The third chapter in a story about turfgrass nitrate leaching

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Abstract

Nitrate concentrations of groundwater are increasing in residential areas. One probable cause is input of nitrogen fertilizers to maintain healthy turfgrass. This study was conducted to evaluate differences in nitrate concentrations in soil water between sites fertilized with chemical or organic fertilizer. To obtain nitrate concentrations leaching below turfgrass and evaluate the impact to groundwater in Suffolk County, NY we installed suction lysimeters at one meter and collected monthly samples of soil water from January 2003 to January 2006 beneath two sites treated with chemical fertilizer, five sites treated with organic fertilizer, one site not treated with fertilizer and one forest site (2005 only). We also installed lysimeters at variable depths at four of these sites and collected monthly samples. Yearly average concentrations under fertilizer turfgrass reach values much higher than those under forest cover (0.08 ppm) and higher, on average, than unfertilized turfgrass (0.90 ppm) but remain below the drinking water standard of 10 ppm nitrogen as nitrate. The use of organic fertilizer alone does not guarantee lower nitrate concentrations in the pore water. Some of the highest concentrations were found beneath sites fertilized by organic fertilizers, however, the likelihood of concentrations of soil water to exceed this standard are 20% for sites treated with organic fertilizer and 32% for sites treated with chemical fertilizer. It is unlikely that turfgrass fertilization alone would raise groundwater concentrations above the drinking water standard. There is evidence from the variable depth profiles that nitrate concentrations are not conservative with depth but decrease with depth. A better understanding of this process will aid in evaluating turfgrass fertilization impact on groundwater quality.

Introduction

Concentrations above the current Environmental Protection Agency drinking water standard of 10 ppm nitrogen as nitrate (NO_3-N) is know to cause blue baby syndrome in infants. It is important to prevent drinking water from reaching these levels not only for health concerns but due to high remediation cost. All potable water on Long Island, NY is derived from groundwater heightening the need to minimize contamination. Nitrate is being detected more often and at higher concentrations in Suffolk County groundwater within the past decade. Other researches have noted that fertilizer is a major source of nitrate in Long Island (Flipse and Bonner, 1985; Flipse et al., 1984; Kreitler et al., 1978; Porter, 1980). A major land use in Suffolk County, 25% as mapped in the late 1970's, is turfgrass. Nitrogen is an important nutrient needed for healthy, green turfgrass. The soils on Long Island have low pH and lack nutrients needed to support turfgrass and so the need for fertilizer application. Lime is also added to maintain a proper pH and provide Ca and Mg. Irrigation is required during the summer since the rainfall on Long Island is not enough to maintain most turfgrass species.

We measured NO_3-N concentrations of soil water collected monthly from January 2003 to January 2006 at one meter beneath turfgrass and forest sites in addition to samplers from depth profiles beneath four turfgrass sites. We present these data in the framework of our evolving hypotheses and assumptions as they changed over the course of our three year study.

Overview

2003 and 2004

- Initial Questions
  - How does turfgrass maintenance influence nitrate concentrations in groundwater?
  - What is the difference between nitrate concentrations in soil water collected at one meter between organically fertilized, chemical fertilized and not fertilized turfgrass sites?
- Assumptions
  - Nitrate concentrations at one meter are below the depth of turfgrass influence.
  - Nitrate concentrations are conservative, i.e. remain unchanged, from one meter to the groundwater table.

   - Organic fertilizer should have a reduced affect compared with chemical fertilizers.
- Methods (Munster, 2003)
   - Installed soil water samplers, suction lysimeters, at one meter below turfgrass at (1) two sites treated with chemical fertilizer (2) five sites maintained by an organic landscaper and (3) one site not fertilized.
   - Installed multiple suction lysimeters at different depths for two sites treated with chemical fertilizer and two sties treated with organic fertilizer.
   - Sampled monthly for soil water.
   - Measured nitrate concentrations at the Marine Science Research Center, Stony Brook University using the nutrient analyzer, a colorimetric method.
- Major findings
   - Fertilizer practices between sites are not easily compared due to differences in site characteristics.
   - The use of organic fertilizer alone does not guarantee lower nitrate concentrations.
   - Nitrate is not conservative from 60 cm to 150 cm depth.
      - Of the four sites, one has increasing nitrate concentration from 100 cm to depth, two have decreasing nitrate concentrations from 100 cm to depth and for one site remains unchanged.

2005

- New Questions
   - What controls nitrate concentrations at one meter?
   - What controls changes in nitrate concentrations with depth in the unsaturated zone?
   - How can we distinguish which fertilizer practice minimized nitrate concentrations in the groundwater?
- New Assumption
   - Decreases in nitrate concentrations with depth are likely from denitrification.
- New Methods
   - At three sites we split treatment so that half the site was fertilized with chemical fertilizer and the other half with organic fertilizer and installed new lysimeters at

one meter in the new treatment areas. In this way the affects of site properties should be minimized.

