Influence of gypsum amendment in the nutrient phytoremediation potential of three native, aquatic plants found in agricultural ditch systems

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ABSTRACT

Agriculture is heavily scrutinized because of its nutrient contributions to global water quality. Although no "silver bullet" management practice exists to completely remediate all agricultural pollutants, combinations of practices with a measure of demonstrated success hold promise as a means to reduce agriculture's contribution to global water pollution. Twelve, 379 L mesocosms (1.32 m x 0.70 m x 0.66 m) were constructed by layering 16 cm of Lexington silt load atop a base of 22 cm of washed sand. Three mesocosms (each) were planted with monocultures of either *Leersia oryzoides* L. Sw., *Typha latifolia* L., or *Sparganium americanum* Nutt. (n=9), while three mesocosms were left unvegetated to serve as controls. Gypsum (167 g) was added to each individual mesocosm to simulate a recommended field application (reduced for scale). Water amended with nitrate, ammonium, and phosphate (8 mg/L each) was pumped through each mesocosm using a metered piston pump to deliver an 8 h retention time for each system. After the 8 h exposure, nutrient-amended water ceased, and the system was allowed to sit for 40 h. Approximately 48 h following the original nutrient amendment initiation, the system was flushed with unamended water for another 8 h retention time to simulate effects of system flushing. Overall phosphate mass mitigation was above 50% in all plant species, while control (unvegetated) mesocosms had 71±1% retention, likely due to the addition of the phosphorus-binding gypsum. Ammonium mass mitigation was less efficient, ranging from 41±9% in *T. latifolia* to 56±18% in *L. oryzoides*. Overall nitrate mitigation ranged from 12±49% in *S. americanum* to 49±7% in controls. Based on comparisons to previous phytoremediation studies, gypsum amendments do not appear to enhance plants' abilities to mitigate diverse nutrients in runoff water. In the case of unvegetated controls, however, gypsum did appear to enhance nutrient mitigation capabilities.

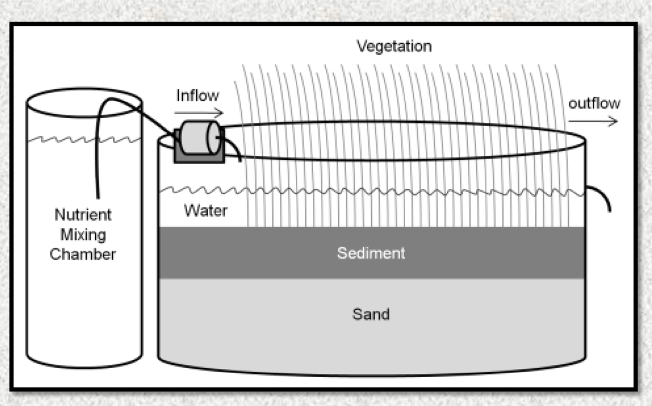
INTRODUCTION

- Approximately 11% (7,899) of the 74,863 reported impairments in 303(d) waters listed nutrients as the primary pollutant (US EPA 2015).
- Agriculture is a contributor of non-point source pollution, especially nutrients, to US surface waters (Carpenter et al. 1998).
- Increased nitrogen (N) and phosphorus (P) concentrations contribute to increased eutrophication in downstream aquatic receiving systems, as well as hypoxic zones in the Gulf of Mexico.
- Aquatic vegetation can enhance removal of N by direct uptake and incorporation into plant biomass (Hoagland et al. 2001; Silvan et al. 2004).
- Depending upon plant species used and the nutrient loading rate, plant uptake has been shown to account for between 3 and 60% of P removal (Greenway and Woolley 2000; Kuusemets et al. 2002).
- Flue gas desulfurization (FGD) gypsum is an industrial byproduct promoted for agricultural use to improve soil physical properties and bind excess phosphorus.
- Goal of study is to determine if gypsum aids in nutrient retention in systems with aquatic plants.

