PROTECTING GROUND AND SURFACE WATER

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Protecting ground 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 percent of the pesticides applied are used for agriculture 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.

In the late 1980's, golf was faced with a dilemma. On one hand, regulatory agencies responding to public concern routinely initiated environmental monitoring programs of ground 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 over zealous federal and state regulators looking for point source polluters raised concerns about a recreational game which 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.

In 1991, the game of golf needed to have answers to environmental questions, and the USGA wanted these answers based on scientific facts, not emotions. The USGA initiated a three-year study of the fate of pesticides and fertilizers applied under golf course conditions. This article first briefly describes what is known about the fate of chemicals used on golf courses and provides some supporting documentation to help choose a pesticide. Highlights of the research projects are then summarized.

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 breakdown into by products which are biologically inactive.

What processes influence the fate of pesticides and fertilizers applied to turf? In general, there are six categories 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 soil mobility, it is not necessarily the best criterion. In addition to pesticide solubility, the pesticides affinity to adhere to soils or sorption must be considered.

Sorption

The tendency of a pesticide to leach or runoff is strongly dependent upon the interaction of the pesticide with solids within the soil. The word sorption is a term that includes the process 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.

This difference is important because pesticides may become increasingly absorbed with time (months to years) and desorption (or release) of the absorbed pesticide may be reduced with time. The unavailable or undetachable 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) nature of the soil solution. In general, sandy soils offer little in the way of sorptive surfaces. Soils containing higher amounts of silt, clay and organic matter contents provide a rich 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}. A K_{oc} less than 300 to 500 is considered low. The strength of adsorption is inversely related to the pesticide's solubility in water and directly related to its partition coefficient. For example, chlorinated hydrocarbons are strongly adsorbed, while phenoxy herbicides like 2,4-D are much more weakly adsorbed.

Microbial Degradation

Pesticides are broken down 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, phosphorus, sulfur, 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 though 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 also influenced by factors such as: pesticide concentration, temperature, soil water content, pH, oxygen status, prior pesticide use, soil fertility, and microbial population. These factors change dramatically with soil depth and greatly reduce microbial degradation as pesticides migrate below the soil surface (See Figure 2).

Persistence of a pesticide is expressed as the time required for 50 percent of the original pesticide to breakdown into other products. This length of time is termed a half-life (DT_{50}). Half-life measurements are commonly made in the laboratory under uniform conditions. On the golf course, soil temperature, organic carbon and moisture content change constantly. These 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 is the combined pesticide breakdown that results from chemical, biological, and photochemical processes under field conditions which was of the most interest in the USGA sponsored studies.

Volatilization and Evaporation

Volatilization is the process by which chemicals transform 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 are generally lower following a late afternoon or an early evening pesticide application rather than in the late morning or early afternoon when temperatures are increasing. Volatilization also will increase with air movement and can be greater from an unprotected areas than from areas with windbreaks. Immediate irrigation is usually recommended for highly volatile pesticides to reduce loss.

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 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 ground or surface water contamination (See Table 2). In most all cases, level areas away from surface waters (rivers, lakes, or wetlands) will not be prone to pesticide runoff. 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 low in 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. When possible select a pesticide that poses the least threat to rapid leaching and runoff and is relatively non-persistent (See Table 3).

This is only a very brief overview of the processes which affect pesticide and nutrient fate. The the USGA sponsored environmental research projects, which were conducted from 1991 through 1994, not only support what is known about pesticide and nutrient fate, but often show that turfgrass:

- reduces runoff
- increases adsorption on leaves, thatch and soil organic matter
- maintains high mircrobial and chemical degradation rates
- reduces percolation due to an extensive root system, high plant uptake and transpiration rates.

Turfgrass areas generally rank second only to undisturbed forests in their ability to prevent pesticides and nutrients from reaching ground and surface water. Highlights from the USGA sponsored environmental research projects include the following:

University of Nebraska, Dr. Horst

- At 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 2 months in fairway-managed turf/soil. Thatch played a significant role in pesticide adsorption and degradation.

Iowa State, Dr. Christians

- Pesticides and fertilizers applied to Kentucky bluegrass have the potential to leach through a 20 inch soil profile under certain conditions.
- Pesticide and fertilizer leaching can be greatly reduced during the four weeks after a pesticide or fertilizer application by applying more frequent, light irrigations rather than less-frequent, heavy irrigations.
- The thatch layer in a mature turf reduces pesticides from leaching into the soil profile.

University of Georgia, Dr. 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 the leaching prediction model for agriculture (GLEAMS), this leachate should have been 50 to 60 ppb, a significantly higher number.
- 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 of chlorthalonil found to leach through the simulated USGA greens was less than 0.2% of the total applied.

