Executive Summary: Gaseous Losses and Long-Term Fate of Nitrogen Applied to Kentucky bluegrass Turf

Bruce Branham, Principal Investigator
Richard Mulvaney, Co-Principal Investigator
Brian Horgan, Graduate Student
University of Illinois
Department of Natural Resources and Environmental Sciences
Urbana, Il 61801
and
Jim Baird, Co-Principal Investigator
Eldor Paul, Co-Principal Investigator
Susan Redwine, Graduate Student
Michigan State University
Department of Crop and Soil Sciences
E. Lansing, MI 48824

This project has made considerable progress in 1999. Two field studies were conducted at the University of Illinois to measure denitrification in the field. The long-term research plots at Michigan State University continue to receive inputs of 2 or 5 lbs N/M/Yr; and the lysimeters in those plots are being continuously monitored for nitrate leachate content. Within each fertilization rate are two lysimeters that have been monitored since the spring of 1998. Beginning in August of 1998, the nitrate content of the leachate from the high N treatments has diverged markedly from the nitrate content of the plots receiving 2 lbs N/M/Yr. In the early spring of 1999, the leachate draining from the turf receiving 5 lbs N/M/Yr was consistently in the range of 7-8 PPM of NO_3-N while the turf receiving 2 lbs N/M/Yr was consistently in the 2-3 PPM range. These numbers are higher than those found in earlier studies and indicate that nitrate leaching may be a more important avenue of loss than earlier research indicated. These soils may be reaching equilibrium for the particular fertilizer rates they are receiving or they may still need additional time to reach equilibrium. In either case the data is very interesting.

The denitrification work at the University of Illinois is providing the first glimpse at denitrification under field conditions. Early work by Torello and Mancino indicated that denitrification would only occur under very wet soil conditions and at elevated temperatures. However, these studies were conducted in growth chambers under artificial conditions.

We conducted two denitrification experiments in 1999, one initiated on 20 May and the other on 9 August. Six lysimeters were sunk into the turf leaving approximately 3" headspace in each cylinder. A brass plate could be sealed on to each lysimeter to form a gas tight system that could be sampled for evolution of $^{15}N_2$ gas. Each lysimeter would be covered for 3 hours per day following the start of each experiment and a gas sample collected at the end of that 3 hour period for later analysis. At the start of each experiment, we applied 1 lb N/M as KNO_3. The nitrate was 99% enriched with a stable isotope of nitrogen, ^{15}N, to permit detection of the nitrogen gas coming from the fertilizer. Since water is critical factor in denitrification due to its role in causing anaerobosis, we were careful not to overwater these sites and replaced 80 % of ET twice per week.

Measurable gas loss was detected on 27 of the first 28 days following application. These values ranged from 13 ug N to 1333.8 ug N per nine-hour monitoring period. By extrapolating the gas loss rates obtained over 9 hours of sampling to 24 hours, we estimated that 4.5% of the applied N was loss by denitrification.

The second experiment began in August when soil temperatures were warmer. A 3.5" rain event fell four days after the fertilizer application which favored denitrification. Denitrification losses were detected on 21 of the first 22 days following fertilizer application and we estimated a total loss of nearly 15% of the applied N. Losses ranged from 9.1 ug N at 19 days after fertilizer application to 4368 ug N the day following the 3.5" rain.

While the observed losses are not huge, there are two very important points to be gained from this research. First, this research demonstrates that denitrification is a process that occurs frequently, almost daily, in fine-textured turf soils. Even though the soil is not anaerobic, there are anaerobic microsites within the profile where denitrification may take place on a frequent basis.

Second, denitrification is a very difficult process to study. This approach not only allows us to measure the loss of ^{15}N by denitrification; it also estimates the loss of ^{14}N from the soil nitrogen pool. By adding ^{15}N labeled fertilizer we not only measure the loss of the labeled fertilizer, the label-fertilizer lets us "see" the denitrification of unlabeled N as well. As long as the labeled fertilizer is present, we can measure denitrification of it as well as the total denitrification occurring in that soil lysimeter. This is a powerful technique to study this dynamic process.

