Potential Groundwater Contamination from Pesticides and Fertilizers Used on Golf Courses

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THE environmental consequences of golf course construction and maintenance practices have captured much media attention over the last five years. Unfortunately, most of that attention has been negative. As scientists, the most galling aspect of the criticism from the media has been that it generally is based upon perceptions, hearsay, and innuendo. A few people have decided that golf courses are bad for the environment and have set out to make a case to the public, regardless of the facts about golf course management practices. It is against this backdrop that the USGA Green Section Research Committee wisely initiated a three-year research program to develop specific information concerning the effects of golf course management practices on the environment.

A review of the scientific literature provided just a handful of articles on pesticide or nutrient leaching from turfgrasses. In the design of the experiments conducted at Michigan State University (MSU), it was foremost in our experimental plan to make sure that our studies were realistic. Golf courses must be managed. Management is key to a sound, environmentally responsible system.

Turf is an excellent system to minimize leaching of pesticides and nutrients. However, a turfgrass system is highly managed, and even the best system can give poor results if poorly managed. Conversely, a poor system can often give good results when managed well. Researchers carry an important burden since the design of their research systems can dramatically influence the results obtained. It was our intent from the outset of these studies to design an experiment that would be realistic, using treatment levels that a reasonable golf course superintendent would employ.

Experimental Design

To study potential groundwater contamination, the best technique available is the use of a lysimeter, a bucket-like device to collect soil water and to monitor agrochemical movement. There are many types of lysimeters available that use various techniques for collecting soil water. At MSU, we constructed what we termed *soil monolith lysimeters*. These lysimeters were constructed of stainless steel and had a diameter of 44.5 inches and a depth of 4 feet. They are termed monolith lysimeters to indicate that the cores are captured intact with undisturbed profiles of soil.

To construct these lysimeters, a steel cylinder, open at both ends, was pushed into the ground until filled with soil. The cylinder was then removed with the soil, inverted, and a base with a drain port was installed. We believed that by making the lysimeters 4 feet deep, whatever pesticide or fertilizer reached that point could potentially continue on and eventually reach groundwater. At a soil depth greater than 4 feet, the biological activity that can transform these products is greatly reduced.

The intent of our study was to gain an understanding of the leaching behavior of nitrogen, phosphorus, and some of the pesticides commonly used in turfgrass management.

Fate of Nitrogen in Turf

The most extensive portion of this research project examined the fate of nitrogen (N) in a Kentucky bluegrass turf grown on a sandy loam soil. It was designed to compare the fate of a single N application applied in the early spring (what we termed a *conventional N application timing*) to an application made in the fall (what is often called a *late fall or dormant N application*).

On April 26, 1991, urea was applied at a rate of 0.8 lb N/1000 ft² to the large lysimeters and to 40 smaller, open-ended cylinders that we called microplots. These 8"-diameter PVC pipes were installed in the soil near the large lysimeters and were 24" deep. We had gone to extensive efforts to preserve the soil structure in the large lysimeter, and it did not seem reasonable then to dig into the soil in the lysimeter to take soil samples. Therefore, the microplots were treated exactly as the large lysimeters, and sets of four of these microplots were exca-

vated periodically throughout the study to permit examination of the form and depth of the applied N, and transformations that were occurring. On November 7, 1991, a second set of lysimeters and microplots was treated with urea at a rate of 0.8 lb N/1000 ft². The seasonal nitrogen application schedule as well as the soil sampling schedule are displayed in Tables 1 and 2.

The two nitrogen regimes were designed to compare the impact of an early spring versus late fall N application on the fate and

Table 1
Seasonal Nitrogen Application Schedule During 1991*

Early Spring Schedule	Late Fall Schedule
April 26⁺	June 4
June 4	July 12
July 12	August 19
August 19	September 27
September 27	**November 8**

⁺Dates in **bold type** received nitrogen enriched in ¹⁵N on those dates only.

*This schedule was followed in 1992 and 1993 without the ¹⁵N applications

Table 2
Soil Sampling Dates for Spring and Fall Treatments

Date	Treatment Sample
May 14, 1991	Spring
June 21, 1991	Spring
October, 1991	Spring
November 26, 1991	Spring, Fall
May 26, 1992	Spring, Fall
June 29, 1992	Fall
November 30, 1992	Spring, Fall
May 14, 1993	Spring, Fall
November 30, 1993	Fall

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Before (top) and after (above). Stainless steel lysimeters were installed without disturbing the soil profile in the cylinder. An adjacent access port enabled researchers to collect samples.

it was water, clippings, thatch, or soil, was analyzed for the ^{15}N content. If the ^{15}N content was above the natural background of 0.36%, then that N must have come from the enriched application. This approach allowed us to follow over the next three years these two N applications made in 1991.

