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Cover Photo:

This issue of the Green Section Record *contains the results of 11 university research projects initiated by the USGA in a three-year study to investigate the fate of pesticides and fertilizers applied to turf under golf course conditions.*

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What Happens to Pesticides Applied to Golf Courses?

by DR. MICHAEL P. KENNA
Director, USGA Green Section Research

Golf courses and the environment. No issue will have a greater effect on the way golf courses are built and maintained, now or in the future. Golf courses have been heralded as sanctuaries and condemned as waste sites, depending on your point of view. What's the truth? The game of golf needed answers to environmental questions, and the USGA wanted these answers based on scientific facts, not emotions.

In 1991 the USGA initiated a three-year study to investigate the fate of pesticides and fertilizers applied to turf under golf course conditions, develop alternative (non-chemical) methods of pest control, and determine the impact of golf courses on people and wildlife. This issue of the Green Section Record *contains the results of the 11 university research projects that involved pesticide and nutrient fate. The first article, by Dr. Michael Kenna, briefly describes what is known about the fate of chemicals used on golf courses and provides some supporting documentation to help golf course personnel select a pesticide. Highlights of the research projects are summarized in his article, but the research articles themselves should be read to learn more about the particulars of each project.*

PROTECTING goundwater and surface water from chemical pollutants is a national initiative. The Environmental Protection Agency (EPA) estimates that 1.2 billion pounds of pesticides are sold annually in the United States. About 70% of the pesticides applied are used for agricultural production of food and fiber. Only a small fraction of this amount is used on golf courses. Yet, increased public concern about chemicals has drawn attention to golf because of the perception that the intense maintenance on golf courses creates the potential for environmental contamination.

Figure 1
Processes Affecting the Fate of Pesticides in Soils

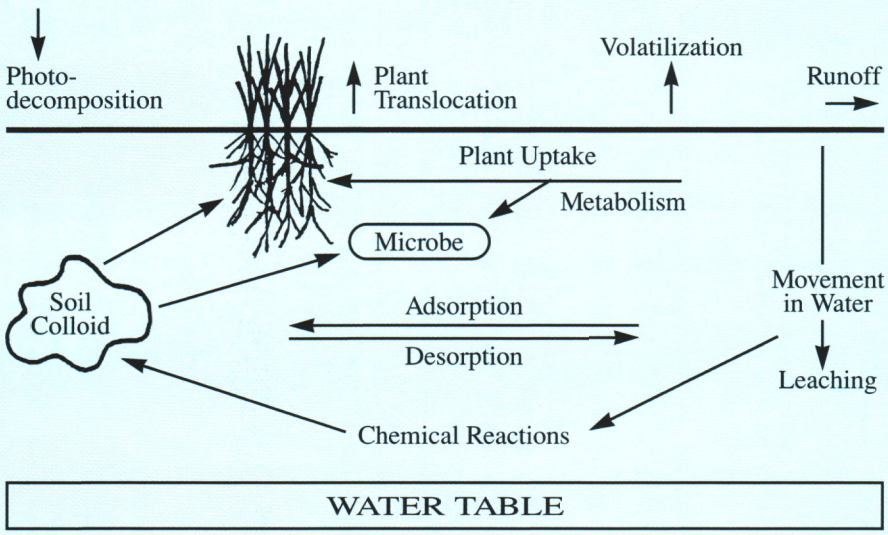
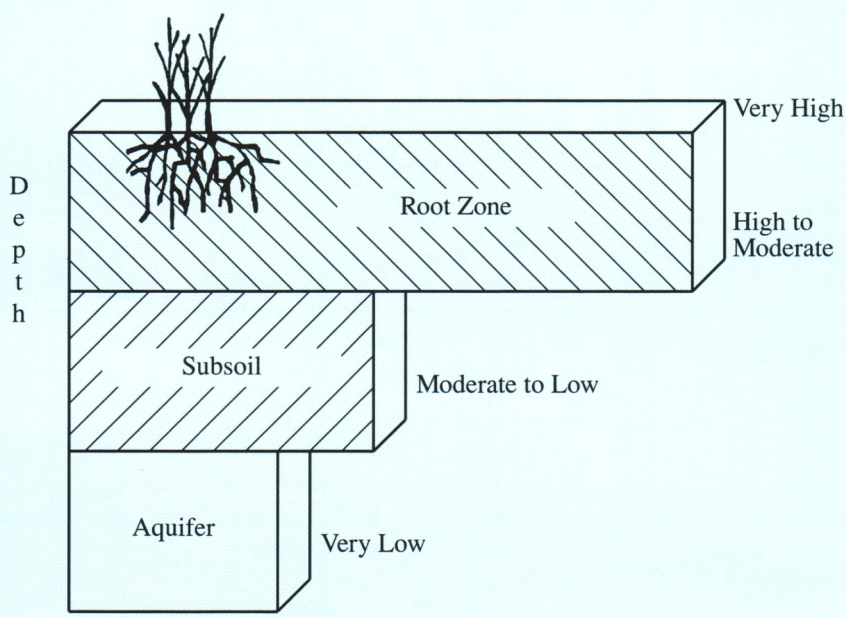


Figure 2
Changes in Microbial Activity with Depth



In the late 1980s, golf was faced with a dilemma. On one hand, regulatory agencies responding to public concern routinely initiated environmental monitoring programs of groundwater and surface water. On the other hand, very little public information was available on the behavior and fate of pesticides and fertilizers applied to turfgrass. Probing, sometimes overzealous federal and state regulators looking for non-point source polluters raised concerns about a recreational game that had relied on the integrity of chemical companies and the EPA to provide products and guidelines that protect the environment. There were lots of questions but few answers.

The Fate of Chemicals Applied to Golf Courses

Do golf courses pollute the environment? No, they do not. At least not to the extent that critics state in undocumented media hype. Golf course superintendents apply pesticides and fertilizers to the course, and depending on an array of processes, these chemicals break down into by-products that are biologically inactive.

In general, there are six processes that influence the fate of chemical products applied to golf courses.

1. Solubilization by water.
2. Sorption by soil mineral and organic matter.
3. Degradation by soil microorganisms.
4. Chemical degradation and photo-decomposition.
5. Volatilization and evaporation.
6. Plant uptake.

The relative importance of each process is controlled by the chemistry of the pesticide or fertilizer and environmental variables such as temperature, water content, and soil type (see Figure 1).

Solubility

The extent to which a chemical will dissolve in a liquid is referred to as *solubility.* Although water solubility is usually a good indicator of the mobility of a pesticide in soils, it is not necessarily the best criterion. In addition to pesticide solubility, the pesticide's sorption, or affinity to adhere to soils, must be considered.

Sorption

The tendency of a pesticide to leach or run off is strongly dependent upon the interaction of the pesticide with solids within the soil. The word *sorption* is a term that includes the processes of adsorption and absorption. Adsorption refers to the binding of a pesticide to the surface of a soil particle. Absorption implies that the pesticide pene-

trates into a soil particle. The adsorbed or absorbed pesticide is often referred to as bound residue and is generally unavailable for microbial degradation or pest control.

Factors that contribute to sorption of pesticides on soil materials include: a) chemical and physical characteristics of the pesticide; b) soil composition; and c) the nature of the soil solution (Table 1). In general, sandy soils offer little in the way of sorptive surfaces. Soils containing greater amounts of silt, clay, and organic matter provide a richly sorptive environment for pesticides.

Adsorption of pesticides is affected by the partition coefficient, which is reported as K_d or, more accurately, as K_{oc}. For example, a K_{oc} of less than 300 to 500 is considered low.

Microbial Degradation

Pesticides are broken down by microorganisms in the soil in a series of steps that eventually lead to the production of CO_2 (carbon dioxide), H_2O (water), and some inorganic products (i.e., nitrogen, sulfur, phosphorus, etc.). Microbial degradation may be either direct or indirect. Some pesticides are directly utilized as a food source by microorganisms. In most cases, though, indirect microbial degradation of pesticides occurs through passive consumption along with other food sources in the soil. Regardless, microbial degradation is a biological process whereby microorganisms transform the original compound into one or more new compounds with different chemical and physical properties that behave differently in the environment.

Degradation rates are influenced by factors such as: pesticide concentration, temperature, soil water content, pH, oxygen status, prior pesticide use, soil fertility, and microbial populations. These factors change dramatically with soil depth, and microbial degradation is greatly reduced as pesticides migrate below the soil surface (Figure 2).

Persistence of a pesticide is expressed as the term half-life (DT_{50}), which is defined as the time required for 50 percent of the original pesticide to break down into other products. Half-life values are commonly determined in the laboratory under uniform conditions. On the golf course, soil temperature, organic carbon, and moisture content change constantly. These and other factors can dramatically influence the rate of degradation. Consequently, half-life values should be considered as guidelines rather than absolute values.

Chemical Degradation

Chemical degradation is similar to microbial degradation except that the breakdown of the pesticide into other compounds is not achieved by microbial activity. The major chemical reactions such as hydrolysis, oxidation, and reduction are the same. Photochemical degradation is a different breakdown process that can influence the fate of pesticides. It was the combination of chemical, biological, and photochemical breakdown processes under field conditions that was the focus of the USGA-sponsored studies.

Volatilization and Evaporation

Volatilization is the process by which chemicals are transformed from a solid or liquid into a gas, and is usually expressed in units of vapor pressure. Pesticide volatilization increases as the vapor pressure increases. As temperature increases, so does vapor pressure and the chance for volatilization loss. Volatilization losses generally are lower following a late afternoon or an early evening pesticide application than in the late morning or early afternoon, when temperatures are increasing. Volatilization also increases with air movement, and losses can be greater from unprotected areas than from areas with windbreaks. Immediate irrigation is usually recommended to reduce the loss of highly volatile pesticides.

Plant Uptake

Plants can directly absorb pesticides or influence pesticide fate by altering the flow of water in the root zone. Turfgrasses with higher rates of transpiration can reduce the leaching of water-soluble pesticides. In situations where the turf is not actively growing or where root systems are not well developed, pesticides are more likely to migrate deeper into the soil profile with percolating water.

Good Management Can Make a Difference

A primary concern when applying pesticides is to determine if the application site is vulnerable to groundwater or surface water contamination (Table 2). In most cases, level areas away from surface waters (rivers,

Table 1
Chemical and Physical Properties of Pesticides: Values That Indicate Potential for Groundwater and Surface Water Contamination

Pesticide Characteristic	Parameter Value or Range Indicating Potential for Contamination
Water solubility	Greater than 30 ppm
K_d	Less than 5, usually less than 1
K_{oc}	Less than 300 to 500
Henry's Law Constant	Less than 10^{-2} atm per m^{-3} mol
Hydrolysis half-life	Greater than 175 days
Photolysis half-life	Greater than 7 days
Field dissipation half-life	Greater than 21 days

From EPA 1988 as reported by Balogh and Walker, 1992

Table 2
Factors Contributing to Greater Risk for Groundwater and Surface Water Contamination — The More of These Conditions Present, the Greater the Risks

Chemical	Soil	Site	Management
High solubility	Porous soil (sand)	Shallow water table	Incomplete planning
Low soil adsorption	Low organic matter	Sloping land	Misapplication
Long half-life (persistent)		Near surface water	Poor timing
Low volatility		Sink holes/ abandoned wells	Over-irrigation

lakes, or wetlands) will not be prone to pesticide runoff, and if the depth to groundwater is greater than 50 feet on fine-textured soils, the chances for deep percolation of pesticides is greatly reduced. More attention to the pesticide's characteristics is needed when applications are made to sandy soils with little organic matter or sloped areas with thin turf and low infiltration rates.

The most important thing a golf course superintendent can do when applying pesticides is to read and follow the label directions. From planning and preparation to storage and disposal, following label directions will significantly reduce the risks of contaminating our water resources. Select a pesticide that poses the least threat of rapid leaching and runoff and is relatively non-persistent (Table 3).

The Rest of the Story

This is only a very brief overview of the processes that affect what happens to pesticides and nutrients in the environment. The rest of this issue of the *Green Section Record* is devoted to the USGA-sponsored environmental research projects, which were conducted from 1991 through 1994 (Table 4). Compared to agricultural crops, the results not only build on what is known about pesticide and nutrient fate, but often show that turfgrass systems:

- Reduce runoff.
- Increase adsorption on leaves, thatch, and soil organic matter.
- Maintain high microbial and chemical degradation rates
- Reduce percolation due to an extensive root system, greater plant uptake, and high transpiration rates.

These results reinforce the view that turfgrass areas generally rank second only to undisturbed forests in their ability to prevent pesticides and nutrients from reaching groundwater and surface water.

Highlights from the USGA-sponsored environmental research projects follow:

University of Nebraska, Dr. Garald Horst

- After 16 weeks under golf course fairway management conditions, detectable residues of isazofos, metalaxyl, chlorpyrifos, and pendimethalin pesticides found in soil, thatch, and verdure were 1% or less of the total application amount.
- The average DT_{90} (days to 90% degradation) of the four applied pesticides was two months in fairway-managed turf/soil. Thatch played a significant role in pesticide adsorption and degradation.

Iowa State University, Dr. Nick Christians

- Pesticides and fertilizers applied to Kentucky bluegrass have the potential to leach through a 20" soil profile if irrigated improperly.
- Pesticide and fertilizer leaching can be greatly reduced during the four weeks after a pesticide or fertilizer application by irrigating lightly and more frequently, rather than heavily and less frequently.
- The thatch layer in a mature turf significantly decreases the amount of pesticides from leaching into the soil profile.

University of Georgia, Dr. Al Smith

- Data from research on simulated putting greens indicated that the concentration of 2,4-D, mecoprop, dithiopyr, and dicamba in soil leachate was below 4 ppb (parts per billion). According to a leaching prediction model for agriculture (GLEAMS), this leachate should have been 50 to 60 ppb, a significantly higher number. This indicates that current prediction models overestimate the potential leaching of pesticides through turfgrass systems.
- Less than 0.5% of the applied 2,4-D, mecoprop, dithiopyr, and dicamba was found in the leachate from the simulated USGA putting greens over a 10-week period.
- No chlorpyrifos or OH-chlorpyrifos (first order metabolite) was detected in the leachate from the simulated putting greens in the greenhouse or field evaluations.
- Small quantities of chlorthalonil and OH-chlorthalonil were found to leach through the greens. However, the amount was less than 0.2% of the total applied.
- Data from fairway runoff plots with a 5° slope indicate that there is a potential for small quantities of 2,4-D, dicamba, and mecoprop to leave the plots in surface water during a 2" rainfall at an intensity of 1" per hour. The runoff was attributed to poor infiltration on a high-clay soil.

Michigan State University, Dr. Bruce Branham

- Nitrate leaching was negligible; less than 0.2% of the applied nitrogen was recovered at a depth of 4 ft below the surface (deepest system among all the studies).
- The nitrogen detected was at least 10 times below the drinking water standard (0.43 ppm nitrate in spring and 0.77 ppm nitrate in fall).
- It is estimated that up to 34% of the nitrogen volatilized.
- Only two (dicamba and triadimefon) of the eight pesticides evaluated were detected in the percolate at 4 ft (levels of 2 to 31 ppb).
- 2,4-D is potentially very mobile, but did not show up in the percolate.
- Phosphorus leaching potential is very low except in some sandy soils with low adsorption ability, where phosphorus applications require closer management.
- The root zone and thatch had a high biological activity, which enables turf to work like a filter when pesticides and fertilizers are applied.

University of Massachusetts, Dr. Richard Cooper

- Volatile pesticide loss over the two-week observation period ranged from less than 1% of the total material applied for the herbicide MCPP, to 13% of the total applied for the insecticides isazofos and trichlorfon.
- Volatile loss reached a maximum when surface temperature and solar radiation were greatest. To minimize volatility, the best time for application is late in the day.
- Total volatile loss for each compound was directly related to vapor pressure. For all materials evaluated, most of the volatile loss occurred during the first 5 days following application. Volatile residues were undetectable or at extremely low levels 2 weeks after application.
- Pesticide residues for all materials were rapidly bound to the leaf surface, with less than 1% of all residues dislodging (rubbed with cotton gauze) eight hours after application.
- Irrigating treated plots immediately after application greatly reduced volatile and dislodgeable residues on the first day following treatment.
- Volatile losses were far below (up to 1000 times) levels that should cause health concerns.

University of Nevada, Dr. Daniel Bowman

- When the turf was maintained under a high level of management, nitrate leaching from both tall fescue and bermudagrass turf was very low. A total of 1% or less of the applied nitrogen was lost in the leachate.
- Irrigating the two turfgrasses with adequate amounts (no drought stress) of moderately saline water did not increase the concentration or amount of nitrate leached.
- Higher levels 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 nitrogen uptake capacity of the turf root system is severely impaired by drought, high salinity, or both. Under such conditions, it will be necessary to modify management practices to reduce or eliminate the stresses, or nitrate leaching could be a problem.

University of California, Dr. Marylynn Yates

- Turf maintained under golf course fairway and putting green conditions used most

DIANE CHRENKO BECKER

The results of the environmental fate research projects were reported at a special meeting of the USGA Turfgrass Research Committee, university researchers, and Green Section staff held at Golf House in April 1994.

of the nitrogen applied — even with over-irrigation.

• Under the conditions of this study (bi-weekly applications of urea and sulfur-coated urea), little leaching of nitrate-nitrogen (generally less than 1% of the amount applied) was measured. No significant differences were found in the percent leached as a result of irrigation amount or fertilizer type.

• Leaching of 2,4-D was very low in soils that contained some clay, which adsorbs the pesticide; however, up to 6.5% leached from the sandy putting green soil. Irrigation amount did not significantly affect the amount of leaching.

• Less than 0.1% of the carbaryl leached, regardless of soil type. The irrigation amount did not significantly affect the amount of leaching.

• Little volatilization of 2,4-D was measured (≤ 1%) from any of the plots, although the difference in the amount volatilized was significantly different between the two turfgrass species used (bentgrass vs. bermudagrass) and the surface characteristics (green vs. fairway).

• Little volatilization of carbaryl was measured (≤ 0.05%) from any of the plots.

• Based on uniformly low volatilization results, turf may require different volatility regulations than agricultural crops.

University of Florida, Dr. George Snyder

• A total of 98-99% of the insecticide applied stayed in the thatch layer.

• Greater movement of the fenamiphos metabolite occurred than expected, and different management practices may be warranted with this product.

• Less than 1% of the applied pesticides were found on cotton cloth immediately after spraying.

Cornell University, Dr. Martin Petrovic

• More leaching occurred in newly planted turf than in mature, established turf.

• Nitrogen leaching did not exceed EPA drinking water standards.

• During the first year, MCPP leached from a coarse sand with poorly established turf (50-60% leached through the profile). This treatment was a "worst case" scenario.

• During the second year, a 7" rain (hurricane conditions) immediately after application caused substantial leaching from all soils.

Penn State University, Dr. Thomas Watschke

• Significant differences between water runoff from ryegrass (more) versus creeping bentgrass (less) occurred because of the presence of more stolons, more organic matter, and higher density in bentgrass.

• Infiltration rate differences did not occur between the two turfgrass species.

• Over time, the increase in thatch resulted in decreased runoff.

• The irrigation rate had to be doubled (6"/hr) in order to produce any runoff, which indicates that turf is good at holding water.

• More than half of all the runoff water samples analyzed contained no pesticide. The remaining contained pesticide concentrations of less than 10 ppb of the pesticides.

• All reported nitrogen and phosphorus concentrations in runoff were less than EPA drinking water standards.

Washington State University, Dr. Stan Brauen

• The addition of organic matter, in this case sphagnum peat, proved to be the most important factor reducing nitrogen leaching from newly constructed greens.

• "Spoon feeding" or light applications of fertilizer on 14-day vs. 28-day intervals significantly reduced nitrogen leaching from young greens.

• As putting greens matured, nitrogen fertilization rate was the major factor affecting leaching. Rates of 8 lbs or less of nitrogen per 1000 sq ft per year resulted in little or no nitrate leaching.

• Light applications of slow-release (or water-insoluble nitrogen) sources on a frequent interval provided excellent protection from nitrate leaching.

Table 3
Summary of Pesticide Properties and Potential for Surface and Subsurface Losses[a]

Pesticide		Water Solubility (ppm)	Soil Adsorption K_{oc}	Half-Life DT_{50} (days)	Persistence Classification[b]
Common Name	**Trade Name**				
Insecticides and Nematicides					
Acephate	Orthene	818,000	2	3	—
Bendiocarb	Turcam	40	570	3-21	3-5
Carbaryl	Sevin	32-40	79-423	6-110	4
Chlorpyrifos	Dursban	0.4-4.8	2,500-14,800	6-139	2-4
Diazinon	Diazinon	40-69	40-570	7-103	2-4
Ethoprop	Mocap	700-750	26-120	14-63	2
Fenamiphos	Nemacur	400-700	26-249	3-30	3-5
Isazofos	Triumph	69	44-143	34	2
Isofenphos	Oftanol	20-24	17-536	30-365	1-3
Trichlorfon	Proxol	12,000-154,000	2-6	3-27	3-5
Fungicides					
Anilazine	Dyrene	8	1,070-3000	0.5-1	5
Benomyl	Tersan	2-4	200-2,100	90-360	1-2
Chloroneb	Terraneb	8	1,159-1,653	90-180	1-2
Chlorothalonil	Daconil 2787	0.6	1,380-5,800	14-90	2-4
Etridiozole	Terrazole	50-200	1,000-4,400	20	3
Ferarimole	Rubigan	14	600-1,030	20	1
Fosetyl Al	Alliette	120,000	20	1	5
Iprodione	Chipco 26019	13-14	500-1,300	7-30	3-4
Mancozeb	Dithane or Fore	0.5	2,000	35-139	1-2
Maneb	Manzate	0.5	2,000	12-56	2-4
Metalaxyl	Subdue or Apron	7,100-8,400	29-287	7-160	1-4
PCNB	Terraclor	0.03-0.44	350-10,000	21-434	1-3
Propamocarb	Banol	700,000-1,000,000	1,000,000	30	3
Propiconazole	Banner	100-110	387-1,147	109-123	1
Thiophanate-methyl	Fungo	3.5	1,830	10	4
Thiram	Spotrete	30	670-672	15	4
Triadimefon	Bayleton	70	73	16-28	3-4
Vinclozolin	Vorlan	3	43,000	20	—
Herbicides					
Atrazine	Aatrex	33-70	38-216	17-119	1-3
Benefin	Balan	0.1-1	781-10,700	2-130	5
Bensulide	Betason	5.6-25	740-10,000	30-150	1-3
Bentazon	Basagran	2,300,000	35	20	—
DCPA	Dacthal	0.05	4,000-6,400	13-295	1-3
2,4-D acid	Many Names	682-1,072	20-109	2-30	3-5
2,4-D amine	Many Names	200,000-3,000,000	0.1-136	2-23	3-5
2,4-D ester	Many Names	12	1,100-6,900	—	—
Dicamba, acid		4,500-8,000	0.4-4.4	3-315	1-5
Dicamba, salt	Banvel	80,000	2.2	3-315	1-5
DSMA	Many Names	254,000	770	—	—
Endothall	Endothal	100,000	8-138	2-9	4-5
Ethofumesate	Prograss	51-110	340	20-30	3-4
Glyphosate, acid	Roundup	12,000	2,640	7-81	2-4
Glyphosate, amine	Roundup	900,000	24,000	30-50	2-4
MCPA, ester	Rhonox	5	1,000	8-69	2-4
MCPA, salt	MCPA	270,000-866,000	20	4-21	3-5
MCPP	Mecoprop	660,000	20	21	3
MSMA	Daconate	—	—	1000	1
Oxidiazon	Ronstar	0.7	3,241-5,300	30-180	1-3
Pendimethalin	Prowl	0.275-0.5	5,000	8-480	1-4
Pronamide	Kerb	15	990	60	—
Siduron	Tupersan	18	420-890	90	2
Simazine	Princep	3.5-5	135-214	13-94	2-4
Triclopyr, amine	Turflon	2,100,000	1.5-27	30-90	2-3
Triclopyr, ester	Ester	23	780	30-90	2-3
Trifluralin	Treflan	0.6-24	3,900-30,500	7-533	1-4

[a]Pesticide properties and potential for surface and subsurface losses were summarized from information presented in Balogh and Walker (1992).

[b]Persistence classes: 1 = highly persistent, 2 = moderately persistent, 3 = moderately short-lived, 4 = short-lived, 5 = very short-lived.

[c]The maximum concentration is based on a worst case model and assumes rain occurs one day after application of a pesticide.

Vapor Pressure (Pa)			Potential Surface Losses			Potential Subsurface Losses			
			Max. Conc. in	SCS Rating[d]			GUS[e]	SCS	Pesticide
20C	25C	30C	Runoff (g/m³)[c]	Sediment	Soluble	GUS	Ranking	Ranking	Trade Name
—	—	—	—	—	—	—	—	—	Orthene
—	6.9E-04	—	5.6	Small	Large	0.87	Nonleacher	Small	Turcam
2.0E-04	1.8E-04	1.7E-02	1.7	Small	Medium	1.52	Nonleacher	Small	Sevin
1.2E-03	2.5E-03	1.2E-02	0.6	Medium	Small	0.32	Nonleacher	Small	Dursban
1.9E-02	—	—	1.7	Large	Large	2.65	Intermediate	Small	Diazinon
—	5.1E-02	—	1.7	Small	Medium	2.68	Intermediate	Large	Mocap
—	1.3E-02	1.3E-04	1.7	Medium	Large	3.01	Leacher	Large	Nemacur
4.3E-03	1.2E-02	—	1.7	Small	Large	3.06	Leacher	Large	Triumph
5.3E-04	—	—	1.7	Medium	Large	2.65	Intermediate	Medium	Oftanol
1.1E-03	—	—	1.7	Small	Medium	3.00	Leacher	Large	Proxol
—	—	—	0.6	Small	Small	0.00	Nonleacher	Small	Dyrene
1.3E-03	1.3E-08	—	5.6	Large	Large	1.66	Nonleacher	Small	Tersan
—	4.0E-01	—	5.6	Large	Large	1.98	Intermediate	Small	Terraneb
—	—	1.3E-00	1.7	Medium	Medium	1.27	Nonleacher	Small	Daconil 2787
1.3E-02	—	—	0.6	Medium	Medium	1.30	Nonleacher	Small	Terrazole
—	2.9E-05	—	0.6	Medium	Large	2.55	Intermediate	Large	Rubigan
1.3E-03	—	—	5.6	Small	Medium	0.00	Nonleacher	Small	Alliette
2.7E-05	—	—	1.7	Small	Large	1.32	Nonleacher	Small	Chipco 26019
1.3E-02	—	—	5.6	Large	Large	1.54	Nonleacher	Small	Dithane or Fore
1.3E-04	—	—	5.6	Large	Large	1.54	Nonleacher	Small	Manzate
2.9E-04	6.4E-04	—	5.6	Medium	Large	3.43	Leacher	Large	Subdue or Apron
6.7E-03	3.2E-01	—	0.6	Medium	Small	0.39	Nonleacher	Small	Terraclor
—	8.0E-01	—	0.6	Medium	Small	-1.48	Nonleacher	Small	Banol
1.3E-04	5.6E-05	—	0.6	Large	Large	2.00	Intermediate	Medium	Banner
1.3E-05	—	—	5.6	Medium	Medium	0.74	Nonleacher	Small	Fungo
1.3E-03	1.0E-03	—	5.6	Small	Large	1.38	Nonleacher	Small	Spotrete
1.1E-04	—	2.0E-03	5.6	Small	Large	2.15	Intermediate	Medium	Bayleton
—	—	—	—	—	—	—	—	—	Vorlan
4.0E-05	8.8E-05	1.9E-04	5.6	Medium	Large	3.24	Leacher	Large	Aatrex
4.0E-03	1.0E-02	5.2E-03	0.6	Large	Medium	-0.05	Nonleacher	Small	Balan
—	1.3E-04	—	0.6	Large	Large	2.08	Intermediate	Medium	Betason
—	—	—	—	—	—	—	—	—	Basagran
—	3.3E-04	—	5.6	Large	Medium	0.80	Nonleacher	Small	Dacthal
1.1E-03	1.0E-03	—	1.7	Small	Medium	2.69	Intermediate	Medium	Many Names
—	—	1.1E-07	1.7	Small	Medium	2.00	Intermediate	Medium	Many Names
—	2.3E-01	—	—	—	—	—	—	—	Many Names
—	4.9E-01	—	1.7	Small	Medium	4.24	Leacher	Large	
—	—	—	—	—	—	—	—	—	Banvel
—	—	—	5.6	Large	Small	2.31	Intermediate	Small	Many Names
—	1.0E-03	—	0.6	Small	Medium	2.28	Intermediate	Medium	Endothal
—	6.5E-04	—	1.7	Small	Medium	2.17	Intermediate	Medium	Prograss
—	negligible	—	5.6	Large	Large	0.00	Nonleacher	Small	Roundup
—	negligible	—	—	—	—	—	—	—	Roundup
2.0E-04	—	—	0.6	Medium	Medium	1.39	Nonleacher	Small	Rhonox
—	—	—	1.7	Small	Medium	3.77	Leacher	Large	MCPA
1.3E-05	—	—	1.7	Small	Medium	3.51	Leacher	Large	Mecoprop
—	negligible	—	5.6	Large	Small	0.00	Nonleacher	Small	Daconate
1.3E-04	—	—	0.6	Large	Medium	0.88	Nonleacher	Small	Ronstar
—	4.0E-03	—	0.6	Large	Medium	0.59	Nonleacher	Small	Prowl
—	—	—	5.6	Medium	Large	3.02	Leacher	Large	Kerb
—	8.0E-04	—	5.6	Medium	Large	2.69	Intermediate	Medium	Tupersan
8.1E-07	—	—	5.6	Medium	Large	3.35	Leacher	Large	Princep
—	1.6E-04	—	1.7	Medium	Large	4.49	Leacher	Large	Turflon
—	9.5E-03	—	1.7	Medium	Large	1.84	Intermediate	Medium	Ester
1.5E-02	—	—	0.6	Large	Medium	0.17	Nonleacher	Small	Treflan

[d]USDA Soil Conservation Service pesticide and water quality screening ratings.

