The Fate of Nitrogenous Fertilizer Applied to Differing Turfgrass Systems

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Peter F. Schuchman
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Department of Geosciences
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Abstract

Nitrate is a widespread contaminant of groundwater supplies at the local and national levels. Leaching of nitrogen from turf systems is of concern for environmental and economic reasons. Past studies have documented that nitrogenous fertilizer applied to a turfgrass system can pose a threat to groundwater quality. Nitrate levels in potable groundwater must remain below 10 mg/L and, in suburban environments, levels can be elevated by lawn fertilizers as well as sewage septic systems. Overfertilization can be an unnecessary expense not only for the homeowner but for golf courses, municipal parks and others involved with turf management. The turfgrass system is complex and a complete study requires an examination of multiple variables.

This study initiates, a tension lysimeter system, in two study plots to assess the leaching of nitrate from fertilizer through a turf system. The observations from this installation will be continued as part of an ongoing study of the sites on Long Island. The two sites, located at the State University of New York (SUNY) at Stony Brook and the Suffolk County Water Authority (SCWA) at Oakdale, differ in the nature of turfgrass cover and management. The turfgrass at the SUNY site is newly planted sod and the SCWA turfgrass is greater than ten years in age. The SUNY site is fertilized according to the suggestions from the sod company and the SCWA is fertilized and managed by an outside landscaping company. The tension lysimeter system allows for the collection of soil water in a manner that minimizes soil disturbance. Nitrate nitrogen concentrations, were on average below drinking water standards, but some of the samples were above the standard. At these levels, the turfgrass system poses a threat to groundwater quality, depending on the extent of fertilization.
I. Introduction

The American suburban landscape with lush green lawns is part of our national culture and identity. Over the past year, Americans have spent more on their lawns than they have at the movies, an astonishing 17.4 billion dollars (PLCAA, 2001). The maintenance of the suburban lawn often requires the use of artificial or organic fertilizers. These fertilizers contain ample amounts of nitrogen, which is an essential element for
healthy turf growth, as well as other nutrients. In addition, they can often be mixed with pesticides and herbicides. Nitrogenous fertilizer applied to ornamental turf could pose a threat to groundwater quality (Petrovic, 1990). The fate of fertilizer nitrogen is a concern in highly populated suburban regions that rely upon groundwater as their sole source of municipal water. Management of fertilizer nitrogen must consider plant uptake, atmospheric loss, soil storage, and runoff in order to lessen the amount of nitrate that leaches into groundwater.

Maintaining high quality surface and groundwater supplies is a concern at the national and local level. Groundwater accounts for 86% of the total water resources in the USA and provides 24 to 95% of the drinking water supply for urban and rural areas respectively (Petrovic, 1990; Scott, 1985). On Long Island, NY, groundwater is the sole source of drinking water for the two counties of Nassau and Suffolk (Hughes and Porter, 1983). The development of these counties with their growing populations has had an effect on groundwater quality over the past century. During this time, much of the landscape has changed from rural agriculture to suburban development. These development patterns are particularly noticeable in Nassau and Western Suffolk Counties where the largest single crop cultivated is ornamental turf. (Porter, 1980) Nitrate concentrations in the region’s groundwater have increased markedly during this period of development, and a significant amount of this increase is attributed to lawn and garden fertilizer as well as cesspool and septic tank discharges. (Flipse et al., 1984) Of the nitrogen species, nitrate poses the greatest threat to groundwater quality due to its mobility and health threat.

The management of nitrogen is essential to protect the region’s drinking water supplies and the ecological balance of marine bays and harbors. This study aims to monitor the fate of nitrogen applied to ornamental turf and measure for nitrate nitrogen leaching from the study sites. The monitoring will implement tension ceramic cup lysimeters to collect and analyze soil waters. The project has two study sites: one is located by the Earth and Space Sciences Building at State University of New York (SUNY) at Stony Brook, NY; the other is located at the Suffolk County Water Authority (SCWA) Administration Building in Oakdale, NY. The two sites differ in the age and nature of their plots. The SUNY site will be used to examine the fate of fertilizer applied to newly planted sod and the SCWA site will be used as a control site, with a turf system that has been established for many years. Soil waters will be collected by the lysimeter system at various depths, to assess the leaching of nitrogen through the turf root zone and subsequently into the groundwater supplies.