MATERIALS AND METHODS

- Experiments conducted using twelve, 379 L Rubbermaid® mesocosms (132 cm x 70 cm x 66 cm) (Figure 1).
- Each mesocosm had a sand base (22 cm) followed by an additional 16 cm of organic silt / clay (50:50) mixture overlay.
- Sediment (Smithdale-Lucy association) collected from University of Mississippi Field Station, Abbeville, MS, USA
- Three mesocosms (each) were planted with *Typha latifolia* (broadleaf cattail), *Sparganium americanum* (American bur-reed), and *Leersia oryzoides* (rice cutgrass). Remaining three mesocosms served as unvegetated controls
- Plants collected from natural populations in unamended / undisturbed ponds at the University of Mississippi Field Station
- Following plant transfer, mesocosm were filled with laboratory well water, and plants were allowed to acclimate for eight weeks prior to nutrient amendments.
- Each mesocosm was amended with 167 g of FGD gypsum. (Based on 1 ton / acre recommendation; scaled to size of mesocosm)
- Nutrient target stocks (8 mg L^{-1} each) for NH_4, NO_3, and PO_4 were prepared from analytical grade chemicals [$(NH_4)_2SO_4$, Na NO_3, and K_2HPO_4] and amended to mixing chambers filled with laboratory well water before being delivered to mesocosms via FMI ® metering pumps.

Figure 1.



Sparganium americanum (American bur-reed)

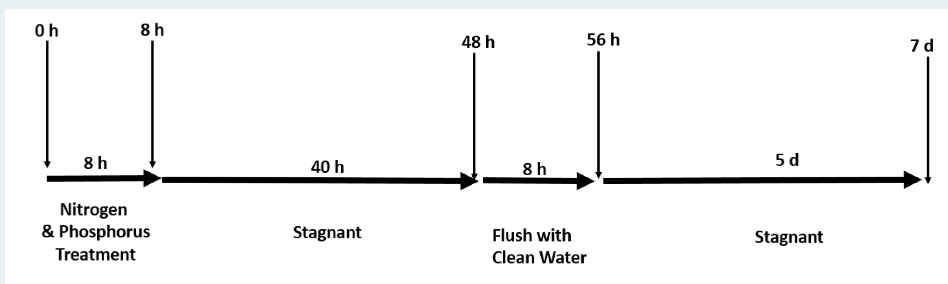
Typha latifolia (broadleaf cattail)

Leersia oryzoides (rice cutgrass)

Unvegetated Control

MATERIALS AND METHODS (cont.)

- Each mesocosm had an 8 h hydraulic retention time
- 16 h prior to nutrient amendment, water levels in each mesocosm were reduced by 25% of their maximum volume to simulate the influence of low-grade weirs during initial experimentation.
- Mesocosms were exposed to flowing, nutrient-enriched water for 8 h, allowed to sit undisturbed for 40 h, then exposed to flowing, "clean" (i.e. no nutrient enrichment) water for an additional 8 h to simulate flushing effects of second storm event.