- Data from fairway runoff plots with a 5 degree 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 inch rainfall at an intensity of 1 inch per hour. The runoff was attributed to a high clay soil. This could be prevented by waiting 4 hours to water, and only applying ¼ to ½ inch of irrgation.

Michigan State University, Dr. Branham

- Nitrate leaching was negligible, less than 0.2% of the applied nitrogen was recovered at a depth of 4 feet below the surface (deepest system among all the studies).
- The nitrogen detected was 10 times below the drinking water standard (0.43 ppm nitrate in spring and 0.77 ppm nitrate in fall).
- It is estimated that 0 to 34% of the nitrogen volatilized.
- Only three of the eight pesticides evaluated were detected in the percolate at four feet (levels of 2 to 31 ppb).
- 2,4-D is 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 and thus require closer management.
- The root zone and thatch had a high biological activity which works like a filter.

University of Massachusetts, Dr. 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 application for the insecticides isazofos and trichlorfon.
- Volatile loss reached a maximum when surface temperature and solar radiation were greatest. In order 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, the majority of volatile loss occurred during the first 5 days following application. Volatile residues were undetectable or at extremely low levels two weeks after application.
- Pesticide residues for all materials were rapidly bound to the leaf surface, with less than 1% of all residues dislodging eight hours after application.
- Irrigating treated plots immediately after application greatly reduced volatile and dislodgeable residues on the first day following treatment.
- Volatility was far below (up to 1000 times below) levels that should cause health concerns.

University of Nevada, Dr. 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.
- Very efficient uptake of applied nitrogen by the turf root system resulted in low levels of nitrate leaching from the two turfgrasses.
- 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 will be a problem.

University of California, Dr. Yates

- Turf maintained under golf course fairways and putting green conditions used all of the nitrogen applied - even with over irrigation.
- Based on uniformly low volatilization results, turf may need different volatility regulations than agricultural crops.
- 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 to adsorb the pesticide; however, up to 6.5% leached from the sandy putting green soil (expected level). 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 and bermudagrass).
- Little volatilization of carbaryl was measured (≤ 0.05%) from any of the plots.

University of Florida, Dr. Snyder

- A total of 98 to 99% of the insecticide applied stayed in thatch layer.
- More movement of the fenamiphos metabolite occurred than expected and may warrant different management practices may be warranted.

Cornell University, Dr. Petrovic

- More leaching occurred in newly established turf than in established turf.
- Fertilizer leaching did not exceed EPA drinking water standards.
- During the first year, extensive MCPP leaching on a coarse sand with poorly established turf occurred under a "worst case" use described on the label (50 to 60% leached through the profile).
- During the second year, a 7 inch rain (hurricane conditions) after application caused more substantial leaching on all soils.

Penn State, Dr. Watsche

- Significant differences between runoff of ryegrass (more) vs. creeping bentgrass (less) occured because of the presence of more stolons, more organic matter, and higher density in bentgrass.
- No differences occured among the turfgrass species for infiltration rates.
- Over time, the increase in thatch decreased runoff.
- The amount of irrigation was doubled (6 inches) in order to produce any runoff and indicates that turf is good at holding water.
- More than one half of all the samples analyzed had no pesticide in the runoff water. The remaining half had less than 10 ppb of the pesticides.
- All nitrogen and phosphorous runoff was less than EPA drinking water standards.

Table 1. Chemical and Physical Properties of Pesticides: Values Which Indicate Potential for Ground and Surface Potential for Ground 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_c	Less than 300 to 500
Henry's Law Constant	Less than 10^{-2} atm 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 ground and surface water contamination. The more of these conditions present, the greater the risks.

Chemical	Soil
• High Solubility • Low Soil Adsorption • Long Half-life (persistent) • Low Volatility	• Porous Soil (sand) • Low Organic Matter
Site	**Management**
• Shallow Water Table • Irrigated/Sloping Land • Near Surface Water • Sink Holes/Abandon Wells	• Incomplete Planning • Misapplication • Poor Timing • Over Irrigation