Soil sampling provided a total picture of the N distribution at each sampling time. The soil sampling regime was designed to obtain four samples during the year of the ^{15}N application, two samples in the second year, and one sample in the third year of the study. Clippings were collected weekly and analyzed for ^{15}N concentration. Water from the large lysimeters was collected as needed, or approximately once every two weeks. The water was tested for NO_3, NH_4, and ^{15}N concentrations. Only volatile losses of NH_3 (ammonia volatilization) or N_2 and N_2O (denitrification) were not accounted for directly. We assume that whatever we did not recover from soil, water, and plant tissue was lost to volatilization.

Heading into the study, our biggest concern was the potential for NO_3 leaching to groundwater. This turned out to be an insignificant loss mechanism for N applied to turf in our study. By any measure, nitrate leaching was negligible. Figures 1 and 2 show data for total nitrogen recovered in the leachate and also show the fertilizer nitrogen that came directly from the applications of ^{15}N-enriched fertilizer in 1991. When examined over the entire course of the study, nitrogen in the leachate averaged 0.43 mg N/L for the spring treatments and 0.77 mg/L for the fall treatments. These values are very low and would approach what would be considered background levels. Note that in both Figures 1 and 2, the labeled fertilizer from the application made in 1991 was just beginning to appear in samples collected at 890 days after the application of the fertilizers. Thus, it took nearly 2.5 years for the nitrate to move through four feet of soil.

Nitrate is not adsorbed by soils and therefore moves freely with downward flowing water. Pesticides typically are adsorbed by soil particles to varying degrees. Some pesticides, such as dicamba and 2,4-D, are only weakly adsorbed by soils. Other pesticides, such as pendimethalin and chlorothalonil, are very strongly adsorbed by soils, and as such their movement through the soil would be much slower than that observed with nitrate. It should be noted, however, that irrigation scheduling, and in particular irrigation frequency and amount, have a large effect on the potential movement of pesticides and fertilizer through soil.

Data in Figure 3 show the seasonal leachate collected from the lysimeters. Relatively small amounts of leachate are collected during the summer months. Evapotranspi-

potential movement of N to groundwater. Each program resulted in the same amount of N being applied on an annual basis, and there were four applications in common. The only difference in the two programs was the timing of the fifth application and the form of the N during the 1991 early spring and late fall applications. Those applications were made with urea enriched with ^{15}N.

^{15}N is a stable isotope of nitrogen, present in naturally occurring nitrogen at 0.36%. The nitrogen applied to the lysimeters and microplots contained 25% ^{15}N. Therefore, any sample taken during the study, whether

ration uses large quantities of soil water and prevents rapid downward movement of rainfall or irrigation. As the soil dries from the use of water by plants, the storage capacity of the soil increases and a large rain event may result in little downward water movement if the surface soil is relatively dry. However, if irrigation is used to keep the soil moisture content near field capacity, then subsequent rain events could be expected to result in significant deep leaching of water and the materials dissolved in the water.

So if fertilizer nitrogen is not being leached, what is its fate in turf? This portion of the data serves to highlight the excellent biological activity of turfgrass systems. The high level of surface organic matter associated with a turf contributes to a correspondingly high level of microbial activity. The microorganisms associated with turf are responsible for metabolizing pesticides and using nutrients to support their growth. The data in Tables 3A and 3B display the distribution of the applied labeled N in the clippings, verdure, thatch, and soil at several times during the course of the study. Note the small amount of applied N that actually was found below the soil surface, regardless of application timing. The clippings, verdure, and thatch accounted for 69% to 92% of the recovered ^{15}N for both treatments throughout the course of the experiment. Thus, the turf consumed most all of the applied N despite the fact that the actual fertilizer recovered in the clippings was only about 33% of the amount applied.