Turf may represent an agricultural system that is susceptible to significant losses from denitrification. In most cropping systems, denitrification will occur in the spring when soils are wet and fertilizer has been recently applied. Denitrification is much less likely to occur in the summer because most cropping systems are unirrigated and the soil dries out quickly. Since denitrification is a microbially mediated process, potential denitrification rates are much higher under warmer soil conditions. In turf, because of frequent irrigation, we have soils that are much more likely to develop anaerobic profiles or microsites in the summer when denitrification rates will be highest.

Annual Report

Gaseous Losses of Nitrogen Applied to Kentucky Bluegrass Turf

Bruce Branham, Principal Investigator
Richard Mulvaney, Co-Principal Investigator
Brian Horgan, Graduate Student
University of Illinois
Department of Natural Resources and Environmental Sciences
Urbana, Il 61801
and
Jim Baird, Co-Principal Investigator
Eldor Paul, Co-Principal Investigator
Susan Redwine, Graduate Student
Michigan State University
Department of Crop and Soil Sciences
E. Lansing, MI 48824

Research initiated in 1999

Brian Horgan is a PhD student who began working on this project in January of 1998. He spent the first year preparing for these experiments. Several technical challenges had to be met before initiating the field studies with ^{15}N including the development of an air-tight lysimeter system; the development of a gas sampling system to permit atmospheric sampling 9 hours a day from the field installed lysimeters; learning and modifying the mass spectrometer that is used to differentiate $^{28}N_2$, $^{29}N_2$, and $^{30}N_2$; and development of a technique to determine the atmospheric volume which includes headspace plus soil pore space.

Two experiments were conducted in 1999. Both were field studies designed to measure the denitrification losses from fertilizer applied to turf in the field. The experiments were initiated on May 20 and August 9 and concluded when dilution of labeled N was not detectable by mass spectrometric analysis, which occurred at approximately 4 to 6 weeks after fertilizer addition.

The fertilizer source was KNO_3 applied at a rate of 5 gm/m^2 (1 lb N/1000 ft^2) and was 99 % enriched with ^{15}N. The high level of ^{15}N enrichment is necessary to detect denitrification in the field. Following fertilizer application, all lysimeters received 6 mm of overhead irrigation and monitoring for denitrification began immediately following fertilizer application. There was only one treatment, KNO_3 fertilization, with 2 replications and 3 subsamples per replication. Each subsample was sampled once per day for a 3-hour period. This allowed us to sample one replication for 9 hours each day. This approach avoided problems that would occur if one lysimeter was covered for 9 hours at a time. An exception to this approach was used when periodic night samples were collected following heavy rain events (yielding an approximately 12 hour sampling period). However, covering at night is far less disruptive to the turf than covering during the day. Therefore, for each replication, 3 gas samples were taken every day for the duration of the experiment. These samples were analyzed separately by mass spectrometric analysis to minimize temporal variability between samples.

The gas sampling procedure employed in these experiments consisted of covering the lysimeter with a brass lid equipped with toggle valves. The toggle valves allowed sampling of the confined atmosphere within the lysimeter after circulating the air to ensure a uniform gas sample.

Progress and Results

A critical factor in measuring gaseous flux from soil is the volume from which the gas sample is taken. When measuring denitrification from non-saturated soil systems, the volume will include a portion of soil pore space. Previous methods to estimate this volume simply used a ruler. Under saturated conditions the ruler method would give satisfactory results; however, in non-saturated conditions, volume determinations would be underestimated and thus would result in inaccurate mass measurements of evolved N_2 based on an ideal gas calculation. A further complication arises when plants are present due to the volume occupied by plants and the internal plant volume available for gas exchange.