Figure 1
Processes Affecting the Fate of Pesticides in Soils

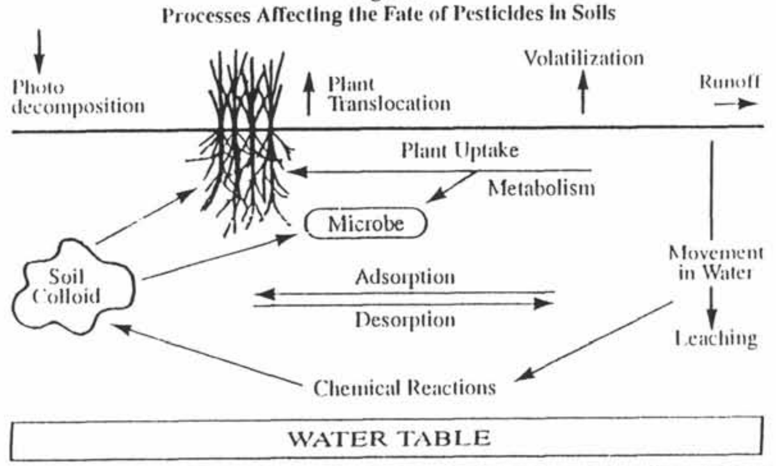

Figure 2
Changes in Microbial Activity with Depth

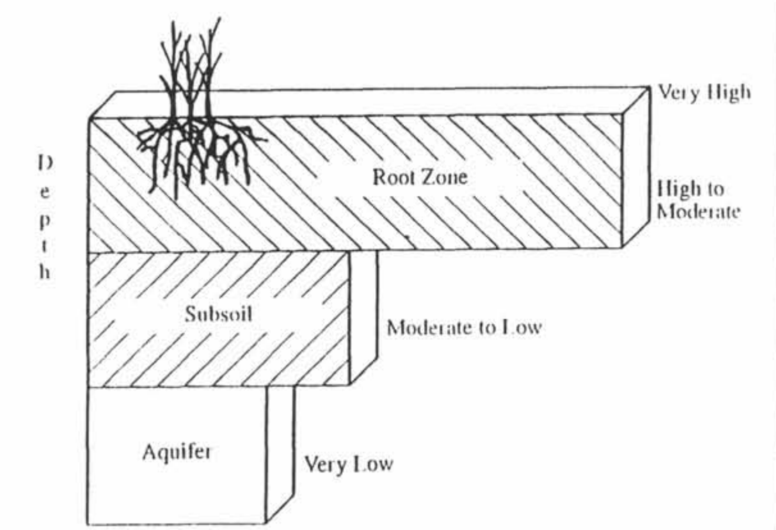

Table 3. Summary of pesticide properties and potential for surface and subsurface losses.

Pesticide		Water Solubility	Soil Adsorption	Half-life	Persistence	Vapor
Common Name	Trade Name	(ppm)	Koc	DT50 (days)	Classification	20 C
Insecticides and Nematicides						
Acephate	Orthene	818,000	2	3		-
Bendiocrab	Turcam	40	570	3-21	3-5	-
Carbaryl	Sevin	32-40	79-423	6-110	4	2.0E-04
Chlorpyrifos	Dursban	0.4-4.8	2,500-14,800	6-139	2-4	1.2E-03
Diazinon	Diazinon	40-69	40-570	7-103	2-4	1.9E-02
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	4.3E-03
Isofenphos	Oftanol	20-24	17-536	30-365	1-3	5.3E-04
Trichlorfon	Proxol	12,000-154,000	2-6	3-27	3-5	1.1E-03
Fungicides						
Anilazine	Dyrene	8	1,070-3,000	0.5-1	5	-
Benomyl	Tersan	2-4	200-2,100	90-360	1-2	1.3E-03
Chloroneb	Terraneb	8	1,159-1653	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	1.3E-02
Ferarimole	Rubigan	14	600-1,030	20	1	-
Fosetyl Al	Alliette	120,000	20	1	5	1.3E-03
Iprodione	Chipco 26019	13-14	500-1,300	7-30	3-4	2.7E-05
Mancozeb	Dithane or Fore	0.5	2,000	35-139	1-2	1.3E-02
Maneb	Manzate	0.5	2,000	12-56	2-4	1.3E-04
Metalaxyl	Subdue or Apron	7,100-8,400	29-287	7-160	1-4	2.9E-04
PCNB	Terraclor	0.03-0.44	350-10,000	21-434	1-3	6.7E-03
Propamocarb	Banol	700,000-1,000,000	1,000,000	30	3	-
Propiconazole	Banner	100-110	387-1,147	109-123	1	1.3E-04
Thiophanate-methyl	Fungo	3.5	1,830	10	4	1.3E-05
Thiram	Spotrete	30	670-672	15	4	1.3E-03
Triadimefor	Bayleton	70	73	16-28	3-4	1.1E-04
Vinclozolin	Vorlan					-
Herbicides						
Asulam	Asulox					-
Atrazine	Aatrex	33-70	38-216	17-119	1-3	4.0E-05
Benefin	Balan	0.1-1	781-10,700	2-130	5	4.0E-03
Bensulide	Betason	5.6-25	740-10,000	30-150	1-3	-
Bentazon	Basagran					-
DCPA	Dacthal	0.05	4,000-6,400	13-295		-
2,4-D acid	Many Names	682-1,072	20-109	2-30	3-5	1.1E-03
2,4-D amine	"	200,000-3,000,000	0.1-136	2-23	3-5	-
2,4-D ester	"	12	1,100-6,900	-		-
DCPA	Dacthal				1-3	-
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	2.0E-04
MCPA, salt		270,000-866,000	20	4-21	3-5	-
MCPP	Mecoprop	660,000	20	21	3	1.3E-05
MSMA	Daconate	-	-	1000	1	-
Oxidiazon	Ronstar	0.7	3,241-5,300	30-180	1-3	1.3E-04
Pendimethalin	Prowl	0.275-0.5	5,000	8-480	1-4	-
Pronamide	Kerb					-
Siduron	Tupersan	18	420-890	90	2	-
Simazine	Princep	3.5-5	135-214	13-94	2-4	8.1E-07
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	1.5E-02