The data in Table 3 indicate that turfgrass roots must compete with a very active microbial population for applied N. The nitrogen used by microorganisms is turned into complex organic compounds within the microorganisms. However, these microorganisms are relatively short-lived, and when they die the nitrogen is released as complex forms of N. Thus, even when a quick-release form of N is applied to the turf, a large fraction of the N is captured by a microbial population that turns this quick-release N into slow-release N. The rapidly utilized applied N results in very little free NO_3, which is the mobile form of N. Complex forms of N do not move downward to any extent in soils.

Although these data paint a very favorable picture of N fate in turf, some questions remain. First of all, how much of the non-recovered N was lost to volatilization? This is an open question and one that needs to be answered. If significant amounts of N are lost to denitrification, this could have negative environmental consequences. Secondly, our data indicate that added N is being converted into organic forms of N or soil organic matter. Soil organic matter content in the soil will not increase forever, and at some point an equilibrium will be reached. When that

occurs, what will happen to the N added every year? If clippings are being removed, then enough N would have to be added to replace that which is removed with the clippings. But we know from our own experience that even if we return clippings, the turf benefits from additional N. If leaching is not occurring, then returning clippings

Table 3A
Recovery of Fertilizer Nitrogen (^{15}N) from Clippings, Verdure, Thatch, Soil, and Leachate for the Spring Applied N (in Kg/ha)

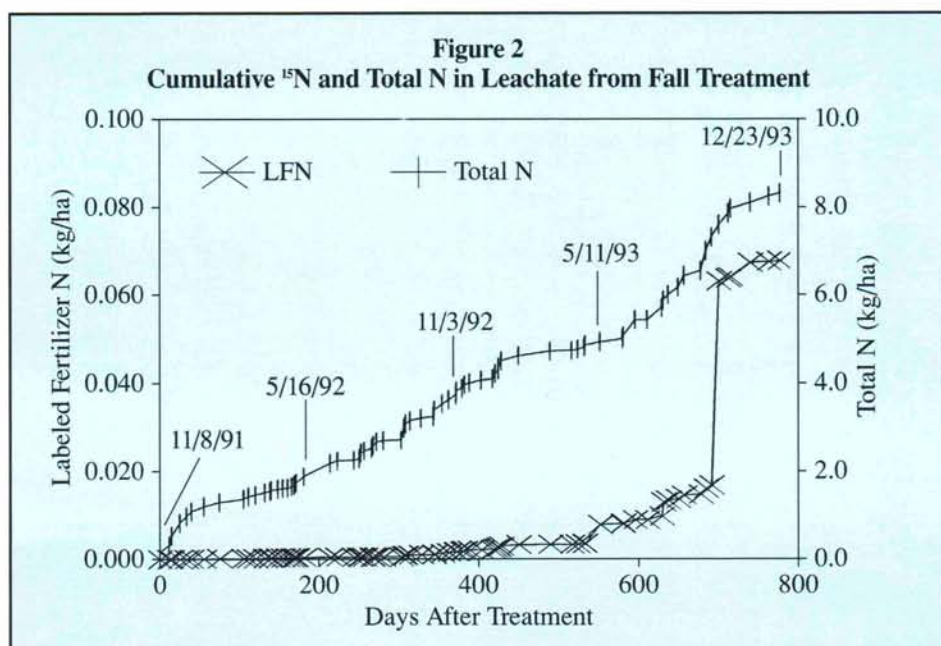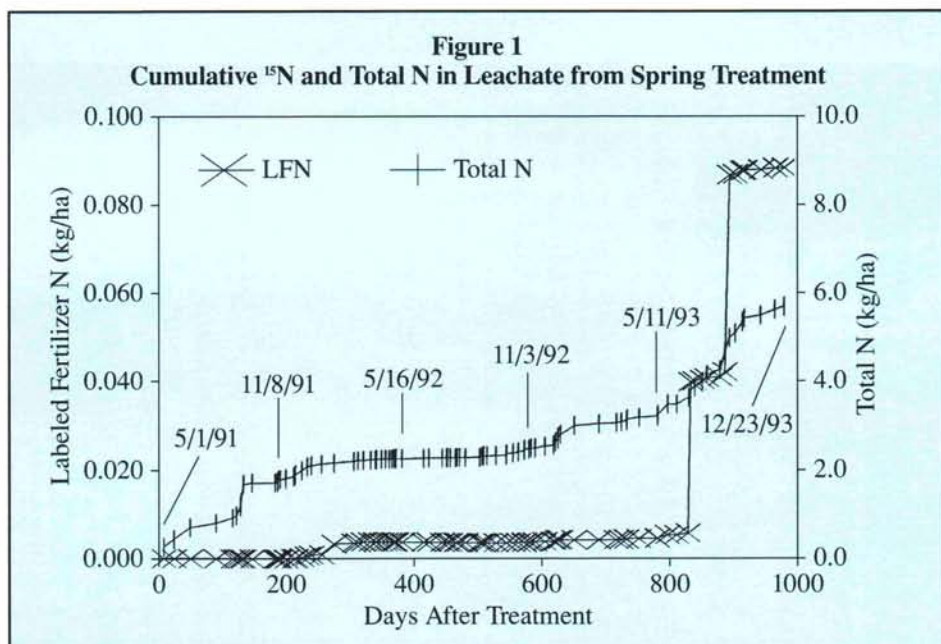| Date	Clippings	Verdure	Thatch	Soil	Leachate	Total	Recovery %
5/14/91	0.94	14.2	12.2	3.2	0	30.5	78
6/21/91	7.83	8.0	12.2	4.3	0	32.4	83
10/14/91	11.9	3.4	7.4	6.2	0	28.84	74
11/26/91	12.1	3.0	12.5	6.7	0	34.39	88
5/26/92	12.9	1.5	13.7	8.0	0.004	36.06	92
11/30/92	13.7	1.0	8.4	6.6	0.004	29.63	76
5/14/93	13.9	0.7	5.2	5.3	0.005	25.14	64