- ➢ Installed rain gauges at each site.
- ➢ Installed one lysimeter beneath the forest floor at one meter.

❖ Major findings

- ➢ Patterns in nitrate leaching varied between years.
- ➢ Average nitrate concentrations under fertilized turfgrass reach values much higher than the forest and slightly higher than the non fertilized turfgrass site.
- ➢ Most average values are below the drinking water standard.
- ➢ Results from split sites suggest that soil properties play a vital role in controlling nitrate concentrations of soil water.

Results and Discussion

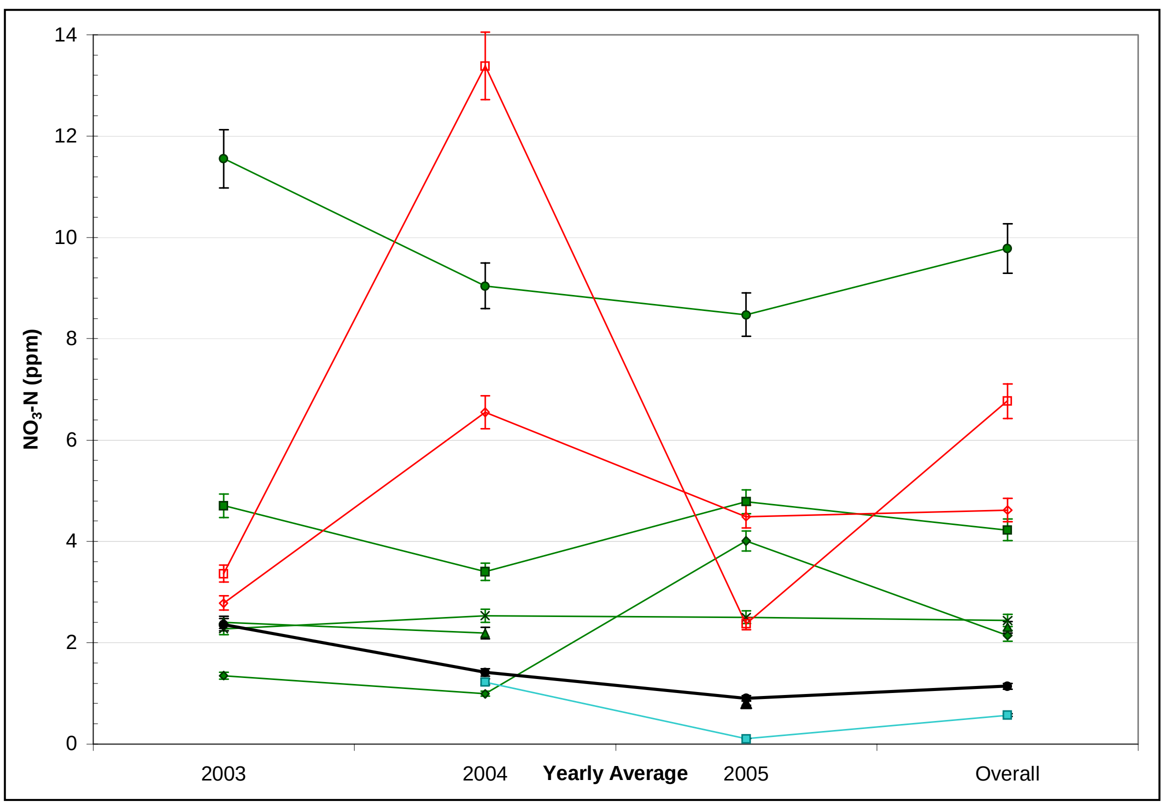

Figure 1 Yearly average NO_3-N concentrations collected from the one meter lysimeters for each site.

The first significant result from data collected in 2003 was that the yearly average nitrate concentrations at one meter were highest below two of the sites fertilized with organic fertilizers (Figure 1). We concluded that site and soil properties controlled nitrate concentrations more than fertilizer type since the other three sites treated with organic fertilizer were similar to the site not fertilized (Munster et al., 2005). An overview of the site properties are presented in Table 1. To better compare the sites we evaluated possible nitrate leaching indices and concluded that infiltration rate multiplied by soil organic

Table 1. Overview of measured site properties.

Site	Ground water Depth	Soil Survey Classification	Treatment Type (sprinklers)	Infiltration Rate	Turfgrass Age	Thatch thickness	Soil Organic Matter in Upper 15cm
	(m)			(cm/min)	(yrs)	(cm)	(SOM/g soil)
Oakdale	2.4	Cut and fill land	Organic (yes)	1.05	6	0.17	0.0245
Huntington	9.1	Riverhead and Haven soils	Organic (yes)	1.55	10	0.83	0.0696
Stony Brook	13.7	Riverhead and Haven soils	Chemical[2] (no)	0.20	4	0.17	0.0341
Oakdale	2.4	Cut and fill land	Chemical[1] (yes)	0.40	47	0.42	0.0594
Hauppauge	10.7	Haven loam	Organic (yes)	0.55	23	0.62	0.0561
Coram	18.3	Carver and Plymouth sands	Organic (yes)	0.30	8	1.42	0.0355
E. Hampton	2.4	Bridgehampton silt loam	Organic3 (yes)	0.10	22	1.33	0.0799

matter created a reasonable index for site comparison (Figure 2). An increase in leaching index predicts increased yearly average nitrate concentrations at one meter. A linear fit yields acceptable R^2's for 2003, 2005 and the January 2003 through January 2006 overall three year average. Data from 2004 was skewed due to unexplainable high concentrations at one of the sites with a low leaching index.

