Duplicity of wetland plants in nutrient flux within agricultural drainage ditches in Mississippi

Kröger R.[1*], M.M. Holland[1], M.T. Moore[2] and C.M. Cooper[2]

[*1] Department of Biology, University of Mississippi, University, MS 38677
[2]USDA-ARS, National Sedimentation Laboratory, Oxford, MS 38655

Corresponding author:
kroger@olemiss.edu

Abstract

Drainage ditches, as integral components of the agricultural landscape, remove surface run-off and act as major conduits of nutrients from agricultural lands to receiving waters. These ditches are filled with wetland plants, providing additional surface area for microbial interactions as well as acting in a small, yet important assimilatory capacity. However, their assimilatory function is negated in winter with seasonal die-back and the release of assimilated nutrients into the system. We tested the hypotheses of whether plants, given the opportunity, will firstly assimilate higher concentrations of nutrients, such as nitrogen and phosphorus, and whether with subsequent decomposition these concentrations are released back into the water column. Given the opportunity *Leersia oryzoides,* a dominant wetland ditch plant species, will assimilate significantly higher concentrations of nitrogen ($p < 0.001$) and phosphorus ($p < 0.001$) in aboveground biomass. Subsequently, the senescence of aboveground biomass yielded significantly higher levels of phosphorus ($\pm$ 5.2 mg/l). However, there were no significant differences in nitrate, nitrite or ammonia levels between treated and untreated treatments, suggesting that denitrification and microbial processes were removing these products from the system. Using *Leersia oryzoides* as our model the seasonal dieback and duplicity of drainage ditch vegetation in nutrient assimilation during the growing season and re-release of phosphorus in the winter will have effects on downstream environments.

Key words: nutrients, wetland, assimilation, drainage ditch

Introduction

Wetlands have numerous mechanisms by which nutrients are assimilated and transformed. One such mechanism of nutrient removal is plant nutrient uptake. Wetland plants generally take up only very small quantities (<5%) of nutrients from influent waters(Hammer 1992). This amount is still insignificant compared to the loading rates measured flowing into the wetlands (Brix 1994, Younger & Batty 2002). However, plant uptake of nutrients is of quantitative importance in low-loaded wetland systems, such as drainage ditches associated with agricultural runoff (Peverly 1985, Richardson 1985).

Vegetation assimilation rates and nutrient concentrations tend to be highest in the early growing season and decrease as the plant matures and senesces (Johnston 1991). A distinct seasonal response is noted in temperate wetland system drainages: senescence in the winter and growth in the summer (Dolan et al. 1981). Emergent macrophytes lose nutrients rapidly upon death and decomposition (Boyd 1970, Gaudet 1977), with nutrient loss highest through rain leaching. *Typha latifolia* L. and *Phragmites australis* (Cav.) Trin. ex Steud. leaves lost 90 – 93% of their potassium, sodium, nitrogen and phosphorus after 20 days of tissue senescence (Boyd & Hess 1970, Gaudet 1977). With the possibility of using vegetation for pollution control, there have been several efforts to determine the relationships between the nutrient status of emergent macrophytes and their environment (Klopatek 1978). However, it has been noted in most studies that the contribution of plants to nutrient removal is often only temporary because of the loss of nutrients at senescence(Cronk & Fennessy 2001). Greenway (1997) compared nutrient levels in plant tissues between high nutrient loaded wetlands and control wetlands: total phosphorus and total nitrogen levels were 2 mg/g and 7mg/g higher respectively in high loaded wetlands than in control wetlands. Very few studies have examined the associated re-release of nutrients of wetland species following senescence.

In this study we tested two hypotheses. The first was to test the theory of luxury uptake (Cronk & Fennessy 2001), whether plants given the opportunity will assimilate higher concentrations of nutrients, such as nitrogen and phosphorus. The second hypothesis suggested plants that do assimilate higher concentrations of nutrients will, with subsequent tissue senescence, release higher concentrations back into the water column.

Methods and Materials

The decomposition experiment took place in a temperature controlled greenhouse at the University of Mississippi Field Station (UMFS). The purpose of the decomposition experiment was to follow up on work already undertaken at the UMFS (Davis & Holland 1998) on understanding the dynamics and relationships between nutrients in simulated agricultural runoff and wetland vegetation. Vegetation was collected from ponds at the UMFS in the summer and winter of 2004. These ponds were selected as they formed the basis of a simulated nutrient release experiment by the USDA-ARS National Sedimentation Laboratory over the last calendar year, and thus provided an excellent opportunity to compare between nutrient uptake and release of treated and non-treated ponds. A measured 25ha runoff concentration of nitrogen and phosphorus was applied to each simulated agricultural drainage ditch every two weeks for one year**.** The vegetation was taken out of the ponds in summer, as it was at this time when plant nutrient uptake is maximized, and again in winter after the first frost, as this the time when the plant was naturally beginning to senesce.

