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Technical Note

Alum application to improve water quality in a municipal wastewater treatment wetland: Effects on macrophyte growth and nutrient uptake

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ABSTRACT

Application of low doses of alum to treatment wetlands to reduce elevated outflow winter phosphorus concentrations were tested in mesocosms vegetated with either *Typha domingensis*, *Schoenoplectus californicus*, or submerged aquatic vegetation (SAV) (*Najas guadalupensis*-dominated). Alum was pumped to experimental units at a rate of 0.91 g Al m^{-2} d^{-1} and water quality monitored for 3 months. The alum application significantly improved the outflow water quality and overall the growth of the plants was unaffected by the alum application. Biomass and growth varied between species and through time, but no significant effects of alum application were detected. The concentrations of nutrients and mineral elements in the aboveground tissues differed between species and over time, but only the concentration of Al in plant tissue was increased by alum additions. The concentration of Al was 50-fold higher in alum-treated SAV as compared to the control, and in *Typha* and *Schoenoplectus* the concentrations were 4- and 2-fold, higher, respectively. The N/P ratios in the plant tissues were low (<10) suggesting that their growth and biomass was limited by nitrogen. The research suggests that a continuous or seasonal low-dosage alum application to treatment wetlands provides an effective tool to maintain discharge concentrations within permitted values during the inefficient winter treatment times. We suggest that the use of alum should be restricted to treatment wetland areas dominated by emergent vegetation as the effects of the elevated Al concentrations in SAV needs further study.

1. Introduction

Nutrient and contaminants are removed in treatment wetlands through a number of abiotic and biotic removal mechanisms such as physical settlement, plant and microbial uptake, sorption and denitrification in the case of nitrogen (Brix, 1997; White and Reddy, 1999, 2000; Conkle et al., 2008). In wetland systems that have been operated for decades, treatment effectiveness has been found to decline and few methods are available to restore the treatment capacity including soil removal (Wang et al., 2006) and prescribed burns (White et al., 2008). There is also decreased efficiency of nutrient removal during the winter months as biological activity decreases or from an increase in nutrient loading, due to additionally permitted wastewater, which calls for new or improved wetland management tools to maintain water quality within acceptable limits. One possible option involves the inactivation of nutrients through the use of chemical amendments (Malecki-Brown et al., 2007).

While alum ($Al_2(SO_4)_3{\cdot}14H_2O$) has been used for P inactivation in lakes and for P removal in wastewater treatment plants for decades (Welch and Schrieve, 1994; Berkowitz et al., 2006), there has been little research done until recently on its potential effectiveness in treatment wetlands (Malecki-Brown and White, 2009; Malecki-Brown et al., 2009). When added to water, alum rapidly dissociates forming aluminum ions that are immediately hydrated (Cooke et al., 1993), and an insoluble, gelatinous poorly crystalline $Al(OH)_3$ floc is formed through several rapid hydrolytic reactions (Ebeling et al., 2003).

Aluminum toxicity in plants is related to the activity of the Al^{3+} ion, having several different effects on the plant. The most notable result of Al toxicity in upland plants is the inhibition of root elongation and respiration (Schier, 1985; Jarvis and Hatch, 1986) resulting in roots that are thickened, stubby, brittle, and often inefficient in nutrient absorption. There are five possible mechanisms by which Al toxicity affects the cellular function within plants (Taylor, 1989). First, Al may disrupt the structure and function of the plasma membrane which serves as a wall between the cytosol and external environment. A second mechanism of Al toxicity is the inhibition of ATP (Viola et al., 1980) and DNA synthesis as well

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as mitosis. Aluminum also disrupts cellular function by inhibiting cell elongation. The Al binds to the free carboxyls of pectin resulting in cross-linking of the molecules, decreasing the cell wall elasticity, which in turn inhibits root elongation (Klimashevskii and Dedov, 1975; Matsumoto, 2000). Aluminum stress also results in disruption of mineral nutrition. The disruptions could arise from reduction in mycorrhizal association (Entry et al., 1987). Aluminum also interferes with the absorption and transport of Ca and Mg in plants, resulting in reduced Ca concentrations in the roots and shoots of Al stressed plants (Baligar et al., 1987; Bennet et al., 1987; Thornton et al., 1987).

Acidification associated with alum dosing is likely, in concert with the increased Al concentrations, to result in Al toxicity and elevated concentrations in the aquatic plants (Gensemer and Playle, 1999). The aim of the present study was to assess the effects of a continuous low-dosage of alum on plant growth and nutrient uptake of the dominant vegetation types in a polishing wetland system receiving tertiary domestic wastewater. This is, to the authors' knowledge, the first study where the effect of alum dosing in treatment wetlands on wetland vegetation has been studied. The study was conducted in the winter months, the period of time when the P removal rate of the wetland was the lowest (Wang et al., 2006).