Previous studies have found a relationship between fertilizer type and nitrate leaching concentrations (Maeda et al., 2003; Shaddox and Sartain, 2001; Waddington and Turner, 1980). To minimize effects caused by site and soil conditions, in 2005 three of the sites were treated with both organic and chemical fertilizers at similar application times. Due to the fertilizer specifications the chemical fertilizer was applied four times during the year and at much higher application rates than the organic fertilizer which was applied

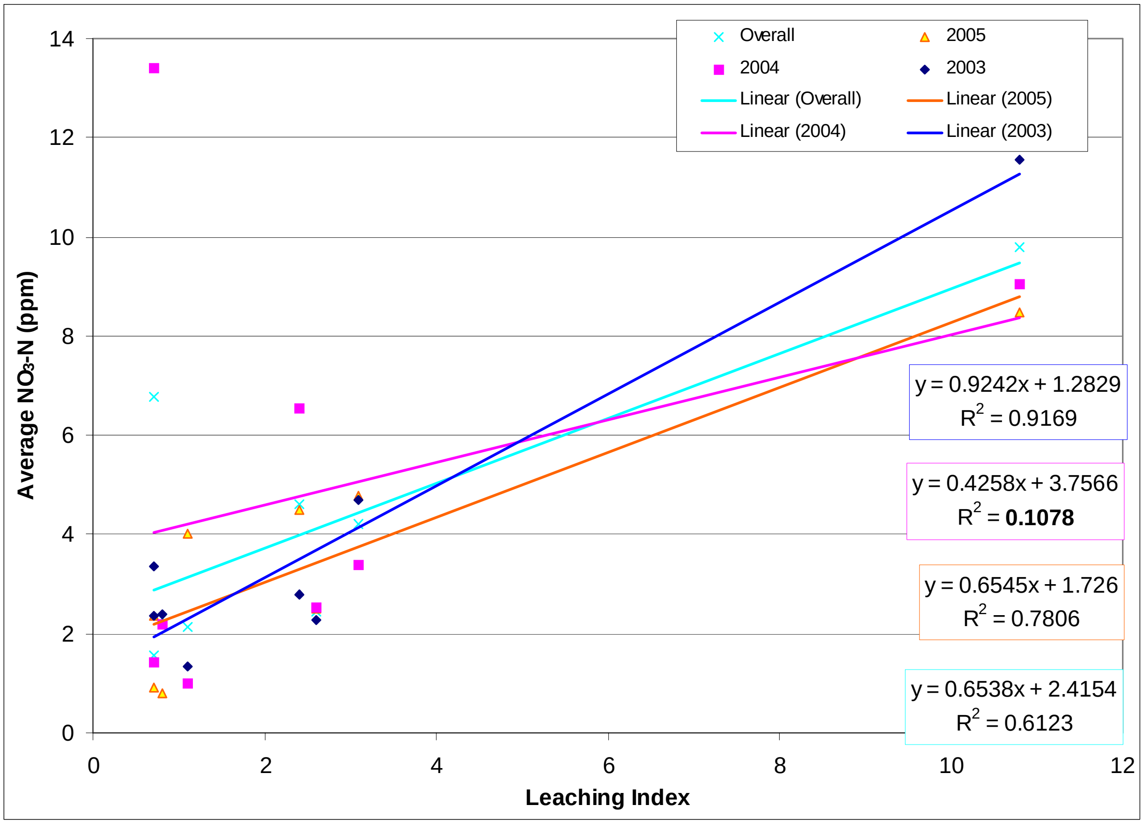

Figure 2 Leaching index vs. Average NO_3-N concentration collected from the one meter lysimeters. Leaching index is calculated as infiltration Rate (cm/min) multiplied by soil organic matter (g/g) ($x10^{-2}$) Regression lines are a linear fit using excel. All years except 2004 yield acceptable R2 values.

three times during the year. Approximately 270 kg-N/ha/yr was applied at the chemical sites and 150 kg-N/ha/yr at the organic sites. Soil water at one meter was collected from May to December of 2005. Table 2 presents average concentrations from June to

Site	Chemical (ppm)	Organic (ppm)	Duration 2005
Hauppauge	14.04*	10.60	June-Sept.
Huntington	14.43*	7.59	June-Dec.
Oakdale	5.42	14.5*	June-Dec.

