* and *C. indica* in late October or early November is recommended. However, *L. salicaria* aboveground tissues should be harvested in September. In Jiaxing, the constructed FTWs of *T. dealbata* exhibited the best seasonal applicability.

1. Introduction

Considerable attention has been directed toward the poor water quality and limited habitat value of China's urban rivers, because the creation of impervious surfaces has caused these modified ecosystems to transform from clear water resources into severely eutrophic water bodies as a result of the excessive transport of nutrients and other pollutants into the rivers (Streb, 2013). Urban stormwater runoff pollution, which is serious especially for earlier runoff, is one of the reasons leading to the eutrophication of urban river, lakes, and coastal waters, and eventually, algal bloom (Laber et al., 1997; Kim et al., 2007). As one of the largest uncontrolled nonpoint sources of pollution to receiving waters, urban stormwater runoff should be treated before it flows into rivers (Guido et al., 2014). Urban stormwater ponds, similar to other best management practices (BMPs) for stormwater management, provide storage and water quality treatment for urban stormwater through sedimentation (Semadeni-Davies, 2006; Wang and Sample, 2013). In Sweden, the United States, and some other developed countries, the international trend of constructing retention ponds to manage urban stormwater runoff and improve water quality has proved popular (Semadeni-Davies, 2006; Chang et al., 2013). However, urban stormwater ponds are much less effective in treating pollutants in dissolved form, such as nutrient and metals (Shilton, 2006). To enhance the performance of wet ponds in removing dissolved pollutants without the need for additional space, more floating treatment wetlands (FTWs), which are a relatively new stormwater treatment practice, should be established.

As an emerging BMP for stormwater treatment, FTWs consist of macrophytes growing on floating beds, which sustain and support terrestrial macrophytes, and may be uniquely sustainable and

* Corresponding author.
E-mail address: jbzhang@fudan.edu.cn (J. Zhang).

http://dx.doi.org/10.1016/j.ibiod.2016.05.007

economical as an ecologically friendly treatment practice with widespread applicability in water bodies, including urban stormwater retention ponds (Hubbard et al., 2011; Zhao et al., 2012; Shao et al., 2014). Macrophytes in FTWs, together with microorganisms in their root zone, remove nutrients through direct or indirect uptake into their tissue (Breen, 1990; Billore et al., 2008). As a promising ecotechnology, FTWs are favored by water quality management practitioners for the following advantages: their improved efficiency in eliminating the dissolved forms of N and P from water, scalable nature, relative simplicity of construction, no required land acquisition, additional esthetic values, and low installation costs, which can be further reduced if locally available (wetland) plants and materials, such as man-made plastic bottles and natural bamboo, can be recycled (Li et al., 2007; Stefani et al., 2011). Another important factor is that the damaging effects of severe water level fluctuation can be avoided because the plants grow on floating beds rather than root in sediments (Headley and Tanner, 2006).

Previous studies have shown that floating wetlands can be effective systems for removing the nutrients present in domestic and agricultural wastewaters, swine lagoons, and hyper-eutrophic lake waters (Hubbard et al., 2004; Wu et al., 2006; Yang et al., 2008; Moortel et al., 2010; Xian et al., 2010; White and Cousins, 2013). With regard to the combination of FTWs with retention ponds, the performance of existing retention ponds may be improved and urban stormwater runoff quality may be managed effectively and economically (Headley and Tanner, 2012; Winston et al., 2013). Except for a few recently published FTW studies, actual urban stormwater runoff has not been widely tested (Tanner and Headley, 2011; Chang et al., 2012; Wang and Sample, 2014). In addition, the vast majority of research on FTW performance has been conducted during periods of active plant growth. From these studies, significant water quality improvement was achieved. However, knowledge on the temporal variation of nutrient distribution in FTW plant tissues and the seasonal applicability of different plant species is deficient. Further studies should focus on the plant species selection and nutrient distribution of macrophytes related to the seasonal pattern of change and nutrient reduction.

The objectives of this paper are as follows: (i) to compare the potentials of three aquatic macrophytes for treating urban stormwater runoff using FTWs, (ii) to determine the best seasonal applicability of vegetation-constructed FTWs, and (iii) to investigate the harvesting strategy for the best macrophytes.