2. Materials and methods

2.1. Site description

A mesocosm study was set up at the City of Orlando's Wastewater Division Easterly Wetlands (OEW) which is a 494 ha polishing (nutrient removal) constructed wetland system located east of Orlando in Florida, USA. The wetlands consist of 16 deep marsh cells dominated by either cattails (*Typha domingensis*), giant bulrush (*Schoenoplectus californicus*), or a combination of the two, and two mixed marsh cells dominated by a mixture of submergent and emergent macrophytes including *Ceratophyllum demersum*, *Limnobium spongia*, *Najas guadalupensis*, *Nuphar luteum*, *Nymphaea odorata*, *Pontederia cordata*, *Sagittaria lancifolia*, and *Sagittaria latifolia*. The influent total P (TP) concentration from 1988 to 2005 ranged from 0.02 to 3.30 mg L^{-1} (overall average 0.22 mg L^{-1}), and usually the effluent concentrations were much lower than the 0.2 mg L^{-1} TP discharge permit (Wang et al., 2006). However, effluent TP concentrations have been approaching the permit limit during winters in recent years (Wang et al., 2006). The goal of this specific paper was to examine the effect of alum addition on submerged and emergent plant uptake and growth.

2.2. Mesocosm establishment

Eighteen circular (diameter 1.54 m, depth 0.88 m) polyethylene mesocosms were established in June 2004 utilizing a randomized block design. The setup included triplicate experimental and control mesocosms planted with the three dominant vegetation types found within the OEW, i.e. either *T. domingensis*, *S. californicus* or submergent aquatic vegetation (SAV). Each mesocosm contained a polyvinyl chloride drain which permitted control of water levels to within ±3 cm. The water flowing through the mesocosms originated from the outflow of cell 15 of the OEW (Wang et al., 2006), pumped to a head tank and distributed via gravity to each mesocosm at a rate of 370 L d^{-1}. This provided a hydraulic loading rate of 19.8 cm d^{-1}, and a retention time of approximately 2.7 d at a water depth of 53 cm.

Approximately 0.3 m of homogenized soil from a dredged spoil pile with a mixture of material removed from some of the OEW cells was added to each mesocosm, and the mesocosms were planted on June 30, 2004, to begin a 5 month grow-in (stabilization) period. All vegetation was collected from the OEW. The six SAV mesocosms were established with *N. guadalupensis* at a density of 2.18 kg wet weight (WW) m^{-2}. The *Typha* and *Schoenoplectus* mesocosms were stocked with 15 whole plants per mesocosm, averaging 1.88 kg WW m^{-2} for *Typha* and 1.04 kg WW m^{-2} for *Schoenoplectus*. The leaves of the *Typha* and *Schoenoplectus* plants were cut to a length of 79 cm to begin the grow-in period with uniform plants. A 53 cm water column was maintained in the SAV mesocosms throughout the entire grow-in, while in the emergent mesocosms, a 28 cm water column was maintained for the first month in order to allow the plants to establish before raising the water column to 53 cm for the remainder of the study. After the 5-month grow-in period (ending December 1, 2004), liquid alum (4.3% as Al^{3+}) was pumped from a head tank via timer-controlled peristaltic pumps to the triplicate treatment mesocosms through black polyethylene tubing at a rate of 0.91 g Al m^{-2} d^{-1} for 3 months resulting in a total addition of 68 g Al m^{-2} while no alum was added to the triplicate control mesocosms for each plant type. This loading rate was found to be sufficient in a previously conducted static core experiment (Malecki-Brown et al., 2007).

2.3. Water quality

Temperature, pH, conductivity and dissolved oxygen (DO) in the water were analyzed on-site at mid-morning using a handheld meter (YSI 85, YSI Inc., Yellow Springs, OK, USA). Water samples were collected from each mesocosm 14 times during the grow-in period, then twice weekly for the first month of Al dosing, and weekly for the remainder of the experiment. Water samples were filtered (0.45 μm) and analyzed for the different forms of N and P as well as dissolved organic C (DOC) and Al. For details about methods see Malecki-Brown et al. (2009).

2.4. Plant growth and biomass

Plant aboveground biomass was determined from one 25 cm × 25 cm quadrant harvested from each mesocosm upon initiation and completion of the Al dosing. Emergent species were clipped at the soil surface while all SAV falling within the quadrant, throughout the water column was collected. All plants were rinsed thoroughly with tap and then distilled water, all visible algae or epiphytes wiped off, and then placed in paper bags and dried at 40 °C until constant weight was reached.

Green stem counts were taken in the *Typha* and *Schoenoplectus* mesocosms every 2 wk over the course of the Al dosing period. The rate of aboveground production of *Typha* and *Schoenoplectus* was estimated by measuring shoot or leaf increments over time. In each mesocosm, triplicate newly emerged shoots were tagged loosely around the base for identification purposes. On each subsequent sampling date the individual *Typha* leaves were tagged and labeled as they emerged. *Typha* leaf and *Schoenoplectus* shoot lengths were measured from the soil surface to the most distal portion of the leaf or shoot weekly during the 3-month experiment and biweekly thereafter until all tagged plants were dead (within 46 wk). A nonlinear regression curve of leaf length to dry weight biomass was established for both *Typha* and *Schoenoplectus* by collecting thirty *Schoenoplectus* shoots of various sizes from cell 1 (R^2 = 0.95), and twelve *Typha* plants (69 leaves) from cell 10 within the OEW (R^2 = 0.93). Aboveground production was then calculated by multiplying the total leaf growth during the life span of the plants with the number of shoots or stems in the mesocosms. The P and N uptake associated with growth was calculated by multiplying the aboveground production with the mean P and N concentrations in the tissues. The growth in the SAV mesocosms was not determined. For this short-term exposure to alum, it was hypothesized