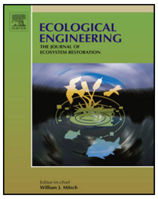
Ecological Engineering 61 (2013) 207–215

Contents lists available at ScienceDirect

Ecological Engineering

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



Floating treatment wetland aided remediation of nitrogen and phosphorus from simulated stormwater runoff

Sarah A. White*, Matthew M. Cousins[1]

School of Agricultural, Forest, and Environmental Sciences, Clemson University, E-143 Poole Agricultural Center, Clemson, SC 29634-0319, United States

ARTICLE INFO

Article history:
Received 15 February 2013
Received in revised form 24 July 2013
Accepted 20 September 2013
Available online 26 October 2013

Keywords:
Urban stormwater
Agricultural runoff
Dissolved oxygen
pH adjustment
Temperature moderation
Aquatic macrophyte
Beemats
Juncus effusus
Canna flaccida

ABSTRACT

Floating treatment wetlands are potential alternatives to traditional constructed wetlands for remediating nutrient-rich water. This study examined the remediation efficacy of floating treatment wetlands planted with *Canna flaccida* and *Juncus effusus* in a replicated trough system over two growing seasons at two nutrient loading rates. Plant growth parameters were measured on a biweekly basis, and water quality parameters were monitored weekly. Plant shoots and roots were harvested at the end of the first growing season, and biomass was dried, ground, and analyzed for nutrient content. *Juncus* plants fixed 28.5 ± 3.4 g N per m^2 and 1.69 ± 0.2 g P per m^2, while *Canna* fixed 16.8 ± 2.8 g N per m^2 and 1.05 ± 0.2 g P per m^2. More N and P were fixed in the below-mat biomass of both species than in the above-mat biomass, thus whole-plant harvest may be a critical management strategy for floating treatment wetlands. During the first season, when nutrient addition rates simulated stormwater loading conditions, effluent nutrient concentrations were very low and averaged 0.14 ± 0.04 mg L^{-1} total N and 0.02 ± 0.01 mg L^{-1} total P. During the second season, nutrient-loading rate into treatment wetlands was doubled to simulate a more nutrient-rich runoff, and effluent nutrient concentrations averaged 0.79 ± 0.3 mg L^{-1} total N and 0.12 ± 0.03 mg L^{-1} total P. Floating treatment wetlands may prove most effective in low nutrient environments where it is necessary to polish water quality to extremely low P concentrations.

Published by Elsevier B.V.

1. Introduction

Stormwater runoff from urban or agricultural sources contains nutrient, metal, and chemical contaminants. If introduced into surface waters, these contaminants can negatively impact water quality, degrading ecosystem health. The ever-increasing scope of urban development along with the rise of the modern environmental movement has heightened public concerns about water quality and availability. These concerns have encouraged the implementation of regulations mandating water quality criteria and limiting nutrient releases into the environment (USEPA, 2010a,b). In an effort to facilitate adherence to present and future regulations and to prevent environmental damage, best management practices (BMPs) designed to reduce the negative impacts of stormwater runoff and runoff contaminants (nutrients and metals) have been developed and applied (Scholes et al., 2008).

Some commonly applied BMPs for runoff management include detention basins, retention ponds, wetland basins and channels, biofilters, and media filters (Leisenring et al., 2010). These technologies are effective at slowing runoff and have effectively reduced nitrogen (N), sediment, copper, and zinc levels in runoff water (Ellis et al., 1994; Leisenring et al., 2010; Scholes et al., 2008; Taylor et al., 2006; White et al., 2011). Despite the success of BMPs for other contaminants, these methods cannot achieve consistent phosphorus (P) removal (Dunne et al., 2012; Hoffmann et al., 2012; Pant et al., 2001). Thus, additional BMP technologies need to be developed to attain desired P removal rates and to reduce potential for environmental damage.

