Loss of Nitrogen and Pesticides from Turf via Leaching and Runoff

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Introduction

Although the game of golf has grown dramatically in popularity during the past 20 years, with more than 25 million golfers in the United States alone, it faces one of its greatest challenges from people who believe that golf courses and course maintenance practices are having a deleterious impact on our environment. One of people's greatest fears is that the fertilizers and pesticides used to maintain golf courses will pollute their drinking water supplies, including both surface and groundwater sources. People are concerned about the effects of high nutrient levels on human health and the ecology of surface waters, and about the potential effects of elevated pesticide levels in drinking water on cancer and other health problems. Claims have been made by some people that up to 100% of the fertilizers and pesticides applied to golf course turf end up in our water supplies, a claim with no basis in fact, but one that has generated emotional reactions from people who are unaware of what happens to chemicals in the environment.

By the mid-1980's the construction of new golf courses was growing dramatically, yet many proposed golf courses were being rejected by local governments and regulatory agencies because of the perception that these courses would pollute public water supplies. Unfortunately, the game of golf and the turfgrass industry had little research information to refer to when responding to these concerns. Thus, when the United States Golf Association decided in 1989 to sponsor a significant amount of research on environmental issues, the area identified to receive the greatest amount of work concerned the effects of fertilizers and pesticides on surface and groundwater resources.

In sponsoring environmental research, the strategy of the USGA's Turfgrass and Environmental Research Committee was to take a mass balance approach to studying what happens to fertilizers and pesticides applied to golf courses. In other words, studies were conducted on the major pathways of chemical fate in the environment, including leaching, runoff, plant uptake and utilization, microbial degradation, and volatilization and other gaseous losses. The studies were conducted at twelve universities throughout the United States, representing the major climatic zones and turfgrass types. (see Table 1).

It was felt that by generating lots of data, a solid foundation would be built for determining how golf course activities affect the environment

The initial environmental research was conducted from 1991 through 1993, and follow-up studies are being carried out from 1995 through 1997. For the sake of providing an overview of the results of these studies, representative data from both periods will be presented.

The subject will be divided into the following topics:

- Nitrogen leaching
- Nitrogen runoff
- Pesticide leaching
- Pesticide runoff

Nitrogen Leaching

Golf courses use a significant amount of nitrogen fertilizer, and there is concern that nitrogen leaching is affecting groundwater supplies. Seven different universities investigated N leaching, most using bucket lysimeters to measure leaching potential. In general, very little N leaching occurred when nitrogen was applied properly - i.e. according to the needs of the turf and in consideration of soil types, irrigation regimes and anticipated rainfall. Representative of these results was the work at Michigan State University, which utilized 4-foot deep lysimeters with undisturbed soil profiles. After 2.5 years, less than 1% of the applied nitrogen had leached through the 4-foot profile. Most of the rest was recovered in the clippings, thatch, and soil, and it is presumed that some volatilization also occurred.

Researchers at Iowa State University observed similar results when N was applied at moderate rates and lightly irrigated (four 0.25-inch vs one 1-inch applications) after application. However, up to 40 times the amount of N was leached after the single 1-inch application, perhaps in part due to macropore flow caused by earthworm activity.

At the University of California at Riverside, N leaching from a USGA profile sand-based green was generally less than 1% when N was applied lightly and frequently.

On the other hand, N leaching was significant when N was applied at heavy rates and under less-than-ideal circumstances. For example, during the first year of the study at Washington State University, on immature turf grown on a pure sand rootzone medium, N leaching amounted to 7.6% at an annual application rate of 12 lbs. N/1000 sq. ft. Leaching was significantly less when peat was added to the sand (USGA mix), occurring at a level of about 3%. On pure sand, N concentrations exceeded federal standards several times at the 12 lb. rate during the first year, whereas N concentrations never exceeded federal standards from the sand/peat mix. Significantly less leaching also occurred when less N was applied (4 & 8 lbs) and when application frequency was increased (22 vs 11 times annually). During years two and three, on mature turf, much less N leaching occurred for all treatments.

Averaging results over all seven leaching projects during year 1 (establishment year), N leaching from pure sand rootzones was about 11%, from sand/peat rootzones about 4%, and from loamy sand, sandy loam, and silt loam rootzones about 1% or less.