Leersia oryzoides (L.) Sw. was chosen, as it was found to be the most abundant and dominant species within the wetland mesocosms sampled. The experiment consisted of three treatments. Treatment 1 was labeled “treated” and consisted of nutrient enriched vegetation. Treatment 2 was labeled “untreated” and consisted of vegetation from a control pond that was not treated with nutrient runoff. Treatment 3 was the control and no vegetation was placed in these decomposition bags. Treatments 1 and 2 consisted of eight ¼ 55 gallon plastic drums, while treatment 3 had four plastic drums. Each drum was filled with 95L groundwater from the UMFS. A set mass of dry weight (approx. 800g) (minus the bag’s weight for comparative purposes) of *L. oryzoides* was placed in decomposition bags in each drum of standing water for 12 weeks. The decomposition bags had a 5mm mesh diameter and were weighted to submerge the vegetation. Water samples were taken on a weekly basis and analyzed for total nitrogen, total phosphorus and ammonia. Nitrate and nitrite were determined using a Dionex Ion Chromatograph fitted with a conductivity detector for seven anion analysis. Total phosphorus and ammonia were determined analytically using the ammonia persulfate and phenate digestion methods respectively. The control was used primarily to show that water nutrient concentrations were not fluctuating throughout the course of the experiment.

Results and Discussion

A comparison between the nutrient contents of *Leersia oryzoides* in the treated and untreated ponds reveals significant differences in tissue nutrient concentrations. Given the opportunity *L.oryzoides* undertakes luxury uptake. The total nitrogen content was significantly ($p < 0.001$) higher in treated vegetation (13.20 mg/g ± 2.08) than untreated vegetation (8.4 mg/g ± 0.5) (Figure 1). Similarly, total orthophosphate was significantly ($p < 0.001$) higher in treated vegetation (3.85 mg/g ± 0.25) than untreated vegetation (1.91 mg/g ± 0.32). These results have significant effects on the C:N ratio within the plant tissue.

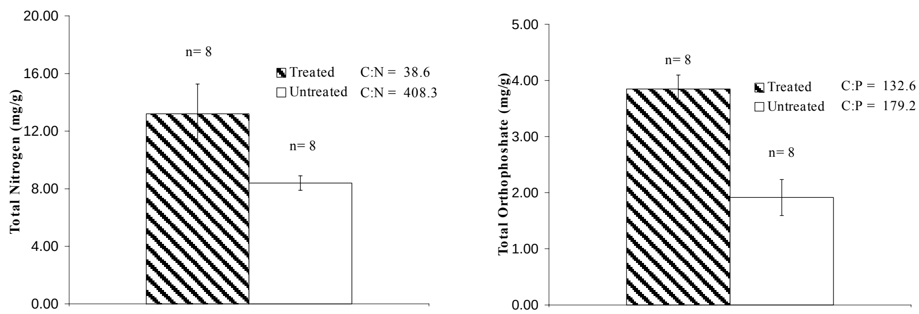

Figure 1. A comparison of total nitrogen and phosphorus concentrations (mg/L) between nutrient treated and untreated *Leersia oryzoides* in summer 2004

A higher tissue phosphorus concentration in summer resulted in a higher phosphorus concentration being re-released when the plants senesce (Figure 2). The significant difference is evident throughout the course of the experiment, and at termination, the water column of the treated vegetation had a significantly higher concentration than the untreated. The control shows that the water nutrient content does not change throughout the course of the experiment. Thus changes in nutrient concentrations within each treatment's water column were a result of the release of nutrients through tissue senescence. However, there is a reduction over time in total orthophosphate (TOP) concentration without the presence of an outlet (Figure 2). This reduction in concentrations was hypothesised as a result of microbes and algae assimilating and utilizing the leached inorganic P in metabolism and organic matter production.