Floating treatment wetlands (FTWs) may be the most readily applicable BMP for further reducing phosphorous levels (Chang et al., 2012). Floating treatment wetlands have been successfully used to remove nutrients, metals, and glycol from stormwater runoff and wastewater (Chang et al., 2012; Chong et al., 1999; Headley and Tanner, 2006; Hubbard, 2010; Hubbard et al., 2004; Mohan et al., 2010; Nahlik and Mitsch, 2006; Tanner and Headley, 2011; Zhou and Wang, 2010). Unlike conventional free water surface and subsurface flow wetlands that are often used to remediate nutrient-rich waters, FTWs can be established within existing water retention infrastructure. As a result, FTWs do not require

---

* Corresponding author. Tel.: +1 864 656 7433; fax: +1 864 656 4960.
E-mail address: swhite4@clemson.edu (S.A. White).

[1] Present address: Department of Pathology, Johns Hopkins University School of Medicine, Baltimore, MD 21205, United States.

0925-8574/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.ecoleng.2013.09.020

that additional land area be devoted to water treatment activities; thus FTWs are likely to have lower initial investment costs because extensive site work is not necessary for FTW installation (Winston et al., 2013).

Though similar to traditional constructed wetlands in many ways, FTWs rely on artificial buoyant scaffolds to support plant material. These floating scaffolds elevate plant crowns above the water level, permitting establishment of marginal, semi-aquatic, and aquatic species in deeper waters. Because the root systems of the species in the FTW are suspended in the water column rather than rooted into sediment or gravel substrate, the amount of root surface area in the water column is greater. This increased root surface area in the water column provides additional habitat for bacterial colonization (Stewart et al., 2008), potentially facilitating increased contaminant uptake and transformation in the water column. The suspended root masses of FTWs filter sediments from the water column while facilitating nutrient and metal removal (Tanner and Headley, 2011). This is a key difference between FTWs and traditional wetland systems where the bulk of contaminant processing occurs in the sediment or gravel matrix rather than in the water column (Edwards et al., 2006; Tanner and Headley, 2011).

Some FTW systems rely on active plant harvest (e.g. Beemats, a commercially available FTW scaffold) to facilitate additional nutrient removal and to limit internal nutrient cycling, while others do not utilize plant harvest (e.g. Biohaven^{TM}, a commercially available FTW scaffold) to assist with nutrient removal. Plant harvest facilitates removal of nutrients, especially P, from internal wetland cycling processes (Hoffmann et al., 2012; White et al., 2010). However, when plants are harvested, organic carbon is also removed, potentially limiting the amount of organic carbon available to support the growth of microbial communities which process N (Lin et al., 2002). Thus, there are benefits and potential downfalls for management of FTWs in either an active or passive manner.

This paper summarizes two seasons of replicated experiments designed to characterize the N and P removal capacity of FTWs. These data provide baseline information needed to develop criteria for the use of FTWs as BMPs for nutrient remediation of urban stormwater or agricultural runoff. It is critical not only to understand the capacity of FTWs to remove nutrients, but also to understand potential ecological effects if they are deployed in settings where stormwater would reach organisms sensitive to changes in pH, dissolved oxygen, or temperature. The specific objectives of the present study were to:

1. quantify FTW-mediated nutrient removal from simulated runoff water at two nutrient loading rates,
2. quantify plant uptake of nutrients into both above- and below-mat biomass and characterize plant growth in different nutrient loading contexts, and
3. characterize the impact of FTWs on effluent physico-chemical parameters: dissolved oxygen, pH, and temperature.

