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Aeration and plant coverage influence floating treatment wetland remediation efficacy

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ABSTRACT

Nutrient contamination of waterways is a growing concern, instigating the emergence of floating treatment wetland systems (FTWs) to remove nutrients from water. To determine if aeration of water systems enhances nutrient removal efficacy or nutrient fixation within plant tissues, aeration in combination with FTW installation techniques were investigated. During two separate trials with *Juncus effusus* and *Canna flaccida*, treatments consisted of either aerated or non-aerated mesocosms, with varying coverage and planting density combinations. Aeration increased the dissolved oxygen levels within each mesocosm, but reduced the removal of nitrogen and phosphorus from the water column in comparison to non-aerated systems. Plant samples collected from 100% planting density treatments that were aerated had a greater nitrogen uptake than non-aerated by as much as 55% or 13.5 g/m^2 at harvest. Some discrepancies between plant uptake and water column nutrient levels can be attributed to microbially-mediated nitrogen losses (e.g., denitrification).

1. Introduction

As water quality degradation concerns grow in public and private sectors, evaluation of remediation technologies to treat contaminants has increased. One such remediation technique is the use of floating treatment wetlands (FTWs) to remove excess levels of nitrogen (N) and phosphorous (P) from water systems. Floating treatment wetlands are often installed in existing storm water retention ponds. In many cases, especially when found in neighborhoods or other public spaces, these retention ponds have pre-existing fountains and other aeration methods. Aeration has proven to affect the speciation and remediation of contaminants in many constructed wetlands, however no previous literature has considered the impact upon FTWs (Dong et al., 2012; Ong et al., 2010; Zhang et al., 2010).

The effect of aeration has been evaluated multiple times for both surface and subsurface constructed wetlands (Bowmer, 1987; Maltais-Landry et al., 2007, 2009; Zhang et al., 2010). The effect of aeration on P removal has varied across studies (Dong et al., 2012; Zhang et al., 2010). Remediation of ammonium (NH_4^+-N) has been reported to consistently increase with aeration (Butterworth et al., 2013; Dong et al., 2012; Liu et al., 2013; Ong et al., 2010); however, nitrate (NO_3-N) removal was higher in either non-aerated or intermittently aerated systems (Butterworth et al., 2013; Fan et al., 2013). This transformation of N correlates with the anaerobic and aerobic conditions supporting nitrification and denitrification (Fig. 1). Nitrification is the oxidation of ammonium or ammonia (NH_3) to nitrite and then to nitrate (Tanner et al., 2002; Wu et al., 2009). Nitrosomonas bacteria first convert ammonium to nitrite. Then nitrobacter convert nitrite to nitrate, both forms of N that are readily absorbed by plants. Denitrification is the microbial-mediated conversion of nitrate into nitrogen gas (N_2) via nitrite, nitric oxide (NO), and nitrous oxide (N_2O) (Tallec et al., 2008; Wu et al., 2009). Dissolved oxygen (DO) concentration plays an important role in nitrification and denitrification because nitrification is strictly aerobic (DO $>$ 2.0 mg/L) while denitrification is strictly anoxic (DO $<$ 1.0 mg/L) (DeBusk, 1999; Tallec et al., 2008).

Nitrification and denitrification are the main pathways for N removal in CWs, but they usually do not occur simultaneously in a single wetland cell due to conflicting oxygen demands (Liu et al., 2013). Floating treatment wetlands can be compared with CWs in this scenario because if fountain and aeration methods are installed within retention ponds, they are likely to be continuously used rather than intermittently turned on and off, possibly homogenizing the pathway for N removal. Within retention and urban ponds, water column stratification is typical with great heterogeneity of thermo-chemical indices (McEnroe et al., 2013). For example, DO concentrations increase at the surface of ponds during the daytime, leading to possible supersaturation, and then decrease during the evening hours (Wetzel, 2001). However, FTWs stabilize and decrease DO levels beneath the floating mat, possibly

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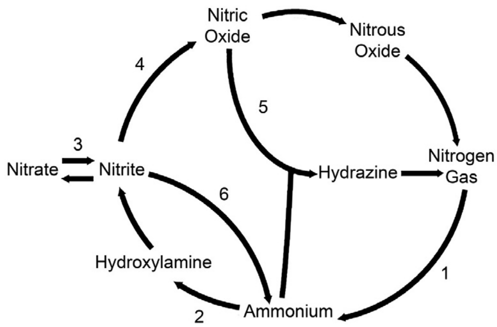

Fig. 1. Reactions of the microbial nitrogen cycle. (1) Nitrogen gas fixation; (2) aerobic ammonium oxidation by bacteria and archaea; (3) aerobic nitrite oxidation; (4) denitrification; (5) anaerobic ammonium oxidation; and (6) dissimilatory nitrate and nitrite reduction to ammonium (Jetten, 2008).

changing water column stratification and thus the effect of aeration on nutrient removal in comparison to CWs (Wang and Sample, 2013; White and Cousins, 2013).

Zhang et al. (2010) determined that with aeration, less surface area was needed to remediate organic matter and N compared to a non-aerated CW system. To better employ FTWs within surface water bodies, additional knowledge related to economics of installation and maintenance, specifically the percent of pond surface area covered and planting density, are needed. The objective of this work was to quantify the effect of percent surface area covered, planting density, and aeration on FTW efficacy for treating nutrients in surface runoff.