Table 2. Yearly average NO_3-N concentrations for the sites treated with both chemical and organic

December for Oakdale and Huntington and June only to September for Hauppauge due to lack of water in one of the Hauppauge lysimeters. The average nitrate concentration was higher beneath the site treated with organic fertilizer at Oakdale while at Huntington and Hauppauge the sites treated with chemical fertilizer had a higher average concentration than the organic site. Minimizing difference in site conditions did not yield clear conclusions if chemical or organic fertilizers have higher concentrations at one meter. These results are interesting but still inconclusive as lysimeters may take up to a year to reach equilibrium with the surrounding soil (Litaor, 1988). This is suspect since the three newly established lysimeters were the sites with the higher average concentrations.

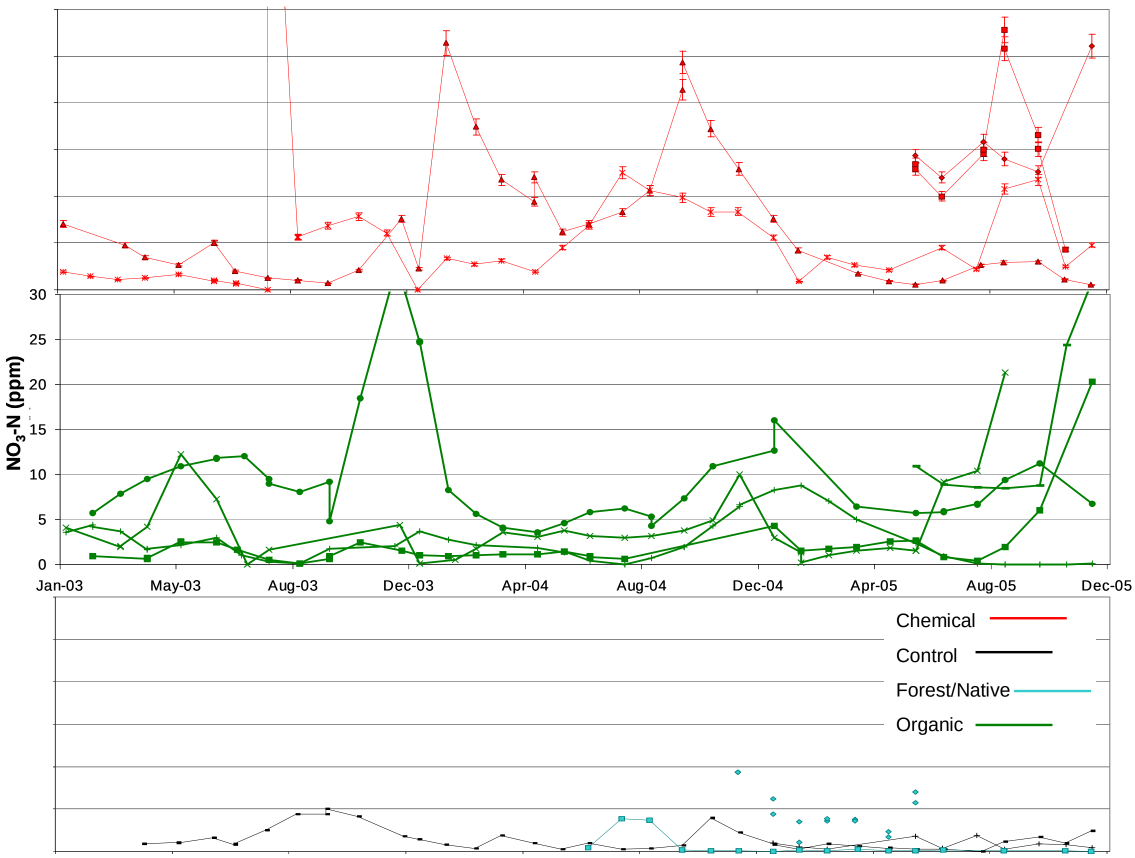

Figure 3 Monthly NO_3-N concentrations collected from the one meter samplers at all sites from January 2003 to January 2006. All plots are on the same X and Y scaling.

Monthly nitrate concentrations at one meter varied between years, at times showing large spikes in concentrations (Figure 3). These spikes are of concern since they are above the drinking water standard, where the yearly averages are generally below the drinking water standard (Figure 4). It is these spikes that we would like to minimize to reduce the impact of turfgrass fertilization on nitrate concentrations in groundwater. A useful way to understand the impact of these spikes is to evaluate probability plots. We utilized the program Minitab to calculate these curves. Minitab calculates the cumulative distribution function and associated confidence intervals based on parameters estimated from the data. As shown in Figure 5 a site treated with chemical fertilizer is likely to have concentrations at one meter above 10 ppm NO_3-N 32% of the time and sites treated with organic fertilizer are likely to have concentrations at one meter above 10 ppm NO_3-N 20% of the time, a value lower than the sites treated with chemical fertilizer. The site