[e]Groundwater Ubiquity Score and leaching potential rating based on pesticide degradation and organic matter partitioning.

Table 4
Summary of Subsurface and Surface Pesticide and Nitrogen Fate Research Projects

Project No.	University Researchers	Fertilizer Fate Treatments Evaluated	Pesticide Fate Treatments Evaluated	Irrigation	Soil	Turfgrass Area	Measured Parameters
1	Penn State Univ. Dr. Thomas Watschke	Mixed sources include NH_4NO_3 and urea compounds. Three 49 kg N/ha rates were applied per year.	Triumph (isazofos) MCPP (mecoprop)	Enough to force runoff plus natural precipitation	Silt loam	Creeping bentgrass and ryegrass fairways	Leachate and runoff
2	Michigan State Univ. Dr. Bruce Branham and Dr. Paul Rieke	Nitrogen (as urea) and phosphorus early spring/late fall. Total added was 196 kg/ha/yr as urea.	2,4-D dicamba Triumph (isazofos) Daconil (chlorothalonil) Rubigan (fenarimol) Subdue (metalaxyl) Bayleton (triadimefon) Banner (propiconazole)	Normal irrigation to maintain turf	Sandy loam	Kentucky bluegrass rough	Leachate
3	Cornell Univ. Dr. Martin Petrovic	Labeled methylene urea applied in four applications (45 kg/ha/yr)	Triumph (isazofos) Bayleton (triadimefon) MCPP (mecoprop)	Normal and wet rainfall year with additional irrigation	Coarse sand, sandy loam, and silt loam	Bentgrass fairways	Leachate
4	Iowa State Univ. Dr. Nick Christians Univ. of Nebraska Dr. Garald Horst	Nitrogen and phosphorus were applied to undisturbed soil columns	pendimethalin Triumph (isazofos) Dursban (chlorpyrifos) Subdue (metalaxyl)	Nitrogen: after fertilization, 2.5 cm as one application and 0.625 as 4 small increments. Pesticides: Irrigation and rainfall to maintain turf.	Silt loam	Kentucky bluegrass rough	Leachate (nitrogen and pesticides) and volatilization (nitrogen only)
5	Univ. of California Dr. Marylynn Yates	Urea and SCU at 134 and 268 kg/ha/yr	2,4-D Sevin (carbaryl)	Two irrigation regimes, 100% ETc and 130% ETc	Modified sand and peat mix for greens and sandy loam and loamy sand for fairways	Bermudagrass fairways and creeping bentgrass greens	Leachate and volatilization
6	Washington State Univ. Dr. Stan Brauen Dr. Gwen Stahnke	Mixed granular and soluble nitrogen at 2 application timings (14 and 28) and 3 rates (195, 390, and 585 kg/ha/yr)	To maintain turf only — not part of study objectives	Normal irrigation to maintain turf	Modified sand and sand/peat putting green mixes	Creeping bentgrass green	Leachate
7	Univ. of Nevada Dr. Dan Bowman Dr. Dale Devitt	NH_4NO_3 applied monthly at 50 kg/ha/yr	To maintain turf only — not part of study objectives	Various concentrations (15 to 60 ppm) of a saline water source used to irrigate turf	Loamy sand	Bermudagrass fairway and tall fescue rough	Leachate
8	Univ. of Georgia Dr. Al Smith Dr. David Bridges	To maintain turf only — not part of study objectives	Weedar 64 (2,4-D amine) Banvel (dicamba) MCPP (mecoprop) Daconil (chlorothalonil) Dursban (chlorpyrifos)	0.625 cm daily and one 2.54 cm weekly event to simulate rainfall	Leaching: modified sand putting green recommendations comparing 80:20 and 85:15 sand/peat root-zone ratios by volume. Runoff: fine-textured soil, 5% slope.	Leaching: creeping bentgrass and bermudagrass putting greens. Runoff: bermudagrass fairways	Leachate and runoff
9	Univ. of Massachusetts Dr. Richard Cooper Dr. John Clark	To maintain turf only — not part of study objectives	Triumph (isazofos) Proxol (trichlorfon) MCPP (mecoprop) Bayleton (triadimefon)	Normal irrigation to maintain turf	Silt loam	Bentgrass fairway	Volatilization and dislodgeable residues
10	Univ. of Florida Dr. George Snyder Dr. John Cisar	To maintain turf only — not part of study objectives	Nemacur (fenamiphos) Dyfonate (fonofos) Dursban (chlorpyrifos) Triumph (isazofos) Oftanol (isofenphos) Mocap (ethroprop) 2,4-D Dicamba	Normal irrigation to maintain putting green turf in South Florida	Modified sand and peat putting green recommendations	Bermudagrass putting green	Leaching and dislodgeable residues

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Glossary of Terms

Absorption: The process by which a chemical passes from one system *into* another, such as from the soil solution into a plant root or into the matrix of a soil particle.

Acidic Pesticide: A pesticide whose neutral (molecular) form becomes negatively charged as pH is increased.

Adsorption: Retention of a chemical onto the surface of a soil particle.

Aquifer: A water-containing layer of rock, sand, or gravel that will yield useable supplies of water.

Basic Pesticide: A pesticide whose neutral (molecular) form becomes positively charged as pH is lowered.

Cationic Pesticide: A very strong, basic pesticide whose positive charge is independent of pH.

Degradation: The chemical or biological transformation of the original parent compound into one or more different compounds (degradates, intermediates, metabolites).

Desorption: The detachment of a pesticide from a soil particle.

Equilibrium: A state of dynamic balance, where forward and reverse reactions or forces are equal and the system does not change with time.

Groundwater: Water that saturates cracks, caverns, sand, gravel, and other porous subsurface rock formations. "Aquifers" are the zones in which readily extractable water saturates the pores of the formation.

Half-Life: The time required for one-half of the original pesticide to be degraded into another compound.

Hydrolysis: A chemical degradation process resulting from the reaction of an organic molecule (pesticide) with water under acidic or alkaline conditions.

Humus: The stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues has decomposed. Usually dark colored.

K_d: See Soil Partition Coefficient.

Kinetic: A study of time-dependent processes. The kinetics of pesticide adsorption indicate the rate at which pesticides are adsorbed by soil particles.

K_{oc}: See Organic Carbon Partition Coefficient.

Leaching: The downward movement by water of dissolved or suspended minerals, fertilizers, chemicals (pesticides), and other substances through the soil.

MCL (Maximum Contaminant Level): An enforceable, regulatory standard for maximum permissible concentrations as an annual average of contaminants in water. MCLs are established under the Federal Safe Drinking Water Act, which assures Americans of a safe and wholesome water supply. The MCL standards of purity are applied to water distribution systems after the water has been treated, regardless of a surface water or groundwater source. They are health-based numbers which by law must be set as close to the "no-risk" level as feasible.

Microorganism: A biological organism, microscopic in size, found in soils and important in the degradation of most pesticides.

Mineralization: The complete transformation or degradation of a pesticide into carbon dioxide (CO_2), water (H_2O), and other inorganic products.

Nonpoint Sources of Contaminants: Water contaminants coming from nonspecific sources; for example, from agriculture and municipal runoff.

Nonpolar: A term used to describe a molecule (pesticide) whose electric charge distribution is evenly distributed (no regions of positive or negative charge). Nonpolar compounds are characterized as being hydrophobic (water-hating) and not very soluble in water but readily bound to organic matter.

Organic Carbon Partition Coefficient: A universal constant used to describe the tendency of a pesticide to sorb to the soil organic fraction component of a soil. Often abbreviated as K_{oc}.

Oxidation: A chemical reaction involving the addition of an oxygen atom or a net loss in electrons.

Percolation: The downward movement of water through soil.

pH: A numerical measure of acidity used to distinguish alkaline, neutral, and acidic solution. The scale is from 1 to 14; neutral is pH 7.0; values below 7 are acidic, and above 7 are alkaline.

ppb (parts per billion)**:** An abbreviation indicating the parts or mass of a pesticide in a billion parts of water or soil.

ppm (parts per million)**:** An abbreviation indicating the parts or mass of a pesticide in a million parts of water or soil.

Point Sources of Contaminants: Water contaminants from specific sources such as a leaking underground gasoline storage tank, back-siphoning of an agrichemical into a well, or spillage of a chemical near a water supply.

Polar: A term used to describe a molecule (such as a pesticide) whose electrical charge distribution results in positively and negatively charged regions on the molecule. Polar compounds are characterized as being hydrophilic (water-loving) and readily soluble in water but not strongly bound to organic matter.

Salt: A solid ionic compound (pesticide) made up from a cation other than H^+ and an anion other than OH^{1-} or O^{2-}.

Soil Organic Matter: The organic fraction of soil, which includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. See also Humus.

Soil Partition Coefficient: A "soil specific" unit of measure used to describe the sorption tendency of a pesticide to a soil. Often abbreviated as K_d or K_p.

Solubility: The maximum amount of chemical that can be dissolved in water.

Sorption: A catch-all term referring to the processes of absorption, adsorption, or both.

Transpiration: Most of the water lost by plants evaporates from leaf surfaces by the processes of transpiration. Transpiration is essentially the evaporation of water from cell surfaces and its loss through the anatomical structures of the plant.

Vapor Pressure: A numerical unit of measure used to indicate the tendency of a compound (liquid or solid) to volatilize or become a gas. A commonly used unit of measurement for pesticide vapor pressure is millimeters of mercury (abbreviated: mm Hg).

Volatilization: The process by which chemicals go from a solid or liquid state into a gaseous state.

Water Table: The top of an unpressurized aquifer, below which the pore spaces generally are saturated with water. The aquifer is held in place by an underlying layer of relatively impermeable rock. The water table depth fluctuates with climatic conditions on the land surface above and the rate of discharge and recharge of the aquifer.

The Fate of Pesticides and Fertilizers in a Turfgrass Environment

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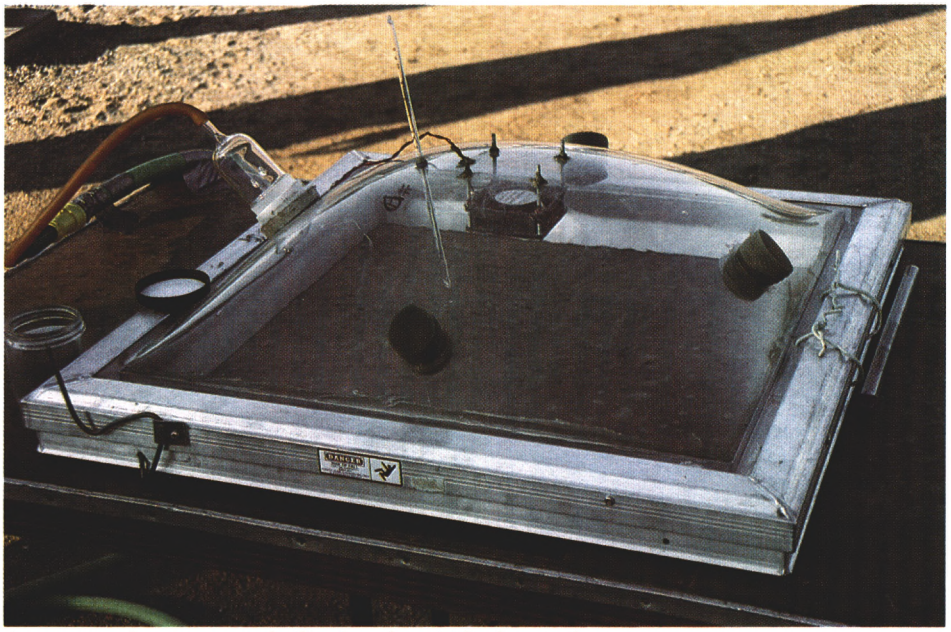


A system used to measure volatilization of pesticides from turfgrasses.

ENVIRONMENTAL protection has become a national issue in the past several years. While concerns focused on cleaning up contaminated surface waters in the 1970s, the focus in the 1980s and into the 1990s has been on groundwater. More than one-half of the population of the United States relies on groundwater for all or part of its potable water. Up to 95% of rural residents obtain their water supplies from wells. Domestic uses account for only 18% of the groundwater used in this country, while almost two-thirds of the groundwater withdrawn in the U.S. is used for irrigation. In California, up to 20 billion gallons of groundwater is used every day for all irrigation purposes. The heavy dependence on groundwater for both domestic and agricultural uses makes groundwater a very valuable resource that must be protected from contamination.

Widespread use of pesticides has been made in agriculture during the past 40 years. California alone accounts for 25% of the pesticides applied in the United States. Prior to 1979, little monitoring of groundwater for the presence of pesticides was practiced because it was assumed that they were not sufficiently long-lived and mobile to pose a threat to groundwater. However, the discovery of a soil fumigant, 1,2-dibromo-3-chloropropane (DBCP) in well water in Lathrop, California, triggered widespread groundwater sampling programs. As a result, approximately 10,000 wells in the state have been analyzed for pesticide residues. The monitoring program detected more than 50 different pesticides in 23 California counties.

To try to prevent or minimize future groundwater contamination by pesticides, AB2021, the Pesticide Contamination Prevention Act, was passed in 1985. As a result of this bill, the use of several pesticides is being restricted in some areas of the state. In addition, the California EPA's Department of Pesticide Regulation is monitoring the groundwaters and soils of the state for the presence of more than 50 other pesticides. If these compounds are detected, their use may be restricted as well.

In addition to pesticides, nitrates have received a great deal of attention. Contamination of groundwater by nitrates is one of the major sources of non-point source pollution in the United States. A recent survey by the United States Geological Survey (USGS) suggested that the use of fertilizers in agriculture is a large contributing factor to elevated nitrate levels.

There has also been concern expressed over exposure to pesticides by routes other than drinking water. In California, a number of pesticides have been designated as potential toxic air contaminants. Thus, consideration of pesticide volatilization is an important aspect to consider in an environmental fate study, both from a pesticide efficacy and an environmental contamination standpoint.

The purpose of this research project was to study the fate of pesticides and fertilizers applied to turfgrass in an environment that closely resembles golf course conditions. The goal was to obtain information on management practices that will result in healthy, high-quality turfgrass while minimizing detrimental environmental impacts. By simultaneously looking at interactions between soils, turfgrasses, irrigation amounts, pesticides, and fertilizers, questions about "best management practices" for turfgrass growth and maintenance will be able to be answered.

METHODS

Site Construction

A site was constructed specifically for the purposes of this project at the Turfgrass Research Facility at the University of California, Riverside. The site consists of 36 plots, each of which measures 12 ft × 12 ft. The fairway area consists of 24 plots, 12 each of two different soil types (a sandy loam and a loamy sand) that were located randomly in the fairway area. Because the soil types were distributed randomly in the fairway area, borders were constructed to contain the soil in its respective plot. The putting green area has 12 plots that were constructed using 18"

Table 1
Summary of Results from Nitrogen and Pesticide Leaching and Pesticide Volatilization Experiments

Turfgrass Species	Source of N	Irrigation	Soil	N Leached (%)	2,4-D Leached (%)	Carbaryl Leached (%)	2,4-D Volatilized (%)	Carbaryl Volatilized (%)
Creeping Bentgrass (putting green)	SCU	100% ETc	sand/peat	0.56	7.580	0.0240	1.05	0.030
	SCU	130% ETc	sand/peat	0.55	2.250	0.0450	0.96	0.034
	Urea	100% ETc	sand/peat	0.71	4.180	0.0690		
	Urea	130% ETc	sand/peat	1.69	2.490	0.0220		
Tifway II Bermudagrass (fairway)	SCU	100% ETc	loamy sand	0.47	0.071	0.0027	0.52	0.038
	SCU	130% ETc	loamy sand	0.58	0.260	0.0100	0.72	0.047
	Urea	100% ETc	loamy sand	0.30	0.280	0.0180		
	Urea	130% ETc	loamy sand	0.75	0.190	0.0045		
	SCU	100% ETc	sandy loam	0.67	0.071	0.0017	0.43	0.025
	SCU	130% ETc	sandy loam	1.71	0.300	0.0230	0.50	0.021
	Urea	100% ETc	sandy loam	0.57	0.042	0.0032		
	Urea	130% ETc	sandy loam	0.63	0.056	0.0015		

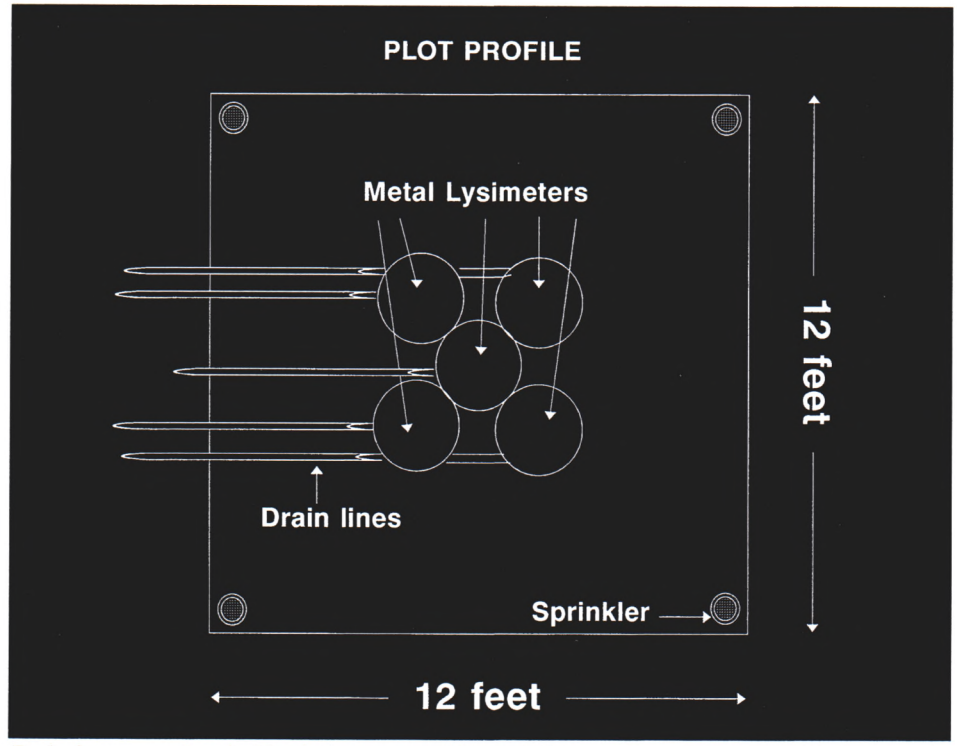
[1]Average of three replicate values

of Caltega IV green sand with 15% sphagnum peat.

To enable us to obtain samples of leachate from each of the plots, collection devices had to be constructed. Lysimeter assemblies, consisting of 5 metal cylinders, were placed in the center of each of the 36 plots. Each of the lysimeters has a metal drain pipe at the bottom that extends the length of the field and terminates at a retaining wall on the south side. The lysimeter assembly and drain system were fabricated using only metal so that there was no potential for pesticide adsorption. This allowed us to make a quantitative determination of the mass of pesticide leaching through the turfgrass.

The irrigation system was designed so that each of the 36 plots could be irrigated individually. Each plot has 4 sprinklers, one at each corner. The entire irrigation system is outside of the lysimeter assembly so that there is no potential for adsorption of the pesticides to the PVC pipe. The irrigation is controlled electronically; scheduling was determined based on the evapotranspiration requirements of the turfgrass.

Sod was laid on the plots in February 1992. Creeping bentgrass (*Agrostis palustris*) was installed on the green plots, and hybrid bermudagrass (*Cynodon dactylon* by *Cynodon transvaalensis* var. Tifway II) on the fairway plots.



Each plot was equipped with a lysimeter assembly consisting of five metal cylinders with metal drainpipes on the bottom.

Experimental Design

All turfgrass soil-type combinations were subjected to two irrigation regimes: 100% crop evapotranspiration (ETc) and 130% ETc beginning in March 1992. The 100% ETc treatment is the optimal amount of water required by the turfgrass to grow and maintain itself in a healthy state. Thus, 130% ETc is above the optimum water requirement, but is well within the range of standard practice within the industry.

Two fertilizer treatments were established for the plots. The green plots were fertilized at a rate of 1 lb N/1000 sq ft per month, and the fairway plots at a rate of 0.5 lb N/1000 sq ft per month. The two fertilizer sources were urea and sulfur-coated urea (SCU). The SCU applied to the green plots was in the form of miniprills to minimize losses during mowing operations. Fertilizer was hand-applied twice per month to each plot individually to ensure even distribution of the fertilizer.

Trimec® Bentgrass Formulation (pbi/Gordon Corporation, Kansas City, MO) was applied to all plots in May and August, 1993. This formulation contains 0.45 lb 2,4-D per gallon in the form of a dimethylamine salt. The herbicide was applied at a rate of 1.8 oz and 3.2 oz per 1000 sq ft for the green and fairway plots, respectively. Sevin® brand

XLR plus (Rhone-Poulenc Ag Company) insecticide was applied to the plots in August, 1993, at a rate of 6.1 oz and 10.7 oz per 1000 sq ft for the green and fairway plots, respectively. This formulation of carbaryl contains 4 lb active ingredient per gallon.

Sample Collection

Samples of drainage water were collected from each of the 36 plots on a weekly basis. The samples were analyzed to determine the concentration of nitrate, phosphate, carbaryl, and 2,4-D present. Drain volumes were measured and recorded several times per week, allowing a calculation of the mass of nutrients and pesticides leaching from the plots.

The volatilization of 2,4-D and carbaryl was measured during an experiment conducted in August, 1993. Immediately after pesticide application, a volatilization flux chamber was placed directly on the turf in each of the designated plots. The air above the surface of the turfgrass was pulled out of the chamber at a very low rate (approximately 10 liters/minute). As it was removed, the air was passed through a polyurethane foam plug (PUF) that adsorbed any pesticides present in the air. Air from outside the chamber was drawn into the chamber to replace the air that was removed. Any pesticides in the outside air were removed as the air was drawn into the chamber. The PUFs were replaced every four hours. The position of the flux chamber was rotated between two marked spots on the plots to minimize damage to the turfgrass. The volatilization experiment was conducted for 7 days.

RESULTS AND DISCUSSION

Leaching Studies

The mass of nitrate-N that leached through the turf was calculated by multiplying the volume of water that drained through the lysimeters in a given plot each week by the concentration of nitrate-N in the leachate that week. Between April 1992 and December 1993, 47.85 g of nitrogen was applied to the 13.2 sq ft surface area of each fairway lysimeter. Of that amount, between 0.30% and 1.71% (less than 1 g) was not used by the turfgrass and leached through the plots. These results are summarized in Table 1. An analysis of variance showed that there was no significant difference in the percent of nitrate-N leached through the plots caused by the different treatments (i.e., soil type, fertilizer type, or irrigation amount).

In the putting green plots, between 0.56% and 1.69% of the applied nitrogen leached through the turfgrass. Once again, none of the treatments caused any significant differences in the observed mass of nitrate-N that leached through the plots.

The mass of 2,4-D that leached through the plots varied considerably, from approximately 0.055% on the sandy loam plots receiving 100% ETc to approximately 5% on the green sand plots receiving 100% ETc (Table 1). An analysis of variance using all the plots confirmed that the soil type significantly affected the mass of 2,4-D that leached through the soil. This result is not unexpected, as pesticides can be adsorbed to the clay fraction of soil. The pesticide 2,4-D has an adsorption coefficient of approximately 20 cm^3/g. This compound would not be expected to adsorb to a great extent to the soil, although it will adsorb if clay is present. The sandy loam soil contains 12.9% clay; thus, adsorption would be expected to be greater in this soil than the other soils, which have clay contents of less than 2%. When only the fairway plots were considered, soil type did not significantly affect leaching, reflecting the small differences in clay content between the two fairway soils.

The mass of carbaryl that leached through the plots was very low, ranging from 0.0015% to 0.07%. When all plots were considered, the soil type was significantly correlated with the mass leached, similar to the situations with 2,4-D. However, when only the fairway plots were considered, soil type was not significantly correlated with the mass of carbaryl leached.

Volatilization Studies

Volatilization of 2,4-D into the air above the turfgrass was measured during an experiment performed in August, 1993. The mass of 2,4-D that volatilized from the plots is shown in Table 1. The percent volatilized ranged from less than 0.5% to approximately 1%. An analysis of variance indicated that there was a significant difference in the percent that volatilized between the green, fairway, and control plots. The difference between the green and fairway plots was also significant, suggesting that the differences may be due to the turfgrass species or to the difference in cutting height.

The mass of carbaryl that volatilized from the plots was very small: between 0.021% and 0.047% of the amount applied. No significant differences in the percent of carbaryl volatilized resulted from the different treatments.

Turfgrass Quality

The turfgrass was rated approximately every two weeks to enable us to assess any effects of the different treatments on the quality of the turfgrass. No significant differences were found for any of the plots as a result of the different irrigation or fertilizer treatments. However, there was a significant difference in the quality of the turfgrass on the sandy loam plots compared to the loamy sand plots. The scores for the loam plots averaged approximately one rank higher than the loamy sand plots during the same week.

CONCLUSIONS

The overall conclusion that can be made on the basis of the experiments performed at the University of California, Riverside, is that, in general, there is very little potential for groundwater or air contamination from turfgrass chemicals under our conditions. The only exception noted was for the leaching of 2,4-D in the putting green plots where the soil was too sandy to prevent the movement of a portion of the chemical below the rootzone. Specific conclusions from this research are:

1. Under the conditions of this study (i.e., biweekly applications of urea and sulfur-coated urea), little leaching of nitrate-nitrogen (generally less than 1% of the amount applied) was measured. No significant differences in percent leached as a result of irrigation amount or fertilizer type was documented.

2. Leaching of 2,4-D was very low in soils that contained some clay to adsorb the pesticide; however, up to 7.5% leaching was measured in sand. Irrigation amount did not significantly affect the amount of leaching.

3. Less than 0.1% of the carbaryl leached, regardless of soil type. Irrigation amount did not significantly affect the amount of leaching.

4. Little volatilization of 2,4-D was measured ($\leq 1\%$) from any of the plots, although the difference in the amount volatilized was significantly different between the two turfgrass species used.

5. Little volatilization of carbaryl was measured ($\leq 0.05\%$) from any of the plots; no significant differences between the treatments occurred.

6. Neither fertilizer type nor irrigation amount caused any significant differences in the quality of the turfgrass as determined by biweekly turfgrass ratings.

These results cannot necessarily be extrapolated to all golf course situations, however. For example, some modifications in the fertilizer application program had to be made for the purposes of this study. The SCU was applied on a biweekly basis to make it on the same schedule as the urea, which would not be the case on a golf course. Thus, the amount applied at any one time was relatively small compared to what might be applied on a golf course. This could have had an impact on the amount of leaching measured. We are planning to conduct further studies that follow a more typical golf course fertilization program to try to answer this question.

Potential Movement of Pesticides Following Application to Golf Courses

by DR. AL SMITH
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CURRENTLY, there are more than 14,000 golf courses in the United States. Assuming an average size of 120 acres per course, there are more than 1.68 million acres of turfgrass in the golf course industry. If we assume that there are two acres managed as putting greens per 18-hole course, there are about 25,300 acres of golf course greens in the United States.

The National Golf Foundation estimates that there are 24.5 million golfers in the United States, and by the year 2000 the number of players could easily exceed 30 million. To keep up with both present-day needs and the rapidly increasing number of golfers, it has been suggested that a golf course must be opened every day for the next 10 years.

Although agriculture is by far the largest user of pesticides in North America, specialty turfgrass areas are typically the most intensively managed biotic systems. The public demand for high-quality turfgrass and uniform playing surfaces on golf courses often requires the use of intensive management strategies to control pests. These management practices on so many acres are resulting in increased interest by the general public concerning the environmental impact of these practices. A critical issue facing the golf course industry is the environmental fate and safety of pesticides used for management. The enhanced interest in pesticide use is, in general, a response to the increased use of pesticides since the 1960s, the advancements in technology that allow scientists to detect pesticide contamination at very low concentrations, and recent articles in the popular press such as the article "Poison in Your Backyard" (published in *Family Circle* magazine).

The public alarm raised about pesticides in the 1960s has been translated into legislative controls. This has resulted in more rigid testing of pesticides prior to their registration and attempts to restrict the use of certain pesticides by anyone other than trained applicators. Concern about human and environmental welfare has been an important concept behind this legislation, and the growing concern will ultimately result in more legislated controls on the use of pesticides. With increasing controls placed on pesticide use, such as mandatory posting of the area to be treated, public inquiries will continue to increase.

