

# The Use of a Novel Aerobic Wetland To Reduce Pollutants Associated with Contaminated Runoff

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## ABSTRACT

Pollution from agricultural and urban runoff is a significant contributor to the eutrophication of surface waters. Constructed wetlands are currently used as a means to collect, store and treat these polluted waters. Our research examined the effects of both poly and monoculture vegetated wetlands in nutrient reduction for contaminated stormwater. The wetlands were recirculating vertical flow systems (RVFCW) comprised of three modules: a vegetated layer, a filtration module and a final aerobic phase. A synthetic wastewater, nitrate (25 mg/L NO<sub>3</sub>-N), reactive phosphorous (0.19 mg/L) and TOC (3 mg/L) was used. After four months, vegetative units reduced nitrate loads by 62% while non-vegetated units had a net gain of 33%. Nitrate reduction was greatest in polyculture systems containing both annual and perennial species. The largest nutrient load reductions and evapotranspiration rates were observed in systems comprised of native southeastern Pennsylvania weeds, demonstrating possible phytoremediative potentials for these species.

## INTRODUCTION

Recent studies indicate that the majority of water quality impairments in our nation's surface water results from non-point source pollution and other nontraditional sources (U.S. EPA 2006). Constructed wetlands (CW) have been widely studied for their treatment potential of agricultural runoff (Hammer, 1989, Braskerud, 2002, Kovacic, 2000, Schulz, 2001, Tanner, 2005, Kantawanichkul, 2005). Traditionally, the composition of plant species in wetlands is often dominated by one or a few species (Galatowitsch, 1999). However, the phenology (life cycle) of nutrient accumulation and release in mono-specific stands may actually influence the eutrophication of aquatic systems (Kao et al. 2003). When analyzing nutrient input-output studies in constructed wetlands, the importance of species diversity and richness in nutrient retention is often overlooked. Nutrient uptake and losses is highly variably among differing plant species and greatly affects a system's nutrient cycling capabilities (Hobbie 1992, Knops et al. 2002). Studies have shown that net primary production and nutrient retention in ecosystems increases as the number of plant species increases (Hooper et al. 1997). This research focused on pollutant retention in mono versus polyculture RVFCWs in removing nutrients associated with contaminated runoff.

## MATERIALS AND METHODS

**Construction.** Eight microcosm-scale RVFCW's units were constructed for the project. Each unit consisted of a two tiered structure, with each tier being 55 by 40 by 30cm. Synthetic wastewater (SW) was used in this research and formulated on the basis of high-nutrient runoff concentrations, such as agricultural and golf course runoff. Analysis of (SW) indicated the following initial composition: 25mg/L Nitrate, 0.19 mg/L reactive phosphorus, and 3.0 mg/L TOC.

**Experimental Treatments.** The influence of vegetation on nutrient removal in the RVFCW was examined using four treatments.

**Table 1. Treatment Wetlands**

TREATMENTS	CLASS	SPECIES
MP (Monoculture)	Perennial	<i>Carex stipate</i>
PA (Polyculture)	Annual	<i>Phytolacca americana</i> <i>Chenopodium album</i> , <i>Setaria faberi</i>
PPA (Polyculture)	Perennial / Annual	<i>Carex stipate</i> , <i>Phytolacca americana</i> <i>Chenopodium album</i> , <i>Setaria faberi</i>
U (Non-vegetated)	NONE	NONE

**Sampling.** Units were run with 40L of wastewater, a recirculation time of 3-4 days and a flow rate of 0.4L/min. The units were subjected to a continuous dosing of SW during the 17 week study. After plant establishment, effluent water samples were collected. Twice each week 20 L of effluent water was drained from the units and replaced with 20L of fresh (SW). Recorded data was separated into four distinct phases (early stage [E], weeks 1-5; mid-stage [M], weeks 6-9; late stage [L], weeks 10-14; and final stage [F], weeks 15-17) for statistical comparison using ANOVA ( $p < 0.01$ ) (d.f = 27) with an a posteriori Bonferroni multiple comparison test.

Early and late phase data sets were selected for comparison as optimal periods most likely to represent the wastewater treatment potential of the systems. The early phase (weeks 2-5) was a period of initial establishment and steady growth within the microcosms. Late phase data (weeks 10-14) evaluated the systems function for possible saturation and breakthrough. Biomass was harvested for further comparisons.

## RESULTS

**Nitrate.** Vegetated systems were more efficient at reducing  $\text{NO}_3$  loads compared to non-vegetated systems ( $P < 0.001$ ). Over the 17 weeks, average total nitrate effluent loads from all vegetated units were 66% lower than influent loads. Total nitrate removal from each system over the 17 week period was: U(-33%) > MA(58%) > PA(67%) > PPA(83%).

Systems (MA) and (PPA) both removed nitrate to levels below regulatory limits during the early phase. Nitrate was not significantly removed in (PA) during the early stage,

likely due to the slow growth of the weeds. During the early stage planted sedge appeared responsible for the majority of nitrate removal.

