Report as of FY2006 for 2006NJ100B: "Nitrate removal in urban wetlands: examining the roles of vegetation, soils, and hydrology in the creation of hot spots and hot moments of denitrification"

Publications

- Conference Proceedings:
  - Palta, Monica M. and Joan G. Ehrenfeld. 2007. Nitrate removal in urban wetlands: Examining the roles of vegetation, soils, and hydrology in the creation of hot spots and hot moments of denitrification. 2nd Symposium of the Meadowlands Environmental Research Institute, Lyndhurst, New Jersey. (Poster presentation)
  - Palta, Monica M. and Joan G. Ehrenfeld. 2007. Nitrate removal in urban wetlands: Examining the roles of vegetation, soils, and hydrology in the creation of hot spots and hot moments of microbial activity. Poster to be presented at the 92nd Annual Meeting of the Ecological Society of America, San Jose, California. August 5-10, 2007.

Report Follows

Project Summary:

Problem and Research Objectives

The scale at which "hot spots" and "hot moments" of nitrogen (N) removal occur via denitrification has not been well-defined, and there has been little work relating plant biology, hydrologic regime, and soils with N removal function in floodplain restoration efforts. The role of riparian vegetation in nitrate (NO_3^-) removal from surface and groundwater in particular is poorly understood. Though *Phragmites australis* is identified as a noxious weed in restoration designs, the extent to which *Phragmites* invasion or eradication affects nutrient cycling is not known. *Phragmites* has substantial and deeply rooted belowground biomass and high levels of carbon (C) exudation relative to other dominant marsh plants, as well as high levels of N uptake in tidal marshes; these characteristics suggest that patches of wetland containing *Phragmites* may serve as "hotspots" of denitrification. Recent research suggests, however, that the magnitude and direction of impact of *Phragmites* on N cycling may be system-specific. Differences in hydrologic conditions and soils between wetland areas may lead to differences in N removal ability of *Phragmites*. Soil textures vary in permeability and depth of the rooting zone, affecting the availability of labile C, NO_3^-, and oxygen to denitrifiers in the period following a saturation (rain) event.

My project took advantage of a 17 ha site (Teaneck Creek Conservancy, Bergen County) in which monospecific *Phragmites* stands are located on adjacent patches of clayey, silty, and organic soils. The presence of these adjacent patches enabled me to isolate the effects of soil type and soil-generated differences in hydrology on the spatial and temporal distribution of "hot spots" and "hot moments" of NO_3^- removal. My goal was to determine the temporal and spatial variability in denitrification within and among replicate areas within each of these three soil types, thus both helping to define the dimensions of "hot spots" and "hot moments" in N removal and examining the drivers behind such phenomena.

My hypotheses were (1) there will be significant differences in both spatial and temporal variability among the three soil types that will be correlated with their hydraulic properties, thus demonstrating that differences in soil texture are a source of patchiness in dentrification within wetlands; (2) further, the high water retention capacity of the clay soils will result in less within-patch variability and less variability over time than in the silty soil or peaty soil, thus resulting in larger "spots" and longer "moments" in the clays and smaller "spots" and shorter "moments" in the silt and peat; (3) finally, the dimensions of both "spots" and "moments" will be correlated with the abundance and distribution of organic matter available in the soil.

Methodology

The study took place in the Teaneck Creek watershed, a small (0.2 km^2) freshwater stream system in northeastern New Jersey (NJ) that is part of the larger Hackensack River watershed. Teaneck Creek is located in a highly urbanized setting adjacent to Newark, NJ. Research hypotheses were addressed by characterizing soil properties and denitrification rates in different soil types (clayey, silty, and organic soils). Two replicate patches of each soil type were identified for sampling, and two replicate 3x3 meter plots were used in each patch (Figure 1). A "hot spot" of N removal was thus restricted to two spatial levels: between-soil patches and within-soil patch. Only the top 20 cm of the soil profile was considered in NO_3^- removal dynamics.

To identify differences in denitrification rates between soil profile types over time, soil cores were collected from each plot every day for 10 days following a saturation event (> 1" of precipitation). Cores were collected in each of three seasons when temperatures are sufficiently high enough for denitrification to occur: spring (May), summer (July), and fall (November). A "hot moment" of N removal was thus restricted to two temporal levels: within a 10-day soil wetting and drying cycle, and within a given season. In each replicate 3x3 meter plot, one core was collected every day for 10 days. These "fresh" cores were used immediately for static core, acetylene-based measurements of denitrification rate. One "incubating" core was collected on the first day of the 10 day period and immediately replaced in the ground; this core was incubated in the ground for a month prior to extracting it to determine N mineralization rate in each soil type. A KCl extraction was used to determine soil NH_4^+ and NO_3^- content of fresh and incubated cores.