Table 3B
Recovery of Fertilizer Nitrogen (^{15}N) from Clippings, Verdure, Thatch, Soil, and Leachate for the Fall Applied N (in Kg/ha)

Date	Clippings	Verdure	Thatch	Soil	Leachate	Total	Recovery %
11/26/91	0	14.0	24.3	4.8	0	43.1	109
5/26/92	8.5	8.9	21.9	3.8	0	43.1	109
6/29/92	10.5	7.6	13.9	2.8	0.001	34.7	89
9/17/92	12.1	2.6	9.6	6.3	0.001	30	76
11/30/92	12.4	1.7	9.9	6.0	0.002	30.1	77
5/14/93	12.7	1.1	8.6	8.8	0.008	31.2	80
11/30/93	15.0	0.3	6.7	10.0	0.07	31.9	81

Table 4
Application Dates and Physical Properties of Pesticides Applied

Pesticide	Date of Application	Application Rate (lbs a.i./A)	Adsorption (K_{OC})	Half-Life (ΔT_{50}) Days	Water Solubility mg/L
isazofos (Triumph)	8/12/91	2.00	100	34	69.0
chlorothalonil (Daconil)	8/21/91	8.50	1380	30	0.6
dicamba	9/17/91	0.10	2	14	400,000.0
2,4-D	9/17/91	1.00	20	10	890.0
fenarimol (Rubigan)	5/ 3/92	0.70	600	360	600.0
propiconazole (Banner)	6/18/92	0.75	650	110	110.0
triadimefon (Bayleton)	7/21/92	1.35	300	26	71.5
metalaxyl (Subdue)	8/ 5/92	1.35	50	70	8400.0

Figure 1
Cumulative ¹⁵N and Total N in Leachate from Spring Treatment

Figure 2
Cumulative ¹⁵N and Total N in Leachate from Fall Treatment

should produce a relatively closed system where no additional N would be needed. So where does the added N go when soil organic matter is at equilibrium? These questions will need further research before they can be answered.

In summary, nitrogen applied to a dense, well-maintained turf is rapidly utilized by the turf, with little chance of downward N mobility. Timing of N application did not have a large impact on N fate or leaching in this study. Late fall applied N was also rapidly utilized by soil microorganisms and turfgrass plants. Approximately 33% of the applied N was recovered in the turfgrass clippings in the three years following application.

Pesticide Fate

Pesticide fate is a more complex issue than nitrogen fate. While nitrogen can be applied in a variety of forms, the pathways through which all of these forms pass are very similar. In addition, some nitrogen can be found in all naturally occurring water supplies, and the addition of small, incremental levels of N cannot be considered a health hazard.