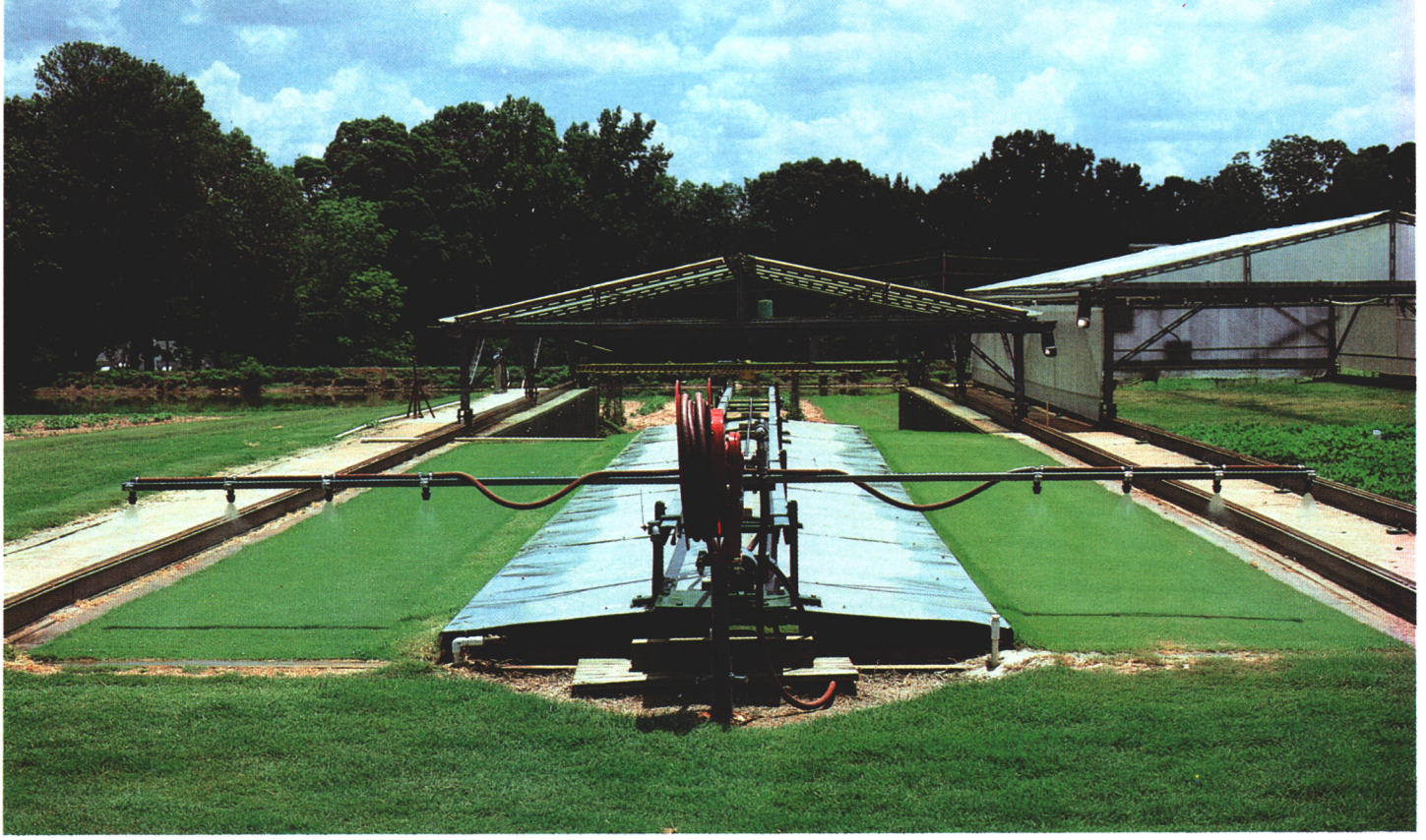
A major concern about the impact of pesticides on the environment is their potential movement into drinking water sources that is facilitated by movement in surface water and groundwater from the treated sites. In response to this concern, a team of scientists at the University of Georgia developed a research program to determine the potential for pesticide movement following application to golf course greens and fairways. The research program was funded, in part, by the United States Golf Association. The initial research was conducted on simulated and miniature golf course greens that were constructed according to the United States Golf Association recommendations for putting green construction. These greens are designed and constructed for ideal infiltration and percolation of water through the rooting medium. The soil mix under the greens contained as much as 98% (wt/wt) sand, allowing for rapid water infiltration and percolation and an extremely low adsorption affinity for most of the pesticides. Therefore, one might expect the pesticides to move rapidly through the sod and enter the drainage water exiting the base of the green.

Lysimeters were developed in the greenhouse and in the field in order to collect the water leachate moving through the greens. The lysimeters were filled with the rooting medium, sand, and gravel according to USGA recommendations and covered with bentgrass or bermudagrass sod. Pesticide treatments were made to the sod, and irrigation and simulated rainfall events were applied through an automatic watering system. The field lysimeter installation was protected from natural rainfall events with an automatic closing/opening rain shelter.

Results of this research indicated that only small quantities of several herbicides — 2,4-D, dicamba, mecoprop (MCPP), and dithiopyr — were found in the water leachate moving through the greenhouse and field lysimeters. The concentrations of these herbicides in the leachate did not exceed 5 ppb (parts per billion), and the total quantity to exit the lysimeters was less than 1% of the applied herbicide. The insecticide chlorpyrifos (Dursban) and the fungicide chlorothalonil (Daconil) were not found in the leachate moving from the treated turf.

In summarizing the relevance of these results, it is necessary to identify the measurement units used. A part per billion (ppb) is equal to adding one teaspoon of table salt to 26 million gallons of water. Therefore, it is clear that the concentration of pesticides in the water leaving the treated greens is very small. The United States Environmental Protection Agency is currently developing drinking water standards for surface waters and groundwater supplies. The standards will be based on the same toxicological resarch used to establish reference doses for food. These standards will be maximum contaminant levels (MCLs) allowed for pesticide concentrations in potable water. The MCLs for only a few pesticides used on turfgrass have been recommended. The recommended MCL for 2,4-D is 70 ppb. The water leaving the lysimeters under the simulated greens contained less than one-tenth this concentration of 2,4-D, and it must be realized that this water would enter into a stream or water reservoir that would dilute the concentration by factors of tens of thousands.

The use of several models and mathematical equations used in agriculture to predict the movement of these pesticides through the greens indicated that at least 10-fold greater concentrations of the herbicides would be expected in the water leachate moving from the lysimeters. These mathematical equations were developed and validated for agricultural row crops, which is a very different situation than is found in a sod where most of the ground surface is covered by thatch. The initial distribution of the chemical applied to turfgrass ultimately determines the amount of pesticide reaching the intended target and the amount of pesticide that will be lost from the turf ecosystem after application. The most desirable scenario for the fate of a pesticide is for the pesticide to control the target pest and to be immediately degraded to carbon dioxide, water, and other basic molecules and/or elements. Probably the reason that there were such low quantities of pesticides found to exit the research lysimeters was due to the



Field lysimeters, maintained as a green, used both bentgrass and bermudagrass. An automatic rain shelter protected the lysimeters from natural rainfall events.

sequestering of the pesticides in the thatch and rooting regions of the sod, allowing for rapid degradation of the pesticide molecules. The extensive, fibrous root system of the sod and the moist conditions of a well-maintained green allow for elevated activity of microorganisms for degradation of the pesticides. This same condition would exist on greens at most golf courses.

In addition to the potential for pesticides to leach through the greens, there also is a potential for the pesticides applied to golf course fairways to enter into the surface waters (e.g., streams) that leave the golf course. We developed small plots to simulate golf course fairways. The bermudagrass sod was placed onto the sandy clay soil that is typical of the southeastern United States. The plot areas had a slope of 5% and drained into individual collection units designed to measure the total water runoff and to subsample the water for measuring the presence of the pesticides. Following application of the pesticides to the plots, simulated rainfall events were used to supply the water for runoff events. Treatment periods were selected that would allow for at least 48 hours without a natural rainfall event. The simulated rainfall was used at 24 and 48 hours after treatment, and natural rainfall events were monitored when they occurred.

Results of this research indicated that over a 25-day period following treatment of the simulated fairways with 2,4-D, mecoprop, and dicamba, seven simulated and natural rain events occurred. An average of 42% of the rainfall water left the plots as runoff and approximately 8% of the applied pesticides left the treated plots in the runoff water over the 25-day collection period. Eighty percent of the herbicides that left the plots in the runoff water moved during the first simulated rainfall event. The rainfall was simulated to give a high-intensity storm event (2" per hour) for a total rainfall of 2". Although this is not an uncommon event for a summer thunderstorm in the southeastern United States, it is a high-intensity event.

These data would indicate that there is a need for additional improvement of the management strategies used on fairways to decrease the amount of pesticides leaving these areas during a rainstorm following application. There are several management strategies that can be adapted for decreasing the quantity of pesticides leaving in the runoff water. The amount of runoff water can be decreased by increasing the rate of water infiltration into the sandy clay soil through soil aerification, coring, and verticutting. A light irrigation following the pesticide application can be used to wash the chemicals from the foliage and soil surface into the soil profile. Generally, a 6-hour period following application of the pesticides used in this study is all that is required for maximum efficacy in pest control. Therefore, the application could be made during a period that has a low chance of rainfall for a 12-hour period, and an irrigation application could be made at 6 hours after treatment so as not to produce runoff. This would place the pesticides in the thatch or grass root zones, and they would not move in the runoff water during a high-intensity storm event. This management strategy will be investigated in ongoing research.

The critical issue facing the research and regulatory institutions responsible for turfgrass management is the development and interpretation of data on the environmental fate and safety of pesticides used in the management of golf courses. The fate of pesticides following application can be measured, as we did, or estimated through use of mathematical models. However, safety cannot be measured, and human risk can only be estimated based on the toxicity of the pesticide and the degree of human exposure. Something is considered safe if its attendant risks are judged to be acceptable. It is commonly agreed that it would be desirable to have **zero** level of pesticides in our drinking water. However, analytical instruments used for measuring the presence of pesticides in air, water, and food are continually being improved so that we can detect smaller and smaller concentrations of the chemicals. In other words, yesterday's **zero** is no longer **zero**, and today's **zero** will not be **zero** tomorrow.

Pesticide Mobility and Persistence in a High-Sand-Content Green

by DR. G. H. SNYDER and DR. J. L. CISAR
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SEVERAL STUDIES dealing with the mobility and persistence of pesticides labeled for use on turfgrass in Florida were conducted over a three-year period (1991 through 1993) at the University of Florida's Ft. Lauderdale Research and Education Center (FLREC) and the Everglades Research and Education Center (EREC) in Belle Glade. These studies were conducted on a research green built by the Florida Golf Course Superintendents Association at the FLREC approximately a year before our studies began. John Foy, USGA Green Section agronomist for the Florida Region, assisted in this effort. The green was constructed generally in line with USGA recommendations, but as often happens, certain modifications were made due to local conditions and materials available. In addition, the green was very large, over one-half acre in size, to accommodate a number of studies over a period of years.

The green, which was sprigged with cv. Tifdwarf bermudagrass, has 10" to 12" of root zone mix and is underlaid with 4" PVC drain tiles covered by a layer of coarse gravel. In the portion of the green where our studies were conducted, the root zone mix and coarse gravel are separated in the traditionally recommended method by a 2" layer of very coarse sand.

The root zone mix is somewhat coarser than the published USGA recommendation, which resulted in a higher-than-ideal saturated hydraulic conductivity and lower water-holding capacity. Thus, the studies were performed under conditions more conducive to percolation than should occur in a USGA green constructed strictly according to suggested particle ranges. However, it is probable that many so-called "USGA greens" in south Florida have hydraulic properties similar to the test area we used in this study.

The golf course superintendents provided the personnel and instructions for maintaining the green throughout the study. They made all decisions pertaining to irrigation, fertilization, mowing, and cultivation. We requested that no pesticides be used on the portion of the green allotted to our studies, but with this one exception, the green was otherwise maintained in a manner typical of that being used for golf courses in south Florida.

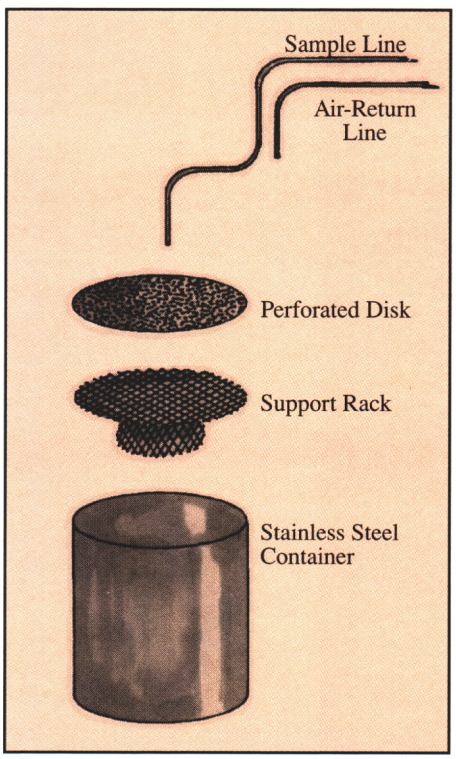


Figure 1. Lysimeter detail, exploded view, showing the support rack and sample line.

Following construction of the green, we installed lysimeters for collecting percolate water. The lysimeters were made from stainless steel "40 quart" stock pots obtained from a restaurant supply house. These pots were approximately 14" in diameter and 16" deep. A stainless steel rack was fabricated to suspend the soil profile a few inches off the bottom of the lysimeter to create a reservoir for collecting percolate (Figure 1).

We excavated a hole in the green to accommodate the lysimeter, which was placed with the top rim 4" below the surface so it would not interfere with aerification procedures. During excavation, we carefully noted the depths of the gravel, coarse sand, and root zone mix. Then, using the same soil materials, supplemented as necessary with additional gravel, intermediate sand, and root zone layers within the profile materials that were retained during construction of the green, the soil profile was reconstructed in the lysimeter, i.e., gravel was placed on the rack in the bottom of the lysimeter, coarse sand was placed over the gravel, and the root zone mix was placed over the coarse sand. All the layers corresponded to the same depths that were observed during the excavation of the hole. The sod piece removed prior to the excavation was replaced over the lysimeter. A total of six lysimeters were installed in the green.

Percolate samples were removed from the lysimeter reservoirs through 0.25" stainless steel tubes that extended from the bottom of the lysimeters to glass collection flasks in a small building adjacent to the green. A second tube extended from just below the support plate to the building to provide air return during percolate withdrawal. The percolate water could be removed from the lysimeter in a few minutes or less by applying a vacuum to the collection flasks. Only stainless steel and glass were used in the lysimeters to minimize pesticide adsorption to sampling device surfaces. Complete details about the lysimeters were published in the *International Turfgrass Research Journal*, Volume 7, 1993.

Near the end of the study, we had the opportunity to install lysimeters in three new greens that were being constructed at a golf course in West Palm Beach. These lysimeters are similar to the ones at the FLREC, except that percolate flows by gravity to collection flasks placed in valve boxes off the back edge of the greens. In this way, golf course personnel can retrieve the percolate water without a vacuum pump. We found that, when working with a cooperative and understanding construction crew, the lysimeters could be installed quite easily during construction of the green. The lysimeters, which are functioning well, have not been used in pesticide studies as yet, but we hope to be able to use them in the future.

Pesticide analyses were conducted in a laboratory developed especially for the project at the EREC. The lab, which was built with University of Florida funds, includes two computer-controlled gas chromatographs (GC), a high-performance liquid chromato-

graph (HPLC), and the equipment required for extracting pesticides from water, soil, thatch, and clippings. The analyses were performed in accordance with a quality assurance/quality control (QA/QC) plan that was approved by the USGA. We also analyzed samples submitted by the USGA's Quality Control Officer to verify the accuracy of our methodology and procedures.

Experiments

The major part of our work determined the persistence and mobility of organophosphate (OP) insecticides and nematicides. Studies involving the herbicides 2,4-D and dicamba are in the final stages of completion at this writing and will be reported at a later date. The materials were applied at recommended rates according to the label instructions. Samples of the thatch, soil, and clippings were taken for several weeks after pesticide application. Percolate was collected twice each week and after rainfalls that produced significant percolation.

We also investigated pesticide dislodgeability (contact removal from turf surfaces) in order to gauge the degree of exposure golfers receive when playing on pesticide-treated greens. In these studies, we measured pesticide residues on leather, cotton or polyester cloth, and golf balls 24 hours after spraying several OP pesticides. These data were used by faculty of the University of Florida Center for Environmental and Human Toxicology for a model risk assessment study that was published in the *USGA Green Section Record*, Volume 33(2), March/April 1994.

Table 1
Organophosphate Pesticides Used on the USGA Green in Persistence and Mobility Studies

Trade Name	Common Name	Dates Applied	Form	Rate ($g \cdot ai \cdot m^{-2}$)
Nemacur	Fenamiphos	13 Nov. 1991	10G	1.125
		27 Jan. 1992	10G	1.125
Dyfonate	Fonofos	13 Nov. 1991	5G	0.439
		27 Jan. 1992	5G	0.439
Dursban	Chlorpyrifos	27 Jan. 1992	1G	0.117
		21 April 1992	2E	0.229
Triumph	Isazofos	21 April 1992	4E	0.229
		15 Sept. 1992	4E	0.229
Oftanol	Isofenfos	21 April 1992	2E	0.229
		15 Sept. 1992	2E	0.229
Mocap	Ethoprop	15 Sept. 1992	10G	2.245

Table 2
Organophosphate Pesticide Recovered in Clippings and in Percolate Water, Expressed as a Percent of Amount Applied

		Total Recovery (% of that applied) in	
Pesticide	Dates Applied	Clippings	Percolate
Fenamiphos	13 Nov. 1991	——	0.06
	27 Jan. 1992	0.38	0.04
Metabolites of fenamiphos	13 Nov. 1991	——	17.69[1]
	27 Jan. 1992	0.14[1]	1.10[1]
Fonofos	13 Nov. 1991	——	<0.01
	27 Jan. 1992	1.17	0.02
Chlorpyrifos	27 Jan. 1992	7.87	0.15
	21 April 1992	0.52	0.08
Isazofos	21 April 1992	0.43	0.09
	15 Sept. 1992	0.38	0.02
Isofenfos	21 April 1992	0.79	0.02
	15 Sept. 1992	0.89	0.01
Ethroprop	15 Sept. 1992	0.44	0.05

[1]Metabolites expressed as a percent of the parent compound applied

Results

For most of the OP pesticides we studied (Table 1), some consistent patterns emerged. Less than 1% of the applied pesticide was removed in clippings, except when granular formulations were used (Table 2). It is likely that some granules that still contained pesticide were recovered with the first or second mowing after pesticide application. For example, we calculated that 7.9% of the chlorpyrifos applied as a 1% granular material was removed with the clippings, whereas only about 0.5% of that applied as a liquid (2E) was recovered in the clippings, even though the application rate used for the liquid was double that for the granular material.

Even less of the OP pesticides appeared in the percolate water; in most cases, less than 0.1% of that applied (Table 2). So what happened to the pesticide? Most of it was retained in the thatch layer until it eventually was decomposed by microorganisms that use it as a source of "food." There was one notable exception to this trend, however. While only a small fraction (0.05%) of the nematicide fenamiphos (Nemacur) was observed in the percolate water, a substantial amount of its sulfoxide and sulfone metabolites, which retain the toxicity of the parent fenamiphos, was observed in the percolate. The metabolites are products created from the parent compound by microorganisms, and they are of environmental concern. They are more water soluble than fenamiphos itself, and for that reason are less well adsorbed by the thatch and more easily transported through the soil with percolate water (Figure 2).

Considerably more metabolite was observed in percolate following the first application of fenamiphos (averaging 17.7% of the fenamiphos applied), which also was the first application of any OP pesticide to the green, than following the second application (1.1%) made a month later. Previous research has suggested that microorganism populations will shift or adjust to use fenamiphos, and presumably for the metabolites, as a source of energy after fenamiphos is introduced into a soil. These microorganisms persist for several years. Therefore, it is reasonable to assume that more rapid degradation of the parent compound and metabolites will occur with repeat applications of fenamiphos.

As part of the dislodgeability studies, we also measured the amount of chlorpyrifos

and isazofos transferred from bermudagrass leaves to cotton cloth following application as a liquid. Less than 1% of the applied pesticide was found on the cloth immediately after spraying the pesticides. Only about 15% of that amount was picked up after irrigating with 0.2" of water. Several hours later, that amount was reduced again by half. By the end of 24 hours, only 1% of the original amount dislodged was found on the cotton cloth.

Implications for Golf Course Management

The data indicate that many OP pesticides are strongly adsorbed in the thatch layer, where they remain until they are microbiologically degraded. Relatively little pesticide was removed with the clippings or dislodged onto various materials. In most cases, only a very small portion of the applied pesticide was detected in percolate water. Nevertheless, practices such as proper irrigation following pesticide application, avoiding application during expected rainy periods, treating only pest-affected areas, and using the lowest rate consistent with the control of the target pest — practices that were not a part of our studies — should further reduce pesticide leaching and are strongly encouraged.

As shown by our data for fenamiphos, some pesticides are more susceptible to leaching than the majority. Superintendents should be especially aware of such pesticides. Alternative pesticides and control measures should be used when possible, and when no such alternatives exist, superintendents should use the pesticides as infrequently as possible, at as low a rate as is consistent with adequate control, limit treatment to affected areas only, and employ all measures and techniques possible to avoid leaching in the area that is treated. It is in the superintendent's best interest to use pesticides wisely.

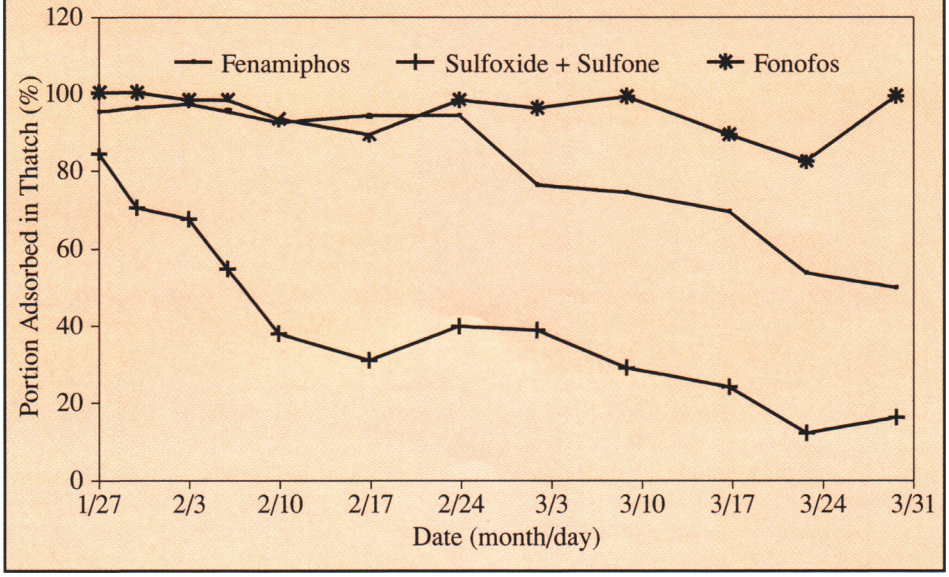
Some individuals within the golf community would prefer that data not be collected that might indicate a possibility of environmental contamination when pesticides are used on golf courses. But while golf requires good turf for playing surfaces, we need to recognize the superintendent's responsibility for the safety of the course's employees and golfers and for protecting his or her employer from lawsuits. At times, the superintendent may have to perform a real balancing act to accommodate all of these interests, and doing so probably should not be his sole responsibility. The ideal situation would be one in which the superintendent, in conjunction with the course ownership and golfers, would jointly develop a policy for balancing the desire for turf quality against pesticide usage, including the use of alternative methods of pest control and an agreement on the choice of pesticides to be used.

The gravel, very coarse sand, and root zone mix depths were measured in the green so that the same depths could be reproduced in the lysimeters.

Regulatory agencies have demanded that some golf courses initiate environmental monitoring programs for various agricultural chemicals, including pesticides, as a condition for being allowed to begin operation or to remain in business. These monitoring programs can be very expensive to develop and maintain. Golf courses could have a few greens equipped with lysimeters similar to the methods we used. At little cost, the lysimeters could provide useful information on the quantity of percolate occurring in response to various irrigation practices. Obviously, if percolation can be avoided or minimized, nutrient and pesticide leaching will be eliminated or reduced. Periodic analysis of the percolate for nutrients and pesticides, especially following applications, would provide information about how successful management practices are in main-

Pesticide was extracted from clippings, thatch, soil, and percolate water for analysis in the Everglades-REC pesticide lab.

Figure 2
Adsorption by Thatch of Fonofos, Fenamiphos, and the Sulfoxide/Sulfone Metabolites of Fenamiphos



taining the materials in the root zone, where they are needed. Where changes in management practices are needed, the changes could be implemented before a regulatory agency begins finding the agrichemicals in groundwater. Such a proactive approach could do much to reassure surrounding communities that golf is acting in a responsible manner to minimize potential adverse environmental impacts.

Golf course superintendents must make many decisions on pesticide usage that have implications beyond mere pest control. Fortunately, the USGA has taken the lead in addressing these concerns through its sponsorship of environmental research. Research needs to be conducted on all classes of pesticides under a variety of management conditions in order to develop the best management practices that provide environmental benefits to all. Clearly, a great deal remains to be done, but the process has begun.

Volatilization and Dislodgeable Residues Are Important Avenues of Pesticide Fate

by DR. R. J. COOPER,
DR. J. M. CLARK,
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University of Massachusetts
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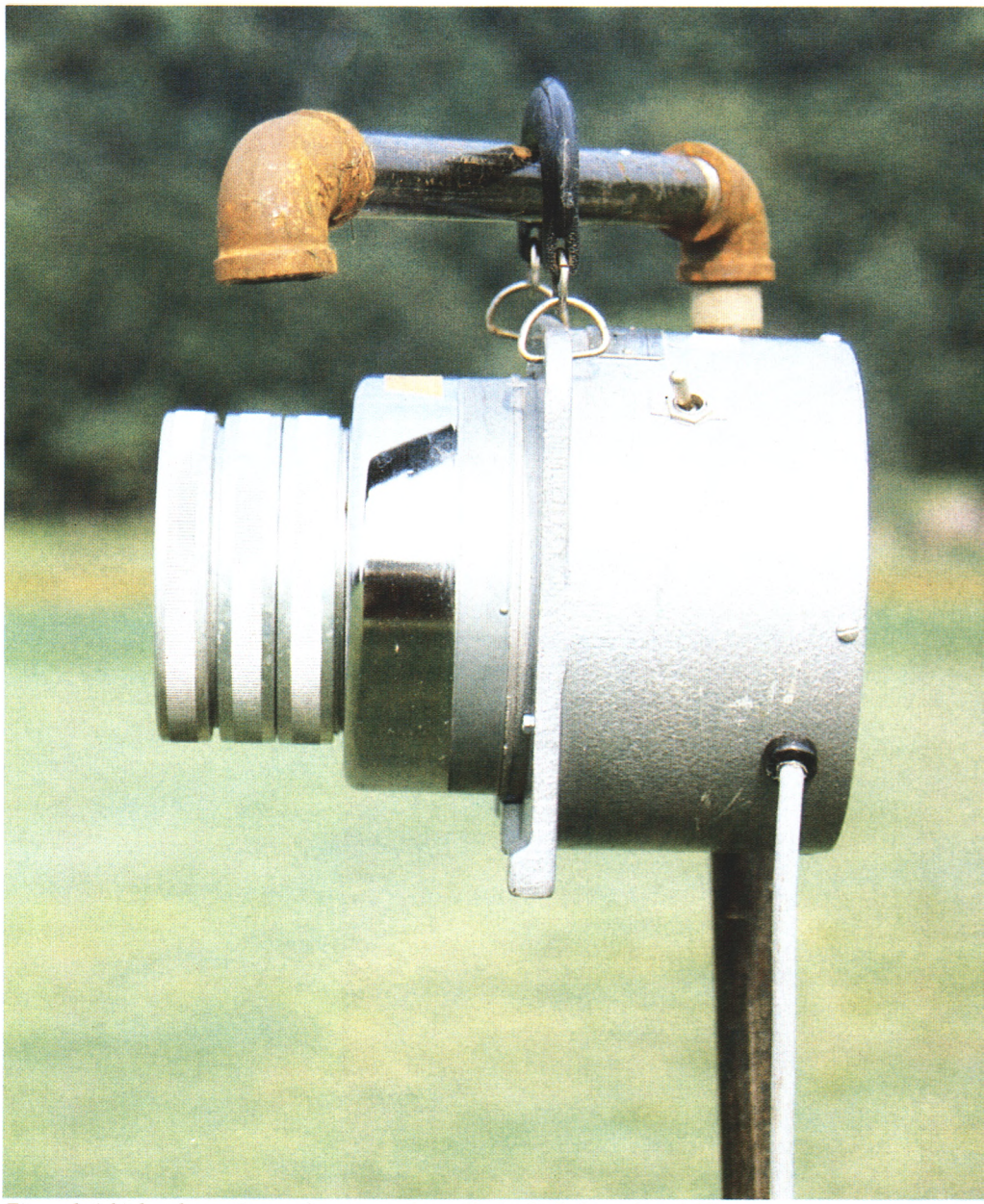


Figure 1. A high-volume air sampler was used to collect volatile loss of pesticides.

VOLATILIZATION can be defined simply as the loss of chemicals from plant and/or soil surfaces by evaporation into the atmosphere. Post-application vaporization of pesticide residues was reported as early as 1946 when scientists concluded that revaporized residues of the herbicide 2,4-D had damaged cotton growing some distance from a 2,4-D-treated field in New Mexico. Numerous field studies during the past 20 years have identified volatilization as a potentially significant avenue of loss from pesticide-treated areas. A review of volatilization by Taylor reported losses as high as 90% following application to field crops or moist soil.