To characterize differences between soil types in hydraulic properties and available C, the following was characterized for each plot in the middle of the study, between summer and fall 10-day sampling periods: total organic N (TON); total organic C (TOC); plant litter biomass; soil texture (% sand, silt, clay). Percent soil moisture and percent organic matter of all soil cores collected during the study were determined concurrently with N processing. In addition, whenever possible, the redoximorphic status of the soil in each plot was measured in the field during core collection using Corning® redox combination electrode.

Linear comparative models (repeated measures PROC mixed and PROC glm) were used to determine whether significant differences existed between soil types in denitrification rate, moisture conditions, and organic matter content over time.

Principal Findings and Significance

The subset of data processed and analyzed thus far largely supports the hypotheses originally proposed. Significant differences in denitrification rate were found between soil types (indicating "hot spots") and between and within seasons (indicating "hot moments"). Further, these differences do appear to be driven, at least in part, by moisture conditions, which influence nitrification rates; the latter is a key process driving denitrification. This study therefore provides important evidence that differences in soil texture are a source of patchiness in dentrification within wetlands, and that restoration projects aiming for higher levels of denitrification within wetlands must carefully consider texture and drainage of wetland soils in their design.

Highly significant ($p < 0.001$) differences were found between soil types over the entire time frame of the study and between seasons. Soil denitrification rates demonstrated the following pattern: organic soils < clayey soils < silty soils (all significantly different from one another at the $p \leq 0.01$ level) (Figure 1). Organic soils showed very low variability in soil moisture, and initial analysis does indicate, as predicted, that clayey soils may demonstrate less variability in denitrification rates than silty soils; further analysis is needed to deconstruct these trends. Though soil moisture rates alone were not a good predictor of denitrification rate, differences in denitrification rates among soil types may be linked at least in part to soil moisture levels, since both silty and clayey soils had significantly ($p < 0.0005$) lower soil moisture than the permanently saturated organic soils (Figure 2). Despite their significant differences in denitrification rates, however, silty and clayey soils had very similar soil moisture on average, and similar variability in soil moisture. This pattern was surprising, given the patterns of drainage typically found on finer (clay, poor drainage) vs. coarser (silt, good drainage) soils. A soil map currently under construction for Teaneck Creek Conservancy linking soil moisture levels to both texture and elevation will also clarify how textural patterns may drive soil moisture patterns across the site.

Differences in soil moisture may be linked to denitrification rates among soil textures due to the influence of soil moisture on rates of soil nitrification. Nitrification rates have not yet been calculated (these samples have not been analyzed yet), but soil extractable nitrate does demonstrate a weak (spring $R^2 = 0.2542$, summer $R^2 = 0.4220$) quadratic trend with denitrification rate (Figure 3), indicating that denitrification rates are highest when soil nitrate is available at intermediate levels. Since nitrification is highest under dry (aerated) conditions, this trend may indicate that, as anticipated, intermediate moisture levels in the soil (wet enough for denitrification to occur, but dry enough for some nitrification to occur, to supply the denitrifying bacteria with nitrate). Though variability is high, available nitrate does appear, on average, to be lowest in the organic soils and highest in the silty soils (Figure 4).

It was hypothesized that organic matter availability in soils would be an important driver of patterns in denitrification, but this prediction is not thus far supported by the data. Organic matter content was not a good predictor of denitrification rate, and though organic matter was significantly ($p < 0.05$) higher in the organic soils than in the silty or clayey soils, denitrification was lowest in the organic soils. Previous work has found that high levels of organic matter in the soil during fall are likely to promote high levels of denitrification during this same season. Soils at Teaneck showed the opposite trend: fall denitrification rates were significantly lower than either spring or summer rates ($p < 0.005$). Additionally, no seasonal trends were found in organic matter content of soils, indicating further that the supply of nitrate, and not organic matter, is likely the most important determinant of denitrification rates in this system.

Figure 1. Average denitrification rates for all three seasons in clayey, silty, and organic soils. Error bars represent standard deviation from the mean.