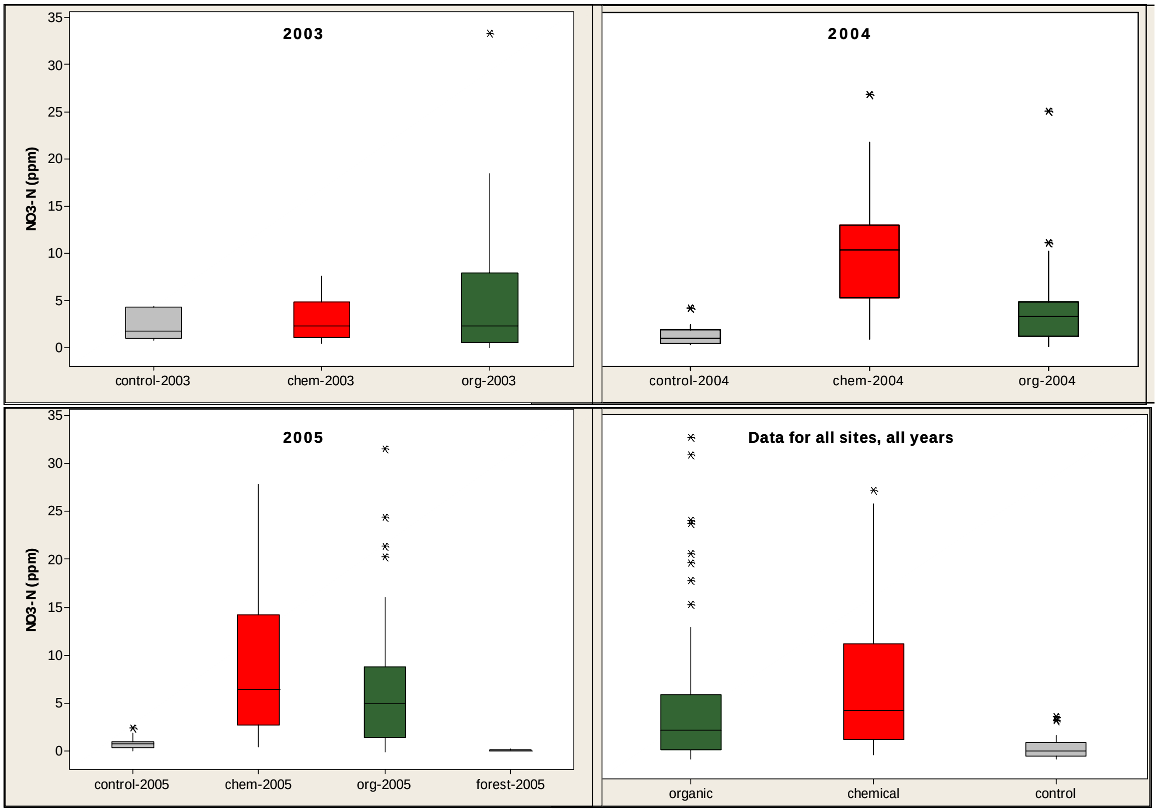

Figure 4 Yearly average NO_3-N concentrations collected from the one meter lysimeters plotted as a function of fertilizer treatment type. The line in the box is the median value. The area in the box covers 50 percent of the data. The outside bars encompass 75 percent of the data and asterisks represent outliers.

treated with no fertilizer has a less than 0.1% chance of having concentrations at one meter greater than 10 ppm NO_3-N.

We may not fully understand why there are variations in concentrations between years and between sites but what is certain is that all fertilized sites have averages above the control and the forest site and that the chemical sites generally have higher concentrations than the organic sites, as shown in Figure 4 and confirmed using the Mann Whitney non parametric statistically test. Most averages are also below the drinking water standard of 10 ppm NO_3-N. It is unlikely that turfgrass practices alone would raise groundwater concentrations above this standard.

The concentrations analyzed at one meter are important for site comparison but may not directly relate to an impact on water quality. We found that nitrate concentrations are not conservative from one meter to depths of 120 and 150 cm as previously assumed. Figure 6 illustrates this well. The plots **a** through **d** show normalized NO_3-N concentrations in the one meter sampler to those of the next deepest sampler.