Following are some of the conclusions or trends observed from the nitrogen leaching studies:

- Generally, properly maintained turf allows less than 1% of the nitrogen applied to leach to a depth of four feet.
- When more nitrogen is applied than is needed, both the amount and the percentage of nitrogen lost increases.
- Sandy soils are more prone to leaching losses than clayey soils.
- Nitrogen leaching losses can be greatly reduced by irrigating lightly and frequently, rather than heavily and less frequently.
- Leaching losses can be reduced by applying nitrogen in smaller amounts on a more frequent basis.
- Irrigating bermudagrass and tall fescue turf with adequate amounts (no drought stress) of moderately saline water did not increase the concentration or amount of nitrate leached.
- Higher amounts of salinity in the root zone, drought, or the combination of these two stresses caused high concentrations and amounts of nitrate to leach from both a tall fescue and bermudagrass turf. This suggests that the capacity of the root system of the turf is impaired by drought, high salinity, or both, and that management modifications may be needed to prevent nitrate leaching.
- In putting green construction, mixing peat moss with sand significantly reduced nitrogen leaching compared to pure sand rootzones during the year of establishment.
- Light applications of slow-release N sources on a frequent interval provided excellent

protection from nitrate leaching.

Nitrogen Runoff

Among the eleven universities investigating fertilizer and pesticide fate in phase one (1991-1993) of our environmental studies, only one looked at nitrogen runoff. The investigation was conducted at the Penn State University runoff plots, which were characterized by slopes of 9 to 13 percent, good quality soil, and turf cover consisting of either creeping bentgrass or perennial ryegrass cut at a Â½-inch fairway height. Typical of that part of the country, the fairway-type plots received 4 lbs. N/1000 ft2 per year. The irrigation water used to simulate rainfall itself contained a relatively high level of nitrate-N, ranging from about 2 to 10 ppm. In no instance throughout the study did nitrate concentrations in the runoff or leaching samples differ significantly from the nitrate concentration in the irrigation water.

The Penn State study was conducted on excellent quality turf and on soil with a relatively high infiltration rate. Although nitrogen runoff was not measured as part of the runoff studies at the University of Georgia, significant amounts of some soluble pesticides did run off there, suggesting that the circumstances at the Penn State plots may not have represented the actual field conditions on many golf course fairways. Thus, it was decided by the USGA Research Committee to expand the runoff studies during phase 2 (1995-1997) of the environmental program.

One such runoff study currently is being conducted at Oklahoma State University, looking at the effects of buffer strips and best management practices on pesticide and nitrogen runoff. Several interesting observations were made during 1995, the first year of the study. During the first simulated rainfall event in July, soil moisture conditions were low to moderate. After a 2-inch rainfall event, less than 1% of the applied nitrogen was collected in the runoff. In August, when the simulated rainfall occurred after 6 inches of actual rainfall the previous week (i.e. high soil moisture), the amount of nitrogen collected after the simulated rainfall averaged over 8%. (See Table 7)

When soil moisture was moderate to low in the Oklahoma study, the presence of an untreated buffer strip (8-16 ft.) significantly reduced N runoff, whereas when soil moisture was high, the buffer strips made no difference. In both cases, less runoff occurred when sulfur-coated urea was applied compared to straight urea. During years 2 and 3 of the study, different maintenance practices, application timing, product formulations, buffer strip characteristics, etc. will be compared.

Following are some of the conclusions or trends observed from the nitrogen runoff studies:

- Dense turf cover reduces the potential for runoff losses of nitrogen.
- Significant runoff losses are more likely to occur on compacted soils.
- Much greater N runoff occurred when soil moisture levels were high, as compared to moderate or low.
- Buffer strips reduced nitrogen runoff when soil moisture was low to moderate at the time of the runoff event, but not when soil moisture levels were high.
- Nitrogen runoff was significantly less when a slow release product (sulfur-coated urea) was used compared to a more soluble product (urea).

Pesticide Leaching

Pesticide leaching studies were conducted at eight universities throughout the United States.

Treatments were made to a variety of soils and turf species, and plots received varying irrigation regimes or rainfall events. During the first year of the studies, most turf areas were relatively immature.

In terms of results, very little pesticide leaching occurred with most products, generally less than 1% of the total applied. However, significant leaching occurred with certain products and under certain circumstances.

Generally speaking, the physical and chemical properties of the pesticides proved to be good indicators of the potential for leaching, runoff and volatilization. Products that exhibit high water solubility, low soil adsorption potential, and greater persistence are more likely to leach and run off. For example, fenamiphos (Nemacur), a commonly used nematicide, is highly water soluble and has low adsorption potential, and its toxic breakdown metabolite tends to persist in the soil. As expected, losses of fenamiphos and its metabolite due to leaching were as high as 18% from a sand-based green at the University of Florida, though when all studies are considered, the average loss was about 5%.