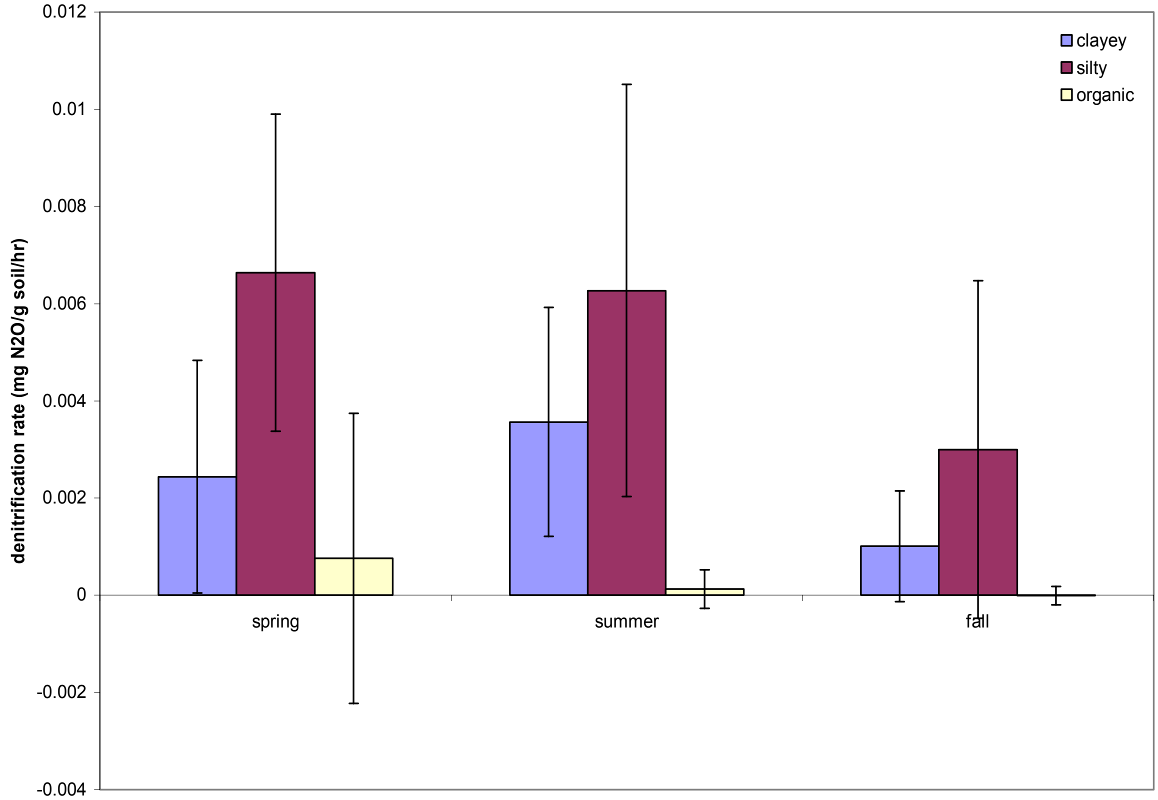

Figure 2. Soil moisture conditions over all three seasons for silty, clayey, and organic soils. Error bars represent standard deviation from the mean.