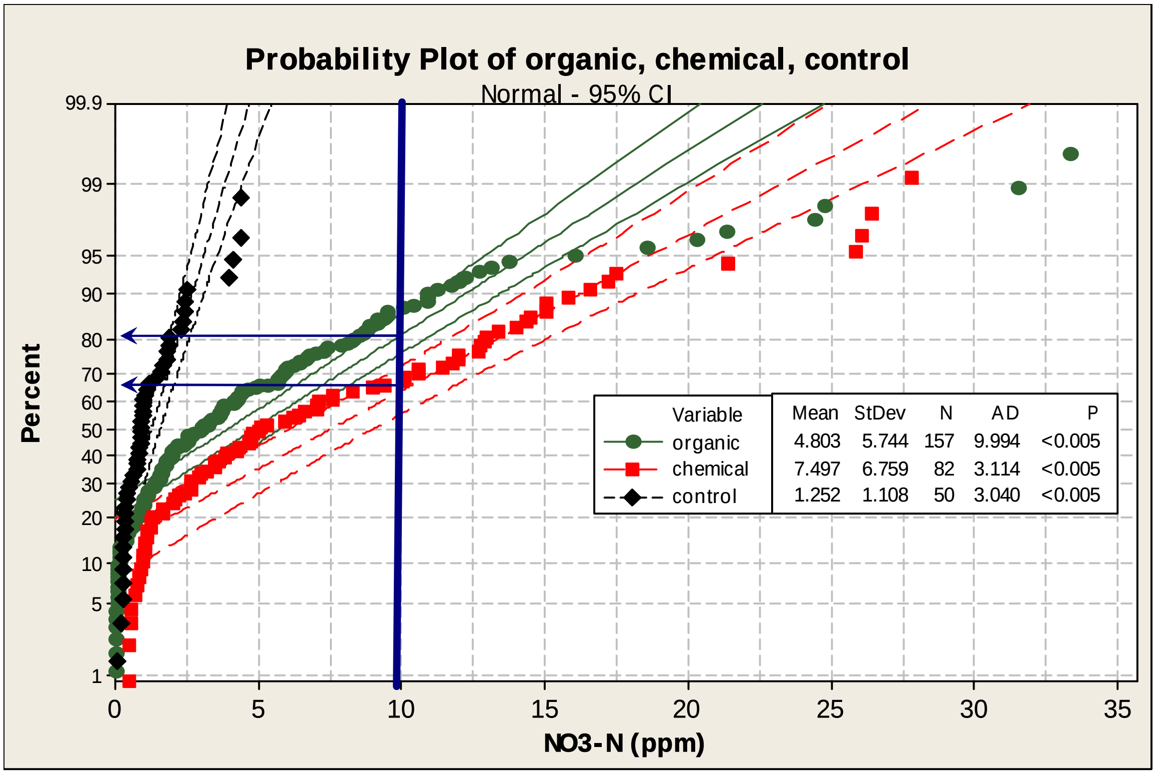

Figure 5 Probability plot for the one meter lysimeters plotted as a function of fertilizer treatment type. There are three fits to the data. The middle curve is the cumulative distribution function and the other two curves are the 95% confidence interval. The table shows the mean, standard deviation, number of samples the Anderson-Darling goodness of fit statistic and the associated p-value.

The Anderson-Darling goodness-of-fit statistic is a measurement of how well the data fit the assumptions and are best used to compare the fit of competing distributions as opposed to an absolute measure of how a particular distribution fits the data. The smaller the value the better the fit.

Values above one indicate that nitrate concentrations decrease with depth and values below one indicate that nitrate concentrations increase with depth. Some of the difference between the one meter and the deeper sampler may be due to heterogeneity of soil conditions, but large normalized values and/or patterns can not only be a function of variability in unsaturated soil hydrologic properties.

Two of the four sites with depth profiles indicate a decrease in nitrate with depth for most of the three year study. The Stony Brook site, treated with chemical fertilizer, has an average concentration of 3.8 ppm NO_3-N at one meter over the three year study while the 150 cm sampler have a value of only 1.71 ppm NO_3-N (Figure 7). This site has high normalized values in January which decrease until early autumn, repeating this trend all three years (Figure 6b), indicating a loss of nitrate with depth. The Oakdale site, treated with organic fertilizer, shows a similar trend to that of Stony Brook (Figure 6d).

Both of these sites are similar in age since establishment, 4 to 6 years, and have the same thatch thickness of 0.17 cm. The Oakdale organic site has an average NO_3-N value of