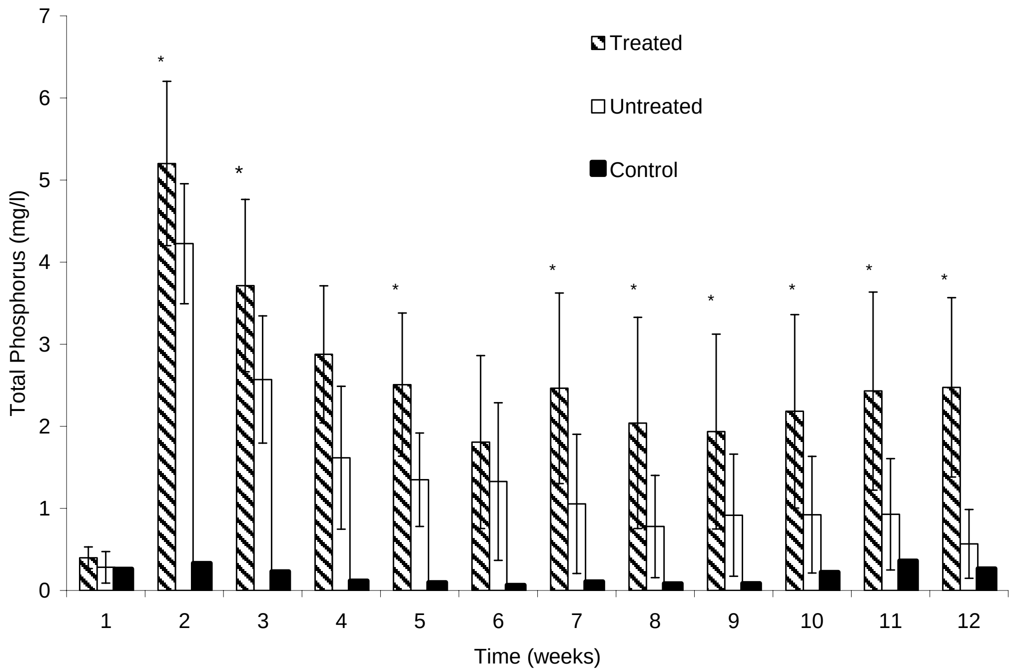

Figure 2. Total orthophosphate concentrations in the water column as a result of tissue senescence, July – September, 2004. *$p < 0.05$, 2 sample equal variance t-test

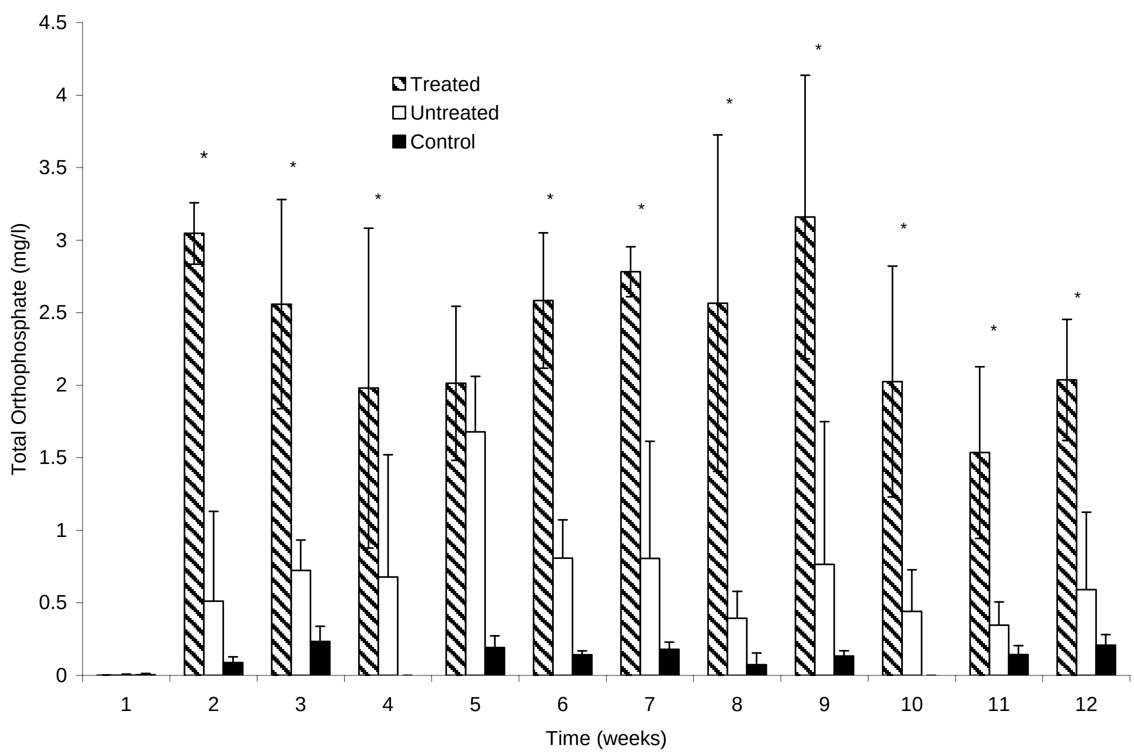

Figure 3. Total orthophosphate concentrations in the water column as a result of tissue senescence, November, 2004 – February 2005. *$p < 0.05$, 2 sample equal variance t-test

In winter (Figure 3) the treated vegetation again released significantly higher concentrations of TOP into the water column, however, the pattern of TOP concentration within the water column lacked the reduction observed over the summer (Figure 3). Most likely the lack of P utilization was a result of microbe temperature dependence. Microbial activity is temperature dependent and colder temperatures resulted in less effective use of TOP in the water column.