Although the quantity and duration of pesticide volatilization from soil and field crops have been studied, volatile losses following pesticide application to turfgrass areas has not been well documented. A dense, perennial turfgrass ground cover is quite different from a plowed field or corn planting, and might be expected to provide a different environment for volatilization. Characterizing pesticide volatility from

Table 1
Pesticides of Interest and Selected Characteristics for Each

Pesticide	Trade Name	Use	Vapor Pressure (mm Hg at 25°C)	Application Rate (lbs ai/acre)
MCPP	Mecomec 4	Herbicide	0	2.0
Triadimefon	Bayleton	Fungicide	1.5×10^{-8}	1.4
Isazofos	Triumph 4E	Insecticide	9.0×10^{-5}	2.0
Trichlorfon	Proxol 80SP	Insecticide	2.0×10^{-6}	8.1

turfgrass is of interest not only because of environmental contamination concerns, but also as a factor that might contribute to reduced effectiveness of the material. The following USGA-sponsored research study was conducted to evaluate the amount of volatile loss following application of several commonly used turf pesticides.

In addition to its potential volatile loss into the atmosphere, a pesticide will usually be present in substantial amounts on the foliage of treated turf following application. Pesticide residues on the leaf surface are referred to as dislodgeable foliar residues (DFR). The amount and longevity of DFR were evaluated along with volatility during the study.

Figure 2
Volatilization of the Fungicide Triadimefon Following Application to Creeping Bentgrass

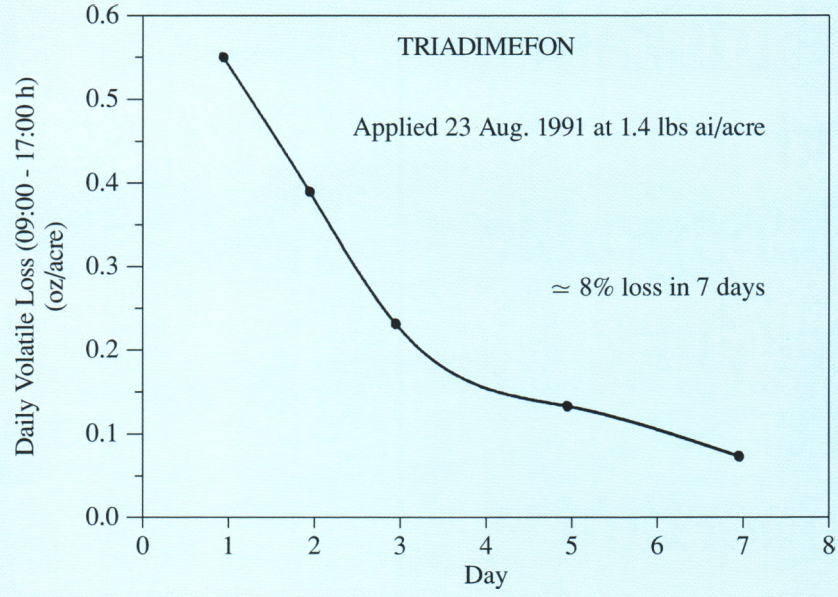
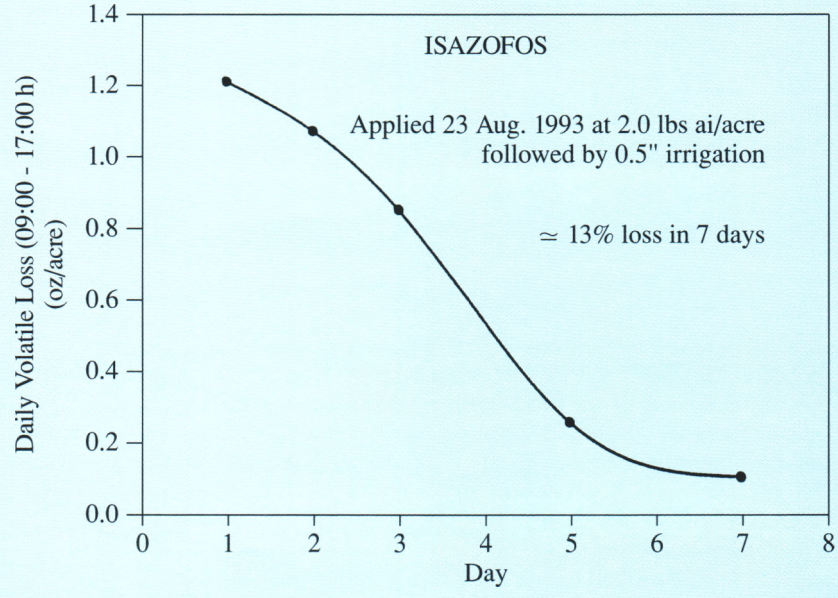


Figure 3
Volatile Loss of the Insecticide Isazofos Following Application for White Grub Control



Research Methods

All experiments were conducted at the University of Massachusetts Turfgrass Research Facility in South Deerfield, MA. During June 1991, a large area was seeded with Penncross creeping bentgrass at 1 lb/1000 sq ft. Throughout the study maintenance of the experimental area was similar to that of a golf course fairway, including mowing at a height of ½" three times per week, and irrigation and pesticide applications (pesticides of non-interest to this study) as needed.

Pesticides applied during the study are listed in Table 1. These materials were chosen for study because they are commonly used on golf courses throughout the country, and little information was available regarding their volatility or foliar residue behavior on turfgrass. For each application, a circular plot with a radius of 33 feet was sprayed. All materials were applied using a 12-nozzle boom sprayer operating at 40 psi with the label-recommended spray volume. Applications were always made before 9:00 a.m., at the highest label rate, in order to assess the maximum potential volatility and DFR levels.

Air samples were collected on approximately 120 milliliters of Amberlite XAD-4 polymer resin contained in a high-volume air sampler located 28 inches above the center of the treated area (Figure 1). For approximately 4 hours, air was drawn through the pesticide adsorption resin at a rate of 28 cu ft per minute. After determining average wind speed at the center of the plot, and the pesticide concentration of the adsorption resin, the amount of airborne (volatile) pesticide loss was calculated using a model developed by Wilson and his associates.

Volatile residues were collected immediately after application (i.e., during application and for an additional 30 minutes) and during consecutive 4-hour sampling periods until 7:00 p.m. on the first day of each experiment. Sampling continued from 7:00 a.m. to 7:00 p.m. on days 2 and 3, and from 9:00 a.m. to 5:00 p.m. on days 5, 7, 10, and 15 of each experiment.

Isazofos application was followed immediately by ½" of irrigation. Trichlorfon was applied twice; once with ½" of irrigation immediately after application and once without post-application irrigation.

Dislodgeable foliar residues were determined by wiping a 1 sq ft area of treated turf with a piece of water-dampened cheese-

cloth to remove pesticide residues. DFR samples were obtained 15 minutes, 3 hours, and 8 hours after application on day 1, and at noon on all other sampling days during the studies.

Results and Discussion

Volatile Loss

MCPP is a herbicide used to control broadleaf weeds in turf, such as clover, ground ivy, and chickweed species. It is often used alone or in a combination product for bentgrass areas. In this study, MCPP was applied at a rate of 2.0 lbs of active ingredient (ai) per acre. On the day of application, only 0.6% of applied herbicide was lost due to volatilization. Volatile loss on day 2 after treatment was determined to be 0.2%, with no volatilization being detected on day 3 or for the remainder of the evaluation. Thus, MCPP exhibited extremely little volatilization potential, showing a total pesticide loss into the atmosphere of less than 1% of the application.

In the northern United States, fungicides are often the most frequently applied golf course pesticide. Triadimefon, a commonly used fungicide, was evaluated after application at a rate of 1.4 lbs ai/acre (Figure 2). Triadimefon loss was most rapid during the 2-hour period immediately following application, with a total loss of 2.5% of the pesticide on day 1 of the study. On day 2, volatility remained substantial, with an additional 2.4% of the application lost. Volatility had declined notably on day 3 of the study so that only 1.5% of applied triadimefon was detected. Although detectable on days 5 and 7 of the study, volatilization loss was substantially less than 1% on both of those sampling days.

Through 2 weeks of sampling, approximately 8% of the triadimefon application was lost by evaporation into the atmosphere, with 7.3% being lost within 5 days of the application. This two-phase pattern of volatile loss, with the greatest loss occurring during the 3-5 day period after application, followed by greatly reduced loss during the second week, is similar to patterns of volatile loss reported from soil and field crops.

It has been suggested that the slower rate of volatile loss typically observed after the first week may have two explanations. The first explanation suggests that remaining residues are less available because they lie deeper within the plant canopy and are trapped in the irregular areas of leaves, stems, and leaf/stem junctions. A second possibility is that since pesticide residues are most available immediately after application, with time the easily evaporated residues are removed until only those residues that are most strongly adsorbed or that have penetrated the leaf surface remain. Both processes contribute to reduced volatility over time, and the relative importance of each has not been determined.

During August 1993, the insecticide isazofos was applied to the fairway at 2.0 lbs ai/acre, followed by 0.5" of irrigation to facilitate movement into the soil for control of white grubs (Figure 3). Maximum volatile loss occurred from 11:00 a.m. to 3:00 p.m. on the day of application, with a total loss of 5.8% for day 1. Volatile loss declined to 3.4% on day 2, 2.7% on day 3, and 0.8% on day 5. Total loss of isazofos by evaporation for the first 7 days following application was 13%. During the second week following application, far less than 1.0% volatility was recorded. This confirmed the two-phase nature of our previous volatility research and the tendency for most volatile loss to occur during the first 7 days following application.

The final pesticide evaluated was the insecticide trichlorfon (Figure 4), another organophosphate insecticide used to control soil-inhabiting insects. Trichlorfon was applied once, followed by 0.5" of irrigation, and again separately with no post-application irrigation. The application rate on both occasions was 8.1 lbs ai/acre. Following the June 1993 application and irrigation, volatile loss of trichlorfon and DDVP (a breakdown product of the insecticide) totaled only 1.8% for day 1 of the study and reached a maximum of 3.8% on day 2 (Figure 4). Volatile loss on day 3 was about 3% of the application and declined to less than 1% by day 5. In total, when trichlorfon was applied and watered-in, volatile loss was approximately 9%.

Trichlorfon volatility following application during September 1991, with no post-application irrigation, is shown in Figure 5. Combined volatile loss of trichlorfon and DDVP on day 1 was 2.8% of the applied compound. This level of loss is substantially higher than that observed following the trichlorfon application with post-application irrigation. Total volatile loss increased on day 2 and then declined for the remainder of the study. Without post-application watering, trichlorfon loss totaled 13% compared to 9% when irrigated. Also, withholding post-application irrigation resulted in less conversion of trichlorfon to its more toxic breakdown product, DDVP.

Dislodgeable Foliar Residues

Following pesticide applications, especially when applying liquid materials, there remains a residue of pesticide on the turfgrass foliage. The quantity and duration of the dislodgeable foliar residues for pesticides studied is summarized in Table 2.

Maximum DFR for MCPP was measured 15 minutes after application and amounted to less than 1% of the application. At 3 hours post-application, when the leaf was dry, residues had dissipated to only 0.14% of the application.

Foliar residue losses of triadimefon 15 minutes after application totaled 2.4% of the total applied product. Residue levels decreased to about 1% by 3 hours after application. As with MCPP, dislodgeable foliar residues were substantially reduced once the spray solution had dried.

Irrigation following the isazofos application reduced DFR from 1.8% of the application when measured 15 minutes after application to almost none (0.01%) 3 hours later. Immediate post-application irrigation of trichlorfon (Table 2) provided a rapid decline in DFR similar to that observed with isazofos. Trichlorfon applied without irrigation resulted in foliar residue levels 4 times higher than for irrigated turf.

Table 2
Dislodgeable Foliar Residues Following Pesticide Application

Sampling Period	MCPP	Triadimefon	Isazofos*	Trichlorfon + DDVP	
	% of applied				
Day 1				non-irrigated	irrigated*
15 min.	0.60	2.4	1.80	—	—
3 hr.	0.10	1.5	0.01	2.0	0.3
8 hr.	0.10	1.0	0.00	1.1	0.2
Day 2	0.08	0.6	0.06	1.0	0.4
Day 3	0.00	0.6	0.02	0.7	0.3
Total for Study	1.00	6.2	1.90	4.8	1.2

*Application followed by 0.5" irrigation

Conclusions

Pesticide volatilization ranged from less than 1% for MCPP to 13% for the insecticides isazofos and trichlorfon during the week following application. The cumulative percentage loss was directly related to vapor pressure. Maximum volatility occurred when solar radiation, surface temperature, and wind speed were greatest.

The pattern of volatile loss was diphasic, with nearly all the measured volatile residues lost within the first week. Irrigating treated turf immediately after application greatly reduced initial volatile loss. The availability of dislodgeable residues declined rapidly following application, with levels typically 1% or less by 8 hours after application. Post-application irrigation was very effective in reducing leaf residues. Foliar residues of isazofos and trichlorfon were reduced to less than 1% of the initial application concentration as a result of post-application irrigation.

Suggestions for Reducing Exposure to Volatile Foliar Residues

• Whenever a choice exists among products or formulations that are equally suitable for a job, choose the less volatile one. Consult your sales representative or refer to the label and material safety data sheets to learn the differences among materials. Be aware that different formulations of a particular herbicide can have significantly different volatility potential. For example, the acid, sodium salt, and amine formulations of 2,4-D have low volatility, while the ester formulation of this herbicide is extremely volatile.

• Weather conditions on the day of application greatly influence volatilization. High wind speeds increase airborne loss of pesticides; thus, if the weather is calm, volatility will be lessened. High air temperatures also increase volatilization. In fact, researchers have reported a three- to four-fold increase for each 18°F increase in temperature. Making applications on cool, cloudy days or in the late afternoon when temperatures are cooling can help to reduce initial volatility.

• Be sure to water-in pesticides immediately after application if the label says to do so. Rainfall and irrigation transport the pesticide deeper into the turf canopy where it can bind to the thatch or soil. This will help to reduce volatile losses. Our research has shown that after many pesticides have dried on the leaf, they are not easily dislodged. Timely irrigation can be a very effective tool to reduce both volatile losses and dislodgeable residue levels.

Figure 4
Volatile Loss of the Insecticide Trichlorfon and the By-Product DDVP Following Application at 8.1 lbs ai/acre With 0.5" of Irrigation

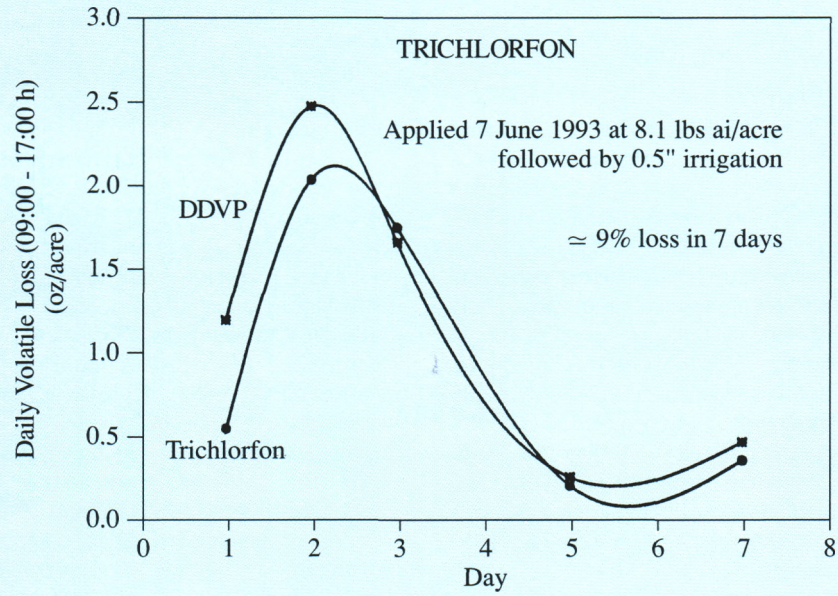
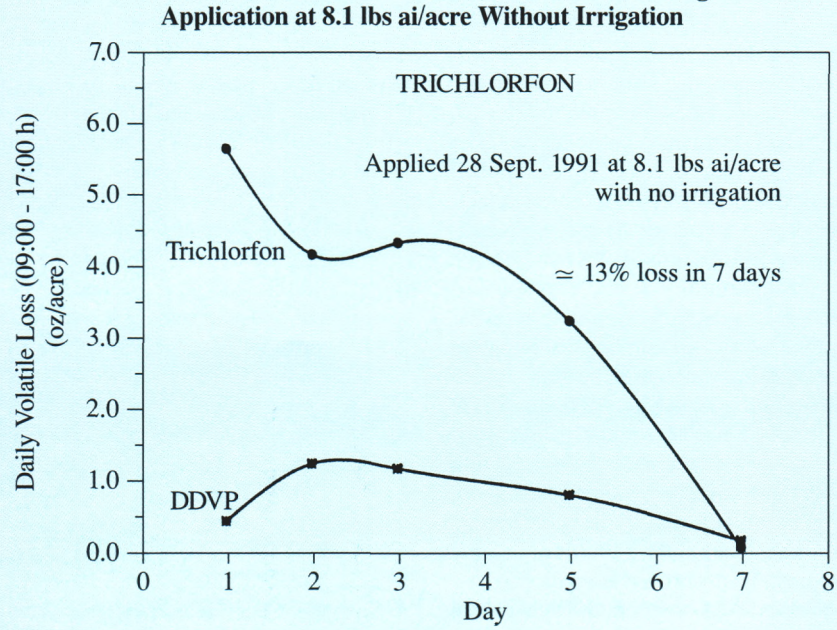


Figure 5
Volatile Loss of the Insecticide Trichlorfon Following Application at 8.1 lbs ai/acre Without Irrigation



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Nitrogen and Phosphorus Fate When Applied to Turfgrass in Golf Course Fairway Condition

by DR. S. K. STARRETT* and DR. N. E. CHRISTIANS
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GOLF HAS GROWN tremendously in popularity in the United States. There are more than 14,000 golf courses that cover more than 1.3 million acres in the U.S. More than 488 million rounds of golf are played annually, and the total number of people who play golf in the United States is more than 27 million (Cohen et al., 1993).

In an urban landscape, turfgrass is partitioned in the following manner: 70% residential lawns, 10% parks and sport facilities, 9% golf courses, 9% educational facilities, 2% cemeteries, and 1% industrial purposes (Cockerham and Gibeault, 1985). Although golf courses are a small part of the total area of turfgrass in the urban community, they are readily visible to the public and are often identified as a possible source of fertilizer and pesticide contamination of groundwater and surface water supplies.

Fertilizers applied to turfgrass areas can have a variety of fates in the environment. They can be taken up by plants, volatilized into the atmosphere, carried by runoff in surface water, adsorbed to soil particles, degraded by biological and chemical processes, and leached through the soil profile (Balogh and Walker, 1992).

A potential detrimental effect of fertilizer usage is the contamination of surface water and groundwater (Balogh and Walker, 1992). Eutrophication of surface waters, the proliferation of aquatic plants, is caused by a surplus of available nutrients. Eutrophication can cause a decrease in dissolved oxygen in waterways, a situation that can kill fish. Phosphorus availability also can be a limiting factor for eutrophication (Mugaas et al., 1991; W. C. Huber, 1993).

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High levels of exposure to some fertilizer nutrients have been reported to be detrimental to humans (Cantor et al., 1988). There is, however, little conclusive evidence of health risks associated with low-level exposure to these nutrients.

Although golf courses have been associated with potential environmental hazards because of pesticide and fertilizer use, these important recreational facilities also provide positive benefits. Some of these benefits include: increased infiltration and reduced runoff compared to bare soil and to agricultural crops, minimal erosion losses, moderation of high temperatures in urban areas, low-cost playing fields, and contribution to the quality of life through aesthetic benefits (Beard, 1993).

Studies on the Fate of Fertilizers

Research results pertaining to the fate of fertilizers applied to turfgrass have been extensively reviewed by Petrovic (1990), and Balogh and Walker (1992). Soil characteristics that affect fertilizer fate include: water content, bulk density, pH, temperature, organic matter, structure, and cation exchange capacity. Climate and slope of the site also are important factors, as are the physiochemical properties, solubility, and chemical concentration of the fertilizer. Management practices that affect fertilizer fate include: application rate, placement, timing of application, formulation, and irrigation practices (Balogh and Walker, 1992).

In recent studies, Joo et al. (1992) investigated the volatilization of nitrogen-15 labeled urea when applied to turfgrass. When irrigation did not follow the liquid urea application, 50% of the urea volatilized within 7 days after the urea application. Starrett (1992) showed that less than 1% of the applied urea volatilized when a liquid urea application was followed with irrigation.

Erosion can be a major carrier of organic nitrogen in surface water runoff from agriculturally managed areas (Haynes, 1986). Turfgrasses greatly reduce erosion by decreasing surface runoff velocity, increasing infiltration, and stabilizing the soil. Few research projects have been conducted to study nutrient losses, specifically on the leaching of nutrients, from turfgrass areas (Petrovic, 1993). It has been claimed, however, that leaching of surface-applied fertilizer is responsible for nitrate in the groundwater in some urban areas (Flipse et al., 1984).

The turfgrass manager cannot control all site factors and climate conditions, but he or she can control irrigation rates, perform soil and plant tests to prevent over-fertilization, and plan the timing and placement of fertilizers (White and Peacock, 1993). Rieke and Ellis (1973) suggest a variety of techniques to reduce nitrogen losses: reduced annual nitrogen rates, lighter and more frequent nitrogen applications vs. single heavy applications, applying nitrogen only to healthy turf, and strict water practices to prevent excessive irrigation.

Iowa State University Research

Iowa State University is one of 21 universities and research centers that conducted environmentally related research funded by the USGA (USGA, 1991). Our research objectives were to investigate the hydrology of undisturbed soil columns with a Kentucky bluegrass turf and intact macropores under a single and split irrigation regime, and to measure the effect of the different irrigation regimes on the fate of nitrogen and phosphorus when they are applied to an undisturbed soil column.

Undisturbed columns of a Nicollet (fine-loamy, mixed, mesic-Aquic Hapludolls) soil

were taken from a 4000 sq ft turfgrass area at the Iowa State University Horticulture Research Station. Undisturbed soil columns were used because the influence of macropores is negated when experiments are done using dried, sieved, and repacked soil columns (Evert, 1989).

The area had been established with Premium Sod Blend® (Parade, Adelphi, Rugby, and Glade) Kentucky bluegrass (*Poa pratensis L.*) and maintained at golf course fairway mowing height (1"). The columns measured 8" in diameter and were excavated to a 20" depth. A 12" heating duct pipe was placed around the column, leaving 2" between the soil column and the pipe. Mortar was poured between the pipe and soil. The undisturbed soil columns were then transported to the greenhouse.

More than 99% of nitrogen has an atomic weight of 14, and less than 0.5% has an atomic weight of 15. Nitrogen-15 is a stable, nonradioactive isotope that has been used for years as a tracer of fertilizer nitrogen applied in agricultural settings. Surface applied nitrogen with a higher concentration of synthetic nitrogen-15 can be used to measure the fate of applied nitrogen. A mass spectrometer is used to determine the atomic weight of the nitrogen present in the soil, plant material, or soil column leachate.

Urea N (46% N), labeled with 5% nitrogen-15, and phosphorus were applied to the surface of the Kentucky bluegrass turf. The pesticides pendimethalin (herbicide), MCPP (herbicide), 2,4-D (herbicide), dicamba (herbicide), isazofos (Triumph, insecticide), chlorpyrifos (Dursban, insecticide), and metalaxyl (Subdue, fungicide) were also applied. The experimental treatments included two irrigation regimes. One treatment consisted of watering the column with 1" of distilled water immediately after the fertilizer and pesticides were applied. The second treatment included a 0.25" application immediately after the fertilizer and pesticide application, and three additional 0.25" applications at 42-hour intervals, yielding a total 1" irrigation spread evenly over a 7-day period. The experiment ran for 28 days. A similar experiment to investigate the fate of nitrogen and phosphorus was conducted over a 7-day period. The goals of our research were to investigate the fate of fertilizers and pesticides applied to turfgrass, and to determine if irrigation practices can be used to affect pesticide and fertilizer movement through the soil profile.

A glass trap system was used to collect volatilized N in the form of ammonia (NH_3). Leachate was collected from the bottom of the columns at various times and immediately frozen. Clipping, verdure, and thatch mat samples were taken from each column, and the soil was excavated in 4" layers at the end of the test period. The soil was then dried, placed in plastic bags, thoroughly mixed, and sampled for analysis of pesticides, ^{15}N, and phosphorus concentrations.

Results

Analysis of the pesticide data is still underway and will be reported on in a later article. Initial observations from the fate of nitrogen and phosphorus research are: a heavy irrigation increases nitrogen transport compared to a light irrigation; macropores may play a role in transport of surface-applied nitrogen through soil profiles; volatilization of liquid urea was less than 3% when followed with irrigation and is reduced to less than 1% under a heavy irrigation; and the irrigation rate does affect P transport after a 7-day period.

The macropore structure found in an undisturbed soil can have a major impact on water and solute distribution in the profile (Thomas and Phillips, 1979). About 10% of the applied nitrogen under the heavy irrigation was collected in leachate within a few hours of the fertilizer application and can be attributed to macropore flow. The heavy irrigation caused some ponding to occur on the soil surface, filling the macropores and allowing rapid flow through the soil profile.

Volatilized nitrogen was less than 3% of the applied nitrogen under either irrigation regime, which agrees with research conducted by Bowman et al. (1987). Applying irrigation immediately after a nitrogen application reduces volatilization by transporting the applied nitrogen slightly below the soil surface, where N is more likely to be adsorbed. The heavy irrigation transported more of the surface-applied N below the soil surface compared to the light irrigation, thereby further reducing N volatilization.

Starrett et al. (1994) reported that phosphorus was found in leachate from 20" undisturbed soil columns covered with Kentucky bluegrass under a heavy irrigation during a 7-day test period (Table 1). Also, 35% of the phosphorus was transported below 8" under the heavy irrigation regime.

What Does This Mean to the Golf Course Superintendent?

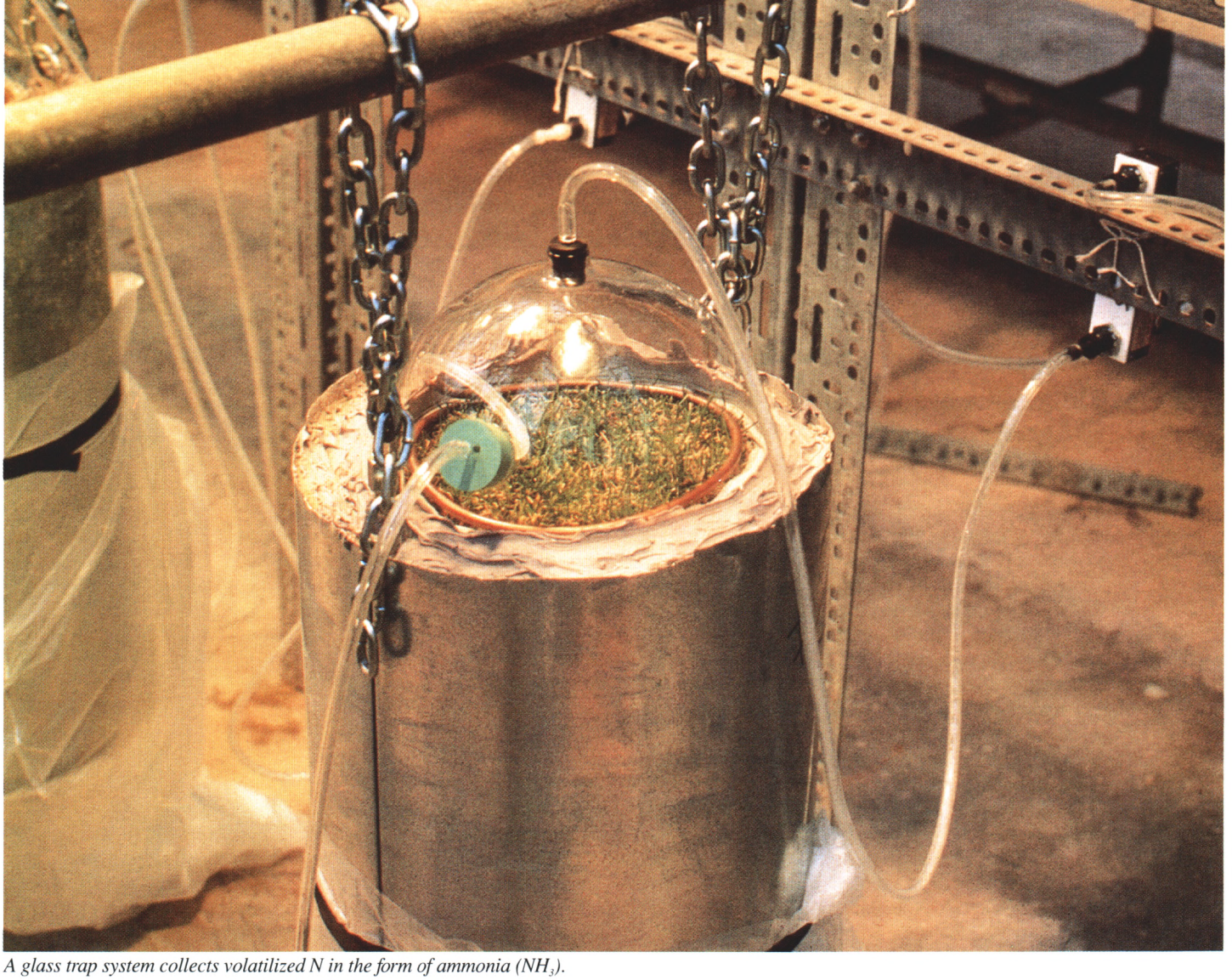
Golf courses can be managed in such a way that even phosphorus, which is known to be fairly immobile, can be moved through a 20" soil profile and potentially into the groundwater. However, there are management practices that the superintendent has control over that can minimize the potential movement of fertilizers through soil profiles. Among these practices is the control of fertilizer application rates. Excessive application rates promote more nitrogen and phosphorus being lost to volatilization and leaching, and less of the applied nutrients being absorbed by the turfgrass. Application timing is important with regard to preventing applied nutrient losses. Applying nutrients just before a heavy rainfall would cause greater losses due to leaching through the soil profile in comparison to light irrigation after applying nutrients.