2. Materials and methods

2.1. *Experimental floating treatment wetland construction*

Experiments were conducted during the spring-fall seasons of 2008 and 2009. The experimental units consisted of 3 experimental FTWs that were constructed in three troughs, two troughs with a surface area of 1.15 m^2 and a volume of 0.59 m^3 and one trough with a surface area of 3.03 m^2 and a volume of 1.89 m^3 (Fig. 1A). Troughs were initially filled with water from Lake Hartwell (Clemson, SC). Floating mats were Beemats. The Beemats FTW scaffold used for these studies were 1 cm thick, 60 cm × 60 cm buoyant interlocking foam mat squares joined using 10 cm nylon connectors and secured with 3 cm locking washers to maintain raft integrity. Each mat section had ten (7.5 cm) pre-cut holes, which were spaced 12 cm on center. Each mat was designed to allow insertion of a plant contained in a specially designed aerator pot (Fig. 1B–D). *Juncus effusus* (Soft rush) and *Canna flaccida* (Golden canna) plants were placed in aerator pots and seated in the Beemats floating mats. The plants were 6.35 cm-diameter, rooted liners, which were established in a soilless potting substrate and supplied by Beeman's Nursery (New Smyrna Beach, FL). Experimental FTWs were installed in the flow-through troughs on April 14, 2008 and April 23, 2009. There were two plantings (2008 and 2009) for all troughs, as plants were harvested at the end of the 2008 study. Rafts were sized such that they covered 95% of the water surface (Fig. 1D).

2.2. *Simulation of nutrient containing runoff*

The experimental FTWs were treated with a continual flow of pond water spiked with nutrients beginning on May 2, 2008 and April 23, 2009. The simulated stormwater runoff solution was prepared by dissolving water-soluble fertilizer (0.10 g/L in 2008 and 0.20 g/L in 2009 of a 20N–2P–20K Nitrate Special Soluble Fertilizer, Southern Agricultural Insecticides, Inc., Hendersonville, NC) in water contained in a large, 2000 L round stock tank. The water soluble fertilizer was completely dissolved in water prior to addition to the stock tank to ensure uniform distribution throughout the stock tank. Flow of the simulated runoff solution from the stock tank into the 3.03-m^2-control/mixing tank was regulated to supply continuous and consistent nutrient loading rates into experimental units. The simulated runoff solution was mixed continuously with additional lake water in the control/mixing tank and then flowed through the 2.5 m control tank before being collected for calibrated distribution within the treatment tanks. Simulated runoff solution flowed at 140 mL/min into the 1.15 m^2 treatment tanks and at 450 mL/min into the 3.03 m^2 tank, achieving a 3-day hydraulic retention time (HRT) for each experimental FTW unit. Rainfall was not measured, but the system was open to air and any rainfall impacts on nutrient presence were accounted for in water samples collected.

2.3. *Water sampling and chemical analysis*

For each experimental FTW ($n = 3$), water samples were collected every 7 days, beginning 3 days after initiation of fertilizer addition. Plant size measurements (shoot height and root length) were collected every 14 days and were made on the same three plants per species per treatment unit over the sampling periods. Water samples (100 mL) were collected and analyzed for NH_3^+-N (Orion Ammonia Electrode 95-12, Thermo Electron Corp., Beverly, MA), anions including NO_3-N, NO_2-N, and PO_4-P (Dionex AS10 ion chromatograph with AS50 auto-sampler, Dionex Corp., Sunnyvale, CA), total organic carbon (dissolved carbon from organic sources that is available for microbial metabolic functions), pH, water temperature (°C) in 2009, conductivity (mS cm^{-1}), oxidation reduction potential (ORP, mVolts), dissolved oxygen, and mineral elements. The mineral elements (total P, K, Ca, Mg, Zn, Cu, Mn, Mo, Ni, Fe, S, Na, B, and Al) were analyzed via inductively coupled plasma emission spectrophotometer (ICP-ES, 61E Thermo Jarrell Ash, Franklin, MA). Quality assurance (QA) and quality control (QC) measures were insured per US EPA method 6010B (USEPA, 1997), method blanks and an ICP QC standard were checked every 10 samples. Detection limits for ICP were guaranteed onsite by the manufacturer for elements of interest to 5 ppb. All water sampling equipment was acid-washed, rinsed with MQ-water (ultrapure), prior to each