2. Materials & methods

2.1. Experimental design

Experiments were carried out over the spring-fall seasons of 2009 and 2010. An experimental system was assembled in Pendleton, SC (34.640, −82.773) consisting of twenty-four 378.5 L structural foam stock tanks (Rubbermaid, Atlanta, GA; Fig. 2). Each stock tank or experimental unit (EU) had a surface area of 1.15 m^2 and a volume of 0.38 m^3. Holes were drilled 6 cm from the rim at one end of each EU to regulate overflow and release of water. Floating mats, 1 cm think and cut to 60 cm × 30 cm, were supplied by Beemats (New Smyrna Beach, FL).

The mats are buoyant, interlocking solid-core foam mats joined with 10 cm nylon connectors. Each section of mat has ten (7.5 cm) pre-cut holes spaced 12 cm on center (Fig. 3). Holes allow insertion of specially designed plastic aerator cups in which to place plants (Fig. 2B). Treatments consisted of 50% and 100% surface coverage using mats with plant densities of either 10 plants (50% or 100% coverage) or 20 plants (100% coverage) (Fig. 3). Twelve of the twenty-four EUs were continuously aerated and twelve had no supplemental aeration. Aeration was controlled by individual aquarium bubblers placed within each

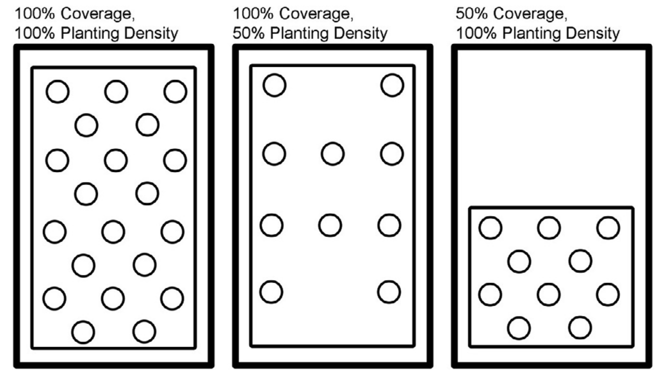

Fig. 3. Experimental layout of the planting coverage and planting density with circles representing plants and inner rectangle the floating mat.

of 12 EUs to provide direct air circulation (Fig. 2C).

Two experiments were conducted, each with a different plant species. The first experiment was conducted with *Juncus effusus* L. (soft rush). On April 21, 2009, 10 cm *Juncus* liners were inserted into aerator cups, and EUs were planted with appropriate number of plants according to treatment design. The experiment was concluded October 29, 2009; *Juncus* plants were harvested March 8 and 9, 2010. The second experiment was conducted with *Canna flaccida* L. (golden canna). On March 23, 2010, *Canna* bare root liners (roots ≈ 10 cm and shoots ≈ 15 cm) were wrapped with coconut coir mat pieces (10 cm × 20 cm), inserted into aerator cups, and each EU was planted with the appropriate number of plants per the experimental design. *Canna* plants were harvested August 31 and September 2, 2010. Due to trials occurring separately, in different years, statistical comparisons between the two species were not conducted; instead analysis were conducted by species by year.

Overall experimental design by year was 1 plant species * 2 aeration levels * 3 plant coverage levels * 3 plant density levels * 4 replicates, with year 1 (2009) conducted using *Juncus* and year 2 (2010) conducted using *Canna*.

2.2. Runoff simulation

Six holding tanks, ranging in volume from 795 L (1 tank), 1135 L (4 tanks) to 1230 L (1 tank) were used to feed EUs. Solutions in the holding tanks were made by mixing water (municipal source) and a water-soluble fertilizer (20N-2P-20K Nitrate Special Soluble Fertilizer, Southern Agricultural Insecticides, Inc., Hendersonville, NC). Solutions flowing from the holding tanks averaged concentrations of 34.6 ± 6.4 mg/L N and 3.8 ± 0.5 mg/L P, representative of agricultural surface runoff (Prystay and Lo, 2001; White, 2013). The water-soluble fertilizer was completely dissolved in water prior to addition to the stock tanks to ensure uniform distribution. Treatments were randomly assigned to groups of four EUs per holding tank. Water distribution lines were plumbed so that water flowed continuously into

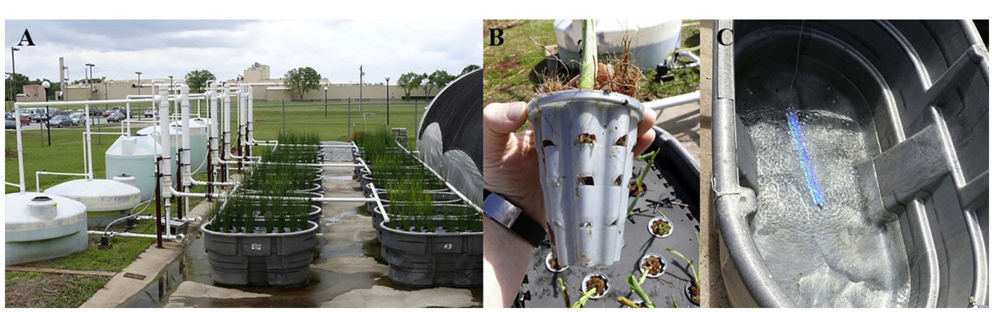

Fig. 2. Experimental setup for floating treatment wetland experiments including: (A) six holding tanks and 24 mesocosms with 378.5 L, (B) aerator cups into which plants are inserted, and (C) the aeration system.