Soil type and rainfall/irrigation amount also were important factors in leaching losses. Table 3 shows the effects of soil type and rainfall on leaching of MCPP and triadimefon (Bayleton), two pesticides whose chemical and physical properties indicate a relatively high potential for leaching. Results show significant leaching from sand profiles, especially under high rainfall conditions, and much less leaching from sandy loam and silt loam soils.

An interesting phenomenon occurred at the University of Florida study when fenamiphos was applied twice at a monthly interval. Although leaching from the first application amounted to about 18%, leaching from the second application was just 4%. These results suggest that microbial degradation was enhanced due to microbial buildup after the first application, thereby reducing the amount of material available for leaching after the second application.

Another interesting by-product of the studies occurred at the University of Georgia, where Dr. Al Smith compared the actual leaching loss of 2,4-D to that predicted by a computer model (GLEAMS) used by the U.S. Environmental Protection Agency (USEPA). He found that the amount leached was a tiny fraction of that predicted by the model. Generally, the model over-predicted the actual amount leached by 10 to 100 times or more for five of the seven pesticides screened by the computer (see Tables 4 & 5).

Following are some of the conclusions or trends observed from the pesticide leaching studies:

- Dense turf cover reduced the potential for leaching losses of pesticides; conversely, more leaching occurred from newly planted turf stands.
- The physical and chemical properties of the pesticides were good indicators of leaching potential.
- Current pesticide fate models used by USEPA over-predict the leaching loss of most pesticides applied to turf.
- Generally, sandy soils are more prone to leaching losses than clayey soils.
- The average DT90 (days to 90% degradation) in turf soils generally is significantly less than established values based upon agricultural systems. Thus, leaching potential for most pesticides is less in turfgrass systems.
- Turfgrass thatch plays an important role in adsorbing and degrading applied pesticides.

Pesticide Runoff

The University of Georgia was the only site to carry out pesticide runoff investigations. The studies were conducted on plots with a 5% slope and a sandy clay soil. Pesticides were applied, and 1-inch simulated rainfall events occurred 24 and 48 hours afterward, at a rate of 2 inches per hour. Under these conditions, only very small amounts of chlorothalonil and chlorpyrifos could be detected in the runoff. However, between 10% and 13% of the 2,4-D, MCPP and dicamba ran off the plots over an 11-day period, producing a relatively high level of contamination (see Table 6). About 80% of this total moved off the plots with the first rainfall event.

The significant loss of herbicides at the University of Georgia runoff project served to focus our Research Committee on the need for more runoff work in the current phase of the environmental research program. So, in addition to follow-up studies at the Univ. of Georgia, new pesticide and fertilizer runoff investigations have been initiated at Oklahoma State University. The purpose of the project is to develop best management practices by investigating how cutting heights and buffers of varying lengths can be used to minimize fertilizer and pesticide runoff. The effects of soil cultivation (core aerification) on runoff potential also is being studied.

As reported in the section on nitrogen runoff, two experiments were conducted at Oklahoma State during 1995, the first when soil moisture was low to moderate prior to the simulated rainfall event, and the second when soil moisture content was very high due to previous heavy rainfall. From Table 7 it is clear that soil moisture content was a significant factor in determining how much of the pesticides ran off the plot areas. Where soil moisture was low to moderate, buffer zones were effective in reducing pesticide runoff; when soil moisture was high they were not effective except for the insecticide chlorpyrifos.

The follow-up runoff study at the University of Georgia also produced some interesting results in 1995. As much as 40-70% of the rainfall left the plots as runoff during simulated storm events. The collected surface water contained moderately high concentrations of treatment pesticides having a high water solubility. For example, less that 1% of the applied chlorothalonil, chlorpyrifos, benefin, and pendimethalin was transported from the plots in runoff water. On the other hand, as much as 9-16% of the 2,4-D, dicamba, mecoprop, and nitrate were transported in the surface water from the first two simulated storm events. Also, the amount of the insecticide trichlorphon that ran off the plots was 5.2 times greater when broadcast as a granular compared to being pressure injected. Finally, the runoff loss of nitrate and several herbicides was much greater when applied to dormant turf as compared to an actively growing turf: 2,4-D 26.0% vs 9.6%; dicamba 37.3% vs 14.6%; MCPP 23.5% vs 14.4%; nitrate 64.2% vs 16.4%.