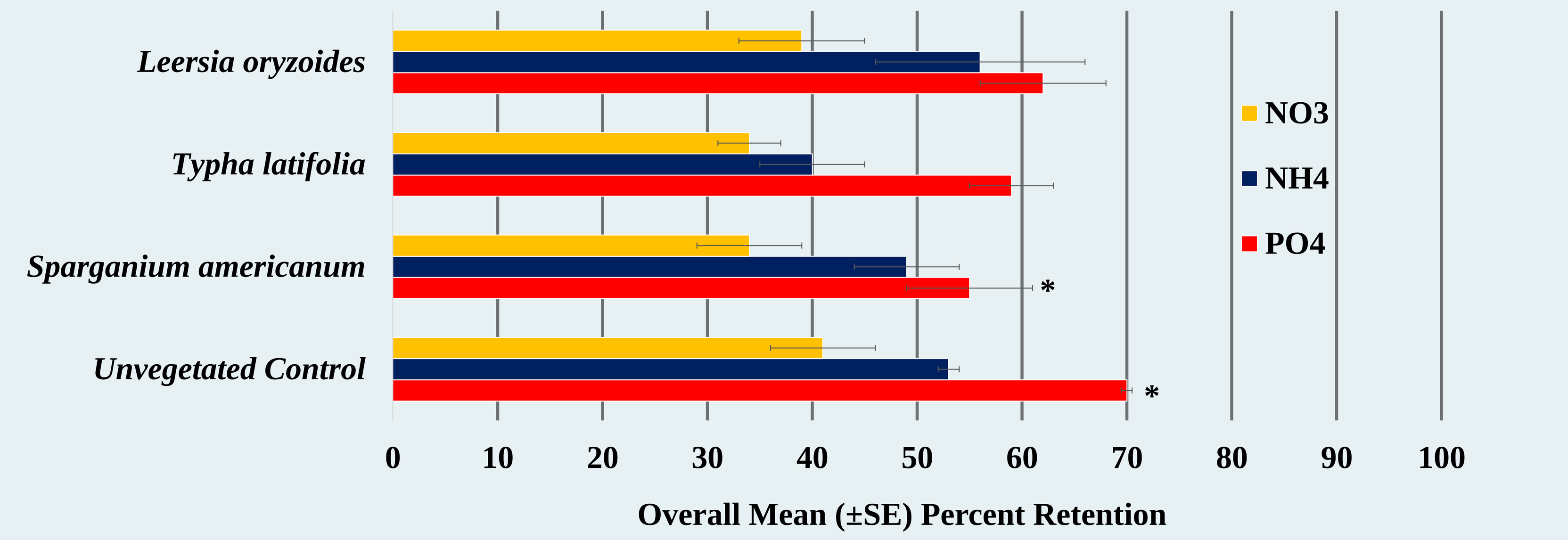


- Outflow water samples were collected at the following times:
  - Background, 2 h, 2.5 h, 3 h, 3.5 h, 4 h, 4.5 h, 5 h, 6 h, 7 h, 8 h, 10 h, 12 h, 24 h, 48 h, 49 h, 51 h, 56 h, 72 h, 168 h (7 d)
- All analyses were conducted using a Lachat QuickChem 8500 Series 2 Flow Injection Analysis system fitted with an ASX-520 autosampler and PDS200 precision dilutor system.
- Detection limits were 1.0 µg L^{-1} for PO_4
  2.4 µg L^{-1} for NH_4
  1.5 µg L^{-1} for NO_x
  0.5 µg L^{-1} for NO_2
- Statistical significance from the control determined using JMP® 8.0.1 software and Student's t-tests with an alpha of 0.05. Significance among plant species utilized ANOVA and Tukey's HSD tests at an alpha of 0.05.
- Aqueous runoff samples were analyzed for:
  - NH_4 (phenate method)
  - NO_3 (cadmium reduction method)
  - PO_4 (ascorbic acid method)