2. Materials and methods

2.1. Experimental site

This experiment was carried out in a greenhouse. The experimental tanks simulated an urban wet pond. The tanks were located in the Jiaxing City, Zhejiang Province at a Jiaxing University site (30°44′N, 120°43′E). The area of the characteristics of urban stormwater runoff consisted of 4.50 km^2 of Jiaxing Middle Ring South Road adjoining Jiaxing University with 100% impervious surfaces. During the experiment period (April–December 2015), the monthly mean air temperature ranged from 8.7 °C to 28.1 °C.

2.2. Design of the experiment

The FTW experiments were conducted from April 6 to December 14, 2015 and were divided into nine stages. One stage (28 days) consisted of four batches, and one batch comprised seven days. In the early investigation in 2014, 12 effective waters of earlier urban stormwater runoff were collected at Middle Ring South Road adjacent to Jiaxing University. Then, the characteristics and pollutants in the water were analyzed. The simulated (experimental) water was simulated urban stormwater runoff, which was collected from local river water after it was used to wash the Middle Ring South Road. The concentrations of COD, TN, and TP of the simulated water were modified in a large reservoir with glucose, carbamide, KH_2PO_4, and freshwater according to the mean concentrations of major pollutants in urban stormwater runoff within 60 min in the early investigation, such as chemical oxygen demand (COD) (129.84 ± 8.52 mg L^{-1}), total nitrogen (TN) (5.15 ± 0.33 mg L^{-1}), and total phosphorus (TP) (0.26 ± 0.01 mg L^{-1}). In this study, the mean physicochemical characteristics of the simulated water were pH (6.98) and dissolved oxygen (DO) (8.93 mg L^{-1}). The mean concentrations of pollutants during the nine stages are described in Table 1. The reservoir ($6 \times 5 \times 2.0$ m, $L \times W \times D$) was built to reserve the simulated water before it was injected into the tanks. Twelve tanks ($3.3 \times 1.5 \times 1.0$ m, $L \times W \times D$) were installed in a greenhouse to facilitate the photosynthesis of macrophytes and exclude the influence of bird droppings, falling leaves, and rainfall (Fig. 1). The 12 floating beds (3.0×1.2 m, L × W) were made from polyvinyl chloride pipes, plastic mesh, and pot holders (Fig. 1). The plants, including *Canna indica*, *Thalia dealbata* and *Lythrum salicaria*, were purchased from the Perennial Root Flowers and Plants in Nanjing Botanical Garden, Nanjing, China. After flushing with tap water, the selected plants (15–20 cm in height) were collected and transported into hydroponic pots and fixed by coir fibers with an initial density of 10 plant m^{-2} in the floating bets (Table 2). In this study, following a completely randomized block design, three treatments with three replicates were designed to test the effects of the three plant species (Table 2). The other plants in the three reserved FTWs were reserved to replace the samples.

2.3. Operation of the experiment

Under batch operational mode, the simulated water in tanks was completely replaced by a volume of 3 m^3 fresh simulated water in the reservoir every seven days when the tanks were completely emptied, except for the FTWs. In this operation, the flow was slow and smooth to avoid disturbing the biofilm and microorganism in the root system of the vegetation. A total of 500 mL water samples of influent water were collected from the reservoir at the start (9:00 a.m. in the first day) of each batch, and the same volume of effluent water was extracted in each tank at the end (8:30 a.m. in the seventh day). Water samples were filtered with a 0.45 μm glass microfiber filter (GF/C, Whatman, USA) to evaluate the effect of the FTWs on simulated water during each batch by determining soluble COD, soluble TN, and soluble TP. The pH was measured before filtration. The TN (Persulfate Digestion UV Spectrophotometry), TP (Potassium Persulfate Digestion Mo–Sb Anti-Spectrophotometry), and COD (Closed Refluxing Titrimetric Method) concentrations of water samples were analyzed following Standard Methods for the Examination of Water and Wastes (APHA, 2005). The pH was recorded on a portable pH meter equipped with microprobes (HACH, LA-pH10, USA). DO was measured by a portable hand-held dissolved oxygen meter (YSI550A, USA). One experimental plant was taken out for analysis in each tank after 28 days (four batches or one stage) and was replaced by reserved plants from reserved FTWs at the end of each stage. The harvested whole plants were taken back to the laboratory and were blotted with absorbent paper after gentle washing with deionized water.

To determine the plant dry weight (DW), each plant sample was separated into belowground (roots and rhizomes) and aboveground (leaves and stems) sections. Roots and rhizomes were washed first with tap water, and then with distilled water to remove any adhering foreign material. Each sample was cut into