What Happens to Pesticides Applied to Golf Courses?

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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

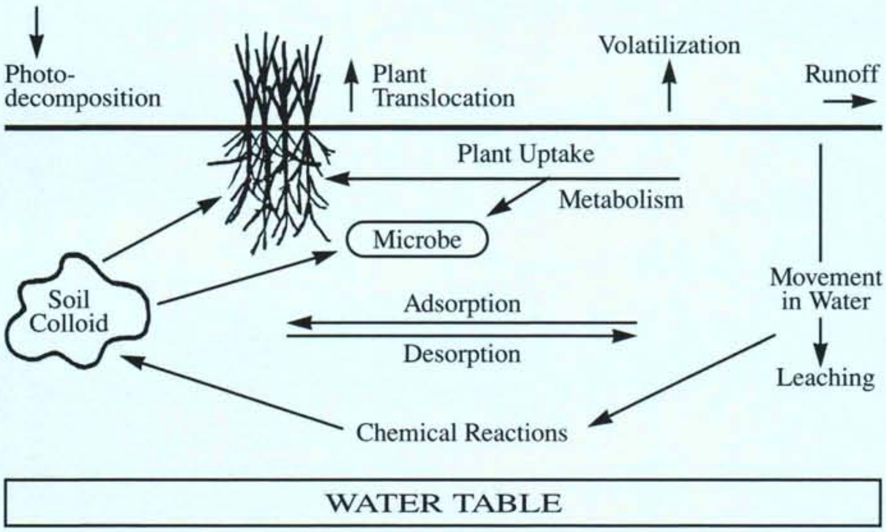
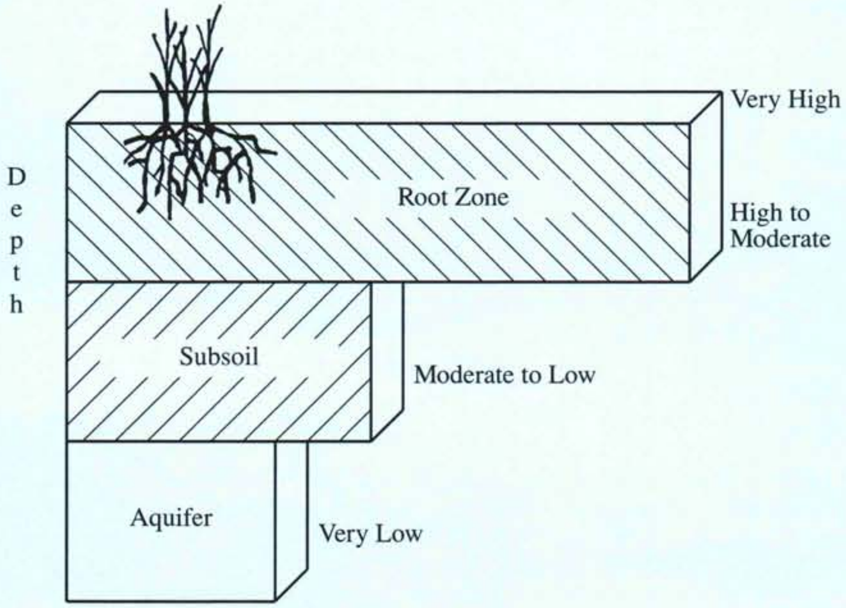


Figure 2
Changes in Microbial Activity with Depth



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 penetrates 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 nonpersistent (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

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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 overirrigation.

- Under the conditions of this study (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 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			Pesticide Trade Name
20C	25C	30C	Max. Conc. in Runoff (g/m^3)[c]	SCS Rating[d]		GUS	GUS[e] Ranking	SCS Ranking	
				Sediment	Soluble				
—	—	—	—	—	—	—	—	—	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.