Proper irrigation practices can also help to reduce nutrient losses. Nitrogen volatilization losses from liquid N fertilizers can be reduced to negligible amounts by lightly watering immediately after application. Also, losses due to leaching can be reduced by irrigation practices. In our study, a 1" irrigation versus four 0.25" irrigations after a surface application of nitrogen increased the amount of nitrogen that leached 20" into the soil profile by 40 times. Careful consideration should be given to these practices before making any management decisions. It is clear that when care is taken in applying fertilizers to golf course turf, losses can be kept to an absolute minimum.

Table 1
Available Phosphorus Concentrations (ppm) in the Soil and Total Phosphorus in the Leachate (mg)[1]

	Heavy Irrigation		Light Irrigation		
Category	Mean	Std. Dev.	Mean	Std. Dev.	Probability[2]
Thatch Mat	18.5	2.9	27.5	8.3	0.073
0-4 in.	6.7	1.5	6.4	1.6	0.735
4-8 in.	2.7	1.0	2.4	0.5	0.502
8-12 in.	2.3	0.8	1.4	0.5	0.031
12-16 in.	2.4	1.3	1.6	1.1	0.208
16-20 in.	3.0	1.6	2.0	1.7	0.288
Leachate[3]	1.0	1.0	<0.1	<0.1	0.024

[1]Values from 7 replications
[2]Probability that a difference exists (lower the value, more likely different
[3]Total P found in leachate (mg)



A glass trap system collects volatilized N in the form of ammonia (NH_3).

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Pesticide Degradation Under Golf Course Fairway Conditions

by DR. G. L. HORST, DR. P. J. SHEA, and DR. N. CHRISTIANS
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GROWING CONCERN about hazards to and in the environment now extends into all areas of life. Many perceive runoff and leaching of fertilizers and pesticides from agricultural, municipal, and industrial operations as well as recreational areas, urban landscapes, and golf courses to be critical environmental problems. Golf course and recreational turf managers rely heavily on pesticides and fertilizers to keep turf and landscapes functional and aesthetically pleasing.

In Nebraska alone, an estimated 10,000 tons of fertilizer and 2,400 tons of pesticide are applied to recreational areas, commercial landscapes, lawns, and golf courses each year. Turf itself may play an important role in prevention of fertilizer and pesticide leaching. In order to protect groundwater from contamination by agrichemicals, one has to understand the relationship between pesticide degradation, solute (pesticide) leaching, and imposed management practices. Many factors influence what happens to fertilizers and pesticides once they are applied to golf course turf or lawn situations, including application timing, rate and total amount of agrichemicals, and water as rainfall and irrigation.

Together with researchers at Iowa State University, Ames, the University of Nebraska, Lincoln, research team examined the fate of pesticides under golf course fairway conditions.

Research results indicate that turfgrass may actually promote pesticide degradation in the environment. The frequent irrigations employed to keep the grass green have been accused of contributing to pesticide leaching and runoff. On the other hand, the relatively high water content and nutrient rich environment in most turfgrass/soil systems may actually promote pesticide degradation, because pesticide availability and degradation rate generally increase as temperature and soil water content increase.

Encasement of the turf/soil column ensures an intact undisturbed profile for pesticide sampling.

The research project initially examined the persistence and mobility of four commonly used pesticides: pendimethalin (Lesco 60 DG, Pre-M®) herbicide, metalaxyl (Subdue®) fungicide, chlorpyrifos (Dursban™), and isazofos (Triumph®) insecticides in turfgrass/soil systems. It was also of interest to determine the relative distribution of these pesticides among the verdure, thatch, and soil components with time after application.

Field Procedures

The field research was conducted in 1991 and 1992 at the University of Nebraska John Seaton Turfgrass Research Facility near Mead, Nebraska, and at the Iowa State University Horticulture Research Facility near Ames, Iowa. Each of the four pesticides was applied (late May to early June each year) to Kentucky bluegrass turf managed as golf course fairway. Intact turf/soil cores from a Sharpsburg soil (silty clay loam) and a Nicollet soil (fine-sandy loam) were removed to a 2 ft depth from field plots before application and 1, 7, 14, 28, 56, and 128 days after application. To maintain the integrity of the samples, the turf/soil cores were encased

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before removal from the field research areas. Pesticide fate and location in the turf/soil core profiles were determined through analysis of the turf/soil cores sectioned into verdure, thatch, and seven depth increments. Quantitative analysis of pendimethalin, chlorpyrifos, metalaxyl, and isazofos was by gas chromatography.

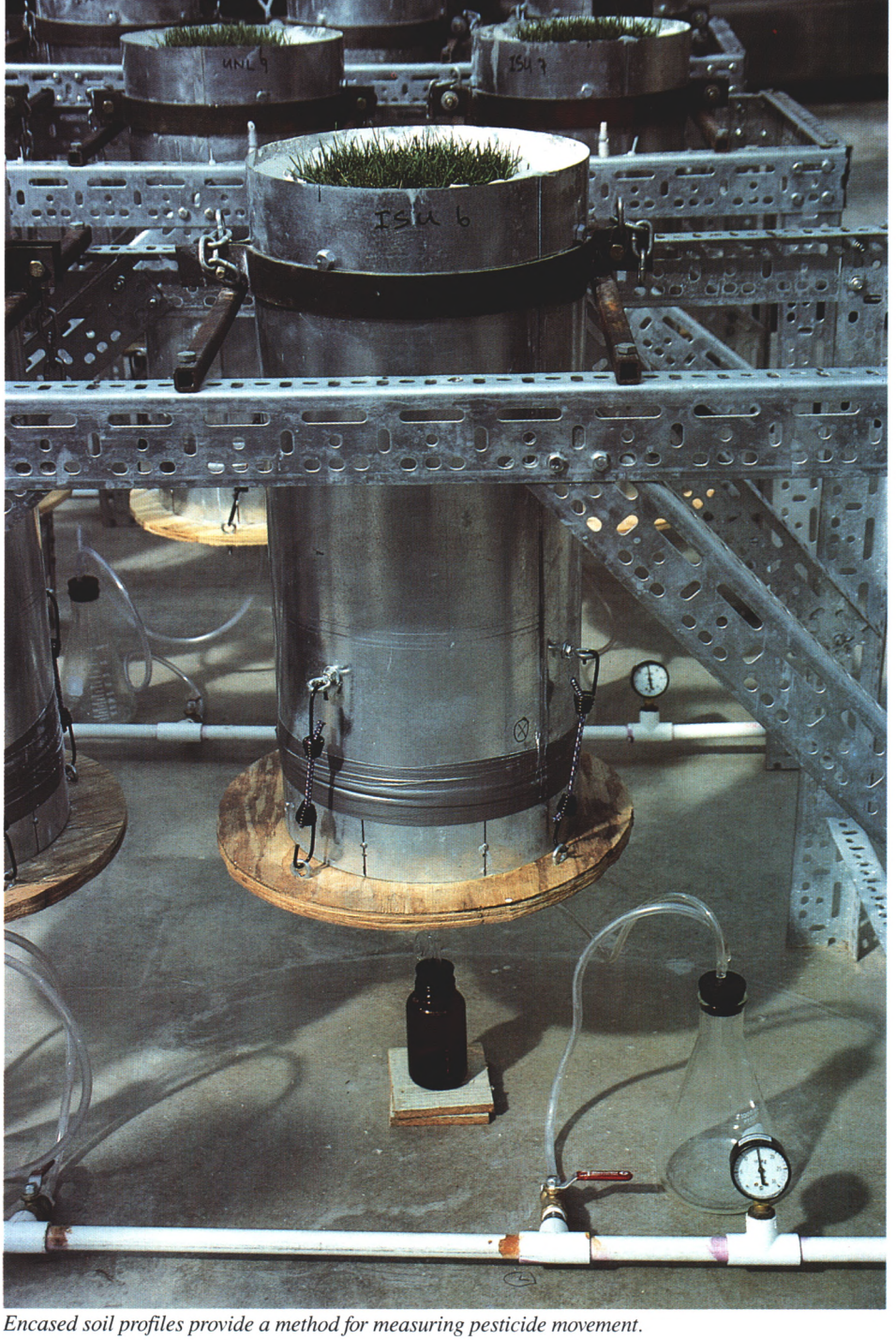
Conclusions

As expected, a compound's individual chemical properties, use location, and climatic factors influenced the level of pesticide residue measured in the turf/soil system. Statistical analysis indicated that years (1991 vs. 1992), the range in sampling times after pesticide application, and the turf/soil component (verdure, thatch, soil) were significant factors influencing pesticide fate and where the pesticides were detected in the turf/soil system (Figure 1). The year (1991 and 1992) factor includes such environmental variables as air and soil temperature, rainfall, irrigation, wind speed, and number of cloudy days. This means the fate of these pesticides will vary from year to year. One also would expect that sampling times for analysis of these pesticides would be significant as the pesticides degrade over time, and the results confirm this. Location (Nebraska and Iowa) influenced the total pesticide residue amounts of isazofos, chlorpyrifos, and metalaxyl detected. This may be due to differences in soil type and weather conditions. A lack of differences in pendimethalin residues between locations could be due to the low solubility and relative immobility of this herbicide.

Variability in isazofos residues indicated a greater response to soil type and to profile component differences such as thatch amounts and weather conditions. Greater amounts of metalaxyl were measured in the Nebraska turf/soil profile in 1991, while samples from the Iowa location had greater detectable amounts of the fungicide in 1992.

Chlorpyrifos levels varied by year of application and location, with more insecticide residues measured in 1992 at the Iowa location than at Nebraska. In contrast, pendimethalin residues were lower in the first year of the research, but differences between locations were smaller than measured for the insecticides isazofos and chlorpyrifos.

While turfgrass verdure contained relatively high concentrations of the chlorpyrifos and pendimethalin pesticides immediately after application, irrigation, rainfall, and mowing reduced the amount of pesticides recovered from the plant material with time. Seven days after application, the verdure contained 10%, 8%, 3%, and 2% of the total amounts of chlorpyrifos, pendimethalin, isazofos, and metalaxyl.



Encased soil profiles provide a method for measuring pesticide movement.

Table 1
Properties of Metalaxyl, Isazofos, Chlorpyrifos, and Pendimethalin*

Pesticide	Water Solubility (mg L^{-1})	K_{ow}	K_{oc}	Half-Life (days)	Vapor Pressure (mPa)	SCS Rating Leaching	SCS Rating Runoff
Metalaxyl	8400	50	50	70	0.63	Large	Large
Isazofos	69	1000	100	34	11.4	Large	Large
Chlorpyrifos	2	100000	6070	30	2.50	Small	Small
Pendimethalin	0.3	150000	5000	90	3.90	Small	Medium

*Data from SCS/ARS/CES Pesticide Properties Database (Wauchope, et al., 1992)

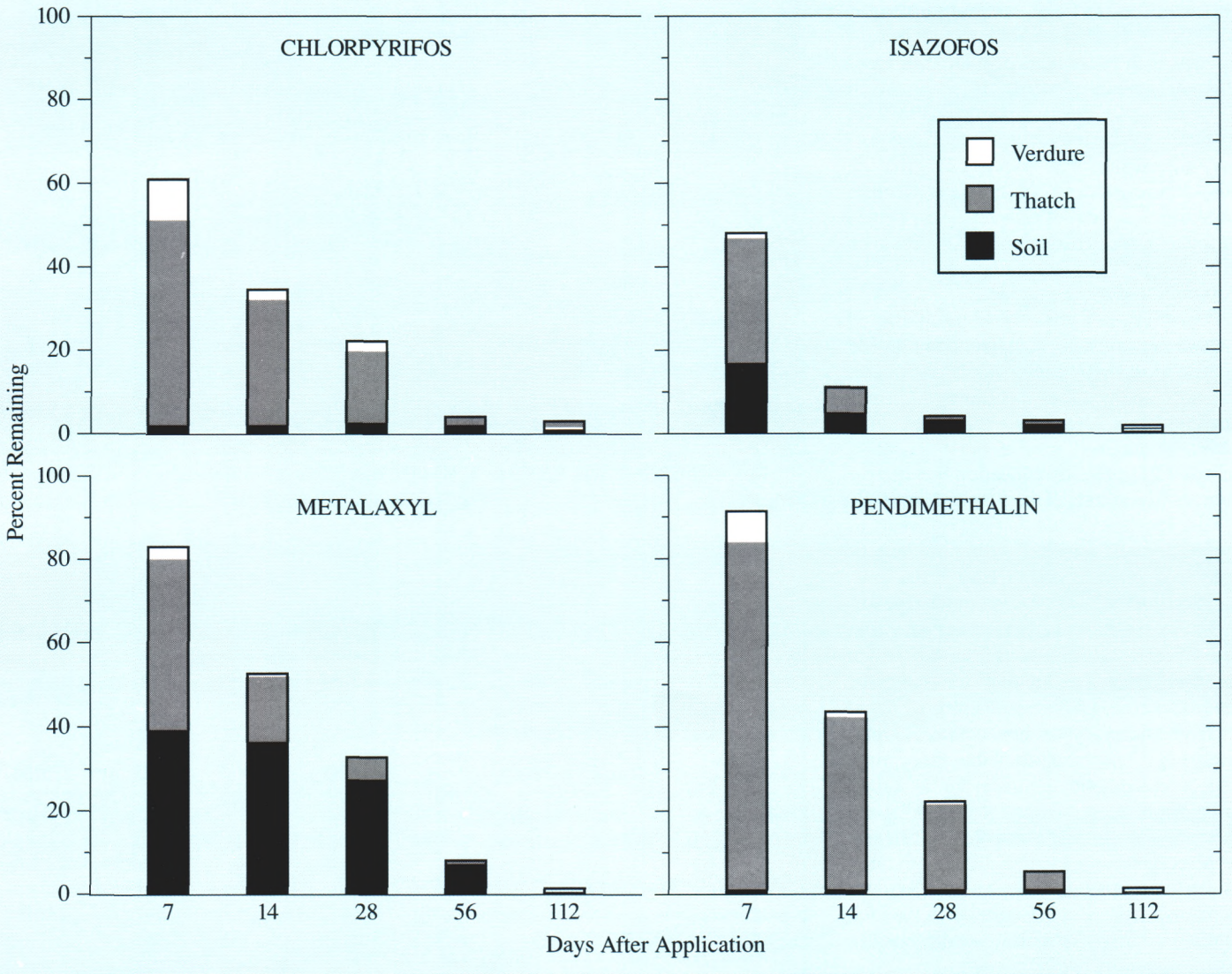
The thatch layer contained the greatest amount of pesticide residues throughout the research monitoring period. Thatch appeared more retentive of pendimethalin and chlorpyrifos than isazofos and metalaxyl. Twenty-eight days after application, thatch contained 21% and 14% of the pendimethalin and chlorpyrifos residue recovered. In contrast, the thatch contained less than 4% of the isazofos and metalaxyl residue recovered at the same time.

Pesticide residues were much lower in soil than in the thatch at all sampling times during the study. Metalaxyl and isazofos were more mobile than chlorpyrifos and pendimethalin. Seven days after application the top inch of soil contained 5% and 17% of the applied isazofos and metalaxyl. Metalaxyl soil residues reached a maximum (22%) at the 1" soil depth 14 days after application. Metalaxyl soil residues recovered from the 2" to 22" depths increased up to 28 days after application. Isazofos residues were lower in the Iowa soil, where more thatch was present. Less than 1% of the chlorpyrifos and pendimethalin was recovered in any soil sample down to 20" over the course of the study.

Pesticide amounts in the soil profile were highly skewed, with the exception of metalaxyl. Generally, the highest amounts of detectable pesticide were at the top 1" and the 1" to 4" soil depths during the monitoring period. The soil contained more metalaxyl than isazofos, which generally was higher than chlorpyrifos and pendimethalin. At several sampling times, metalaxyl was detected throughout the entire 2 ft depth of the soil core profile. However, metalaxyl amounts detected at the end of the 4-month monitoring period were less than 1% of that originally applied.

Based on observed disappearance rates, overall average time to 50% of the original applied pesticide degraded (DT_{50}) values were 16, 12, 10, and 7 days for metalaxyl, pendimethalin, chlorpyrifos, and isazofos, respectively, in the turf/soil profile. These pesticides appeared to degrade more rapidly in the turfgrass environment than typically reported for other agronomic cropping systems. Variability in pesticide residue amounts for each soil depth among the turf/soil core profiles indicated non-uniform dissipation in the soil.

Figure 1
Average Percent Chlorpyrifos, Isazofos, Metalaxyl, and Pendimethalin Remaining in Verdure, Thatch, and Soil of Turf/Soil Systems at Nebraska and Iowa After Application in 1991 and 1992



Dr. Stan Brauen using a moisture probe on the treated plots to monitor the study.

Leaching of Nitrate from Sand Putting Greens

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GOLF IS PLAYED year round in the coastal Pacific Northwest. Summers are dry and often cool, yet the long, mild, wet winters may cleanse nutrients from sand profiles of putting greens and flush them into drainage systems. These conditions suggest to the public that golf course management practices are a potential threat to environmental quality because of the use of pesticides and nitrogen to maintain play, appearance, and turfgrass quality. If true, the result could be groundwater contamination. To complicate matters, golf course putting greens, tees, and other athletic turf areas in the coastal Pacific Northwest are often constructed of sand, some with coarse particle sizes and without amendments in order to reduce construction costs and improve drainage during the wet seasons.

The Problem

Among the questions we wanted to answer is whether nitrate nitrogen applied to putting green profiles constructed of sand or peat/soil-amended sand could potentially leach or move into streams, lakes, or groundwater. If it does move, what is the critical time of year when the leaching would occur, and what daily management practices would reduce the threat of further contamination? Would modified rooting mediums, efficient nitrogen fertilizer practices, minimal fertilization rates, deeper sand profiles, or efficient irrigation practices eliminate the threat while maintaining adequate turf for the playing of the game of golf? The development of this information would serve as the basis in providing guidance for its correction, reduction, or elimination. The objectives of the study

were to quantify the effect of rooting medium, fertilization interval, and annual nitrogen rate on nitrate nitrogen leached from creeping bentgrass putting greens. It was thought that lighter, more frequent applications of fertilizers from slow-release sources might be helpful at mitigating potential leaching losses.

How the Studies Were Conducted

The study was carried out in 36 small lysimeters constructed in a manner similar to USGA putting greens. A lysimeter is simply a term used to describe a system that gives turf scientists the ability to closely measure the inputs and outputs of a system. In this case, the emphasis was on nitrate nitrogen leached.

The turfgrass lysimeters were located 30 miles south of Seattle, Washington, at Washington State University Research and Extension Center, in Puyallup, Washington. Each lysimeter was 32 sq ft, lined with chlorosulfonated polyethylene reinforced liner and fitted with 2" ABS drain tube so leachates that moved through the 12" rooting medium, the 3" intermediate layer, and 3" pea-sized gravel layer could be collected daily. The rooting medium consisted of pure sand (CEC 2.6 meq per 100 g, pH 6.8) or a mixture of 88% sand, 10% sphagnum peat, and 2% screened Sultan silt loam. Particle size analysis of the sand was 4.2% between 1.0 and 4.7 mm, 85.1% between 0.25 and 1.0 mm, 8.5% between 0.13 and 0.25 mm, and 2.2% < 0.13 mm. The effects of rooting medium, annual nitrogen rate, and nitrogen application interval on leached nitrate nitrogen were monitored for two years.

The nitrogen fertilizer rates were 4, 8, and 12 lb N per 1000 sq ft per year. The nitrogen was supplied in granular form as greens-grade blends of ammonium sulfate, ammonium phosphate, isobutylidene diurea (IBDU), sulfur-coated urea (SCU), and methylene urea (MU). The ammonium sulfate and ammonium phosphate quantities were equal for all nitrogen rates, and all of the increase in nitrogen rate from 4 to 12 lb was supplied as IBDU, SCU, and MU (see Table 1). Phosphorus was supplied from ammonium phosphate, and potassium was supplied from potassium sulfate. Fertilizer applications were made every 14 or 28 days in 22 or 11 applications per year. Fertilizers were applied from February through December.

After construction of the lysimeters during the summer of 1991, the area was seeded on October 3. The first rainfall occurred on October 24, 1991, and leachates were collected in plastic 5.5-gallon buckets beginning on October 25. Leachate volumes were measured daily and subsamples were collected daily, when available, for the next two years.

Table 1
Quantity of Soluble and Slow-Release N Applied at Each Fertilizer Application Interval

Nitrogen Rate	Annual Rate (lb N/1000 sq ft)		
	4	8	12
	11 Monthly Applications (lb N/1000 sq ft)		
Ammonium phosphate	0.04	0.04	0.04
Ammonium sulfate	0.20	0.20	0.20
Urea	0.02	0.07	0.13
Slow release[1]	0.10	0.41	0.72
Total Application[2]	0.30	0.72	1.09
	22 "Two Week" Applications (lb N/1000 sq ft)		
Ammonium phosphate	0.02	0.02	0.02
Ammonium sulfate	0.10	0.10	0.10
Urea	0.01	0.04	0.07
Slow release[1]	0.05	0.20	0.36
Total Application[2]	0.18	0.36	0.55

[1]Slow-release nitrogen sources consisted of methylene urea, sulfur-coated urea and IBDU supplied in quantities to provide equal parts nitrogen from each source. Potassium was supplied from potassium sulfate as a part of the mix.

[2]Pounds of nitrogen applied per 1000 sq ft per application.

When Nitrate Leached

During the first fall and spring following seeding and when the creeping bentgrass was very immature, nitrates did leach from the lysimeters. The concentration of nitrate nitrogen in the drainage water increased with annual nitrogen rate applied. Very little nitrate was leached at the 4 lbs per 1000 sq ft rate. Nitrate was present in drainage water until late December and declined to low levels in January and February.

The concentration of nitrate percolating from the lysimeters during the first fall, winter, and spring following construction and seeding was considerably different from the concentrations of nitrate leached during the second fall, winter, and spring after the turf had matured. These nitrate patterns are shown in Figure 1. The differences shown emphasize the changes that occur in the ability of turfgrass to trap nitrogen as the turf matures. Note the large differences in nitrate concentrations from November to June of 1991-92 when lysimeters were fertilized with the 12 lbs N per 1000 sq ft per year rate versus the lower rate of 8 lbs N per 1000 sq ft in 1992-93.

During the first fall, when the turf was young, there were few grass roots and no thatch, and there was no organic matter in the pure sand rooting medium. This resulted in free movement of nitrates through the rooting medium and into the drainage water. Pure sand rooting systems are very susceptible to nitrate leaching immediately after construction. Everyone would have expected this to be the case. As a consequence, nitrates in relatively high concentrations were lost at the highest rate of nitrogen application even though the nitrogen sources were primarily ammonium sources. Little nitrate was leached at the lowest application rate.

The frequency of nitrogen application (14 or 28 days) and the makeup of the rooting medium (pure sand versus organic matter modified sand) were big factors in controlling the quantity of nitrate leached during the first fall and winter when the turf was young. The average monthly nitrate-N concentration of leachate from the pure sand rooting medium was significantly greater than the leachate concentration from the modified sand rooting medium during November 1991 to June 1992.

By the second fall, the turf had become well established. Roots were well defined and a surface thatch had developed. The rooting medium and the frequency of fertilizer application were less important in reducing nitrate movement. Then, the quantity of nitrogen applied was the main factor responsible for nitrate movement into the drainage water.

For the most part, nitrates leached only from lysimeters that were fertilized with 12 lbs of nitrogen per 1000 sq ft per year during the second year. Rooting medium had

little effect in regulating the concentration of leachable nitrate. Frequency of nitrogen application seemed to have some effect on reducing nitrate leaching during the late fall and early winter period. Nitrates could be detected during periods when excessive rainfall was experienced following the heaviest nitrogen applications. Periods when this occurred were when nitrogen applications above 0.4 lb N per 1000 sq ft were applied followed by periods of slow precipitation over the next seven to 10 days and after the rooting medium temperature had declined 33° to 40°F. Under these conditions, halving the rate of nitrogen application and applying on a more frequent interval reduced nitrate movement. As long as the 2" temperature of the rooting medium remained in the above range, plant uptake appeared to be great enough to prevent nitrate accumulation in the leachates. November nitrogen fertilization at moderate rates did not result in leaching of nitrate-N.

The highest concentration of nitrates in leachates occurred in early to mid-spring growth periods. The rainfall pattern was significantly different during the winter and early spring of 1993 as compared to 1992. Precipitation occurred early in January in 1992, resulting in very low levels of nitrate concentration in leachates during January and February. Precipitation was considerably lower in March and early April in 1992 as compared to 1993, which may have resulted in a lower volume of leachates and higher concentration of nitrate-N in 1992. The differences in nitrate concentrations between these two years also may reflect the differences in the maturity of the rooting mediums and the accumulation of organic matter in the rooting medium. Organic matter in the rooting medium had increased to nearly 2% in the pure sand root zone by the end of the second year and approached 2.5% in the modified rooting medium. No nitrates were found in any treatment combination during the summer through mid-fall of either year. This would imply that the risk of leaching nitrates in summer due to unexpected heavy rain or over-irrigation is very low when turfs are fertilized on frequent intervals and the total rate of application does not exceed the moderate rates used in these studies.

The quantity of nitrate that leached through the greens is a function of the nitrate concentration in the drainage water and the volume of drainage water produced. The product of these two values showed that, in the first year, two periods of the year were most sensitive to nitrate leaching. These were in November, four to eight weeks after seeding, and in April and May when soil temperatures fluctuated between 45°F and 55°F. Even though the greens were actively growing during this period of the spring, the root systems still lacked sufficient maturity to be highly efficient in nitrate uptake.

The leaching collection system from the lysimeters provides turfgrass scientists the ability to closely monitor the inputs and outputs from the system. The project at Washington State University studied amended versus non-amended sands with varying N fertilization rates.

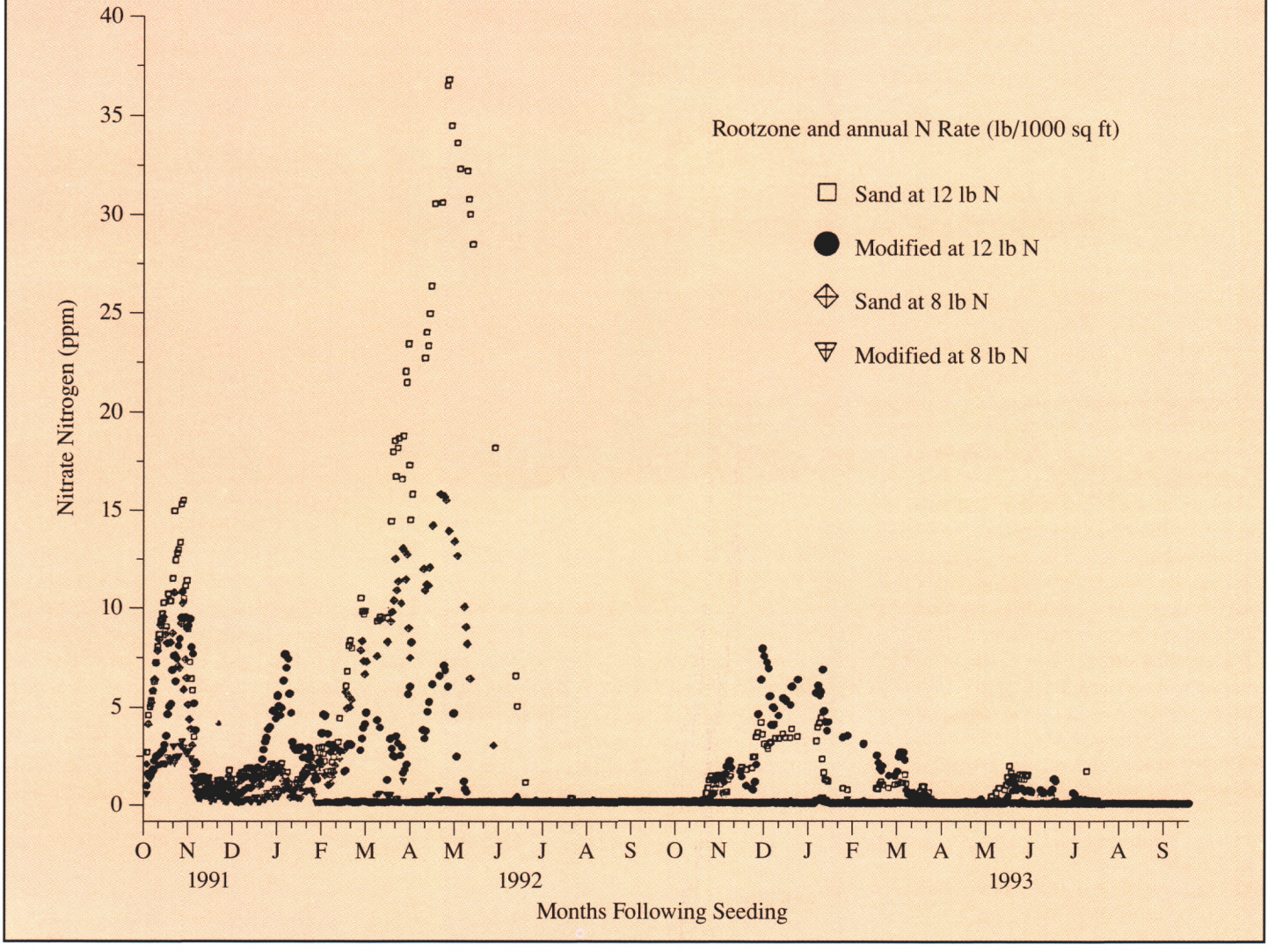
Table 2
Percent of Total Applied Nitrogen Leached as Nitrate

Rooting Medium	Annual N lb/1000 sq ft	Year 1 Percent	Year 2 Percent	Year 3 Percent
Sand	4	5.37	0.06	2.71
	8	6.31	0.04	3.17
	12	7.55	0.70	4.28
Modified (sand/peat)	4	0.33	0.40	0.16
	8	0.91	0.02	0.17
	12	3.37	1.26	2.31

As little as 0.33% and as much as 7.55% of the applied nitrogen was leached as nitrate in the first year. The highest percent nitrate lost was from the 12 lb N per 1000 sq ft per year rate. In the second year, 1.26% was the highest quantity leached. Essentially no nitrate was leached from the 4 or 8 lb rates in the second year in either the pure sand or the modified sand greens (see Table 2). It should be noted that 4 lbs of nitrogen per 1000 sq ft per year was insufficient to support bentgrass or annual bluegrass growth in putting greens under play in the Northwest. But 0.36 lb N per 1000 sq ft (8 lbs N per 1000 sq ft per year rate) applied at two-week intervals was more favorable. At this fertilization rate each 14 days, 2.7 lbs nitrate per acre or 2.1% of the nitrogen applied was leached in the first year. In the second year, only 0.03% of the nitrogen applied was leached.