A new technique was developed to estimate the atmospheric volume within the closed chamber system whereby a known quantity of Neon (Ne) is diluted as it mixes with the air within the chamber. The dilution of Ne is thus proportional to chamber volume. A full description of this technique and the materials used to measure denitrification in a turfgrass system was submitted to the Soil Science Society of America Journal for publication in August, 1999.

The spring demonstrated that immediately following a fertilizer application, there is the potential for loss of nitrogen as N_2 (Table 1). In comparison to soil systems where gas loss typically follows rainfall, a turfgrass system is irrigated and anaerobic microsites seem to be present that result in a more consistent flux of gas. As the enriched nitrate in the soil is diluted, N_2 and N_2O losses were variable with and followed rainfall or irrigation applications. Although these losses are not considered large amounts (approximately 4.5% of applied N), the spring experiment demonstrated the potential for denitrification to be an avenue for N loss from a turfgrass system.

The second experiment was initiated on August 9, 4 days prior to a 3.5 in. rainfall (Table 2). This rainfall event, coupled with a large amount of soil nitrate from applied fertilizer and warm soil conditions lead to a two day N_2 gas flux of approximately 5% of applied N. Total fertilizer loss, when extrapolated to a 24-hr period, approached 15% of applied N. This information becomes extremely important because previous mass balance research could not recover 20-40% of applied N.

In addition to calculating the mass of N emitted from applied fertilizer, the technique used also derives the amount of total nitrogen flux from the soil. The technique is based on the assumption that the N_2 or N_2O evolved from soil treated with ^{15}N-labeled fertilizer can be considered to have originated from a single pool of NO_3^- that is isotopically uniform. This data is included on tables 1 and 2 for the spring and summer experiment, respectively. Interestingly, the total amount of nitrogen that denitrified during the experiments was 62% greater in the spring and 39% greater in the summer than that evolved from the fertilizer. For both experiments, N_2O emissions were not a significant portion of evolved nitrogen gases from applied fertilizer. For this reason this data is not shown, however, for the mass balance, these data were included.

During the course of the two experiments, clippings were taken every week and upon completion of both projects, the lysimeters were removed from the ground and divided into 0-5, 5-10, 10-20, and 20-25 cm sections. Soil, thatch and clippings have been stored and will be analyzed beginning this fall for ^{15}N content. Data will then be compiled and a mass balance of applied fertilizer will be determined. This study will be the first study that samples all forms of loss from the applied fertilizer. We did not monitor NH_3 but also did not apply any ammonical form of N. This experiment should allow us to recover nearly 100 % of what was applied. Other experiments have had to guess gaseous losses as the difference between what was recovered and what was applied. Since errors in these types of experiments can be large, gaseous losses derived in this manner have little hope of being correct.

Future Research

We intend to repeat these studies in 2000 with some modifications. We are currently considering the purchase of a time domain reflectometry system that will permit us to monitor volumetric soil moisture content within each lysimeter. This will permit the correlation of gas loss with soil moisture content. We know that soil moisture is critical in creating anaerobic conditions, but our experiments indicate that anaerobic microsites exist when the soil is not saturated. Knowing the moisture content in our soils will give us a better understanding of the dynamics of anaerobic conditions in turf soils.

These studies are shedding new light on nitrogen dynamics within a turfgrass system. It is important to continue to understand how this process works in turf soils.