Nitrate levels over the summer and winter were highest in the control tubs and remained around 1.2mg/l throughout both experiments (Figure 4). The nitrate levels within the untreated and treated barrels were significantly reduced from control levels to zero (Figure 4). Even though plant tissue concentrations in the treated and untreated barrels were initially different, the result of tissue senescence was the same. The removal of nitrate from the system through nitrate ammonification is hypothesised as the reason nitrate levels were absent. Simple bacterial diagnostic tests suggested that there were nitrate ammonification bacteria present (e.g. *Agrobacterium* and *Bacillus*).

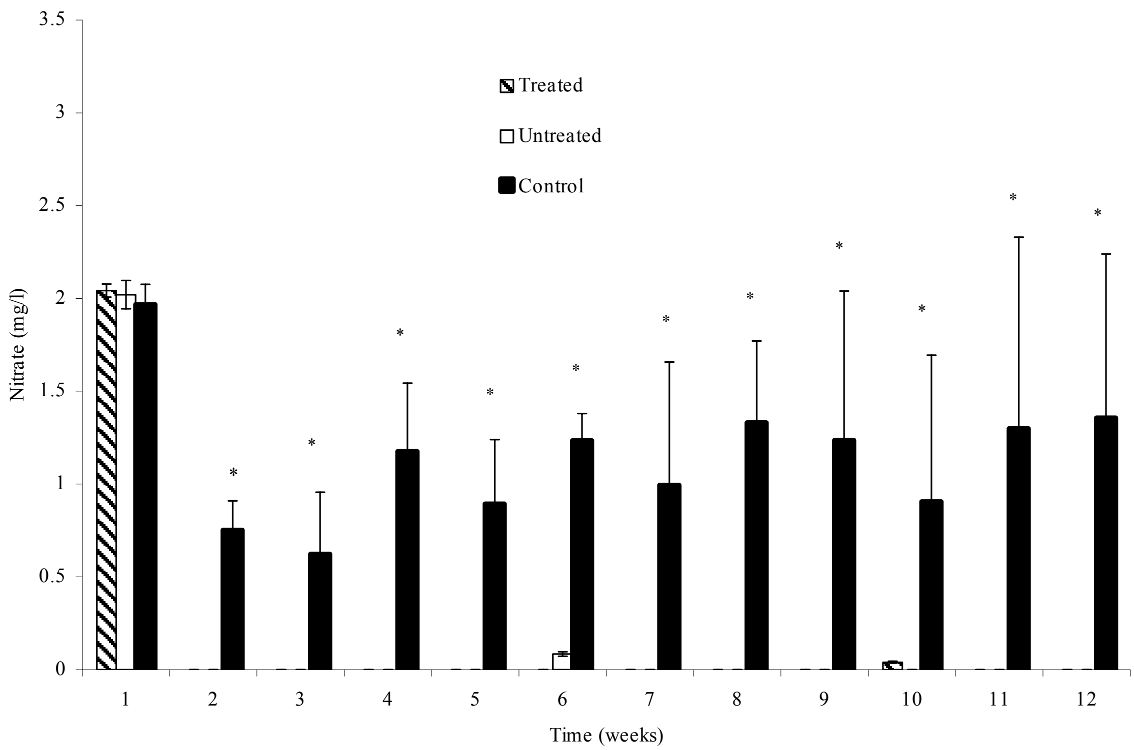

Figure 4. Nitrate concentrations in the water column as a result of tissue senescence July – September, 2004. A similar result occurred over winter, where the control barrels had significantly higher concentrations of NO_3^- than treated and untreated barrels.

The presence of nitrate-ammonification bacteria could provide reasons for the low concentrations of ammonia that occurred in both treated and untreated treatments. There were no significant differences in ammonia concentrations between treated, untreated and control barrels. Low concentrations of ammonia, the absence of nitrate and nitrite and the high C:N ratios of both treated and untreated vegetation suggests the nitrate ammonification was the dominant process in nitrogen flux within the barrels, rather than nitrification/denitrification (Cronk & Fennessy 2001).