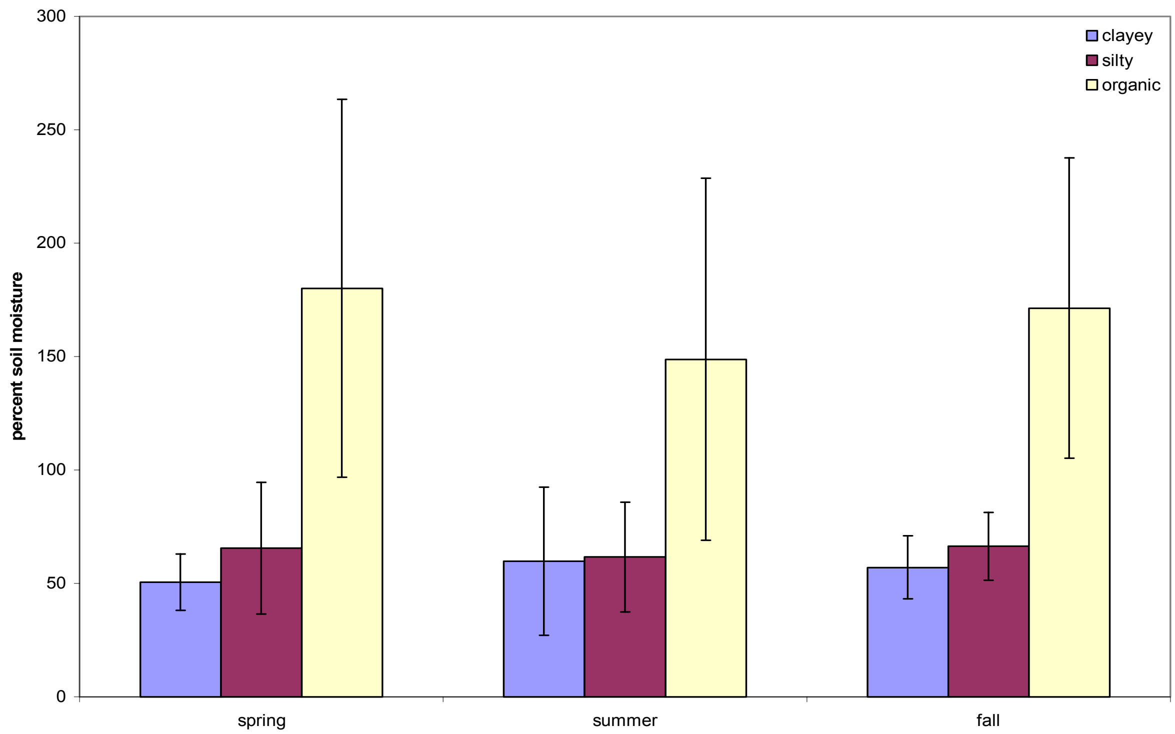

Figure 3. Summer denitrification rates vs. summer soil available nitrate for all sites.

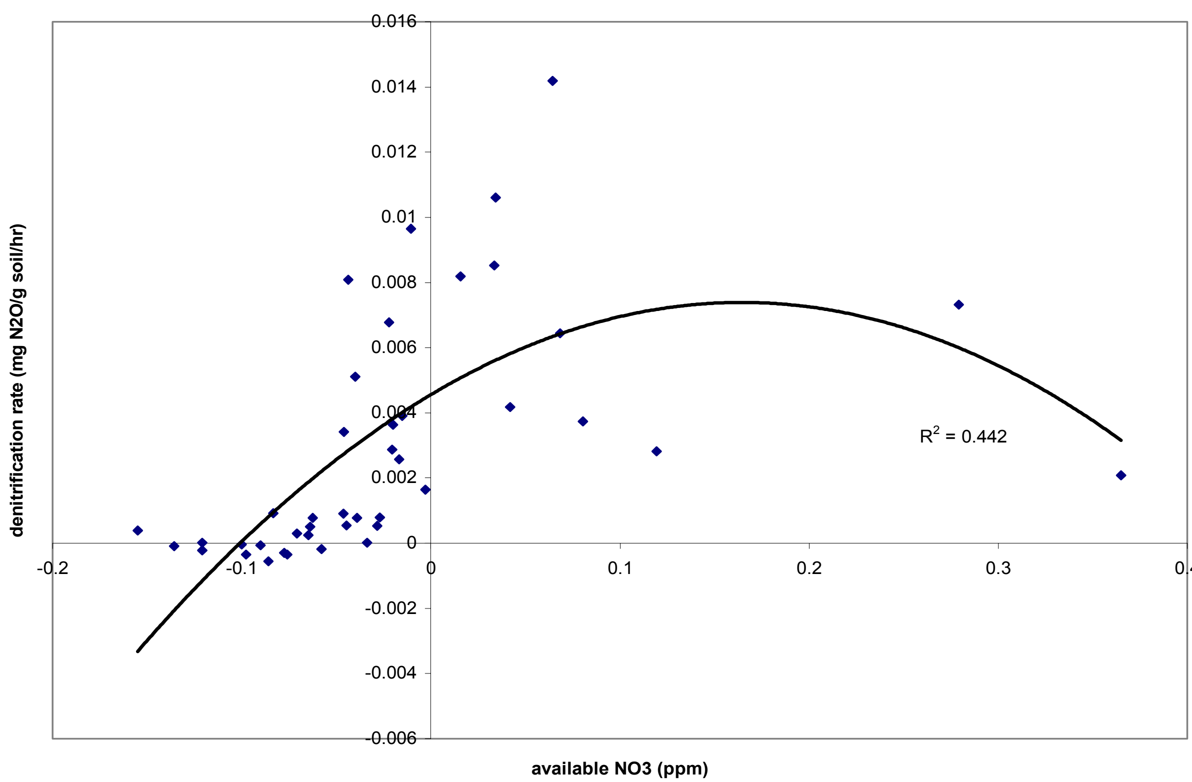

Figure 4. Average available nitrate over spring and summer seasons for each soil type.