Pesticides represent a different case. Pesticides generally are man-made, and their appearance in drinking water is a direct consequence of their use by man. Declaring any level of a pesticide in drinking water as *safe* has turned out to be an issue charged with a great deal of emotion. The main concern with pesticide use is human exposure,

although other issues such as non-target effects of pesticides also are important. Human exposure occurs from direct inhalation of the pesticide's active ingredient, which can occur if the pesticide is volatile, through contact with treated plant surfaces, or through drinking water. We chose to examine the potential for pesticide leaching into groundwater, since that issue has the widest potential human impact and has been the subject of most of the regulatory and media attention.

Pesticide leaching is controlled by two primary factors. First, the chemical properties of the pesticide are very important. Some pesticides adsorb strongly to soils while others adsorb very weakly or not at all. Soil adsorption is typically expressed as an adsorption coefficient, K_{oc}. A K_{oc} value of less than 100 indicates that a pesticide is very mobile in soils. A K_{oc} value between 100 and 1000 indicates that a pesticide is moderately mobile, and that mobility would be determined by other factors such as soil type and persistence. A K_{oc} value of 1000 or more usually indicates that a pesticide is immobile.

A second important factor in determining the potential for pesticide leaching is the length of time a pesticide remains in the soil. The term *half-life*, ΔT_{50}, is commonly used to describe pesticide persistence. A half-life is the time, usually measured in days or weeks, that it takes for the pesticide to break down and reach one-half of its initial concentration. If a pesticide has a ΔT_{50} of less than 30 days, it is considered non-persistent. Even if the K_{oc} value is less than 100, there is little chance the pesticide will move to groundwater, since it breaks down so rapidly. If a pesticide has a ΔT_{50} of 30 to 120 days, it is considered moderately persistent, and a ΔT_{50} greater than 120 days is considered persistent.

To determine the potential of pesticides to move to groundwater when applied to turf, we treated Kentucky bluegrass turf in large lysimeters with eight different pesticides that are routinely used on turf. The eight pesticides, application dates, and physical properties are shown in Table 4. Water samples from the lysimeters were collected continuously throughout the three-year period and analyzed for each of the applied pesticides.

The results generally were positive; six of the eight pesticides applied were never detected in leachate samples. Two were detected with some frequency. Those two were triadimefon (Bayleton) and dicamba. The detection levels of triadimefon were usually less than 10 PPB, although the highest concentration detected was 31 PPB on the 86th day after application (Figure 4). In light of the data on nitrate leaching, which showed it took 2.5 years for a non-adsorbed

compound to move through the lysimeters, this very quick movement of triadimefon must surely represent a phenomenon termed *macropore flow*. A well-structured soil is composed of many large pore spaces of macropores. During heavy rainfall or irrigation, these large pores rapidly conduct surface water deep into the soil profile. If a pesticide or nutrient is applied in the vicinity of macropores, it is possible that the chemical could be moved much deeper into the soil profile than would be expected normally. This phenomenon must have occurred in order to see the leaching in such a short period of time following application.

Water samples from the lysimeters will continue to be collected and tested for pesticide residues during the next two years. It is difficult to predict future results, although data from other researchers who have collected leachate from soil depths shallower than the four feet used in these studies would indicate the chance of detecting high concentrations of pesticides is small.

As discussed earlier, the issue of pesticide residues in groundwater is a difficult one. The best approach is to choose pesticides that have little chance of reaching groundwater. New pesticides being developed for the market generally have much better environmental characteristics than older pesticides, which tend to be more persistent. Over time we believe that pesticide manufacturers will continue to meet the needs of the golf course industry by developing safer, more active products.

One of the best ways to reduce pesticide leaching is to develop more active products. This has already happened in the herbicide area. Ten to 15 years ago, many herbicides were applied at rates of 5 to 10 lbs of active ingredient per acre. Today, many new herbicides are being applied at rates as low as 1 to 2 ounces of active ingredient per acre. By reducing the active ingredient load applied to the turf by 50 to 100 times, the chance of moving any of these herbicides to groundwater is quite small. Thus, with the development of short-persistence pesticides that require low use rates, pest problems in turf and other crops should be adequately controlled at low cost to the environment.

The golf course industry has been and still is targeted for criticism regarding pesticide and fertilizer use. The research presented here indicates that much of this criticism is misdirected. Turf, as a system, has a high level of microbial activity which, combined with the large amount of surface organic matter, creates a unique environment that minimizes the possibility of substantial downward movement of agrochemicals.

Figure 3
Drainage from Spring and Fall Treated Lysimeters and Cumulative Precipitation and Irrigation

Figure 4
Leaching of Triadimefon through Monolith Lysimeters