During the late phase, nitrate removal in (PPA) ( $P < 0.05$ ) and (PA) ( $P < 0.001$ ) was higher than the respective early stage and below regulatory limits. Nitrate removal in (MA), however, fell below required levels. Harvesting of sedge during week 9 significantly reduce nitrate removal ( $P < 0.01$ ) within the system. There was no difference in nitrate removal between (PPA) and (PA) during late phase. Weeds had the greatest contribution to nitrate reduction, as the sedge appeared no longer important.

**Phosphorus.** Weekly influent  $\text{PO}_4$  loading was 14 mg. Initial  $\text{PO}_4$  loads in the effluent of the vegetated systems were 2-3 times higher than un-vegetated units. Excess  $\text{PO}_4$  from the vegetated systems may have resulted from the microbial decomposition of abundant plant matter as well as any residual  $\text{PO}_4$  that was contained within the sedge plug soil. Phosphorus removal was low and constant in non-vegetated units. Comparison between early and late phase vegetated units showed a reduction in  $\text{PO}_4$  effluent loads over time ( $p < 0.001$ ). Systems containing weeds, (PPA, PA) had the greatest  $\text{PO}_4$  reductions ( $p < 0.001$ ), and had the greatest vegetative biomass of all systems.

**Abiotic Parameters.** Abiotic parameters often influence that productivity and longevity of biological treatment systems. Effluent pH, conductivity and dissolved oxygen (DO) were measured in the four systems for all sampling occurrences. Evaporative water loss was also recorded. Vegetation appeared to have no influence on pH and DO levels within the systems. DO levels of influent waters averaged 4.2  $\text{O}_2/\text{mL}$ . Effluent DO levels did not fluctuate substantially from influent values, indicating that both vegetated and unvegetated systems remained throughout the experiment. The pH in all units averaged 7.9 and was well within the range of optimal pH values for productive treatment wetlands. Water loss in non-vegetated units was low and constant in both stages. The (MA) experienced no change in both stages, however (PPA) and (PA) showed significant increases ( $P < 0.001$ ) in water loss between early and late stages, demonstrating the importance of weeds in contributing to evapotranspirational water loss. Water loss was significantly greater ( $P < 0.01$ ) when weeds were present. Conductivity values were low and constant within un-vegetated units, but significantly greater ( $P < 0.01$ ) in (PPA) and (PA) during the late stage, likely due to the large water loss within these systems.

## DISCUSSION

The vegetated RVFCW microcosms were effective in reducing the nitrate load from the wastewater. This demonstrated that the majority of the nitrate removal was from vegetative assimilation. The polyculture systems containing weeds were observed to have the highest densities of vegetation (biomass) and proved to be best at removing nutrients. System (PPA) with the greatest species diversity had the greatest  $\text{NO}_3$  removal rate. The sedge plugs established good early growth and were effective in removing nitrate during the first month of the experiment. Weeds established themselves later and appeared to be most effective in removing the nitrate during the last half of the experiment. When biomass was harvested there was a sharp decline in the reduction of nitrate. Harvesting of

perennial vegetation in the constructed wetlands did not significantly contribute to increased nitrate reduction.

Annual plants tend to have shorter germination times than perennials (Shipley et al. 1991). Often, this results in more rapid colonization and immediate uptake of available nutrients. It may be beneficial to harvest soft tissue annual species to promote rapid annual growth and decrease the input of nutrients to the wetland due to vegetative senescence. Most problems associated with eutrophication occur during the growing season and the contribution of seasonal nitrogen and phosphorus retention by plants can be significant (Kao et al. 2003). Increasing species diversity by incorporating annual and perennial plants into a constructed wetland may increase the systems capacity for nutrient retention.

Systems in which weeds were present (PPA, PA) had the greatest overall PO<sub>4</sub> load reductions and water loss due to evapotranspiration. The total leaf surface area was greatest in the weeds species and assumed to contribute to the higher evapotranspiration rates. Data suggests that the presence of emerging vegetation had an influence on increased phosphorus reduction rates. Lower phosphorous losses have been attributed to systems that have greater plant species richness (Kao et al. 2003). In constructed wetlands, phosphorous removal in wastewaters with high COD may be enhanced by biomass assimilation from the rapid growth of emergent vegetation and microorganisms. The presence of annual species may augment this process even faster.

## **CONCLUSION**

In higher plants, variations in nitrate uptake rates are associated with temporal responses to changing light intensities, temperature and stress conditions as well variations occurring during ontogeny (Imsande, 1994). In constructed wetlands, better management of individual vegetative species growth responses in regards to nutrient assimilation, such as the rapid growth of soft tissue species and the steady sustained growth of hearty perennials, may result in optimizing the removal capacity of nutrients over a longer seasonal period. Overall, the study demonstrates the potential use of vegetated RVFCW for removing nitrate and phosphorus from agricultural runoff. It is suggested that increasing the species diversity by incorporating both annual and perennial vegetation may increase the effectiveness of constructed wetlands in assimilating nutrients associated with agricultural wastewaters.

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