

NUTRIENT AND PESTICIDE MOBILITY IN TURF

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The mobility of pesticides and nutrients in agricultural systems has attracted considerable attention over the past 10 years. Turf has recently been subjected to intense scrutiny regarding the use of pesticides and nutrients and the potential for contamination of ground and surface waters from these practices. The research reported in this paper was sponsored by a 3 year grant from the United States Golf Association (USGA).

Soil movement of any agrichemical is controlled by two primary factors. The chemical nature of the agrichemical and the soil and/or turf to which it is applied. If the agrichemical carries a net negative charge, examples include 2,4-D, dicamba, or NO_3 , then adsorption to soil colloids is effectively zero and the agrichemical moves freely in downward flowing water. Conversely, if the agrichemical carries a net positive charge such as Roundup or diquat, then it is strongly adsorbed to soil colloids and essentially unavailable for downward movement. If an agrichemical does not carry a charge but is neutral, and this includes the vast majority of pesticides used in agriculture, then adsorption to soil colloids is primarily controlled by the water solubility of the pesticide. In general, the more water soluble a pesticide, the more easily it moves through the soil. Another important factor in pesticide movement to groundwater is soil persistence. The more persistence a herbicide the more likely it is to reach groundwater. A very mobile herbicide poses little threat to groundwater if it degrades to other products within a short time of application.

Soil type is an important factor in determining agrichemical mobility. Coarse textured soils tend to allow more rapid flow of water through the soil and thus for a given agrichemical, deeper movement would be expected in a coarse textured soil when compared to a soil with more silt and clay. For pesticides, an extremely important factor in movement is the organic matter content of the soil. Organic matter serves as the strongest sorbent for pesticides, so the higher the organic matter content of a soil, the more strongly a soil would adsorb a pesticide.

With this brief discussion on factors affecting agrichemical movement, let's focus on the results of research at MSU on the fate of nitrogen applied to turf and the movement of pesticides through soil towards groundwater. In order to study nitrate and pesticide leaching, a set of four large, non-weighing lysimeters were constructed at the Hancock Turfgrass Research Center on the MSU campus in East Lansing, MI. Each lysimeter was 1 m² in surface area and 1.2 meters in depth. The purpose of these lysimeters was to determine deep leaching. All of the water that drained through the lysimeters was collected and analyzed for each pesticide applied as well as for NO_3 and NH_4 . These lysimeters served only to measure the amount of these materials in the leachate. In order to follow the fate and movement of nitrogen in the soil, a second approach was taken. Smaller, open-ended lysimeters (microplots) were used to follow the distribution and cycling of nitrogen in the turf and soil below. These lysimeters were 8" in diameter and 24" in depth and were constructed from PVC pipe. The plastic lysimeters were pushed into the ground and treated exactly as the larger lysimeters.

FATE OF NITROGEN IN TURF

The most extensive portion of this research project examined the fate of nitrogen in a Kentucky bluegrass turf. This project was designed to compare the fate of a single N application applied in the early spring (conventional N application timing) or in the fall (late-fall or dormant N application). On April 26th of 1991 urea was applied at a rate of 0.8 lb N/1000 ft²(M) to the large lysimeters and to 40 microplots. The microplots were installed in the soil near the large lysimeters. Since such extensive efforts had been made to preserve the structure of the soil in the large lysimeter, the microplots permitted us to follow what happened in the soil without disturbing the soil in the large lysimeters. Four of these microplots were excavated at various times throughout the study to permit us to examine the form, depth, and transformations that were occurring to the applied N. On November 7th, 1991 a second set of lysimeters and microplots were treated with urea at a rate of 0.8 lb N/M. The seasonal nitrogen application schedule (5 applications of 0.8lbN/M) as well as the soil sampling schedule are displayed in Tables 1 and 2.

Table 1. Seasonal nitrogen application schedule during 1991*.

Early spring	Late fall
April 26⁺	
June 4	June 4
July 12	July 12
August 19	August 19
September 27	September 27
	November 8

⁺Dates in bold text received nitrogen enriched in ¹⁵N on those dates only.
 * This schedule was followed in 1992 and 1993 without the ¹⁵N applications.

The two nitrogen regimes were designed to compare the impact of an early spring versus late fall N application on the fate and movement to groundwater of N. Each program applied the same amount of N on an annual basis and had 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 that was enriched with ¹⁵N. ¹⁵N is a stable isotope of nitrogen, present in naturally occurring nitrogen at only 0.36%. The nitrogen applied to the lysimeters and microplots contained 25% ¹⁵N. Therefore, any sample we took during the study, whether it was water, clippings, thatch or soil, was analyzed for the ¹⁵N content. If the ¹⁵N content was above the natural background of 0.36%, then that N must have come from our enriched application. This approach allowed us to follow these two N applications made in 1991 over the next three years.

Table 2. Microplot sampling dates for spring and fall treatments.