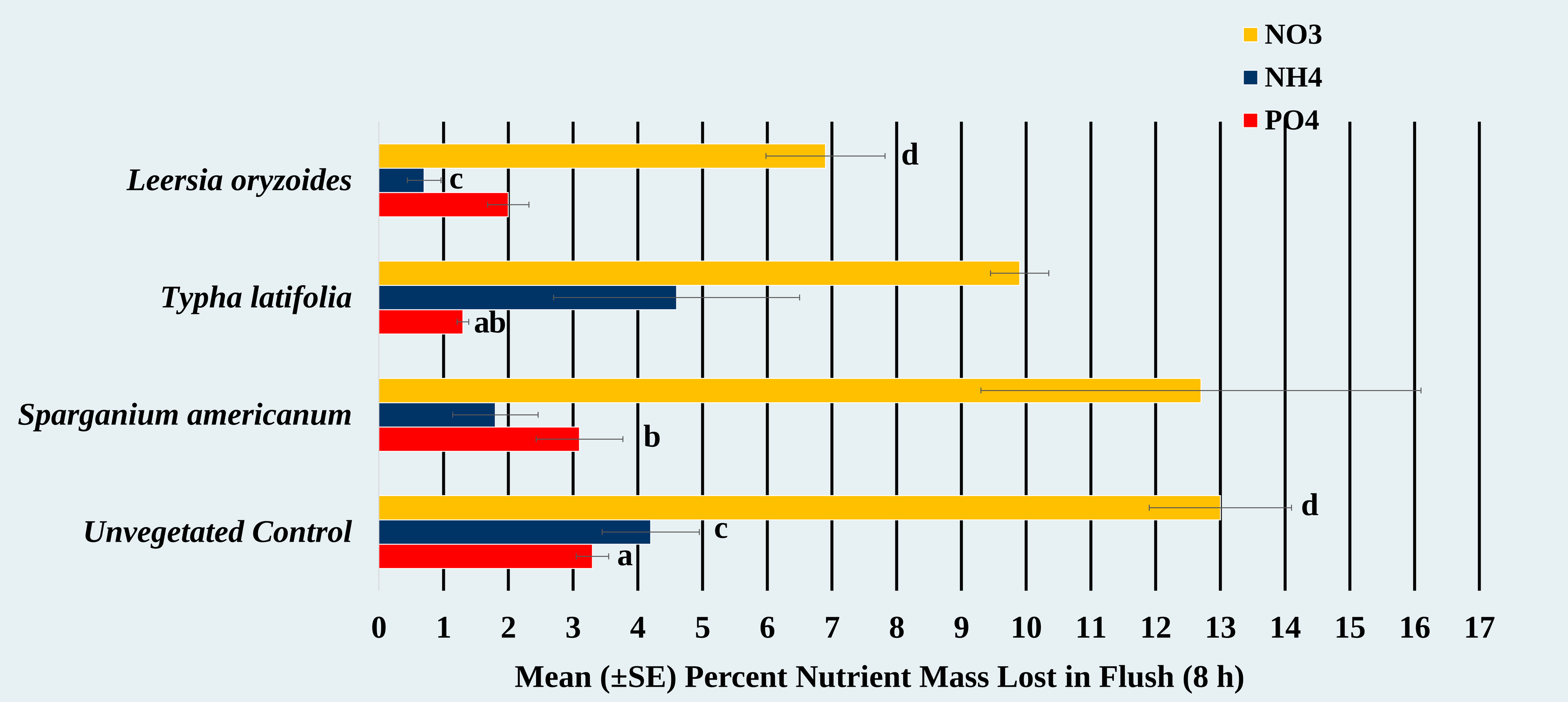
FGD gypsum used in current study

Lachat QuickChem Series 2 FIA

RESULTS



*Indicates statistical significance p = 0.0384



[a]Indicates statistical significance p = 0.0064
[b]Indicates statistical significance p = 0.0437
[c]Indicates statistical significance p = 0.0475
[d]Indicates statistical significance p = 0.0398

RESULTS (cont.)

- No significant difference observed in the inflow mass loads among plants and unvegetated controls for NO_3, NH_4, or PO_4.
- Significant difference in PO_4 mass lost in first 8 h (1 HRT) between unvegetated control (182±6.8 mg) and *Typha latifolia* (290±19.3 mg) (p=0.0404)
- Significant difference in PO_4 mass lost during flush between unvegetated control (23±5.7 mg) and *Typha latifolia* (9.1 ± 0.66 mg) (p=0.0217)
- Significant difference in NO_3 mass lost during flush between unvegetated control (113±33 mg) and *Leersia oryzoides* (54±7.3 mg) (p=0.0460)
- Percent PO_4 mass retention in the first 8 h (1 HRT) ranged from 58% in *Sparganium americanum* to 74% in unvegetated control
- Percent NH_4 mass retention in the first 8 h (1 HRT) ranged from 45% in *Typha latifolia* to 57% in unvegetated control
- Percent NO_3 mass retention in the first 8 h (1 HRT) ranged from 43% in *Typha latifolia* to 54% in unvegetated control

DISCUSSION

- Tyler et al. (2012a,b) reported *Leersia oryzoides* and *Typha latifolia* showed greatest overall potential to decrease loads of NO_3, NH_4, or PO_4.
- Comparing the current study (8 h HRT plus addition of FGD gypsum) to Tyler et al. (2012a,b)(6 h HRT with no gypsum), PO_4 mitigation efficiencies increased in the current study for all plant species (*Sparganium americanum, Leersia oryzoides, Typha latifolia*) as well as the unvegetated control.
- Although FGD gypsum is not promoted for its effects on NH_4, results from the current study indicate improvement in NH_4 mitigation efficiency for *Sparganium americanum, Leersia oryzoides,* and the unvegetated control when compared to Tyler et al. (2012a,b).
- Addition of FGD gypsum decreased NO_3 mitigation efficiency for *Sparganium americanum, Leersia oryzoides,* and *Typha latifolia.* FGD gypsum increased the overall NO_3 mitigation efficiency of the unvegetated control, as well as reducing the mass lost during the flushing event all when compared to results from Tyler et al. (2012a,b).
- During periods of low flow and stagnation, nutrient mitigation via plant uptake and microbial activity on plant tissue and in sediment are important.

DISCUSSION (cont.)

- Pierce et al. (2009) found that both flooding and plant species could influence soil redox potential and N uptake in mesocosm systems.
- Community composition of aquatic vegetation growing in drainage ditches can respond to changes in nutrient levels in the water column, shifting toward plant species that sorb nutrients directly from water as opposed to sediments (Janse 1998).
- Studies using both autoclaved and gamma-irradiated soils have demonstrated microbial communities contribute to the total amount of P removed from water (Sharpley et al. 2007; Huang et al. 2011).

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