In summary, experimental putting greens that were constructed close to USGA specifications were monitored for concentration of nitrate in leachates from October 1991 to October 1993. During the first year, the concentration of nitrate nitrogen leached from their profiles was related to application rate and was strongly modified by the rooting medium and frequency of nitrogen application made to the immature turf. In this same time period, the concentration of nitrate leached from the pure sand rooting medium was much greater than the nitrate leached from the sand rooting medium modified with peat moss. Modified sand greatly reduced the

Figure 1
Daily Nitrate-N in Leachates from Sand and Modified Sand Rootzone Putting Green Lysimeters Fertilized with 8 lb and 12 lb N/1000 sq ft Annually. Values Summarized Over 14- and 28-Day Fertilization Intervals.



total quantity of nitrogen that was lost as compared to pure sand. The frequency of nitrogen application to young turf during the first year significantly affected the level of nitrate-N lost. Although the impact of this factor was much less than either nitrogen rate or rooting medium effects, it did consistently influence nitrate-N concentration in the leachate. The use of modified sand rooting medium, moderate levels of total annual N application and frequent nitrogen applications combined to reduce nitrogen lost in leachates to 2.7 to 3.6 lbs per acre and the percentage of applied nitrogen lost in leachates to as low as 3% to 5%.

In the second year, nitrate-N concentration in the leachates was greatly reduced compared to year one. A significant part of this major change was attributed to more extensive rooting, increase in thatch and increase in organic matter in the rooting medium. The leachate nitrate concentration was rate-related again, but the extent of nitrate leached was not strongly modified by the rooting medium or by how often the turf was fertilized. The nitrate concentration found in leachate from pure sand profiles was similar to that found from modified sand profiles most of the year. In addition, the reduced nitrate concentration in leachates was attributed to a greater quantity of precipitation (2.2") during early spring in 1993, as compared to 1992, resulting in dilution of leachate nitrate concentration. Nearly zero concentration of nitrates was observed in leachates in summer or early winter.

Conclusions

When putting greens were immature and fertilized with a moderate nitrogen rate, the most important factor in limiting nitrate leaching was to modify the rooting medium during construction with organic matter, in this case peat. Applying the fertilizer on 14-day intervals vs. 28 days also was important, particularly during the periods when leaching pressure was high. Managing young greens in this manner essentially eliminated nitrate movement into the drainage system. As putting greens matured and thatch and organic matter levels developed in the pure sand system, nitrogen fertilization rate was the major factor affecting nitrate leaching. Rates of 8 lbs or less nitrogen per 1000 sq ft per year resulted in little or no nitrate leaching. Applying nitrogen fertilizers with at least 70% of the nitrogen source in slow-release form on a frequent interval such as every 14 days provided excellent protection from nitrate leaching. At this point in our study, we conclude that nitrate concentration in drainage water from putting greens can be effectively limited by using appropriate nitrogen application rates, frequent and light nitrogen applications, and a modified sand rooting medium during early establishment.

Potential Groundwater Contamination from Pesticides and Fertilizers Used on Golf Courses

by DR. BRUCE BRANHAM, DR. ERIC MILTNER*, and DR. PAUL RIEKE
Michigan State University

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 ft^2 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 excavated 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 ft^2. 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 ^{15}N on those dates only.

*This schedule was followed in 1992 and 1993 without the ^{15}N 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

*Former research technician and graduate student; currently assistant professor, Utah State University.

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.

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 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-

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 ^{15}N and Total N in Leachate from Spring Treatment

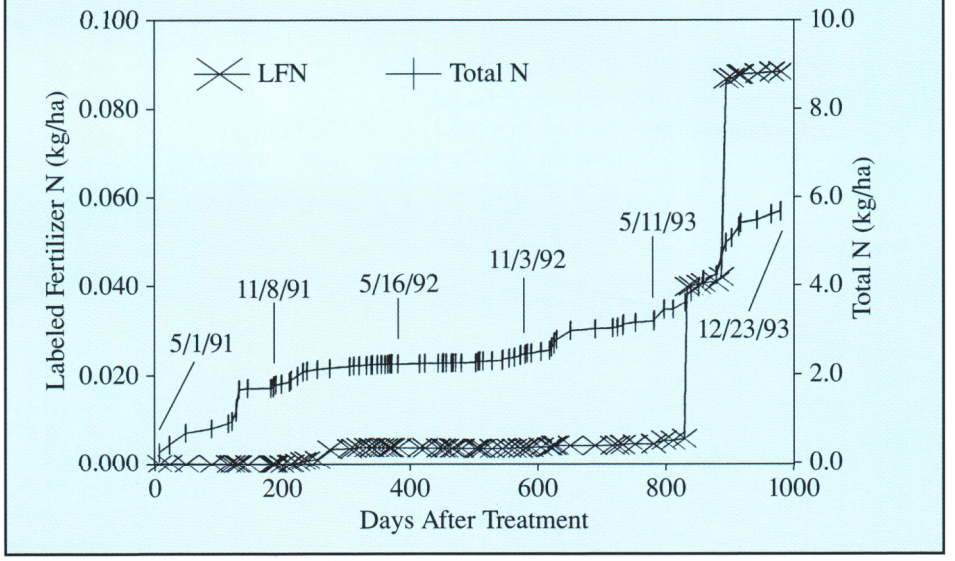
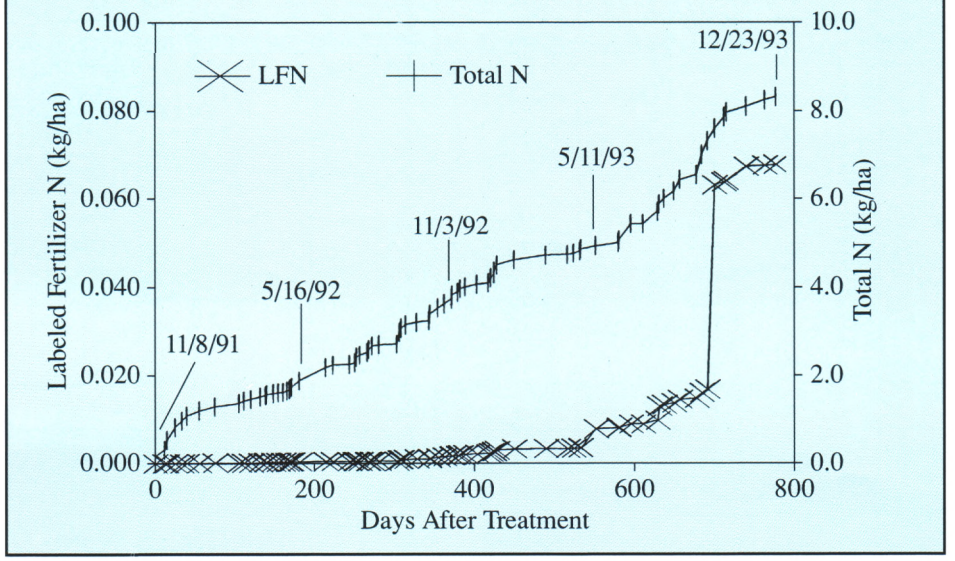


Figure 2
Cumulative ^{15}N and Total N in Leachate from Fall Treatment



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

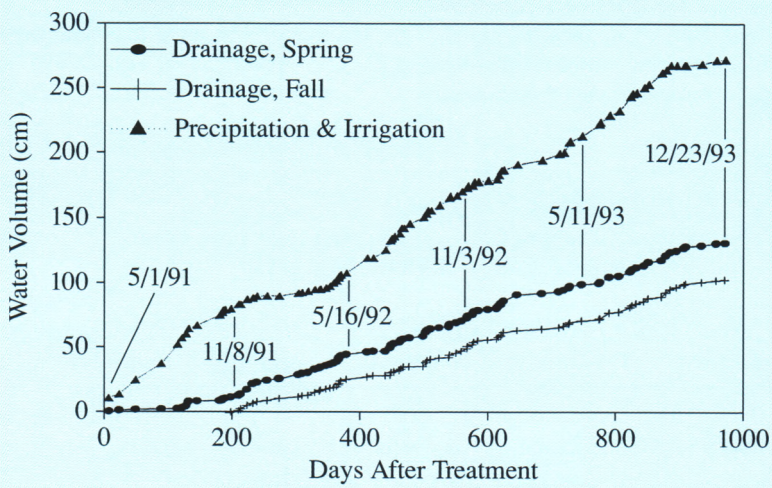
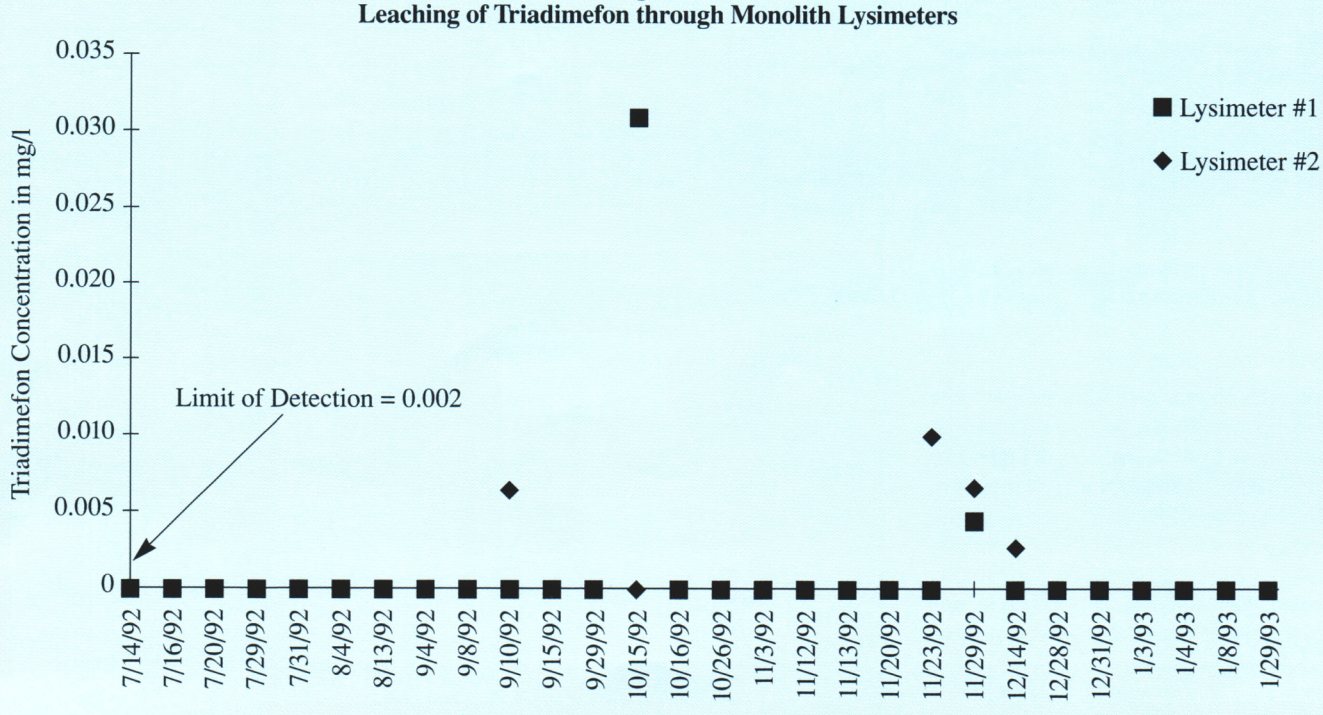


Figure 4
Leaching of Triadimefon through Monolith Lysimeters



The Impact of Soil Type and Precipitation on Pesticide and Nutrient Leaching from Fairway Turf

by DR. A. MARTIN PETROVIC
Cornell University

THREE YEARS AGO, in a project funded by the United States Golf Association, a team of researchers from Penn State University, the University of Massachusetts, and Cornell University set out to establish a more comprehensive knowledge base as to the fate of pesticides and fertilizers applied to experimental fairways in large-scale field research facilities. The three universities divided the research objectives based upon the specialized facilities at each site. The same pesticide and fertilizer materials were used at each site to give the project cohesiveness. Penn State University investigated the extent of pesticide and nutrient runoff from fairway-type turf consisting of either creeping bentgrass or perennial ryegrass. The University of Massachusetts examined volatilization and foliar dislodgeability of pesticides applied to fairway-type turf (creeping bentgrass). Cornell University studied the impact of soil type and precipitation on pesticide and nutrient leaching from fairway-type turf (creeping bentgrass). The results of the Penn State University and University of Massachusetts studies are found elsewhere in this issue.

The objectives of Cornell University's portion of this project were to determine pesticide and nutrient leaching from high-maintenance fairway-type turf as influenced by:

- Soil texture (sand, sandy loam, and silt loam)
- Pesticide properties (persistence and mobility)
- Rainfall differences (moderate and very heavy rainfall patterns)
- Turfgrass maturity (density and organic matter accumulation)

A second objective of this project was to determine the impact of the addition of organic matter (peat) at the time of construction on pesticide leaching from experimental, sand-based putting greens.

During the summer of 1993 we experienced major lightning storm damage to our main research facility, so as of this date not all of the objectives of this research project have been met.

This study was designed to examine a wide range of conditions that are known to affect pesticide leaching. For example, the soils used ranged in texture from sand, with a high potential for pesticide leaching, to a silt loam soil, which has a nominal potential for pesticide leaching. The pesticides used also reflect a range in potential for leaching, with mecoprop (MCPP), trichlorfon (Proxol), and isazofos (Triumph) having a high potential for leaching, and triadimefon (Bayleton) having an intermediate potential for leaching. Climatic factors, like the amount of rainfall and/or irrigation, that also influence pesticide leaching were also evaluated in this project. Table 1 summarizes all the factors studied.

Experimental Conditions

These experiments were conducted in the field to simulate actual golf course conditions, but without the golfers. The sites were

Table 1
Factors Evaluated in Golf Course Environmental Research Project, Cornell University

	Soil		Pesticide	Climatic	
Site	Texture	Leaching	Name	Leaching	Rainfall/Irrigation
Fairway	Sand	High	Isazofos	High	Above normal
	Sandy loam	Intermediate	Mecoprop	High	Normal
	Silt loam	Nominal	Triadimefon	Intermediate	
			Trichlorfon	High	
Green	Sand	High	Triadimefon	Intermediate	Normal
	Sand/peat (80/20)	Intermediate			

Table 2
Pesticides and Fertilizers Applied in Fairway and Green Study

Common Name	Trade Name	Formulation	Rate* of Application	Date of Application
Fairways				
Isazofos	Triumph	4 E	1.5 oz/1000 sq ft	Aug. 25, 1992
Mecoprop	Mecomec	Potassium salt	1.5 oz/1000 sq ft	Sept. 24, 1991
Trichlorfon	Proxol	80 SP	3.75 oz/100 sq ft	July 2, 1992
Triadimefon	Bayleton	25 WP	2 oz/1000 sq ft 4 oz/1000 sq ft	Sept. 24, 1991 Oct. 11, 1991
Fertilizer	Scotts	29-3-7	1 lb N/1000 sq ft	Sept. 1991 Oct. 1991 June 1992 Sept. 1992 Oct. 1992
Greens				
Triadimefon	Bayleton	25 WP	4 oz/1000 sq ft	Oct. 25, 1992

*For pesticides, rates are the amount of product applied

mowed frequently and were fertilized/irrigated at rates typically used on golf courses.

Fairway Studies

Fairways comprise the largest area of the more highly maintained portion of golf courses. Fairways therefore are where the largest quantity of pesticides and fertilizers are used on a high-quality golf course. Fairways usually are built with on-site soils that can range from very sandy soils to very fine-textured clays. It is known that the extent of either pesticide or nutrient leaching is highly dependent on soil properties. Thus, it is important to study nutrient/pesticide leaching from fairway areas representing several soil types.

This research was conducted at the ARESTS (Automated Rainfall Exclusion System for Turfgrass Studies) Facility at the Cornell University Turfgrass Field Research Laboratory in Ithaca, NY. This facility is designed to control all water going onto the turf (rainfall and/or irrigation) and collect all the water passing through the soil (leachate). During the months of May through October, a large cover on wheels (called a rainout shelter) quickly covers the experimental site if rain occurs. This allows us to control the amount of rainfall and irrigation during the growing season. In this study we used historic weather data and applied irrigation water that reaches the plots to mimic a normal rainfall pattern and an above-normal rainfall pattern. In this way we could determine if certain kinds of weather-type years are likely to result in greater pesticide/nutrient leaching than others.

The ARESTS Facility is composed of 27 free-draining lysimeters (plots) that are 12 ft × 12 ft, each containing nine 15"-deep plots divided into three soil types (sand, sandy loam, and silt loam). Each plot is individually irrigated. The site was seeded with Penncross creeping bentgrass in May of 1991. All of the systems are linked with a data acquisition/control system via computer. The site was completed in 1987 but reseeded with Penncross creeping bentgrass in May of 1991. The site was mowed three times per week (clippings removed) and irrigated so that at least 1" of rainfall/irrigation was applied per week.

Pesticides and fertilizer were applied to all but one plot of each soil type, which served as the untreated control treatment. The materials, rates, and dates of applications are shown in Table 2.

Putting Green Study

Highly sandy sites, such as putting greens, are often cited as being the most susceptible to nutrient and pesticide leaching due to high permeability, low organic carbon content, and low cation exchange capacity (CEC).

Inexpensive swimming pools provide a unique and useful means of creating large lysimeters.

During construction, the opportunity exists to modify sand with amendments that possibly will reduce both nutrient and pesticide leaching by increasing the amount of organic carbon and the CEC level. Thus, the objective of this section of the project was to determine the effect of an organic amendment (peat) on the leaching of pesticides from sand-based experimental putting greens. The site for this study is the Cornell University Turfgrass Field Research Laboratory, Ithaca, NY. The site was constructed during 1992 and sodded with washed creeping bentgrass on October 5-6, 1992. Plots consisted of 8 ft diameter USGA putting green profiles containing 12" of root zone mix, a 2" layer of coarse sand, and 4" of gravel at the bottom. Each plot was constructed using a small swimming pool that includes one outlet to collect the leachate. Reed sedge peat amendment was added to the slightly calcarious sand at a ratio of 80:20 sand to peat (v/v). Unamended sand was included as a treatment for comparison. Triadimefon was applied during the week of October 25, 1992.

For both studies there were four replicate plots of each treatment, and averages are shown in the accompanying tables.

Research Findings

The nature of these studies is such that we collected leachate samples from a depth of 15", which is considered the most important zone for retaining and degrading pesticides/nutrients. Under real-life conditions, this water must move deeper through the soil until it reaches the water table. Therefore, the

data presented here are not groundwater quality data, but are estimates of the maximum concentration of pesticide/nutrient that could reach groundwater, assuming a water table depth of 15". On sites with deeper water tables, concentrations would be less.

Pesticides

It was not surprising that pesticides leaching from experimental fairways were influenced by soil type, the characteristics of the individual pesticide, and the amount of precipitation/irrigation, as shown in Tables 3 and 4. This type of experiment is considered a *worst case scenario*: using highly mobile pesticides over a shallow water table on highly leachable soil (sand) and having a rainfall/irrigation pattern likely to cause leaching. However, the extent of the leaching was quite surprisingly high in these unusual cases. For example, 50% to 62% of the applied mecoprop (MCPP) leached from the newly established sand experimental fairway plot. This suggests that newly seeded turf, or other turf stands with very low shoot density, that is grown on very sandy soil is susceptible to pesticide leaching, assuming other factors important to pesticide leaching are present. Results from other research studies and from monitoring studies of actual golf courses have found mecoprop does not leach to any great extent.

We also observed in one case that leaching of the pesticide trichlorfon (Proxol) was unaffected by soil type. This is highly unusual for studies of this nature. However, with some understanding of the nature of this part of the study, the results can be explained. First, a highly water-soluble pesticide that does not easily bind to organic matter was applied, and a large amount of rainfall was received within the first eight days after application (4.4" and 9.6" for the normal and above-normal precipitation treatments, respectively). Highly water-soluble pesticides that do not easily bind onto organic matter can move through the soil via water if they are not quickly degraded. The extreme rainfall that occurred within the first eight days after application resulted in a large amount of pesticide leaching, primarily due to a water flow process known as preferential flow. In this case, water very rapidly moves through soil either in macropores (worm holes, cracks in soil, etc.) in non-sand soils (i.e., sandy loam and silt loam) or in other preferential pathways. The data from this study strongly confirms that preferential water flow did occur on these soils, caused by the heavy rainfall, and that pesticide leaching was heavily influenced by this preferential water flow.

The label for the pesticide isazofos (Triumph) states not to apply this material on sandy areas due to a potential for leaching into groundwater. Our results confirmed that isazofos does leach from sand, but the good news is that very little leaching was observed in the finer-textured soils (sandy loam and silt loam).

Pesticide properties are very important in understanding the potential for pesticide leaching. Triadimefon (Bayleton) is considered to have the lowest potential for leaching of the four pesticides used in these studies. For each soil, by precipitation treatments, the leaching of triadimefon was the lowest of the four pesticides. Little or no leaching was observed on the two finer-textured soils, and some leaching occurred from the sand experimental fairways that were only four months old.

The data are not shown due to the fact that triadimefon leaching from experimental greens was negligible. It is important to point out that these greens were sodded with a dense, washed creeping bentgrass sod two weeks before the pesticide was applied. This dense turf effectively eliminated pesticide

Table 3
The Percentage of Applied Pesticide Leached and Maximum Concentration of Pesticide Found in the Drainage Water from Experimental Fairways

Soil	Precipitation	Pesticide			
		Isazofos	MCPP	Trichlorfon	Triadimefon
		% of Applied Pesticide Leached / Maximum Concentration			
Sand	Normal	10.4 767*	51.00 1900	1.18 140	1.00 190
	Above normal	5.6 544	62.12 1400	3.44 467	2.44 118
Sandy loam	Normal	0.04 15	0.79 21	1.13 118	0.06 8
	Above normal	0.09 122	0.46 70	4.41 302	0.01 5
Silt loam	Normal	0.68 77	0.44 130	0.63 71	0.24 43
	Above normal	0.30 34	1.25 89	3.33 504	0.28 66

*Maximum concentration of pesticide detected in the drainage water (leachate), in ug/L (ppb)

Table 4
The Maximum Concentration of Nitrate and Phosphate Detected in the Drainage Water (Leachate) from Experimental Fairways

Soil	Precipitation	Sampling Period			
		Sept. 13 - Dec. 31, 1991		Jan.-Aug. 10, 1992	
		Nitrate	Phosphate	Nitrate	Phosphate
		– – – Maximum Concentration, mg/L – – –			
Sand	Normal	12.2(1)*	0.17	4.3	0.19
	Above normal	13.2(1)*	0.15	4.8	0.17
Untreated		<0.5	0.06	0.5	0.11
Sandy loam	Normal	3.5	0.08	3.6	0.11
	Above normal	3.1	0.11	3.5	0.09
Untreated		1.7	0.54	0.5	0.11
Silt loam	Normal	4.3	0.11	6.6	0.11
	Above normal	5.9	0.11	5.8	0.12
Untreated		<0.5	0.32	1.1	0.27

*Number in ( ) equals the number of samples above the 10 mg/L drinking water standard for nitrate nitrogen. Only 2 of the 1385 samples analyzed thus far were above 10 mg/L.

leaching (all of the leachate samples were below the detection limit of 5 µg/L), regardless of the root zone composition (sand vs. sand/peat). These data support the notion that dense turfed sites, even on straight sand, are not likely to be prone to pesticide leaching.

Nitrate and Phosphorus

Nitrate leaching into groundwater from golf courses and agricultural land treated with fertilizers is a concern because nitrate was found to be the major contaminant of groundwater in the United States in a recent U.S. Environmental Protection Agency groundwater quality survey of private and public drinking wells. Phosphorus leaching from golf courses could be a concern if the drainage water from the golf course ended up in surface waters like ponds, lakes, and streams where eutrophication threatens water quality.

The accepted drinking water standard for nitrate-nitrogen is 10 mg/L. Only 2 of the 1,385 leachate samples from the experimental fairways analyzed to date were above this standard. Most were way below the standard (< 1 mg nitrate-N/L). Therefore, nitrate leaching from moderately fertilized fairway turf, even from sand, is not significant.

Phosphorus levels in the leachate from the experimental fairways were seldom above the analytical detection limit of 0.05 mg/L. None of the fertilized sites had any leachate samples with concentrations greater than 0.3 mg/L, which often characterizes the phosphorus concentration of eutrophic surface waters.

Summary

As would be expected from any experiment that examines such a wide range of important factors that can affect pesticide/nutrient leaching, there is good and bad news. First the good news:

- Pesticide leaching from experimental fairways was found to be predictable and only occurs under the worst case scenarios. Thus, whenever possible, avoid applying pesticides under worst case scenarios.
- Dense, healthy turf dramatically reduces the risk of pesticide leaching, even on sites with the significant potential for leaching (sand-based putting greens).
- Nitrate and phosphorus leaching from experimental fairways was found to be minimal.

Now for the bad news:

- Turfed sites that are not dense can be prone to substantial pesticide leaching, assuming other conditions for leaching are present (e.g., mobile pesticide applied and water moving through soils).
- Preferential water flow greatly increases the potential for pesticide leaching.

These findings point to several things that golf course superintendents can do to reduce the potential for groundwater contamination via pesticide leaching:

- Know the sites on your golf course that have a high probability for leaching (sandy, low-organic-matter soils, shallow water table, thin turf, or newly seeded sites, and likelihood of excessive irrigation due to an inadequate irrigation system).
- Determine which pesticides are more likely to leach, and use them with caution on sites more prone to leaching. Information on pesticide properties is readily available, but is not listed on the pesticide label.
- Understand the conditions that are important in preferential water flow (period of heavy rainfall and excessive irrigation) and avoid the use of pesticides that are prone to leaching during these periods.

Experiments are underway to determine the effect of turfgrass stand maturity as reflected in density and organic matter accumulation (4-month-old turf vs. 3-year-old turf) on the leaching of mecoprop from experimental fairways. It is our belief that the leaching of mecoprop will be substantially eliminated on turf that has matured.

Publications from This Project:

Petrovic, A. M., R. G. Young, C. A. Sanchirico, and D. J. Lisk. 1991. *Migration of Isazofos Nematocide in Irrigated Turfgrass Soils.* Chemosphere 28:721-724.

Petrovic, A. M., R. G. Young, C. A. Sanchirico, and D. J. Lisk. 1994. *Triadimenol in Turfgrass Lysimeter Leachate After Fall Application of Triadimefon and Overwatering.* Chemosphere 28:(in press).

Petrovic, A. M. 1993. *Leaching: Current Status of Research.* J. Intern. Turfgrass Res. Soc. 1.

Petrovic, A. M., R. G. Young, J. G. Ebel, and D. J. Lisk. 1993. *Conversion of Triadimefon Fungicide to Triadimenol During Leaching Through Turfgrass Soils.* Chemosphere 26:1549-1557.