<u>Date</u>	<u>Treatment sampled</u>
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
September 17, 1992	Fall
November 30, 1992	Spring, Fall
May 14, 1993	Spring, Fall
November 30, 1993	Fall

Soil sampling (Table 2) allowed a total picture of the N distribution at each sampling time. The soil sampling regime was designed to take four samples the year of the ¹⁵N application, two samples in the 2nd year, and one sample in the 3rd year after application. Clippings were collected weekly and analyzed for ¹⁵N concentration. Water from the large lysimeters was collected as needed or approximately once every 2 weeks. The water was tested for

NO_3 and NH_4 concentrations and ^{15}N concentration. Summing all sources of N accounted for all N left in the soil. Only volatile losses of NH_3 (ammonia volatilization) or N_2 and N_2O (denitrification) were not accounted for directly. We can assume that whatever we did not recover from soil, water, and plant tissue was lost to volatilization, although the assumption that recovery from all sources is 100 % is rarely accurate.

Results

Our biggest concern in this study was NO_3 leaching to groundwater. This turned out to be an insignificant loss mechanism for N applied to turf. By any measure, nitrate leaching in this study was negligible. Figure 1 shows the data for the fertilizer nitrogen that came directly from either single application of ^{15}N enriched fertilizer in 1991. When examined over the entire course of the study, nitrate-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 Figure 1, the labeled fertilizer from the application made in 1991 was just beginning to appear with samples collected at 890 days after the application of the fertilizers. Thus, it took nearly 2.5 years for the nitrate to move through 4 feet of soil.

Nitrate is not adsorbed by soils and therefore moves freely with downward flowing water. Pesticides are typically adsorbed by soil particles to varying degrees. Some pesticides, such as dicamba and 2,4-D, are only weakly adsorbed by soils; however, 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. Irrigation scheduling and in particular irrigation frequency and amount will have a large impact on the potential movement of pesticides and fertilizer through soil.

Leachate collected from the lysimeters varied with season. Most drainage events occurred in the fall or late winter/early spring periods. Relatively small amounts of leachate were collected in the summer months. Evapotranspiration uses large quantities of soil water and prevents rapid downward movement of rainfall or irrigation. As the soil dries down from use of water by plants, the storage capacity of the soil increases and a large rain event can 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 should 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 turf. The high level of surface organic matter associated with a turf contributes to a correspondingly high level of microbial activity. The microorganisms associated with a turf are responsible for metabolizing pesticides and for using nutrients to support their growth. The data in Tables 3 and 4 display the distribution of the applied, labeled N between clippings, verdure, thatch, and soil at several times during the course of the study. Note the low amount of applied N that actually reached the soil surface regardless of application timing. The clippings, verdure, and thatch accounted for 69-92 % 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 1/3 of the amount applied (Tables 3 and 4).

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

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	7.83	8.0	12.2	4.3	0	32.4	83
10/14	11.9	3.4	7.4	6.2	0	28.84	74
11/26	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	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 4. Recovery of Fertilizer Nitrogen (^{15}N) from Clippings, Verdure, Thatch, Soil, and Leachate for the Fall Applied N.

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	10.5	7.6	13.9	2.8	0.001	34.7	89
9/17	12.1	2.6	9.6	6.3	0.001	30	76
11/30	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

The data presented above 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 that N is captured by a microbial population that turns this quick release N into slow release N. The rapidity of utilization of applied N results in very little free NO_3^- , which is the mobile N species. Complex forms of N do not move downward to any extent in soils.

While the data presented above paints a very favorable picture of the fate of N in turf, some questions still remain. First, how much of the non-recovered N was lost to volatilization? This is an open question and one which needs to be answered. If significant amounts of N are lost to denitrification, this could have negative environmental consequences. Secondly, our data indicates that added N is being converted to 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 that is added every year? If you are removing clippings then one would have to add enough N 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 should produce a 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 does not have a large impact on N fate or leaching. Late fall applied N is also rapidly utilized by soil microorganisms and turfgrass plants. Approximately 1/3 of the applied N was recovered in the turfgrass clippings in the 3 years following application.

PESTICIDE FATE

Pesticide fate is a much more complex process 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 can not be considered a health hazard. Pesticides are a completely different case. Pesticides 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 a very difficult issue charged with a great deal of emotionalism. The main concern with pesticide use is human exposure although other issues such as non-target effects of pesticides are also important. Human exposure comes from direct inhalation of the pesticide 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 leaching of pesticides into groundwater since that issue has the widest potential human impact and has been the subject of the most regulatory and media attention.

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

over usually indicates that a pesticide is immobile. A second important factor in determining pesticide leaching is persistence. The length of time a pesticide remains in the soil is very important in determining its susceptibility to leaching. The term half-life, $t_{1/2}$, 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 reach one-half of its initial concentration. If a pesticide has a $t_{1/2}$ of less than 30 days it is considered non-persistent. Even if its 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 $t_{1/2}$ of 30-120 days it is considered moderately persistent and if it has a $t_{1/2}$ of greater than 120 days it is considered persistent.

In order to determine the potential of pesticides to move to groundwater when applied to turf, we treated Kentucky bluegrass turf in large lysimeters with 8 different pesticides that are routinely used on turf. The eight pesticides, their application dates and physical properties are shown in Table 5. Water samples from the lysimeters were collected continuously throughout the three year period and analyzed for each of the eight pesticides.