Following are some of the conclusions or trends observed from the pesticide runoff studies:

- Dense turf cover reduces the potential for runoff losses of pesticides.
- The physical and chemical properties of pesticides are good indicators of potential runoff losses.
- Heavy textured, compacted soils are much more prone to runoff losses than sandy soils.
- Moist soils are more prone to runoff losses than drier soils.
- When soil moisture is low to moderate prior to rainfall events, buffer strips are very effective at reducing runoff losses of pesticides.
- Application of soluble herbicides dormant turf can produce very high levels of runoff losses.
- Looking ahead, phase 2 of our environmental research program will continue through 1997. Emphasis is being place on following up on questions raised during the earlier studies, particularly concerning runoff and volatilization losses, the effects of thatch and turfgrass soils on pesticide degradation, and pesticide and nutrient fate modeling. At the end of these studies we should have a good perspective on the potential effects of golf course pesticides and fertilizers on our environment, and on the best management practices that can be utilized to have the most positive impact on the environment.

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TABLE 1. Universities that have conducted USGA-sponsored research on pesticide and fertilizer fate.

University	Nitrogen Leaching	Nitrogen Runoff	Pesticide Leaching	Pesticide Runoff	Volatilization
Penn State	X	X			
Michigan State	X		X		
Cornell	X		X		
Iowa State	X		X		X

UC Riverside	X		X		X
Washington State	X				
Univ. Massachusetts					X
Univ. Nevada	X				
Univ. Georgia	X	X	X	X	
Univ. Florida			X		
Univ. Nebraska			X		
Oklahoma State		X		X	

TABLE 2. A listing by category of the pesticides (common/trade name) mentioned in this paper.

Herbicides	Insecticides	Fungicides
MCPP/Mecoprop	chlorpyrifos/Dursban	chlorothalonil/Daconil
2,4-D/many names	trichlorphon/Proxol	tradimefon/Bayleton
dicamba/Banvel	fenamiphos/Nemacur	metalaxyl/Subdue
benefin/Balan	isazofos/Triumph	
pendamethalin/Prowl	ethoprop/Mocap	
	fonofos/Dyfonate	
	isofenphos/Oftanol	

TABLE 3. Effect of soil type and precipitation rate on the leaching loss of two pesticides from an immature turf, expressed as % of total applied. Cornell University

Pesticide	Precipitation	Sand	Sandy Loam	Silt Loam
MCPP	Moderate	34.85%	1.69%	1.01%
	High	73.76%	0.10%	1.26%
Triadimefon	Moderate	1.00%	0.06%	0.24%
	High	2.44%	0.01%	1.26%

TABLE 4. Predicted loss (using the GLEAMS model) versus observed loss of several pesticides from sand-based putting green rootzone mixes, expressed as percent of total applied, averaged across

all studies.

Pesticide	Predicted Loss (%)	Observed Loss (%)
Isazofos (Triumph)	61.6	0.05
MCPP	82.4	0.08
Ethoprop (Mocap)	50.9	0.05
Fenamiphos (Nemacur)	59.9	4.7
2,4-D	69	2.25

TABLE 5. Predicted loss (using the GLEAMS model) versus observed loss of several pesticides from turf maintained under fairway conditions, expressed as percent of total applied and averaged across all studies.

Pesticide	Predicted Loss (%)	Observed Loss (%)
Isazofos (Triumph)	61.6	2.4
MCPP	82.4	19.31
Dicamba (Banvel)	93.2	39.61
Metalaxyl (Subdue)	77.2	0
2,4-D	69	2.25

1 Average skewed due to high readings from immature turf on sandy soil.

TABLE 6. Runoff loss from bermudagrass plots treated with 2,4- D, MCPP, and dicamba after 1-inch rainfall at 24 hrs, 48 hrs, 5 days and 11 days after treatment, expressed as percent of total applied. Univ. of Georgia

Time after treatment	2,4-D (%)	MCPP (%)	dicamba (%)
24 hrs	7.2	9.6	10.7
48 hrs	2.1	0.9	2.6
5 days	--	0.4	--
11 days	--	0.4	--

TABLE 7. Effect of low/moderate versus high soil moisture levels on pesticide and nutrient runoff losses from bermudagrass maintained as fairway turf, expressed as a percent of total applied. Oklahoma State University

Soil moisture	Dicamba	2,4-D	MCPP	Chlorpyrifos	NH4-N	NO3	PO4
Low/mod.	0.35	0.79	0.81	0.04	0.2	0.09	0.2

High	5.4	8.7	9.3	0.025	5.1	3.1	7.7

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