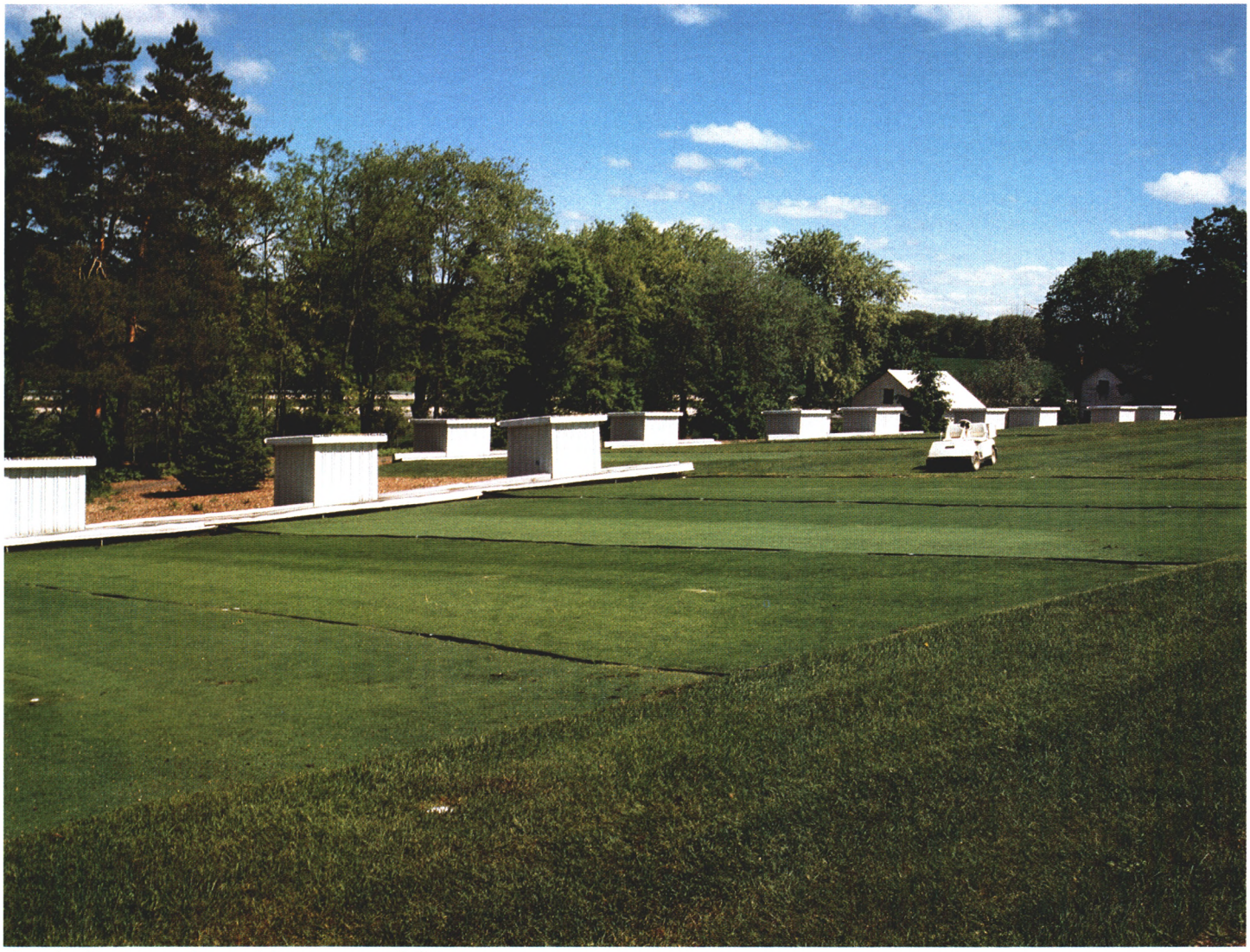
Petrovic, A. M., W. H. Gutenmann, J. G. Ebel, and D. J. Lisk. 1993. *Leaching of Mecoprop Herbicide Through Turfgrass Soils.* Chemosphere 26:1541-1547.

Petrovic, A. M., R. G. Young, C. A. Sanchirico, and D. J. Lisk. 1993. *Downward Migration of Trichlorfon Insecticide in Turfgrass Soils.* Chemosphere 27:1273-1277.

Each lysimeter has an individual collection port to sample and monitor the water moving through the different soil types.

Transport of Runoff and Nutrients from Fairway Turfs

by DOUGLAS T. LINDE, DR. THOMAS L. WATSCHKE, and JEFFREY A. BORGER
Pennsylvania State University



Creeping bentgrass and perennial ryegrass runoff plots.

GOLF COURSES have some potential for offsite movement of nutrients in runoff water because of large, intensely maintained turfgrass areas. A better understanding of this potential would help turf managers as they use management techniques to reduce the possible movement of nutrients from golf courses.

In the limited publications concerning runoff from turfgrass, runoff, sediment, and nutrient transport were significantly reduced by turfgrass systems (Bennett, 1979; Gross et al., 1990, 1991; Harrison et al., 1993; Morton et al., 1988; Watson, 1985). These studies did not include information concerning runoff or nutrient transport from immature turfs or turfs maintained as a golf fairway. Therefore, a study was conducted that assessed runoff and nutrient transport from two commonly used fairway turfs, creeping bentgrass and perennial ryegrass, from seedling stage through maturity.

The growth habit of these two turf species is quite different. Creeping bentgrass is a

fine-textured, stoloniferous (produces aboveground stems called stolons) species. It forms a turf with superior shoot density (>200 tillers/dm^2) when closely mowed and develops a definite thatch layer (Turgeon, 1985). Perennial ryegrass is a medium-textured, bunch-type (non-creeping tufts) species. It forms a turf with a good shoot density (100 to 200 tillers/dm^2) when closely mowed and develops no definite thatch layer (Turgeon, 1985).

The objectives of this study were to determine the amount of nitrate-nitrogen and phosphate in runoff and leachate samples and to compare runoff volumes from the two turf species.

Methods and Materials

The study was conducted on plots at the turfgrass runoff facility located at the Pennsylvania State University's Landscape Management Research Center on the University Park campus. The site has a variable slope (9% to 11%), and the surface soil is a severely eroded clay.

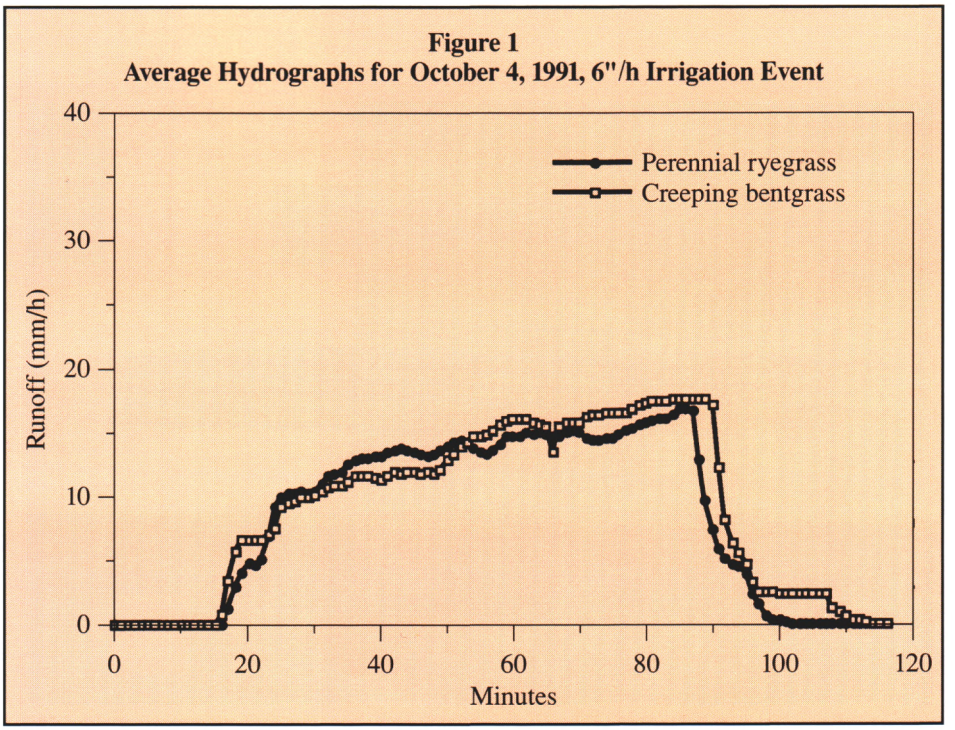
In July 1991, three runoff plots, each 1300 sq ft, were seeded with Penneagle creeping bentgrass, and three plots were seeded with a perennial ryegrass blend (Citation II, Commander, Omega II). Only triple-superphosphate was applied prior to seeding.

Plots were mowed with a reel mower at a height of 0.75" with clippings remaining. Cultivation practices such as core cultivation, verticutting, and spiking were not used during the study. Irrigation, other than that scheduled to provide adequate runoff and leachate samples, was conducted only when the turf was under moisture stress and for durations that would not produce runoff or leachate samples. Tiller density and thatch thickness were determined monthly to help characterize the surface vegetation of the two turfs.

The fertilizer used in the study was a 32-3-10 (N-P_2O_5-K_2O) fertilizer (O. M. Scott & Sons, Marysville), with 0.5% NH_4-N, 24.8% urea and methylene urea-N, P derived from monoammonium phosphate, and K from K_2SO_4. The turfs were fertilized on eight dates from October 1991 to October 1993 at a rate that applied 1 lb N/1000 sq ft. The turfs also were fertilized on one date with urea (46-0-0) at 1 lb N/1000 sq ft.

Water samples were collected from runoff events forced with irrigation and on occasion from rainstorms. Approximately 24 hours following a fertilizer application and on other selected dates, runoff was forced with irrigation at an average rate of 6" per hour to provide runoff and leachate samples for nutrient concentration analyses. A runoff hydrograph and volume were recorded for each plot. Irrigation duration varied from 7 to 35 minutes, depending on the turf species and soil moisture content.

Figure 1
Average Hydrographs for October 4, 1991, 6"/h Irrigation Event



Runoff was sampled at the rate of 16 ml/min throughout an event's duration to form a composite sample. A composite leachate sample was made from four subsurface samples per plot, leached 6" below the soil surface. Nutrient concentration analyses were based on samples collected from a total of 22 irrigated and rainstorm runoff events that occurred between August 1991 and October 1993.

Due to major differences in environmental and hydrologic conditions for each runoff event, comparisons were limited to individual dates. Also, runoff events from rainstorms often did not provide a full data set because runoff did not occur on all plots. In these cases, averages were based on the number of plots that provided data and were not included in any statistical analysis.

Results and Discussion

During the experimental period (August 1991 to October 1993), detectable levels of runoff (>0.6 mm/h) occurred due to rainfall on 5 dates. These runoff events occurred in response to intense rainstorms, usually containing short-term heavy downpours typical of thunderstorms.

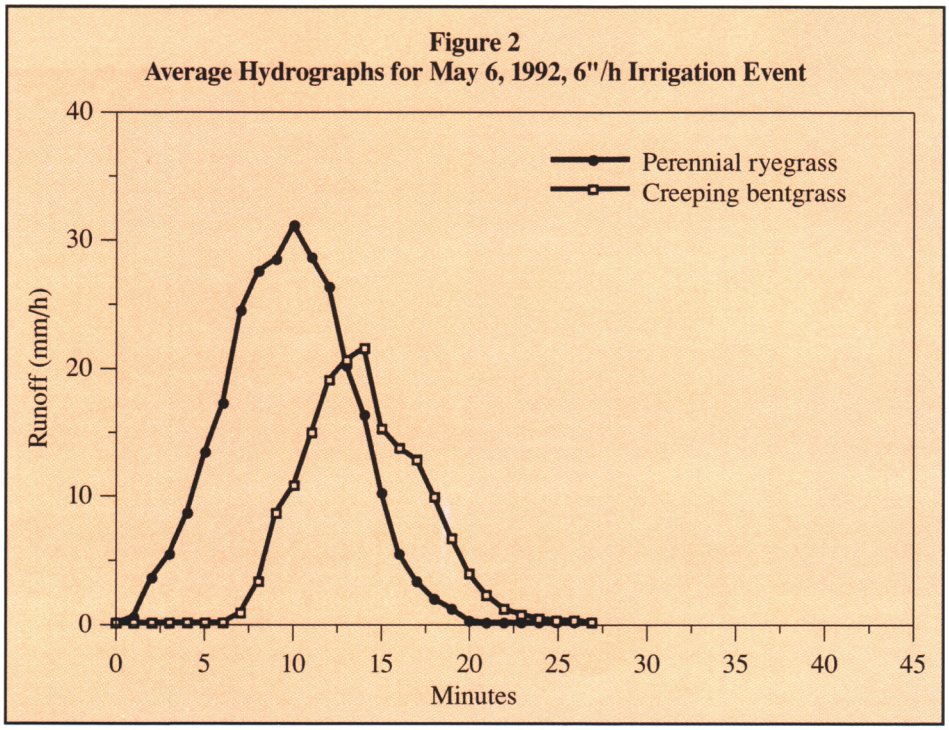
Average runoff volumes for all rainstorm events were lower for bentgrass than ryegrass plots. In addition, runoff volumes were consistently smaller, and the magnitude of the species differences was larger for the rainstorm events than the irrigation events. For example, on June 26, 1992, rainfall caused an average of 22 gallons of runoff from bentgrass and 109 gallons from ryegrass.

As the turfs matured, some interesting observations were made. On October 4, 1991, average runoff from the two turfs was similar (Figure 1). On this date (about 3 months after seeding), the turfs were immature and the bentgrass had not produced stolons or thatch. By the May 6, 1992, event (Figure 2), bentgrass had a significantly higher tiller density (860 tillers/dm^2) than the ryegrass (106 tillers/dm^2), and had begun to produce stolons. For the first time, runoff was found to be significantly different between the turfs. From then to the end of the study, runoff differences between the bentgrass and ryegrass plots were consistent. Runoff from the ryegrass plots occurred more quickly and at greater volumes than from the bentgrass plots. By July 1992, a measurable thatch layer had developed for bentgrass. No thatch was present in the ryegrass plots throughout the study.

When runoff was forced with irrigation in 1992, mean runoff values from bentgrass and ryegrass plots ranged from 1.8% to 22.5% of the total water applied. Values were always lower for the bentgrass plots that year, with 5 of the 7 events having a statistically significant species difference. Values determined by Harrison et al. (1993) for home lawn turfs ranged from 0% to 49%, but rarely exceeded 20% of total applied water.

Four additional experiments (Linde et al, 1994a) were conducted to provide some explanation of the runoff differences that developed between creeping bentgrass and perennial ryegrass. In one experiment, the average infiltration rates for the bentgrass

Figure 2
Average Hydrographs for May 6, 1992, 6"/h Irrigation Event



(2.5"/hr) and ryegrass (1.4"/hr) plots were not significantly different because of high sampling variation, which is typical for such measurements. In a greenhouse experiment that used 2.7 sq ft sloped trays of turf, we found that creeping bentgrass retarded the flow of surface runoff through its vegetation significantly more than perennial ryegrass. We also found that the leaves and stems of mature bentgrass intercepted 113% more water than the leaves and stems of mature ryegrass, and that bentgrass thatch slowed the initiation of runoff because of its high water-holding capacity and increased resistance to water flow.

From those four additional experiments, we determined that the high-density, thatch-forming bentgrass provided a more tortuous (winding) pathway for water movement. This increased the resistance to overland flow, which in turn increased the time that water spent on the turf, therefore allowing for greater overall infiltration on the bentgrass plots. As a result, for intensely maintained turf areas, selecting creeping bentgrass rather than perennial ryegrass would provide greater protection from surface runoff.

Nitrogen (NO_3-N) concentration in runoff and leachate were consistently lower than the 10 ppm drinking water standard set by the USEPA and rarely exceeded 7 ppm. Phosphate concentrations were also low and rarely exceeded 5 ppm.

Total Kjeldahl-N analyses were conducted on 1992 samples to determine the amount of fertilizer N that may not have yet been converted to the NO_3-N form. Because total Kjeldahl-N concentrations were low (rarely exceeding 2 ppm), it was assumed that most of the fertilizer N applied was in the soil above the subsurface sampler and/or did not become soluble and remained on the soil surface. To a lesser extent, the fertilizer could possibly have been converted to NO_3-N, absorbed by foliage and roots, utilized by the plants, and/or lost due to denitrification. As Harrison et al. (1993) had found, there was little indication in the runoff and leachate samples that fertilizer was ever applied.

Nutrient concentration and runoff volume per unit area were used to calculate nutrient loading rates in runoff and leachate for each turf. Loading rates of NO_3-N, phosphate, and total Kjeldahl-N were consistently lower than fertilizer and irrigation inputs of the nutrients.

Conclusions

Although creeping bentgrass reduced runoff more than perennial ryegrass, appreciable transport of NO_3-N, phosphate, and total Kjeldahl-N did not occur from either turf. Concentrations of NO_3-N, phosphate, and total Kjeldahl-N rarely exceeded 7, 5, and 2 ppm, respectively. In fact, nutrient concentrations and loading rates generally reflected those found in the irrigation water. Clearly, the nutrients in the fertilizer used in this study did not move in runoff or into subsurface samplers in amounts greater than found in the irrigation water. Under similar conditions on a golf course fairway, it would be reasonable to assume that little off-site movement of nutrients from the fairway would occur as a result of fertilization.

For golf courses that have potential runoff concerns, the selection of creeping bentgrass, which has more surface vegetation than perennial ryegrass, could reduce the amount of runoff from golf fairways, thereby reducing the potential off-site movement of nutrients and pesticides in runoff water.

The information from this study will be useful in the development of environmental models designed to determine the potential non-point impacts of nutrient applications on water quality. Current models and simulation software are not specifically modified for turfgrass conditions. In addition, the information from this study increases the database that a superintendent may refer to when communicating to others about the influence that golf courses have on the environment. Finally, this and other types of environmental research related to golf courses will be used to develop and refine management practices that the golf course superintendent can implement to protect the environment.

Further information regarding this research may be found in Linde (1993) and Linde et al. (1994a and 1994b).

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The Effect of Salinity on Nitrate Leaching from Turfgrass

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Column lysimeters planted to tall fescue or bermudagrass used to collect leachate in the greenhouse portion of the study.

SOIL SALINITY is a problem in the western United States due to the occurrence of soluble salts in many desert soils and irrigation with moderately saline water. In southern Nevada, irrigation has leached native salts below the root zone, creating a perched saline aquifer estimated at approximately 100,000 acre feet. Having an electroconductivity (EC) of 9 dS m^{-1} (approximately one fifth of seawater), this aquifer represents a potential threat to the deeper primary aquifer. As a resource, however, this aquifer contains enough water to satisfy the irrigation needs of many of the existing golf courses in Las Vegas for the next 20 years. If properly managed, this water supply could be used as an alternative or supplemental irrigation source, decreasing the demand on high-quality water while reducing the potential for contamination of the primary aquifer.

One concern about the use of saline water for turf irrigation, and the focus of our study, is that salinity might increase nitrate (N) leaching from turf. Since nitrogen is the most heavily used nutrient in turfgrass management, this concern is justified. In the case where N application exceeds the ability of the turfgrass to absorb the nitrogen, excess N could move from the soil-plant system into water supplies. The degradation of lakes and streams, the possible permanent contamination of groundwaters, and possible health hazards related to waters high in nitrate are all consequences of inefficient or improper use of nitrogen fertilizers.

Numerous studies have documented the effects of environmental factors and management practices on nitrate leaching from turfgrasses. For example, Brown et al. (2) measured concentrations of nitrate as high as 74 ppm N in the leachate below bermudagrass following application of ammonium nitrate, with total leaching loss of 23% of the applied N. For comparison, 10 ppm NO_3-N is considered the maximum for safe drinking water. Snyder et al. (9) found peak NO_3-N concentrations between 20 and 40 ppm N in

Table 1
Nitrogen Uptake Efficiency for Tall Fescue and Bermudagrass at Three N Application Rates

Efficiency is calculated as average daily N removed in clippings (based on regression analysis) divided by the average daily N addition (monthly divided by 30, amounting to 1.52, 3.03, and 4.55 mg N/column/day for the low, medium, and high N rates, respectively).

Species	N Rate	N Removed in Clippings (mg N/column/day)	N Uptake Efficiency
Tall Fescue	Low	1.38	93
	Medium	2.30	77
	High	3.31	74
Bermudagrass	Low	1.42	95
	Medium	2.60	87
	High	3.68	82

the soil solution below the turf rootzone 5 to 10 days after applying 1 lb N/1000 sq ft as NH_4NO_3. Up to 56% of the applied N was lost during a 3-week period. However, minimizing the downward movement of water by carefully controlling irrigation with tensiometers reduced losses from 56% to 2% (10).

In contrast to these findings, Rieke and Ellis (8) reported little effect of fertilization on nitrate leaching following application of 6 lbs N/1000 sq ft per year to a mixed turf. Starr and Deroo (11) found similar low leaching losses. Mancino and Troll (7) investigated nitrate leaching from a creeping bentgrass turf under conditions favoring heavy leaching losses (sand rootzone, soluble nitrate-based fertilizers, and 46% leaching fraction). When the fertilizers were applied weekly at a rate of 0.2 lb N/1000 sq ft, nitrate leaching averaged less than 0.5% of the applied nitrogen. Even at the rate of 1 lb N/1000 sq ft, cumulative losses averaged only 3.5% for the nitrate sources. Gold et al. (6) reported a maximum flow-rated NO_3 concentration of 1.62 ppm N in the leachate from a home lawn fertilized with 5 lbs N/1000 sq ft per year. Approximately half of the leachate samples had NO_3 concentrations at or below 0.1 ppm N. Cohen et al. (3) monitored NO_3-N in wells at four golf courses on Cape Cod over a two-year period. Nitrate concentrations in the shallow groundwater increased over background in response to turfgrass fertilization at three of the four courses. However, average concentrations were all below 10 ppm NO_3-N. Bowman et al. (1) presented data indicating that rapid biological immobilization, both by the turf and soil microorganisms, may reduce leaching losses by limiting the period of time that the fertilizer N is resident in the soil. However, no studies have investigated the effects of salinity on nitrate leaching.

Since salinity inhibits nitrogen uptake in a number of species, the use of saline irrigation water on turfgrasses could increase nitrate leaching and contamination of groundwaters. The objectives of this research were 1) to determine the effects of salinity and N application rate on nitrate leaching and N mass emission from turfgrass under greenhouse conditions, and 2) to determine the effects of salinity and leaching fraction on nitrate leaching and N mass emission from a bermudagrass and tall fescue turf under field conditions.

Two experiments were conducted to examine the effects of salinity on NO_3 leaching from turfgrasses. The first was a greenhouse study conducted from February through December, 1992, to address the objectives under tightly controlled environment conditions. Monarch tall fescue and NuMex Sahara bermudagrass were grown in PVC columns filled with a loamy sand and outfitted with a vacuum sampling system to collect drainage. Treatments consisted of three N levels (0.5, 1, and 1.5 lbs N/1000 sq ft per month applied as NH_4NO_3) and three irrigation salinity levels (ECs of 0, 1.5, and 3 dS m^{-1} for tall fescue and 0, 3, and 6 dS m^{-1} for bermudagrass) in a 3×3 factorial arrangement. The salinity ranges were chosen as being potentially stressful but non-lethal. Irrigation was scheduled twice each week to provide a relatively high leaching fraction of 30%. This leaching fraction was imposed to rapidly equilibrate rootzone salinity while increasing the potential for NO_3 leaching. Leachate was collected after every irrigation and analyzed for salts and NO_3-N. Clippings were collected and analyzed for total N.

Salt content of the leachate rose steadily during the first four months of the experiment and then leveled off, indicating that a constant salt profile had been attained. Leachate ECs for the 0.1, 1.5, 3.0, and 6.0 dS m^{-1} salt treatments stabilized at approximately 0.3, 4.5, 9, and 15 dS m^{-1}, respectively. These values are close to those predicted based on a leaching fraction of 30%.

Total monthly irrigation data for the April through September period were used to examine the effects of N and salinity on irrigation requirement. In both grasses, the high salinity treatments reduced irrigation by 9% compared to the low salinity treatments, whereas high N increased irrigation 10-14% relative to low-N treatments. Similar effects of N rate (4) and salinity (5) have been reported for water use by bermudagrass turf.

Average monthly NO_3-N concentrations in the leachate ranged from less than 0.1 to 1.2 ppm N in the bermudagrass (Figure 1) and from less than 0.1 to 3.3 ppm in the tall fescue (Figure 2). Highest NO_3 concentrations occurred during February and April, whereas consistently low values were found from June through December. Since the two grasses were growing slowly during late winter/early spring, the high values could be due to a lower growth demand for N. Expressing the NO_3-N concentration as an average based on the total volume of leachate, approximately 0.2-0.25 ppm N is calculated for the bermudagrass leachate and 0.75-1.0 ppm N for the tall fescue leachate. When compared to the tap water, which contained 0.1-0.2 ppm NO_3-N, it is apparent that N applied to bermudagrass contributed very little to net NO_3 leaching. While greater amounts of applied N leached from the tall fescue, the average concentrations were very low, considerably below the critical 10 ppm N level. There were no obvious effects of either salinity or N application rate on the concentration of NO_3 in the leachate from either grass. Significantly, of the nearly 2100 samples analyzed during this study, none was above the critical level of 10 ppm N. These data are consistent with previous results demonstrating the ability of turfgrass systems to rapidly immobilize applied N (1) but further suggest that the N uptake systems of turf roots and associated microorganisms were not appreciably impaired by the moderate salinity levels used in this study.

Cumulative nitrate-N leached over the 11-month experimental period amounted to approximately 10 mg N/column for the tall fescue and 2-3 mg N/column for the bermudagrass, representing 1.0% and 0.3% of the applied N, respectively. This does not consider the amounts of N present in the irrigation water. Much of the total loss

occurred during March through May, with very little additional loss recorded thereafter. This pattern was probably due to the unintentionally high volumes of leachate collected during March and May. Again, there was no apparent or consistent effect of salinity or N application rate on nitrate leaching in either species.

Clipping dry weight and percent N in the tissue were used to calculate the amount of N partitioned to leaf tissue and removed in clippings (Table 1). Nitrogen removal increased with increasing N application rate, but there was no effect of salinity. The average daily N allocations to leaf tissue

Figure 1
Monthly Average NO_3 Concentration in the Leachate from Bermudagrass Turf (Study 1) Fertilized with Three Rates of N and Irrigated with Three Levels of Salinity

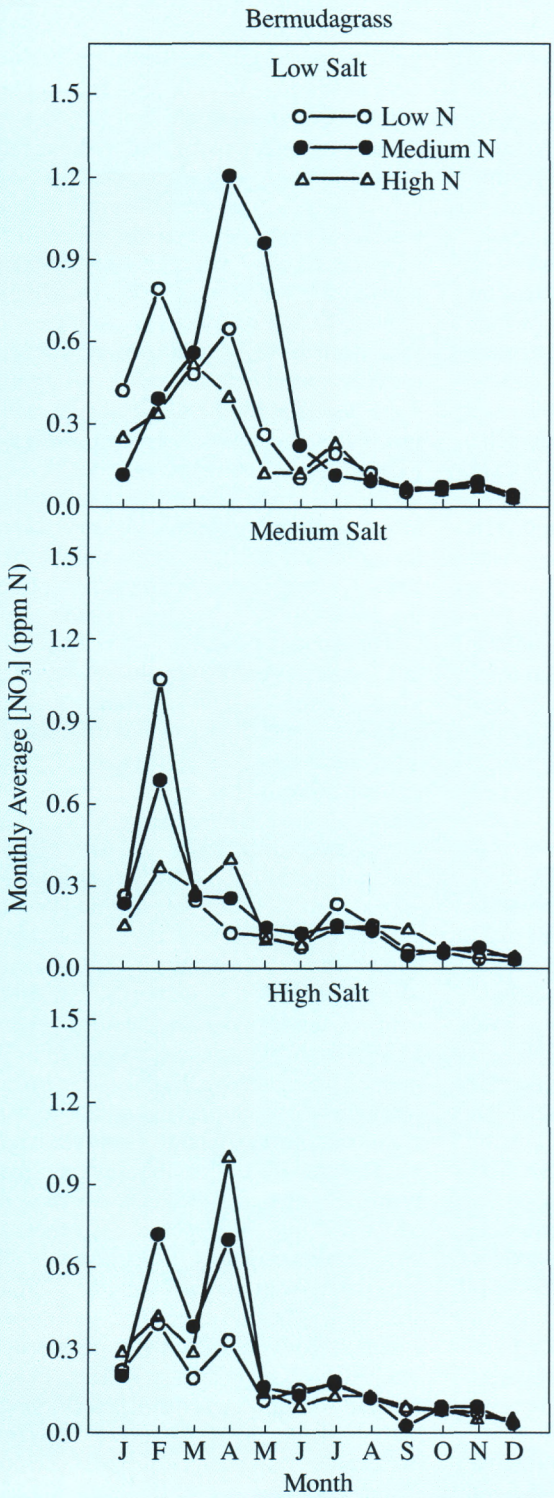
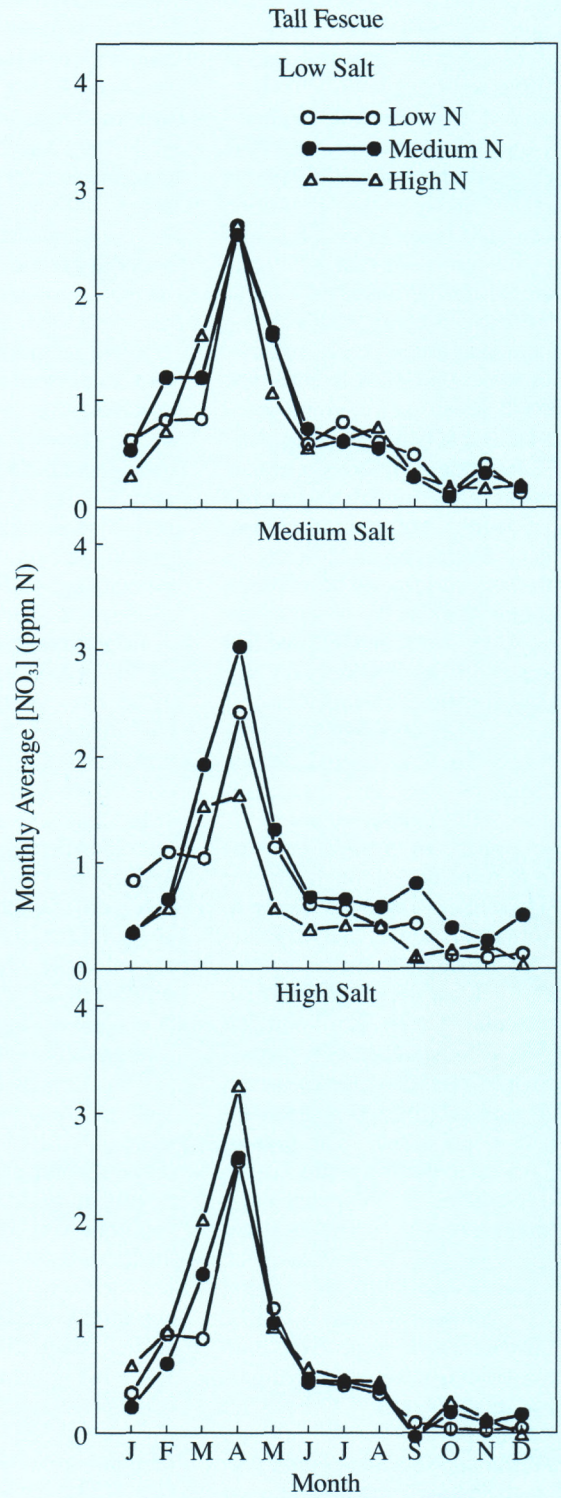


Figure 2
Monthly Average NO_3 Concentration in the Leachate from Tall Fescue Turf (Study 1) Fertilized with Three Rates of N and Irrigated with Three Levels of Salinity



were compared to the N addition rates and used to estimate long-term uptake efficiency. Uptake efficiency decreased in both turf species with increasing N rate (Table 1). At the low N rate, N recovery in clippings was greater than 90% for both species, whereas at the medium and high N rates, bermudagrass clippings contained approximately 10% more of the applied N than the tall fescue clippings. These values indicate very efficient absorption of applied N by the turfgrasses, and suggest that over the long term, a mature turf allocates most acquired N to new leaf tissues. It must be considered that this research was performed on a young turf system with clippings removed, and in which very little soil organic N is likely to have accumulated. Consequently, mineralization of organic N would supply little N to the turf. If mineralization of soil organic N contributed significantly to the N nutrition of the turf, as might be the case in an older turf system, it is probable that additional applied N would not be absorbed as efficiently. Under such conditions, NO_3 leaching might be higher than found in this study.