II. Background

Nitrate and the Nitrogen Cycle on Long Island

Nitrogen is plentiful: in the atmosphere it is nearly 80 percent by total volume, on average 15 percent of living matter. Some crops require 200 lbs/acre/year for survival (L.I. Planning Board, 1978). It exists in multiple forms as part of a complex cycle. Nitrogen found in soil and water originates from atmospheric deposition, application of fertilizer, manure, waste material, and dead plant and animal tissues (West, 2001). Nitrate (NO\textsubscript{3}\textsuperscript{-}) is one of the chemical forms of nitrogen. Other forms of nitrogen commonly found in soil or water may be nitrite (NO\textsubscript{2}\textsuperscript{-}), ammonium (NH\textsubscript{4}\textsuperscript{+}) and organic nitrogen.

Exposure to nitrate in concentrations over 10 mg/l has been associated with a condition called methe-
moglobinemia or “blue-baby” syndrome in infants six months of age or younger (USEPA, 1990). The nitrate fed to the baby, via baby formula or breast milk, is converted into nitrite in the baby’s stomach. Nitrite changes the infant’s hemoglobin (the oxygen carrying part of blood) to methemoglobin, which is unable to bind with oxygen, thus depriving the cells of oxygen (West, 2001). Although it is a serious medical condition, no cases of nitrate-induced methemoglobinemia have been reported between 1990 and 1995 according to an EPA publication (National Research Council, 1995). West speculated that this might be because there is no requirement to report cases of methemoglobinemia. Because of its multiple sources, it is difficult to show concise relationships between nitrate contamination and other health problems. Recent studies have however implicated nitrate exposure as a possible risk factor associated with non-Hodgkin’s lymphoma, gastric cancer, hypertension, thyroid disorder and birth defects (Gilli et al., 1984, Rademacher, 1992). The USEPA (1976) also linked the possible development of cancer from nitrosamines, resulting from the ingestion of water containing high concentrations of nitrate or nitrite (Safe Drinking Water Committee, 1977).

Long Island has historically had problems with contamination of groundwater by nitrate. The early history of the region was agricultural, helping to feed the growing metropolis. Over the last century, development has led to the altering of land use from agrarian to suburban. This combination of past agriculture and 20th century suburban waste began to have a noticeable effect on the Island’s groundwater. In 1949, the detection of nitrate contamination in shallow public supply wells in the Levittown area produced an awareness that eventually led to the abandonment of the Upper Glacial aquifer in the County (Nassau Dept. of Health, 1971; LI Regional Planning Board, 1978). Nitrate levels increased and eventually led to sewering of household wastewater in most of Nassau County and some housing areas in Suffolk County.

Due to the concerns over nitrate contamination, numerous studies have been implemented to determine the sources to the region. In a study during the eighties, Porter found that the two principal sources of nitrogen on Long Island are human waste and fertilized turf (Porter, 1980). This report further stated that the sewering in regions of the county did not necessarily have the desired effect in reducing nitrate levels due to loading from other sources such as fertilized turf, domestic animals, precipitation, and past land use. In a study using nitrogen and oxygen isotope ratios, Bleifuss found that nitrates in the Northport (NY) public supply wells originated from both residential households and past cultivation practices (Bleifuss, 1998).

**Fate of Turf Nitrogen**

Leaching of nitrogen from turf systems is of concern for environmental and economic reasons. Examining turf systems poses interesting questions, for there are multiple variables that must be taken into account. Leaching of fertilized nitrogen applied to turfgrass has been shown to be highly influenced by soil texture, source, rate and timing, irrigation/rainfall and the age of the turf system (Petrovic, 2000 and Porter, 1980).

Leaching is most noticeable during periods when temperature is low and precipitation (minus potential evapotranspiration) is high. These conditions reduce the loss of nitrogen from the turf system by limiting denitrification, ammonia volatilization, microbial immobilization and plant uptake. In northern climates these conditions are found in October through April, which is also a time period when fertilizers are applied to turf. During very dry months with minimal precipitation, leaching of nitrogen should be insignificant, and other avenues of nitrogen loss may dominate. When the soil is dry, the ammonium, which absorbs readily onto negatively-charged soil surfaces, will be reduced to nitrate or nitrite. If the area were then to undergo a deep wa-
tering, the potential for leaching the mobile nitrate would be significant.

The age of the lawn may also contribute to leaching. Lawns greater than 10 years in age have been shown to accumulate nitrogen under turf until equilibrium is reached. Subsequently, the possibility of over fertilizing and leaching of nitrogen would be much greater for such lawns (Porter, 1980). Leaching may also be a threat to newly established sod turf systems, since fertilizers may be applied at a rate greater than the uptake by the vegetation in order to establish the turf.

