Chemosphere 160 (2016) 149–154

Contents lists available at ScienceDirect

Chemosphere

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

Using aquatic vegetation to remediate nitrate, ammonium, and soluble reactive phosphorus in simulated runoff

M.T. Moore [a], [*], M.A. Locke [a], R. Kröger [b], [1]

[a] USDA Agricultural Research Service, National Sedimentation Laboratory, 598 McElroy Drive, Oxford, MS 38655, USA
[b] Water Quality and Ecology Research Unit, USDA Agricultural Research Service, National Sedimentation Laboratory, PO Box 1157, Oxford, MS 38655, USA

HIGHLIGHTS

- *Typha latifolia* decreased soluble reactive phosphorus concentrations in runoff.
- *Panicum hemitomon* decreased nitrate concentrations in year one, but not year two.
- Mixtures of macrophytes may likely increase nutrient retention efficiency.

ARTICLE INFO

Article history:
Received 10 May 2016
Received in revised form
15 June 2016
Accepted 20 June 2016
Available online 30 June 2016

Handling Editor: Shane Snyder

Keywords:
Phytoremediation
Mesocosm
Wetland
Nitrogen
Phosphorus

ABSTRACT

Within the agriculturally-intensive Mississippi River Basin of the United States, significant conservation efforts have focused on management practices that reduce nutrient runoff into receiving aquatic ecosystems. Only a small fraction of those efforts have focused on phytoremediation techniques. Each of six different aquatic macrophytes were planted, in monoculture, in three replicate mesocosms (1.2 m × 0.15 m × 0.65 m). Three additional unvegetated mesocosms served as controls for a total number of 21 mesocosms. Over two years, mesocosms were amended once each summer with sodium nitrate, ammonium sulfate, and potassium phosphate dibasic to represent nitrogen and phosphorus in agricultural runoff. System retention was calculated using a simple aqueous mass balance approach. Ammonium retention in both years differed greatly, as *Panicum hemitomon* and *Echinodorus cordifolius* retentions were significantly greater than controls in the first year, while only *Myriophyllum aquaticum* and *Typha latifolia* were significantly greater than controls in the second year. Greater soluble reactive phosphorus retention was observed in *T. latifolia* compared to controls in both years. Several other significant differences were observed in either the first or second year, but not both years. In the first year's exposure, *P. hemitomon* was significantly more efficient than the control, *Saururus cernuus*, and *T. latifolia* for overall percent nitrate decrease. Results of this novel study highlight inherent variability within and among species for nutrient specific uptake and the temporal variations of species for nutrient retention. By examining this natural variability, scientists may design phytoremediation systems with greater impact on improving agricultural runoff water quality.

1. Introduction

With the US population expected to top 322 million people at the beginning of 2016, and more than seven billion global inhabitants, there will continue to be an intensification of food and fiber production to meet national and international needs (US Census Bureau, 2015). Increased agricultural production will require increases in application of nitrogen (N) and phosphorus (P), through either inorganic fertilizer or manure, to sustain and increase yields in agriculture. Howarth et al. (2002) identified inorganic fertilizers as the single largest global source of reactive N. In 2011, approximately 11.6 million Mg of N and 3.92 million Mg of P were applied to US crops (ERS, 2015; Lerch et al., 2015). It has been estimated that approximately 50% of all N compounds applied in agricultural settings do not reach the intended target and are lost to the surrounding environment (Davidson et al., 2012.) As a result, multiple studies suggest not only is agriculture the largest source of N compounds entering the environment, but N is also the single

---

[*] Corresponding author.
E-mail address: matt.moore@ars.usda.gov (M.T. Moore).
[1] Current address: Covington Civil and Environmental, LLC, 2510 14th Street, Suite 1010, Gulfport, MS 39501 USA.

http://dx.doi.org/10.1016/j.chemosphere.2016.06.071
0045-6535/Published by Elsevier Ltd.

most significant environmental pollutant produced by agriculture (Ribaudo, 2011; Godfray, 2014). Giles (2005) went so far as to suggest that, aside from biodiversity loss and climate change, N pollution is the third largest threat to the planet's existence.

Excessive nutrients can leave the production landscape and enter surrounding aquatic ecosystems, potentially resulting in eutrophication. Eutrophication can lead to zones of hypoxia, causing significant environmental and economic damage. Dodds et al. (2009) estimated the annual total ecological and economic costs of freshwater eutrophication in the US alone at \$2.2 billion. Although the hypoxia concern within the Gulf of Mexico garners much of the national and international attention, there are also approximately 300 hypoxic zones along the entire US coastline (Davidson et al., 2012). To address these serious issues, agricultural policies and support systems must include analyses of innovative best management practices (BMPs) to reduce nutrient loss from the production landscape.

Various BMPs have been suggested to remediate nutrients associated with storm or irrigation runoff. Many of these practices utilize vegetation, whether near field edges as constructed wetlands, riparian buffers, or drainage ditches, or in fields as cover crops or reduced tillage. In the intensively farmed lower Mississippi River Valley states of Arkansas, Mississippi, and Louisiana, ditches drain 1,244,543 ha; 672,546 ha; and 969,331 ha of agricultural land, respectively (USDA, 2012). Several studies have highlighted opportunities for drainage ditch management to decrease nutrient concentrations from agricultural runoff through combinations of biogeochemical and physical processes (Kröger et al., 2007, 2008; Strock et al., 2007; Moore et al., 2010). Increased efforts are focused on identifying specific plant species that will provide the greatest remediation potential in a multitude of different environmental circumstances. Successful nutrient phytoremediation is dependent on many interacting factors between the plants, water quality (e.g. temperature, redox, pH, etc.), flow conditions, and nutrient load. The objective of the current study was to examine the individual ability of six emergent macrophytes [*Typha latifolia* L. (broad-leaved cattail), *Panicum hemitomon* Schult. (maidencane), *Thalia dealbata* Fraser ex Roscoe (powdery alligator-flag), *Echinodorus cordifolius* (L.) Griseb.(creeping burhead), *Myriophyllum aquaticum* (Vell.) Verdc. (parrot feather), and *Saururus cernuus* L. (lizard's tail)] to mitigate N and P concentrations in simulated storm runoff water over two summer seasons.