The results of the first study indicate that irrigation of tall fescue and bermudagrass turf with moderately saline water should not increase NO_3 leaching as long as adequate leaching prevents salts accumulating to toxic levels in the root zone. Measures of growth, such as clipping production or N allocation to leaf growth, were not affected by moderate salinity. This indicates that the grasses were under relatively low stress, and may explain why there was no effect of salinity on NO_3 leaching. If salinity stress were greater, or if multiple stresses were imposed, it is possible that N use efficiency would decline and NO_3 leaching increase. This question is addressed in the field study discussed next.

The second phase of this project was conducted from April 1991 through December 1993 at Horseman's Park, Las Vegas, to examine the effects of salinity and irrigation regime on NO_3 leaching from turfgrasses. This was part of a larger study examining the individual and combined effects of nitrogen application rate, salinity, and drought on turfgrass performance. The plot area measured 131 by 220 ft, with half planted to bermudagrass and half to tall fescue. The present study was confined to those sub-plots at the east and west end of the field receiving NH_4NO_3 at the rate of 1 lb N/1000 sq ft per month.

Seed of NuMex Sahara bermudagrass and Monarch tall fescue was sown June 3-7, 1991, at 1 lb and 8 lbs/1000 sq ft, respectively, and the turfgrasses established by accepted procedures. Good quality water (EC less than 1.0 dS/m) was used to irrigate the turfgrass during establishment. Bermudagrass was overseeded with Palmer Prelude perennial ryegrass (*Lolium perenne* L.) in early October.

A linear gradient irrigation system (LIGIS) supplied the irrigation treatments, with a gradient ranging from 125% of potential evapotranspiration to 0. Briefly, 6 parallel irrigation lines were installed 44 feet apart, with heads spaced at 22 feet (double overlap) on each line. The three lines at the east end of the field supplied good quality municipal water while the three lines at the west end supplied saline water (during turf establishment all lines supplied fresh water). Water from the saline aquifer was blended with fresh water to an EC of 6.0 dS m^{-1} and stored in an on-site reservoir from which it was pumped for irrigation. The established turf was irrigated with all lines for 10 months of the year. The irrigation gradient treatment was imposed for a 60-day period beginning July 8, 1992, and July 7, 1993, by shutting off the outide irrigation line on both the freshwater (east) and saline water (west) sides of the plot. This provided a water gradient on the fresh side and a combined water/salt gradient on the saline side. The experiment thus consisted of four separate treatment combinations, with two species and two salinity levels combined in a factorial arrangement. Outside irrigation lines were turned on again after the 60-day treatment period, reestablishing constant volume irrigation across the plots. Irrigation was scheduled 3 to 5 days per week to supply 125% of tall fescue ET.

Prior to planting, lysimeters (20" diameter by 43" deep) were installed at ground level either close to the gradient irrigation line (full irrigation, non-stressed) or toward the outside of the gradient (deficit irrigation, drought stressed). Lysimeters were equipped with suction extraction cups buried at the bottom. After each irrigation, a vacuum was applied to the extraction cups to collect leachate. Leachate samples were then analyzed for NO_3 concentration, with mass emission of nitrogen calculated as the product of concentration and volume. Total N content of clippings was used to estimate nitrogen absorption by the plant.

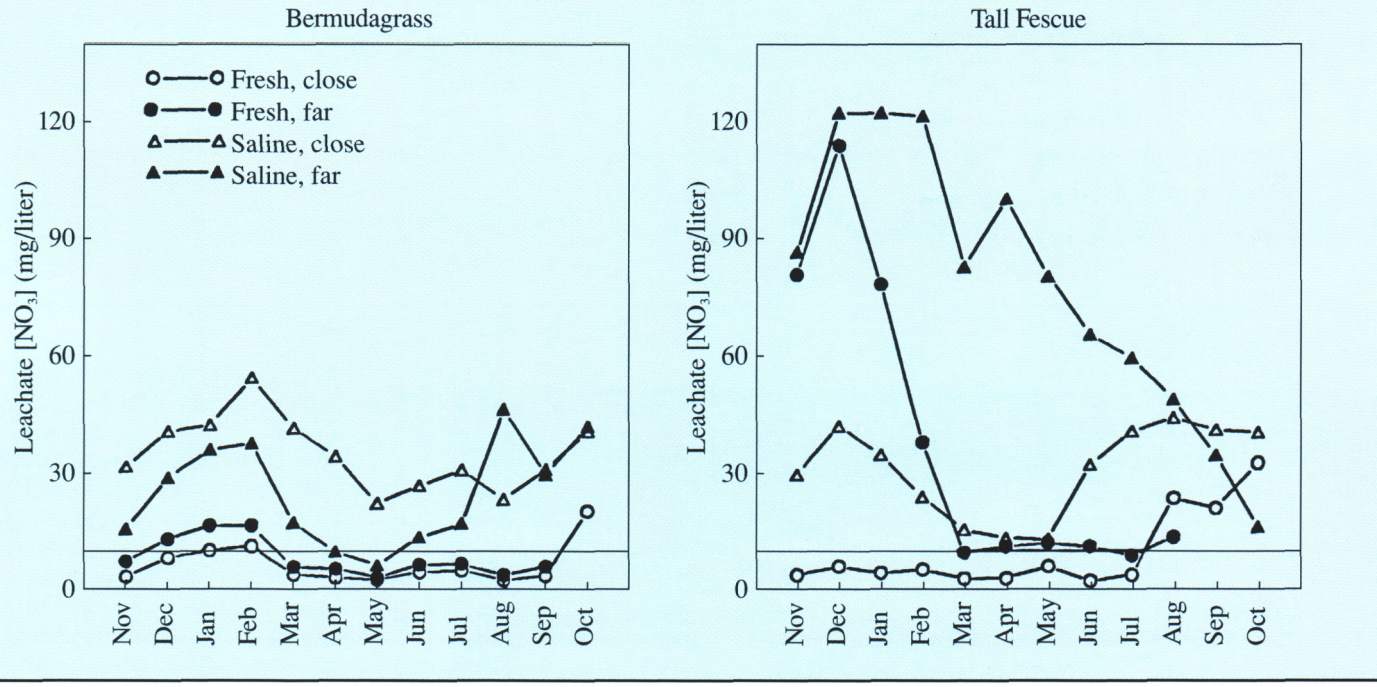
The data presented are from the second year of measurements and represent the more significant leaching data in terms of concentration and amount. However, it is helpful to understand the condition of the turf following the first year of treatment. Turfgrass growing in the lysimeters receiving adequate irrigation did not exhibit stress symptoms during the 60-day dry-down period. Bermudagrass irrigated with fresh water but growing in the outside lysimeters (drought stressed) was significantly impaired by water deficit, with considerable thinning to approximately 25% cover going into the fall of 1992. The combined stresses of drought and salinity (outside lysimeters, saline water) had a similar effect on the bermudagrass, with 25% cover at the end of the 1992 growing season. Tall fescue in the outside lysimeters was severely affected by both drought and the combined stresses to the extent that very few if any individual plants survived the 60-day stress period. Consequently, the outside lysimeters were sodded in late October, 1992, to reestablish the turf.

Nitrate leaching from bermudagrass irrigated with fresh water peaked during January and February, 1993, with concentrations exceeding 10 ppm N (Figure 3, left). It must be noted that the bermudagrass was dormant during this period, and it is unlikely that the overseeded perennial ryegrass had developed an extensive root system. From March through September, leachate NO_3 concentrations from bermudagrass irrigated with fresh water were low, ranging from 2 to 6 ppm N. Salinity increased NO_3 concentrations in the leachate up to 6 fold, with the highest values measured in February and then again in August and October. The highest NO_3 concentrations (nearly 60 ppm N) were associated with the inside saline lysimeters (adequate irrigation), although the bermudagrass appeared healthy and under little stress. It is possible that salinity affected rooting depth or density without appreciably inhibiting shoot growth, thus reducing plant uptake and increasing leaching potential.

The monthly pattern of NO_3 leaching from tall fescue differed from that of bermudagrass (Figure 3, right). Nitrate concentrations were generally low in turf irrigated with adequate amounts of fresh water. Concentrations were higher in turf irrigated with adequate amounts of saline water, with peaks during December, 1992, and then again in late summer, 1993. In both cases, the turf appeared to be under little stress. However, it is possible that heat stress alone or in combination with salinity affected either root activity or shoot demand for N, resulting in lower N absorption and greater leaching.

Very high NO_3 concentrations (up to 120 ppm N) were found in the outside lysimeters (drought stress) during the winter months, regardless of water quality. However, it must be remembered that the turf in these lysimeters died in 1992, and the new sod likely had not developed a deep root system. Further, monthly N applications continued in spite of the turf condition. Coupled with mineralization of the dead root system, it seems likely that there was considerable inorganic N present in the soil. This N would be easily leached when full irrigation was reestablished. Nitrate concentrations from the outside lysimeters irrigated with fresh water declined rapidly during January

Figure 3
Monthly Average NO_3 Concentration in the Leachate from Bermudagrass (left) and Tall Fescue Turf (right) for Inside and Outside Lysimeters Irrigated with Fresh or Saline Water in Study 2



through March, leveling off at approximately 10 ppm N. This may reflect the establishment of a deeper root system in the newly sodded turf, resulting in more efficient N absorption. Concentrations also declined in the outside lysimeters irrigated with saline water, but at a much slower rate. Again, the decline in concentration may be due to new root growth and better N absorption by the tall fescue. The slower rate of decline might indicate that rootzone salinity was restricting normal root growth or that N absorption was affected directly.

Mass emission of NO_3 was calculated based on the average daily N application rate and expressed as N leached relative to applied. Over the course of 1993, approximately 15-25% of the applied N leached from bermudagrass irrigated with fresh water, while 75-100% of the applied N leached from the saline treatments. This compares to approximately 5% of the applied N leaching from the inside, freshwater lysimeters planted to tall fescue. However, salinity alone or in combination with drought increased leaching from the tall fescue to 30-100% of applied N.

Comparing the results of the field study with the greenhouse column study, it is apparent that much higher concentrations and amounts of NO_3 are leached under the field conditions. This may be the result of higher rootzone salinity in the field, the severe impact of drought, or both. Based on growth data, the turf in the greenhouse study was under very little stress, in spite of soil solution salt concentrations approaching 9 and 18 dS m^{-1} for the tall fescue and bermudagrass, respectively. These salt concentrations, however, are low to moderate compared to those developing in the field under deficit irrigation (in excess of 40 dS m^{-1}). Collectively, the data suggest that where rootzone salinity is maintained at moderate levels and in the absence of other stresses, NO_3 leaching from turf is unlikely to be a concern. However, where salts build up in the soil to high levels, or when other stresses such as drought or heat are limiting turf growth, NO_3 leaching may be a very serious problem. Under such conditions, careful fertilizer and irrigation management may help to reduce the potential for NO_3 contamination of groundwater.

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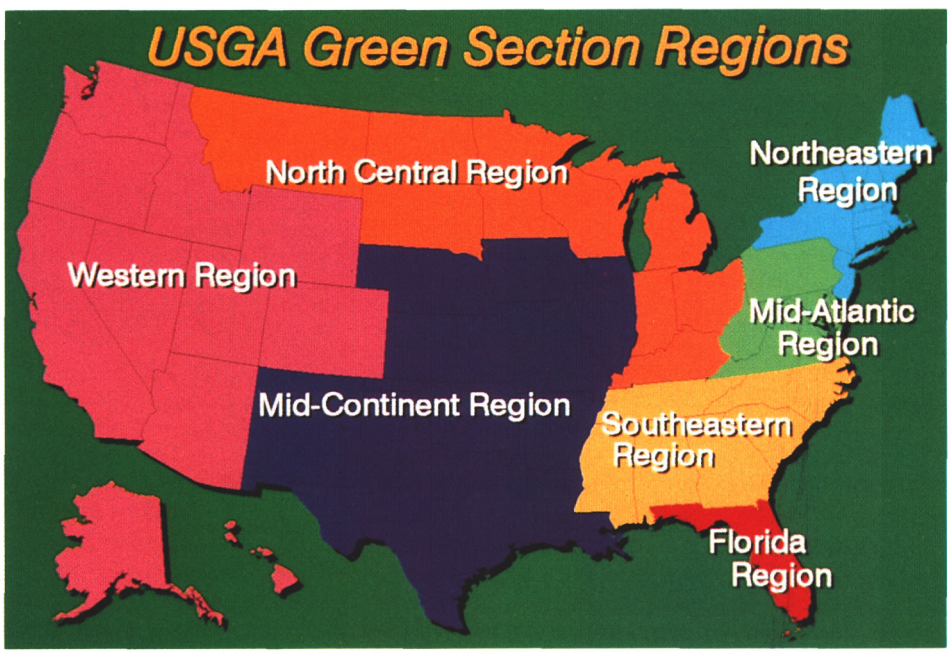
WINTER NEWS NOTES



Several Green Section Regions Are Reorganized For 1995

In an effort to provide better service to the clubs and courses that participate in its Turf Advisory Service, the Green Section has reorganized several of its regions. The changes also will accommodate a slight reduction in the size of the staff, with the retirement of Jim Latham, and will more evenly distribute the current workload among the regional agronomists.

Four of the seven Green Section regions will see changes in the states they serve, and three regions will see changes in personnel as well. The changes are based in part on the success of establishing more than one office in a region, as was done in the Northeastern Region 10 years ago and in the Western Region in 1993. By locating agronomists closer to the areas they serve, we have found that better service can be provided and greater use is made of the Turf Advisory Service.

Beginning in the East, the states of Ohio and Kentucky will become part of the new North-Central Region and will no longer be serviced by the Mid-Atlantic Region office. The North-Central Region will encompass the states of Kentucky, Ohio, Michigan, Indiana, Wisconsin, Minnesota, North and South Dakota, and Montana. These states will be serviced by newly appointed regional director Bob Brame, in Kentucky, and Bob Vavrek, who will stay at his present location near Milwaukee. Stan Zontek and Keith Happ will continue to service the Mid-Atlantic Region.

The Mid-Continent Region will gain the states of Illinois and Iowa in the reorganization, but will give up the states of Colorado and Wyoming. Jim Moore will remain the regional director, located at his office in Waco, Texas, and Paul Vermeulen will be moving from the Western Region office to establish a new office in central Illinois. From there he will provide advisory services to the northern section of the Mid-Continent Region.

The Western Region will pick up the states of Colorado and Wyoming, and will be replacing Paul Vermeulen with Mike Huck, a newly hired agronomist. Larry Gilhuly will remain as regional director from his office near Seattle, and Pat Gross and Mike Huck will continue to service the southern part of the region from their office in Southern California.

It has been more than a decade since major changes were made to the alignment of states in the Green Section's regions. Although the changes may bring new faces to TAS subscribers in some states, they also bring new opportunities for these clubs and courses to obtain a fresh perspective on their maintenance programs. And you can be sure that the agronomist who visits your course is experienced and excited about helping you bring out the best your course has to offer.

Stimpmeter® Available Through the USGA

The Stimpmeter® is available for purchase by turf management professionals through the USGA Order Department. Developed in 1976, the principal purpose of the Stimpmeter is to provide golf course superintendents a means of evaluating the effects of different management programs on the playing characteristics of putting surfaces. It also provides a precise method of evaluating greens for general play or competition play and for maintaining consistency from green to green.

To encourage its proper use, the USGA restricts sales of the Stimpmeter to golf course superintendents and course officials. The Stimpmeter is available through the USGA Order Department for $30 (plus shipping) by calling 1-800-336-4446.

Lois and Jim Latham

Jim and Lois Latham Retire to Texas

If you know anything about the Green Section's Great Lakes Region, then you are bound to know Jim and Lois Latham. And you probably know that after 10 years as regional director and office manager, respectively, Jim and Lois retired at the end of 1994. You might *not* know that both of them worked for the Green Section for 3½ years in the late 1950s, Jim as agronomist in the Southeastern Region and Lois as his secretary. In between, he served for 25 years as agronomist with the Milwaukee Sewerage Commission.

Jim will be sorely missed by his friends and associates on the Green Section staff and by the hundreds of golf courses he has helped along the way. In the terms of the current vernacular, Jim's work as an agronomist for the Green Section has been *awesome*. He's been an extremely hard worker and seemed to thrive on travel. In fact, he was kiddingly referred to as our Road Warrior for his frequent journeys through the hinterlands of Minnesota, the Dakotas, Montana, and Wyoming, visiting golf courses with nothing between them but hundreds of miles of pavement and lots of beautiful scenery.

After a 40-year career in the turfgrass business, Jim and Lois have retired to their native Texas. But unlike some of the putting greens Jim has had to deal with over the years, they're not going to let the moss gain a foothold on them! Lois is taking up golf again, and Jim has accepted a seat on the USGA's Turfgrass Research Committee, where he will attend regular meetings and help make monitoring visits to projects funded by the Committee. He also has agreed to help us sort through old Green Section files (1920 to 1960s) and put together a long-overdue history of the Green Section. With the experience, knowledge, and enthusiasm Jim has yet to offer, we want to be sure that, when asked, he will use that oft-quoted axiom, "With all I have going on in retirement, I wonder how I managed to *work* all those years!"

Their friends on the Green Section staff wish Jim and Lois many happy years in retirement.

Paul Vermeulen

Vermeulen Relocates to a Modified Mid-Continent Region

For seven years Paul Vermeulen enjoyed the ups and downs of life in the California sun, making Turf Advisory Service visits to golf courses throughout California and much of the Southwest. He also assisted other regions when they were in need, making him the most widely traveled agronomist on the Green Section staff. Now Michigan-born Vermeulen has taken a big step returning to the Midwest, establishing an office in Illinois (location not determined at the time of this writing) as part of the restructuring of the Green Section regions. The states of Illinois and Iowa will be joining Vermeulen in the Green Section's Mid-Continent Region, which is overseen by director Jim Moore from his Waco, TX, office. As part of the regional changes, the states of Colorado and Wyoming will join the Green Section's Western Region. In moving to the Mid-Continent Region, Vermeulen is replacing George Manuel, who resigned from the Green Section staff to become the golf course superintendent at the Pine Forest Country Club, near Houston, TX.

Paul brings outstanding experience to his new position. He is a Michigan State grad and received a Master of Science degree from Texas A&M University under the tutelage of Dr. James B. Beard. He can claim some hands-on experience in the Chicago area, having served his summer internship working at the Olympia Fields Country Club during 1983 and 1984, in the midst of the reconstruction of their North Course. Since joining the Green Section, Vermeulen has made more than 1,000 TAS visits throughout the country, written extensively for trade publications, and spoken at countless meetings and conferences. The courses utilizing the Turf Advisory Service in the northern section of the Mid-Continent Regin will be well served by the knowledge and enthusiasm Paul brings to the job.

Bob Brame

Brame Named Director of North-Central Region

Bob Brame, who for five years has served as an agronomist in the Green Section's Mid-Atlantic Region, has been named director of the newly formed North-Central Region. Joining him in making Turf Advisory Service visits in the region will be Bob Vavrek, who for the past four years was an agronomist in the now-defunct Great Lakes Region. Included in the North-Central Region will be the states of Ohio, Kentucky, Indiana, Michigan, Wisconsin, Minnesota, North Dakota, South Dakota, and Montana.

In providing advisory services to the region, Brame will be located at his office in Covington, KY, while Vavrek will work out of the former headquarters office of the Great Lakes Region in Mequon, WI. By establishing two offices in the region, it is hoped to provide more effective, efficient service to clubs and courses that subscribe to the Green Section's Turf Advisory Service. It is expected that Brame will concentrate his visits in the states of Kentucky, Ohio, and Indiana, while Vavrek will visit clubs along the northern border, from Michigan to Montana.

Bob Brame brings a wealth of experience to his new position as director of the North-Central Region. A graduate of Purdue University with B.S. and M.S. degrees in agronomy (turf option), he served from 1973 through 1989 as golf course superintendent at four different courses, the last being the Broadmoor Country Club in Indianapolis, IN. He began his golf career in 1966 as an assistant in a local pro shop, played on the golf team through high school and college, and today can pound a 1-iron as far as most of us can hit our drives.

Bob and wife Rhonda have a son, Scott, and a daughter, Jennifer. The Green Section wishes Bob the very best in his new position.

George Manuel Leaves Green Section Staff

George B. Manuel, agronomist for the USGA Green Section, has left the staff to become the golf course superintendent at Pine Forest Country Club, in Houston, Texas. George joined the staff in 1990 and has made Turf Advisory Service visits in the Mid-Continent Region, working with regional director Jim Moore. George's agronomic expertise and sense of humor will be greatly missed. His friends on the Green Section staff wish him continued success in his new position.

Turf Advisory Service Fee Changes for 1995

To keep up with the increasing costs of providing top-quality advisory services to its member courses and the game of golf, it's necessary for the USGA to increase the fees charged for the Green Section's turf advisory visits from time to time. Despite the increase this year, the USGA will be subsidizing the Turf Advisory Service with more than $1 million in 1995, reflecting a commitment to provide golf courses with the best services from a top-quality staff of 15 full-time agronomists.

Following is the fee schedule for 1995:

	If Paid by May 15	After May 15
Half-Day Visit	$ 900	$1200
Full-Day Visit	$1400	$1700

A visit by a Green Section agronomist is still a bargain for the many benefits that can be realized, perhaps more so now than ever. Please schedule your Turf Advisory Service visit early, and plan to join us for great golfing turf in 1995!

Subscription Changes for the *Green Section Record*

Due to rising production costs, 1995 subscription rates for the *Green Section Record* must be increased. Following is the annual fee schedule for 1995:

U.S. subscription	$15
Canada/Mexico	$18
International (air mail delivery)	$30

Six issues per year provide the most up-to-date information regarding agronomics, equipment, research advances, environmental issues, and maintenance philosophy in the field of turfgrass science. The *Green Section Record* is a favorite magazine of golf course superintendents, Green Committee members, and golfers interested in turfgrass and golf course management. Be the best in the business by reading the best information available in the business!

ALL THINGS CONSIDERED

A LOW-IMPACT GOLF COURSE? PROBABLY NOT!

by KEITH A. HAPP
Agronomist, Mid-Atlantic Region, USGA Green Section

THE USGA and the New York Audubon Society are jointly working to make golf courses enjoyable habitats for golfers and wildlife alike. Golf course architects focus on fitting courses into the environment, allowing for the use of the land while developing green space. The benefits of green space, both physical and emotional, have been documented by research. Turfed areas provide erosion control, filtration following rains, and generate oxygen that is returned to the atmosphere. No matter what the level of maintenance, I propose that many golf courses are not low impact.

Golfers themselves can have a tremendous impact on the manner in which their courses are maintained. Tolerating slight imperfections rather than insisting upon a zero-tolerance base would allow superintendents to implement integrated management approaches. A wait-and-see approach could be utilized. At times slight weather changes can affect disease activities. If the weather changes for the better, disease treatments may not be warranted. For many turf managers, this option is not available. Fear of losing employment more often dictates that preventative pesticide applications are the norm rather than the exception.

Golfers who love the game must be willing to tolerate some minor inconveniences during the season, such as aeration, so that turfgrass managers can implement the cultural programs needed to strengthen the turf and thus provide better wear and disease tolerance. Superintendents know that cultural and chemical programs must be balanced to provide the turf conditions desired. Players should view aerification as a proactive management approach and not postpone it until it is less inconvenient or disruptive. A healthy turf recovers from aerification much sooner, thus minimizing the disruption of play. Sound cultural programs implemented when they are most beneficial will have a tremendous impact on course conditions as well as the environment.

Television golf has given the false impression that golf courses are in perfect condition every day of the year. Perfection is impossible to achieve. Most tournament courses are prepared a year or more in advance to peak for a single week during the season. Even at these courses, during an entire season, turf conditions and playability change. When the superintendent is free to implement foundation cultural programs (when they are most beneficial), changes in turf quality and playability are less noticeable. More consistent playing conditions result.

No matter what the level of course maintenance (budget), golfers can have an impact on how the course affects the environment. If the superintendent says the turf needs to be aerified, then support him or her. Turf quality will be enhanced, but most important, the balance between cultural and chemical inputs can be maintained. Balanced inputs can easily be equated to the turf conditions golfers desire and the "low-impact" golf course most people speak of!

THE USGA

1995 GREEN SECTION NATIONAL & REGIONAL CONFERENCES

NATIONAL CONFERENCE

February 27	Green Section Educational Conference	San Francisco, California

FLORIDA REGION

April 4	Palm Beach Gardens Marriott	Palm Beach Gardens, Florida
April 6	Orlando Airport Marriott	Orlando, Florida

MID-ATLANTIC REGION

April 4	Woodholme Country Club	Pikesville, Maryland

MID-CONTINENT REGION

March 28	Lakewood Country Club	Denver, Colorado
March 30	Old Warson Country Club	St. Louis, Missouri
April 4	Dallas Athletic Club	Dallas, Texas

NORTH-CENTRAL REGION

March 9	Maple Bluff Country Club	Madison, Wisconsin
March 23	Inverness Club	Toledo, Ohio

NORTHEASTERN REGION

April 11	Country Club of Rochester	Rochester, New York
April 13	Colonial Hilton Hotel	Wakefield, Massachusetts
April 18	Headquarters Plaza Hotel	Morristown, New Jersey

SOUTHEASTERN REGION

March 14	Country Club of South Carolina	Florence, South Carolina

WESTERN REGION

March 7	Canterwood Golf & Country Club	Gig Harbor, Washington
March 15	Sharon Heights Golf & Country Club	Menlo Park, California
March 24	University of California — Riverside	Riverside, California
April 5	TBA	Las Vegas, Nevada
April 6	Arizona Country Club	Phoenix, Arizona
April 10	Makena Resort	Maui, Hawaii
May 8	Hillcrest Country Club	Boise, Idaho

TURF TWISTERS

TODAY'S DETECTED DIFFICULTIES

Question: How effective are the new disease detection kits now available for several major turfgrass diseases? (Georgia)

Answer: The kits are very good at allowing the golf course superintendent to confirm what disease is occurring on the turf. However, it isn't advisable to use the kits as your sole method for diagnosing the disease or to predict future diseases. The most reliable method is to identify turf disease using a microscope. A book by Patricia Sanders of Penn State, called *The Microscope in Turfgrass Disease Diagnosis*, shows golf course superintendents how to use the microscope and identify turf fungi using blades of the ailing grass.

OF LONG-RANGE GOALS

Question: Why is it important for our golf course to have Turf Advisory Service visits each season, rather than in alternate years? (Tennessee)

Answer: Once a plan is established by the USGA agronomist, the golf course superintendent, and the green committee, annual evaluations are recommended. This not only provides the course with short-term technical information, but it also allows for goals to be established that focus on the long-term objectives of the course.

IDENTIFY FUTURE COMPLEXITIES

Question: I have been approached by a group of investors who want to begin building a golf course in 1996. Unfortunately, I don't believe they understand the environmental complexities facing golf course construction and maintenance today. Is there a publication available that will help educate them on these crucial issues before they invest their money? (Texas)

Answer: Yes. In 1992, the USGA published a comprehensive book entitled *Golf Course Management and Construction: Environmental Issues*, edited by Dr. James C. Balogh and William J. Walker. It covers a wide range of environmental topics, including conservation of water resources, impacts of fertilizers and pesticides, wildlife and wetlands management, and integrated pest management. This 928-page book is available from the USGA Order Department (1-800-336-4446) for $69.95 plus shipping/handling.