Table 3. (Continued)

Pressure (Pa)		Potential Surface Losses			Potential Subsurface Losses			
		Max. Conc. in	SCS Rating			GUS	SCS	Pesticide
25 C	30 C	runoff (g/m3)	sediment	soluble	GUS	Ranking	Rating	Trade Name
-	-							Orthene
6.9E-04	-	5.6	Small	Large	0.87	Nonleacher	Small	Turcam
1.8E-04	1.7E-02	1.7	Small	Medium	1.52	Nonleacher	Small	Sevin
2.5E-03	1.2E-02	0.6	Medium	Small	0.32	Nonleacher	Small	Dursban
-	-	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	Large	Large	Nemacur
1.2E-02	-	1.7	Small	Large	3.06	Leacher	Large	Triumph
-	-	1.7	Medium	Large	2.65	Intermediate	Medium	Oftanol
-	-	1.7	Small	Medium	3.00	Leacher	Large	Proxol
-	-	0.6	Small	Small	0.00	Nonleacher	Small	Dyrene
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
-	-	0.6	Medium	Medium	1.30	Nonleacher	Small	Terrazole
2.9E-05	-	0.6	Medium	Large	2.55	Intermediate	Large	Rubigan
-	-	5.6	Small	Medium	0.00	Nonleacher	Small	Alliette
-	-	1.7	Small	Large	1.32	Nonleacher	Small	Chipco 26019
-	-	5.6	Large	Large	1.54	Nonleacher	Small	Dithane or Fo
-	-	5.6	Large	Large	1.54	Nonleacher	Small	Manzate
6.4E-04	-	5.6	Medium	Large	3.43	Leacher	Large	Subdue
3.2E-01	-	0.6	Medium	Small	0.39	Nonleacher	Small	Terraclor
8.0E-01	-	0.6	Medium	Small	-1.48	Nonleacher	Small	Banol
5.6E-05	-	0.6	Large	Large	2.00	Intermediate	Medium	Banner
-	-	5.6	Medium	Medium	0.74	Nonleacher	Small	Fungo
1.0E-03	-	5.6	Small	Large	1.38	Nonleacher	Small	Spotrete
-	2.0E-03	5.6	Small	Large	2.15	Intermediate	Medium	Bayleton
-	-							Vorlan
-	-							Asulox
8.8E-05	1.9E-04	5.6	Medium	Large	3.24	Large	Large	Aatrex
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
-	-							Dacthal
1.0E-03	-	1.7	Small	Medium	2.69	Intermediate	Medium	Many Names
	1.1E-07	1.7	Small	Medium	2.00	Intermediate	Medium	"
2.3E-01	-							"
3.3E-04	-	5.6	Large	Medium	0.80	Nonleacher	Small	Dacthal
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	Extra smal	Roundup
negligible	-							Roundup
-	-	0.6	Medium	Medium	1.39	Nonleacher	Small	Rhonox
-	-	1.7	Small	Medium	3.77	Leacher	Large	
-	-	1.7	Small	Medium	3.51	Leacher	Large	Mecoprop
negligible	-	5.6	Large	Small	0.00	Nonleacher	Small	Daconate
-	-	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
-	-	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
-	-	0.6	Large	Medium	0.17	Nonleacher	Small	Treflan

Table 4. Summary of subsurface and surface pesticide and nitrogen fate research projects conducted under golf course conditions which have reported data.

Project No.	University Researchers	Fertilizer Fate Treatments Evaluated	Pesticides Fate Treatments Evaluated	Irrigation	Soil	Turfgrass Area	Measured Parameters
1	Penn State Univ. Dr. Thomas Watschke	Mixed sources include NH4NO3 and urea compounds. Three 49 kg N/ha rates were applied (Fall 1991, Spring and Fall 1992).	Triumph (isazophos) 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 phosphorous Early spring/late fall. Total added is 196 kg/ha/yr as urea.	2,4-D dicamba Triumph (isazophos) 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	Labled methylene urea applied in four applications (45 kg/ha/yr).	Triumph (isazophos) 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. Garald Horst Univ. of Nebraska Dr. Nick Christains	Nitrogen and phosphorous was applied to undisturbed soil columns.	pendimethalin Triumph (isazophos) 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	NH4NO3 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 weight 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 (isazophos) 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 (isazophos) 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