Studies on Long Island have indicated that lawn fertilizers are an important source of nitrate into the region’s aquifer system. In 1984, Flipse, et al. published a report looking at the sources of nitrate in a sewered housing development in central Long Island; the Twelve Pines Study. This study found that fertilizers contributed the largest load of nitrogen into the study area, with 25 kg of nitrogen leaching into the groundwater per acre per year. Being a sewered area, the wastewater, and its nitrogen load, is removed from the area, leaving fertilizers as the major source. Isotopic data supported the argument that the fertilization of residential lawns is the principal source of nitrate nitrogen in this study and in regions with similar wastewater management and hydrology.

The soils of Long Island generally limit losses of nitrogen other than losses due to plant uptake and leaching. This is due to the physical properties of the soil and the relatively acidic precipitation. Long Island soils are dominantly quartz sediment based with a relatively high permeability. These soils are light and well aerated with a low pH, therefore the conditions do not favor gaseous loss of nitrogen by the volatilization of ammonia or through denitrification (Porter, 1980). Petrovic (2000) found that up to 47% of the nitrogen, applied as urea, was lost to leaching. The results are different for other regions, with data ranging from none to half of the applied nitrogen leaching from turf. Overall, it has been assumed that nitrate leaching from turf is a major source for the aquifer system. The Cornell Cooperative Extension Service has estimated that the total nitrogen load in fertilizer applied to all types of turf on Long Island is about 9,300 tons per year, of which 5,600 tons per year may leach to groundwater (L.I. Regional Planning Board, 1978). These figures assume that 55% of the applied nitrogen will leach from the turf systems.

III. Site Description

This study aims to establish experimental plots to study the effects of fertilizer placed upon ornamental turf. With this in mind, we focused on two types of turf systems commonly found in residential suburban communities, an established lawn and a newly installed sod lawn. The principle objective was to establish a sampling system that would allow the establishment of benchmarks for later studies for comparisons of the two systems. The new sod site is located on the campus of the SUNY at Stony Brook and the established site is located at the SCWA Administration Building in Oakdale.

SUNY Stony Brook Site

The SUNY site is located in a plot of lawn found adjacent to the West Side of the Earth and Space Sciences Building. This site was chosen because it was located in a region with minimal foot traffic while affording easy access to the building. The pre-existing lawn covered an area approximately 50 by 10 meters, and was landscaped by the University grounds crew. The site is located at approximately 40°54′53.6″ N lat. and
73°7'34.9” W long. (Figure 1). In the approximate center of this area, a 5 by 3-meter plot was chosen to be the sod study site.

Four tension lysimeters were installed in this area at depths of 40, 100, and 150 cm and spaced at a distance of roughly 1.5 meters from one another (Figure 2 & 3). Three of the four lysimeters were placed in the sod region and one was placed outside the region as a control. This installation is detailed in the section of the report providing greater information about the lysimeter units.

Figure 1 – SUNY Site Map

Prior to the installation of the lysimeters, a sod-cutter was used to clear the pre-existing vegetation. The lysimeters were then installed. At this point the area was prepared for the planting of the sod. Careful attention was placed on following the procedures recommended by the sod manufacturer and industry standards. The soil in the plot was turned over by hand, with rocks being removed from the top four inches beneath the surface. Lime was applied at a rate of 40 lb. per 1000 sq. ft. The plot was then graded with a rake, while peat and fertilizer were added in controlled amounts. The peat was added to a thickness of 4 cm over the site and fertilizer was added at a rate of 3.5 lb. / 1000 sq. ft. After the plot was graded for a second time, it was wetted and a Dura-Sod blend of Fescue and Bluegrass variety turf (a blend of sod recommended and donated by the DeLalio Co., a local company) was installed. Following the installation of the sod turf, the area was watered heavily for the first week to allow the sod to take root. (Irrigation Data can be found in the SUNY Irrigation Table and Figure of the Appendix)
The soil at this site is classified according to the USDA Soil Survey of Long Island as a Riverhead and Haven soils, graded 0-8 percent. These soil series consist of deep, well-drained, moderately coarse textured soils that formed in a mantle of sandy loam or fine sandy loam over thick layers of coarse sand and gravel (Warner et al., 1975). Due to the grading for construction of SUNY facilities the original soil profile was disturbed in this region. During the drilling for the lysimeters, soil was collected and sampled at regular intervals, to be later classified on the basis of grain size.
IV. Methods

**Lysimeter Monitoring System**

A lysimeter monitoring system was installed to gather soil-water samples at the field sites. The system consists of ceramic cup tension lysimeters that enable the collection of soil water from the vadose zone. Ceramic suction cups and plates have to a large extent replaced the classical zero-tension drainage lysimeter (van der Ploeg and Beese, 1977). The tension systems are cheaper and do not destroy the soil structure as much as the larger area zero-tension systems. They can be placed at various depths allowing for the detection and monitoring of groundwater pollutants as they travel from the surface towards the water table. When installed beneath a contaminant source, a porous cup sampler can be used to detect a contaminant as it moves towards the groundwater (Morrison and Lowery, 1990). This allows for an earlier detection of contaminants over standard monitoring well systems, which sample the saturated zone. Lysimeters may also be used to monitor any chemical changes that the contaminant may undergo as it travels through the vadose zone.