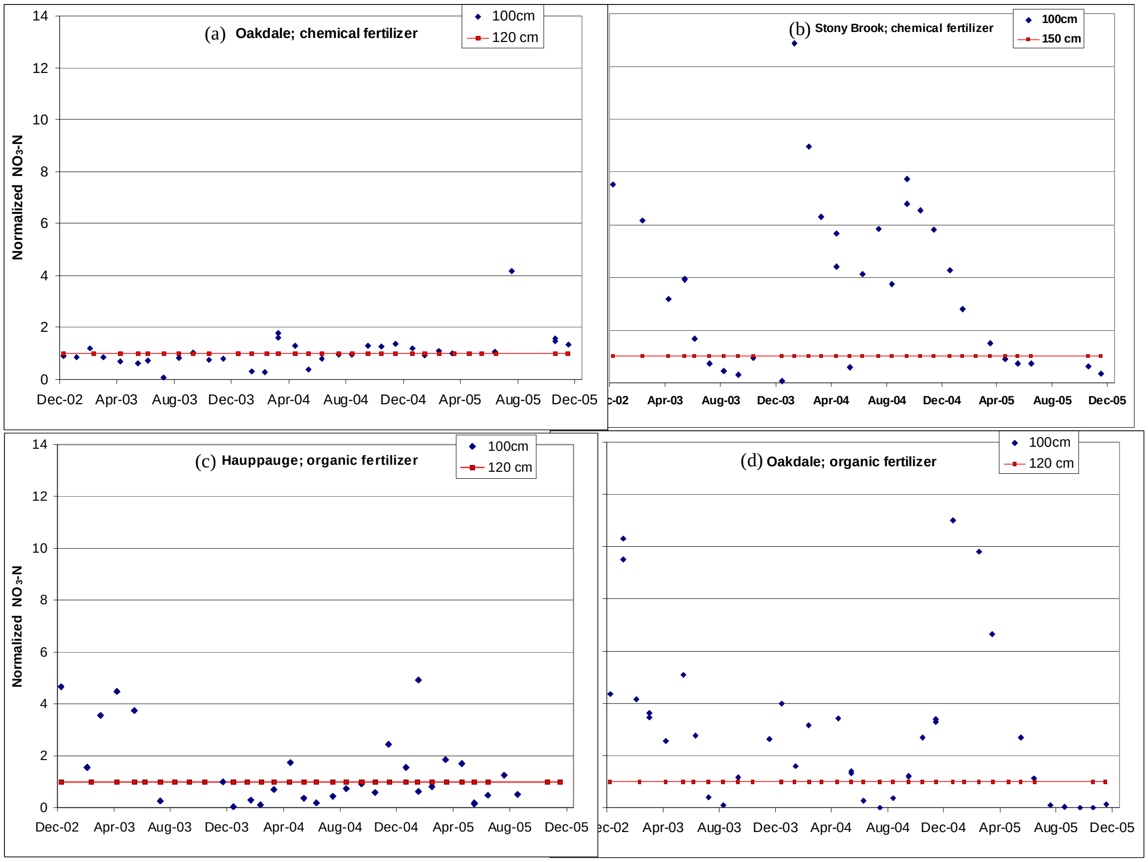

Figure 6 Normalized nitrate concentrations of the four sites with depth profiles of lysimeters. The normalized value is shown for the 100 cm sampler, this values is the monthly nitrate concentration of the 100 cm sampler divided by the deeper sampler, either 120 cm or 150 cm. A value greater than one indicates nitrate has decreased with depth and a value below one indicates an increase in nitrate with depth.

1.93 ppm for the one meter sampler and the 120 cm sample has 0.84 ppm NO_3-N. The Hauppauge site, treated with organic fertilizer, generally has normalized values below one for the three years of the study (Figure 6c), indicating an increase with depth. The average NO_3-N value for the one meter sampler is 3.19 ppm while the sampler at 120 cm has 4.34 ppm NO_3-N. We do not have enough data to conclude why this site is different than the Stony Brook chemical and the Oakdale organic sites since changes in nitrate concentrations are most likely due to variations in other variables not measured in the study, for example; microbiological activity, soil temperature, soil pH, soil moisture and dissolved oxygen concentrations. However, we do know that Hauppauge is much older