Table 1. Spring 1999 experiment

	Rainfall and/or irrigation	^{15}N-labeled N_2 gas loss: Measured mean 9-hr loss	^{15}N-labeled N_2 gas loss: Calculated 24-hr loss	Total N_2 gas loss: Measured mean 9-hr loss	Total N_2 gas loss: Calculated 24-hr loss
	(in)	(μg N)			
20-May	0.2	305.8	815.4	340.8	908.8
21-May	1.25	138.1	368.3	176.6	470.9
22-May	0	1333.8	1520.4	1734.3	1977.1
23-May	0.13	184.0	490.7	287.7	767.1
24-May	0	101.8	271.4	171.0	456.1
25-May	0	51.6	137.6	93.9	250.5
26-May	0	0	0	0	0
27-May	0	29.4	78.5	68.3	182.2
28-May	0.5	97.3	259.4	226.9	604.9
29-May	0	53.9	143.9	133.1	354.9
30-May	0.1	25.8	68.8	73.7	196.6
31-May	0	20.4	54.5	48.3	128.9
1-June	1.25	13.0	34.6	30.9	82.5
2-June	0	60.6	161.5	182.1	485.6
3-June	0	55.5	148.1	154.9	413.1
4-June	0.8	31.2	83.3	91.8	244.8
5-June	0	124.2	141.6	449.1	511.9
6-June	0	44.1	117.5	130.8	348.8
7-June	0.4	18.7	50.0	44.5	118.6
8-June	0	50.6	134.8	218.6	583.0
9-June	0	49.2	131.2	144.0	383.9
10-June	0	15.9	42.4	38.9	103.9
11-June	0.7	16.7	44.5	47.5	126.5
12-June	1.55	33.5	89.3	107.4	286.4
13-June	0.3	147.1	392.3	1214.0	3237.4
14-June	0	345.6	921.7	2888.5	3292.9
15-June	0	66.4	177.2	261.5	697.3
16-June	0	26.5	70.7	97.2	259.2
17-June	0	0	0	0	0
18-June	0.55	0	0	0	0
19-June	0	0	0	0	0
20-June	0	0	0	0	0
21-June	0	3.8	10.2	10.4	27.8
22-June	0.75	0	0	0	0
23-June	0.55	3.4	9.2	10.1	26.9
24-June	0	53.2	141.8	418.3	1115.5
25-June	0	2.8	7.5	14.1	37.6
26-June	0.55	11.1	29.6	43.4	115.6
27-June	0.1	15.2	40.6	75.1	200.3
28-June	0	0	0	0	0
29-June	0	0	0	0	0
30-June	0	0	0	0	0

Table 2. Summer 1999 experiment

	Rainfall and/or irrigation	^{15}N-labeled N_2 gas loss		Total N_2 gas loss	
		Measured mean 9-hr loss	Calculated 24-hr loss	Measured mean 9-hr loss	Calculated 24-hr loss
	(in)	(µg N)			
9- August	0.4	1663.1	4435.0	1769.9	4719.9
10-August	0	272.6	726.8	358.2	955.1
11-August	0.1	99.4	265.2	152.4	406.4
12-August	3.5	463.3	1235.6	688.3	1835.5
13-August	0.05	3185.9	8495.9	4578.7	12209.8
14-August	0	4367.9	4992.5	8821.8	10056.9
15-August	0	782.3	894.2	1892.4	2157.4
16-August	0	178.9	477.1	441.4	1177.1
17-August	0.75	102.4	272.9	214.3	571.3
18-August	0	114.5	305.3	329.2	877.8
19-August	0	63.5	169.2	147.8	394.1
20-August	0	38.0	101.4	75.5	201.4
21-August	0.65	28.6	76.3	79.9	213.1
22-August	0	25.0	66.7	85.8	228.7
23-August	0.35	22.6	60.2	63.9	170.5
24-August	0.3	59.8	159.4	261.4	696.7
25-August	0	52.1	138.9	232.8	620.7
26-August	0	20.1	53.6	82.3	217.6
27-August	0	9.1	24.2	20.7	55.1
28-August	0.5	0	0	0	0
29-August	0	17.2	45.8	46.7	124.5
30-August	0	17.4	46.3	33.1	88.2
31-August	0	0	0	0	0
1-Sept	0.3	0	0	0	0
2-Sept	0	0	0	0	0
3-Sept	0	0	0	0	0
4-Sept	0.65	0	0	0	0
5-Sept	0	0	0	0	0