Literature studies have indicated that there is concern over the validity of the soil water sampled via tension lysimeters as being representative of the true soil water composition. Clearly the application of a vacuum to the vadose zone in the vicinity of the ceramic cup will have a noticeable effect on the kinetics of soil water movement. This altering of the time the soil water spends in contact with soil particles may have an effect on the soil solution if equilibrium conditions are not met as it passes around the soil particles.

**Lysimeter Design**

The study used two different lysimeter designs, although both operated on the same principle. One design uses a sealed 1.9” O.D. PVC body housing, which is fitted with two ports which allow application of a vacuum or pressure and the other to delivery of collected water samples to the surface (Figure 6). The sealed unit, which is 17.5” in length, is connected to a head assembly that enabled a clean and easy application of vacuum/pressure and sampling via pressure dual pressure ports. The head assembly also contains a pressure gauge that allows the operator to apply the proper vacuum/pressure and monitoring the rate at which the vacuum dissipates as soil-water enters the system. The system was built by the Monoflex Division of Campbell Manufacturing, makers of groundwater sampling equipment.

The other lysimeter design, consists of a 1” O.D. acrylic tube again with a ceramic cup at the sampler bottom and a rubber stopper with access port at the top (Figure 7). The system was simpler in design than that previously mentioned, and was used to collect the uppermost samples that were too shallow to be collected with the PVC units.

Both lysimeter units are designed for either the head assembly or rubber stopper above the ground or at grade. However, at both sites minimal disturbance of landscaping practice was the goal, and the units were installed beneath grade. This allows for the plots to be landscaped in much the same manner they would be, if the monitoring system.
Figure 6 – PVC Lysimeter (Image courtesy Monoflex Brochure)

Figure 7 – Acrylic Lysimeter (Image
had never been installed. It also enables the plots to give off a fairly undisturbed appearance. This is important at the SUNY site, which is located alongside a fairly heavily traveled foot-path.

The units were encased in commercially-made round, plastic sprinkler control valve boxes with green plastic covers that blended with the turf. These boxes were set with the cover at grade. Upon a quick inspection, it is difficult to notice that a sampling system has been installed at either plot. These boxes can be locked to eliminate vandalism.

**Lysimeter Installation**

The first step of the installation was to test and assemble the lysimeters at a length specific for their installation. The enclosed lysimeter body is assembled and tested at the factory for leaks prior to shipping. However, fittings may loosen in transit and were re-checked for a proper seal. In order to test for tightness, the units were submerged in a deionized water bath while a positive pressure of 15 psi was applied. Under pressure, the porous ceramic cup should give off small “champagne” type bubbles over its entire surface if no leaks exist. Large bubbles forming at any joints on the body indicate a leak. If a unit displayed signs of leaks (noted on a few of the units) the joints were sealed with Teflon tape, and re-checked. The most common leak was encountered along the joint between the ceramic cup and the PVC body. Leaks were not found with the acrylic body lysimeters, probably because the ceramic cup was attached with an epoxy at the factory.

Following the pressure test, the lysimeter units underwent a vacuum test to the units head assembly. The factory suggested that a plastic membrane (or condom) should be first placed over the ceramic cup, and then a vacuum applied while carefully monitoring pressure drops. For this installation we checked vacuum with the ceramic cups placed entirely in deionized water. This laboratory check tested the factory seal and also allowed some practice with the units outside of the field. While under a vacuum the units would pull water through the ceramic cup into the vessel. Once the vessel was full with water, the unit would hold the vacuum unless it leaked. This test helped to locate leaks that would have caused problems if encountered later in the field.

The complete assembly and sizing of the PVC lysimeter units was done prior to their installation at the sites. The depth of the lysimeter ceramic cup was determined based upon root zone depth and site soil type. The sites were designed to have an array of lysimeter depths to measure any change in nitrate nitrogen concentration through the soil profile. At depths beneath the root zone, nitrate found in the soil water has the capability to leach to the groundwater. The deepest lysimeter was therefore placed at 120 and 150 cm respectively at the SCWA and SUNY site. The location of the lysimeter at SUNY is well above the water table (over 50 feet), while the SCWA site is located just above the shallower upper aquifer of the South Shore (between 1.5 to 2.0 feet).