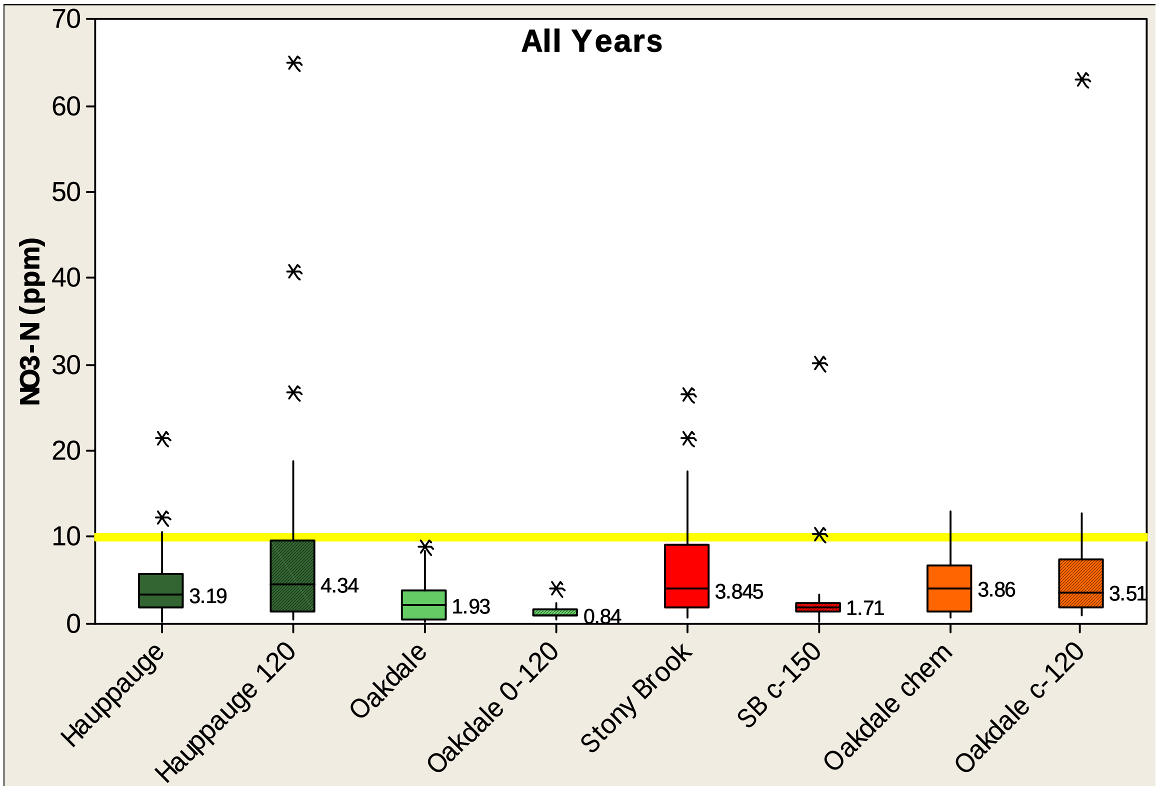

Figure 7 Yearly average NO_3-N concentrations collected from the one meter and the deeper lysimeters for the four sites with depth profiles. The line in the box is the median value. The area in the box covers 50 percent of the data. The outside bars encompass 75 percent of the data and asterisks represent outliers.

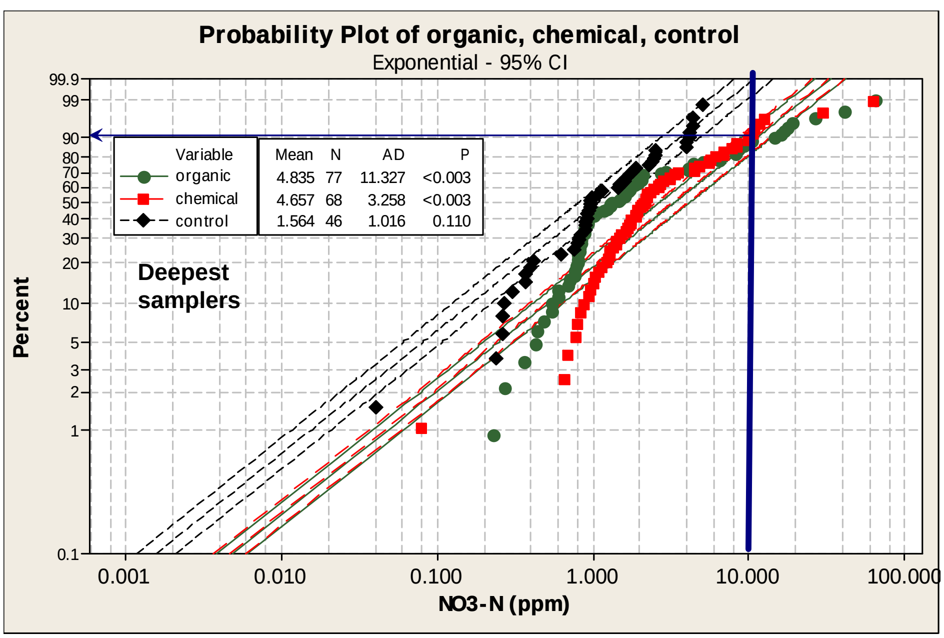

Figure 8 Probability plot for the deeper lysimeters plotted as a function of fertilizer treatment type. The control data is still from the one meter sampler.

(23 years) than these sites, has a thicker thatch layer (0.62 cm) and has more clay and silt content. The fourth site with a depth profile is the Oakdale site, treated with chemical fertilizer, and nitrate concentrations seem to be conservative at this site (Figure 6a) with an average of 3.86 ppm NO_3-N in the one meter sampler and 3.51 ppm NO_3-N in the 120 cm sampler. When evaluating the deeper samplers the probability of the lysimeters to have nitrate concentrations above the drinking water standard decrease to only 10% for all sites (Figure 8).

We installed rain gauges in the spring of 2005 as previous attempts to correlate precipitation and soil water nitrate for 2003 and 2004 was made using average climatic data from CLIMOD (Northeast), which can vary around 6 cm per month over small distances. Total inorganic nitrogen of rain averaged 0.53 ± 2 ppm from May 2005 through December 2005. Precipitation ranged from values less than 10 mm measured in June to full samplers, ~3000 mm, measured in November, but variations in soil water nitrate concentrations were not strongly correlated to rainfall. This is likely due to the low nitrate concentration in rain water compared to fertilizer inputs and the relatively constant influx of infiltration through the year due to the addition of irrigation systems in summer months.

Future work

Deeper samplers should be installed in order to monitor nitrate concentrations near or at the water table to comprehend the flux to the groundwater. In addition denitrification at depth needs to be quantified. We anticipate continual monitoring of all sites.

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