Conclusions

Theory states that given the opportunity wetland vegetation will assimilate higher concentrations of nutrients even though it's not needed for growth or other metabolic functions. This indiscriminate uptake of nutrients is termed luxury uptake (Cronk & Fennessy 2001). *Leersia oryzoides* is a perennial emergent wetland species, which when exposed to elevated nutrient runoff concentrations assimilates higher concentrations of nitrogen and phosphorus in its above ground plant tissue (Figure 1). Subsequently, under senescence *L.oryzoides* re-releases higher concentrations of nutrients, specifically phosphorus in both summer and winter experiments. Nitrate and nitrite release is negated by denitrification, and a small proportion is converted to ammonia by facultative nitrate ammonification bacteria (Laanbroek 1990).

Plants exposed to low-load conditions, such as agricultural runoff, will significantly contribute to the assimilation of nutrients. However, in environments where seasonal shifts in temperature cause senescence of many wetland species, that assimilatory capacity could be negated potentially by the re-release of nutrients into receiving waters specifically phosphorus. Potential solutions to this problem of phosphorus leaching during the winter is the installation of slotted board outlets, increasing retention times in high rainfall periods, and aiding in sedimentation and accumulation of particulate bound phosphorus. Further, the interaction between specific bacterial components and the concentrations over time of nitrate, ammonia and ammonium would be an interesting avenue of research. The interaction between species-specific bacterial associations and specific wetland plants will be the next point for research to truly understand the dynamics of nutrient flux within wetland ecosystems.

Acknowledgements

We would like to thank the University of Mississippi Field Station for the use of the greenhouse and for logistic support. Financial support was gratefully received through the co-operative agreement of the USDA – ARS No. 58-6408-1-095 to the University of Mississippi. Thanks go to Landon Lee, Toyal Flemmons, Lisa Williams and John Hart for sample preparation and analysis.

References

BOYD, C. E. 1970. Production, mineral accumulation and pigment concentrations in *Typha latifolia* and *Scirpus americanus*. Ecology 51: 285 - 290.

BOYD, C. E., & HESS, L. W. 1970. Factors influencing shoot production and mineral nutrient levels in *Typha latifolia*. Ecology 51: 296-300.

BRIX, H. 1994. Functions of macrophytes in constructed wetlands. Water Science and Technology 29: 71 - 78.

CRONK, J. K., & FENNESSY, M. S. 2001. Wetland Plants: Biology and Ecology. Lewis Publishers, NY.

DAVIS, S. A., & HOLLAND, M. M. 1998. Vascular plant species native to Northern Mississippi for use in constructed wetlands for wastewater treatment. Pages 10-19. *Mississippi Water Resources Conference*, Raymond, MS.

DOLAN, T. J., BAYLEY, S. E., ZOLTEK, J., J., & HERMANN, A. J. 1981. Phosphorus dynamics of a Florida freshwater marsh receiving treated wastewater. Journal of Applied Ecology 18: 205 - 219.

GAUDET, J. J. 1977. Uptake, accumulation and loss of nutrients by papyrus in tropical swamps. Ecology 58: 415 - 422.

GREENWAY, M. 1997. Nutrient content of wetland plants in constructed wetland receiving municipal effluent in tropical Australia. Water Science and Technology 35: 135 - 142.

HAMMER, D. A. 1992. Designing constructed wetlands systems to treat agricultural nonpoint source pollution. Ecological Engineering 3: 1 - 34.

JOHNSTON, C. A. 1991. Sediment and nutrient retention by freshwater wetlands: effects on surface water quality. Critical Reviews in Environmental Control 21: 491 - 565.

KLOPATEK, J. M. 1978. Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes in R. E. Good, D. F. Whigham, and R. L. Simpson, eds. *Freshwater wetlands: ecological processes and management potential*. Academic Press Inc, N.Y.

LAANBROEK, H. J. 1990. Bacterial cycling of minerals that affect plant growth in waterlogged soils: a review. Aquatic Botany 38: 109-125.

PEVERLY, J. H. 1985. Element accumulation and release by macrophytes in a wetland stream. Journal of Environmental Quality 14: 137 - 143.

RICHARDSON, C. J. 1985. Mechanisms controlling phosphorus retention capacity in freshwater wetlands. Science 228: 1424 - 1427.

YOUNGER, P. L., & BATTY, L. C. 2002. The role of vegetation in wetland treatment of mine waters. Federal Environment Agency - Vienna, Austria.