The assembly was performed in accordance to the manufacturer’s manual (copies of the manual are included in the reports Appendix). Although the assembly was generally straightforward, a few items were encountered during the installation, which were not addressed in the manual. One important detail was to allow the well head assembly base to slide down along the lysimeter extension casing and body to ensure that the Teflon and polyethylene tubing could be attached at the proper length (Figure 8). This is important because
the tubing was rather stiff and proper length was required to allow the unit to fit together properly. It was also noted that the polyethylene tubing should not be grooved for a seal because of its tendency to cut unevenly, leading to leaks in the system. The Teflon tubing could be grooved smoothly in comparison.

When the units were fully assembled and sized, the ceramic cups were placed in deionized water and a vacuum of 15 inches of mercury was applied for one hour. This procedure pre-wets the porous ceramic cup, and forces water out of the pore spaces. After being under a vacuum for the hour, the units were mostly filled with deionized water. This step was performed to reduce the tendency for the air filled lysimeters to rise in the water slurry. It also allowed for the cleansing of the ceramic cup with a non-contaminated solution. Because of this, the lysimeters required immediate sampling after the installation was completed to remove the deionized water and prevent the dilution of the soil water solutions.

![Lysimeter Well Head Assembly](Image courtesy Monoflex Brochure)

Due to the shallow nature of the lysimeter design, the units were installed by hand. A 15-cm diameter hole was dug using the hand auger and post hole digger. A larger 34-cm hole was then dug around the borehole to a depth of 36-cm. This hole was sized to fit the plastic sprinkler box, which covers and encloses the unit beneath grade.

The depth was measured to allow for 10 cm silica flour (#00 cleaned filter sand) slurry to be placed at the base, beneath the lysimeter unit. When the hole was dug to appropriate depth, the slurry was mixed at a ratio of approximately 20-kg silica flour to 4-liters of deionized water. Upon mixing, the slurry was poured into the hole to a depth of at least 15-cm and then the complete lysimeter unit was placed in the hole. The silica flour was then placed in the hole filling it to a height of at least 10-cm above the ceramic cup. At this point a bentonite grout was used to seal the hole at this height. This was done to prevent surface water from draining through the hole, altering the existing flow conditions. With the deeper units (greater than 100 cm), the pre-existing soil was used to fill the hole to grade. This sandy-soil was sorted, with any material greater than 2 mm removed, and the returned to the hole. When the hole was filled to the appropriate height, the sprinkler box was put in place and positioned around the unit. Then cement was added around the lysimeter sealing the unit in place and preventing water from flowing into the hole (Figure 9).
Lysimeter Operation

The lysimeters, filled with deionized water prior to installation, had to be sampled immediately following installation to remove this deionized water. This water was removed in the same manner as when the unit is sampled at later time. A two-port rubber stopper is used with an Erlenmeyer collection flask (Figure 10) for collecting the samples. A 36-cm piece of polyethylene tubing is placed in one of the holes in the rubber stopper, with at least 2 cm protruding through the stopper. The tube is then placed in the sample recovery valve (blue) of the head assembly. Next, the tube (approximately 36-cm) from the hand pump is attached to the other hole in the stopper and then the valve opened. The pump is used to place a gentle vacuum, removing water from the unit into the flask. It is important to always apply a vacuum in a gentle manner to avoid the slurry to lose continuity with the ceramic cup.

After removing the deionized water from the lysimeter, it must then be “charged” in order to collect soil water. First, the pressure vacuum valve is opened and the polyethylene tube, from the hand pump, is inserted into the fitting. It is important that the sample retrieval valve is closed at this point. The hand pump is used to gently draw a vacuum of 46-54 cm of mercury on the vacuum pressure gauge. Once the correct vacuum is noted, the valve is quickly closed and the line is detached.

Chemical Analysis

The soil water samples collected in the field were stored in a cooler until they were taken to the lab. They were first filtered through a 40 mm paper filter using a vacuum filtration system. The solution was then either frozen or analyzed immediately.

Nitrate nitrogen concentrations were calculated using a HACH DR-2000 Spectrophotometer, set to analyze for high range nitrate nitrogen. The procedure uses a cadmium powder to reduce the nitrate to nitrite (which can be analyzed using a spectrophotometer). The results obtained are thus for the total nitrite and nitrate (oxidized nitrogen) found in the solution. Because nitrite will be converted (under favorable conditions without loss by denitrification and volatilization) to nitrate in the vadose zone this analysis was sufficient to determine the potential for nitrogen leaching.
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