2. Materials and methods

Mesocosms were constructed using 21 Durapride™ high density polyethylene oval containers (1.2 m × 0.15 m × 0.65 m), with a 22 cm base of sand overlain with 16 cm of Lexington silt loam. Mesocosms were planted with monocultures of one of the following six rooted, emergent macrophytes: *T. latifolia* L., *P. hemitomon*, *T. dealbata*, *E. cordifolius*, *M. aquaticum*, and *S. cernuus*. Sand and silt loam used as mesocosm substrate were collected from undisturbed ponds at the University of Mississippi Field Station (UMFS), Abbeville, MS. Likewise, *T. latifolia* and *M. aquaticum* were collected from ponds at the UMFS. All remaining plants were collected from stock ponds at the USDA Natural Resources Conservation Service Plant Materials Center in Coffeeville, MS. Three replicate mesocosms were used for each plant species, in addition to non-vegetated sediment controls, for a total of 21 mesocosms. All mesocosms were randomly arranged, and plants were allowed six weeks to equilibrate within mesocosms prior to test initiation.

2.1. Simulated runoff

Nutrient stocks (10,000 mg L^{-1}) for nitrate, ammonium, and orthophosphate were prepared prior to each of the two summer experiments by using reagent grade (Fisher Scientific) sodium nitrate (60.69 g L^{-1}), ammonium sulfate (47.17 g L^{-1}), and potassium phosphate dibasic (56.26 g L^{-1}), respectively, dissolved in 1 L of deionized water. Mixing chambers were prepared with a calculated volume of well water (1.139 ± 0.022 mg L^{-1} nitrate; 0.025 ± 0.005 mg L^{-1} ammonium; 0.068 ± 0.008 mg L^{-1} soluble reactive phosphorus) and nutrient stocks to reach a target concentration of 5 mg L^{-1} (for all nutrient constituents). Nutrient exposure was constant for 4 h. Prior to exposure, water depth in each mesocosm was reduced to 1/2 of the original volume to simulate hydraulic effects of low-grade weirs commonly used in Mississippi Delta drainage systems (Kröger et al., 2008).

Nutrient-enriched water was pumped into individual mesocosms using Fluid Metering Inc. (FMI™) piston pumps, models QD-1 and QD-2 connected with 0.95 cm (o.d.) x 0.64 cm (i.d.) vinyl tubing to simulate a storm runoff event. Water travelled through each mesocosm, exiting at the surface through a discharge hose (0.95 cm × 0.64 cm) at the opposite end of the mesocosm. Pump flow rates were adjusted so that all mesocosms maintained a 4 h hydraulic retention time (HRT). Mesocosms were exposed to flowing nutrient enriched water for 4 h, then exposed to flowing unamended well water for an additional 4 h to simulate potential flushing effects of a second storm event.

2.2. Sample collection and analysis

In the first year's experiment, water samples were collected in 237 mL HDPE containers prior to nutrient exposure (background) and hourly for 10 h following exposure from an outflow hose at the opposite end from the inflow. The following year, water samples were collected in identical containers at background, 2, 2.5, 3, 3.5, 4, 5, 6, 7, 8, 24, 48, 72 and 168 h post-nutrient exposure. When water was not being pumped through mesocosms, samples were collected by dipping containers at the water surface by the outflow hose. All water samples were analyzed for nitrate, ammonium, and soluble reactive phosphorus using a ThermoSpectronic (Rochester, NY, USA) Genesys 10 ultraviolet (UV) spectrophotometer. The cadmium reduction method was used to determine nitrate, whereas the standard phenate method was used to determine ammonium (APHA, 2005). Soluble reactive phosphorus (filtered orthophosphate) was determined according to the methods of Murphy and Riley (1962). All analyses were performed following filtration using a 0.45 μm cellulose membrane and were completed within 48 h of sample collection. Limits of detection were 0.001 mg L^{-1} for soluble reactive phosphorus at 880 nm and 0.005 mg L^{-1} for nitrate and ammonium at 530 nm in a 50 mm flow cell.

Influent nutrient loads were calculated by multiplying the inflow concentration (μg L^{-1}) by the FMI™ pump rate for each mesocosm during the given time. Effluent loads were estimated by averaging outflow concentrations by sequential time steps and multiplying the mean concentration by the amount of water exiting each tub over associated time periods, which was assumed to be equal to the inflow pump rate, since a constant water level was maintained through the experiment. Percent decrease in nutrient loads exiting mesocosms after the 4 h simulated runoff, percent of nutrient load released from mesocosms during the 4 h clean water flush, and total percentage decrease in nutrient loads exiting mesocosms were calculated from the total influent loads and amount of each nutrient in the effluent over the given time frames. Significant differences in effluent nutrient loads between treatments were determined with JMP 8.0 software using analysis of variance (ANOVA) at an alpha of 0.05. A Tukey's HSD was performed to determine levels of differences between individual treatments.