The results were generally positive; six of the eight pesticides applied were never detected in leachate samples. Two were detected with some frequency. Those two were triadimefon and dicamba. The levels of detection of triadimefon were usually less than 10 PPB although the highest concentration detected was 31 PPB on 10/15/92, 86 days after application (Figure 2). In light of the data on nitrate leaching that 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 phenomena termed macropore flow. A well-structured soil is composed of many large pore spaces or macropores. During heavy rainfall or irrigation, these large pores will rapidly conduct surface water deep into the soil profile. If a pesticide or nutrient was applied close to the occurrence of macropore flow, it is possible that the chemical could be moved much deeper into the soil profile than would be expected. This must have happened in order to see the occurrence of 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 for the next two years. It is difficult to predict future results although data from other researchers who have collected leachate from shallower soil depths than the 4 feet used in these studies would indicate that the chance of detecting high concentrations of pesticides is small.

As discussed earlier, pesticide residues in ground water is a difficult issue. The best approach would be to chose pesticides which have little chance of reaching ground water. While this is not always possible, new pesticides being developed for the marketplace have much better environmental packages than older pesticides which tend to be more persistent than those currently being used. Over time we believe that pesticide manufacturers will meet the needs of the golf course industry by developing safer, more active products. One of the best ways to reduce the leaching of pesticides is to develop more active products and 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 ground water 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.

The turf industry has been and is still targeted for criticism regarding pesticide and fertilizer use. The research presented here would indicate 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 which minimizes the possibility of substantial downward movement of agrochemicals.

Table 5. Application dates and physical properties of pesticides applied.

PESTICIDE	DATE OF APPLICA-TION	APPLICA-TION RATE (LBSAI/A)	ADSORPTION (K_{oc})	HALF-LIFE ($T_{1/2}$) DAYS	WATER SOLUBILITY mg/L
isazofos	8/12/91	2	100	34	69
chlorothalonil	8/21/91	8.5	1380	30	0.6
dicamba	9/17/91	0.1	2	14	400,000
2,4-D	9/17/91	1.0	20	10	890
fenarimol	5/3/92	0.7	600	360	600
propiconazole	6/18/92	0.75	650	110	110

PESTICIDE	DATE OF APPLICATION	APPLICATION RATE (LBS/AI/A)	ADSORPTION (K_{oc})	HALF-LIFE ($T_{1/2}$) DAYS	WATER SOLUBILITY mg/L
triadimefon	7/21/92	1.35	300	26	71.5
metalaxyl	8/5/92	1.35	50	70	8400

Figure 1. Leaching of fertilizer nitrogen from spring or fall applied nitrogen.

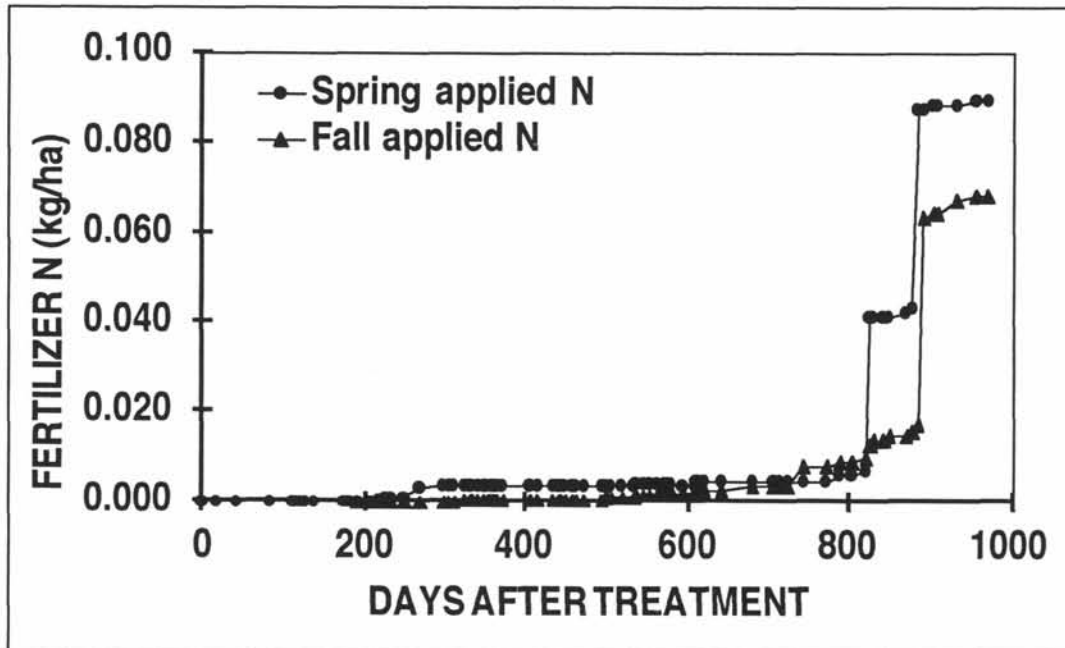


Figure 2. Leaching of triadimefon from monolith lysimeters.

