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The Fate of Pesticides Used on Turf

by Richard J. Hull

Conventional wisdom says Americans are most fearful of virus-caused diseases, nuclear power plants and their toxic wastes, and pesticides used on food crops and in landscape maintenance. In reality, we seem to be at greater risk when driving our cars, smoking cigarettes, or eating fatty food. Killer viruses, nuclear wastes, and pesticides actually hurt relatively few people.

Tempting as it may be to question conventional wisdom, prudence dictates that we treat fear of exposure to pesticides as real — probably not justified, but real. As professional turf managers and producers whose livelihood depends to some extent on pesticides, and whose use of pesticides is often in public view, how do you deal with public concern over pesticide exposure? I wish I had a simple, effective solution to this problem. One rather obvious first step, however, is knowledge. If you understand pesticides, and pesticide concerns, you can educate your clients and others with whom you interact professionally. Turf professionals, knowledgeable about the nature of pesticide exposure resulting from turf management practices and able to discuss these concerns in an informed and calm manner, can probably do more to dispel public fears than anything academics like myself can do or say.

As it happens, questions about the fate of and probable public exposure to pesticides used in turf management are answered at least in part in a series of short articles published in the January/February 1995 issue of the U.S. Golf Association *Green Section Record*. This issue of the *Record* is devoted to reports on a number of research projects on pesticide and fertilizer fate in turf commissioned by the USGA's Green Section. The discussion that follows draws on these and other research reports and some personal observations.

Problems of Pesticides Used on Turf: Public concern aside, are there legitimate problems associated with pesticide usage on turf? An honest answer to that question is "yes." These problems can be broken down into four issues.

1. Pesticides can be transported from the turf in water, either as runoff or as leachate percolating through the soil. This loss of pesticides from turf can result in surface water or ground water contamination. When such water is used for domestic purposes or for irrigation of food crops, the potential for harm exists.

2. People can come into direct contact with turf pesticides that evaporate into the atmosphere and are inhaled, or through physical contact resulting from using turf following a pesticide application. In these cases, pesticide intake via the lungs or through the skin has the potential for causing harm.

3. Repeated use of a pesticide can promote resistance in the target pest, requiring the use of higher rates or even rendering use of the chemical ineffective. Insects are the most likely to develop pesticide tolerance, but examples of pesticide-resistant weeds and pesticide-tolerant, disease-causing pathogens have also been reported. From the perspective of sustainable turf management, acquired resistance to pesticides is probably the most serious problem.

4. Inappropriate pesticide application can destroy populations of insects or microorganisms that are keeping harmful organisms from causing unacceptable damage. In this situation, the use of a pesticide may aggravate or accentuate several other pest problems.

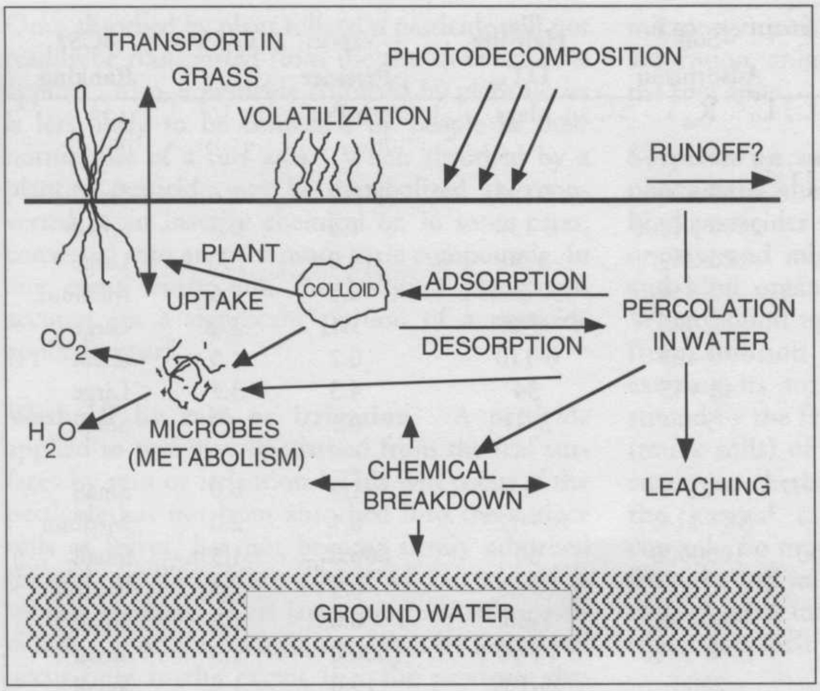

Figure 1. Fate of Pesticides in Soils

In this discussion, I will concentrate on the first two problem areas and leave acquired resistance to pesticides and the impacts of pesticides on non target organisms for another time and other authors. The capacity of a pesticide to become a water contaminant or to come into direct contact with people is what concerns the public most, and this depends largely on a pesticide's persistence or fate in the turf-soil environment.

The ideal pesticide is applied, contacts and quickly kills its target pest and then breaks down into harmless byproducts — usually carbon dioxide, water and simple mineral elements. A few pesticides come close to this ideal, but most persist long enough to be present within the turf environment in measurable amounts for days or months after application. Of course, in some instances, pesticide persistence and extended control (i.e, preemergence herbicides used to control crabgrass) is desirable.

What happens to pesticides applied to turf? Their fate is influenced by many processes, some of which are depicted in Figure 1. Immediately after application, a pesticide can evaporate into the atmosphere from plant and soil surfaces by a process known as volatilization, or it can be lost through photodecomposition.

Volatilization: Loss to volatilization depends on a pesticide's vapor pressure and on climatic conditions, especially temperature. Vapor pressure describes the tendency of a chemical to evaporate. It is an actual pressure, measured and expressed in pressure terms (mm of mercury (Hg), atmospheres or millipascals [mPa]). A high vapor pressure indicates a strong tendency to evaporate. Water has a high vapor pressure (12.8 mm Hg or 1,707,000 mPa) and it evaporates readily. Most pesticides have low vapor pressures (about 0.000002 mm Hg or 0.27 mPa (Table 1) and evaporate much less readily. Even with such low vapor pressures, many pesticides will evaporate if the temperature is high or conditions are otherwise favorable for volatilization, as we shall see later.

Photodecomposition: When a pesticide is exposed to direct sunlight, it can absorb energy from the ultraviolet portions of the spectrum, and that energy can break chemical bonds. This photodestruction of an organic molecule often occurs when the chemical is sprayed and dries on a surface which receives direct solar radiation. Large amounts of some pesticides can be lost through photodecomposition if they are applied in such a way and at a time when exposure to sunlight will occur.

If a pesticide does not volatilize and is not destroyed by sunlight, it can be absorbed through the plant surface or it can be washed off the plant by rain or irrigation.

Absorption by plant leaves: Entry into plant leaves or stems is often the desired fate of pesticides, especially those systemic materials which depend upon movement throughout the plant body for their effectiveness. Systemic insecticides or fungicides must be distributed throughout the plant in order to come into contact with pest organisms. Systemic herbicides depend on absorption and movement to growing points of the weed in order to exert their capacity to kill or inhibit the plant.

Table 1. Pesticide Properties Related to Potential for Contamination

Pesticide Trade name	Water Solubility	Soil Adsorption	Half-life DT_{50}	Vapor Pressure	GUS*	SCS† Ranking
	ppm	K_{oc}	days	mPa		
Insecticides and Nematicides						
Diazinon	40-69	40-570	7-103	19.0	2.6	Small
Dursban	0.4-4.8	2500-14800	6-139	1.2	0.3	Small
Nemacur	400-700	26-249	3-30	13.0	3.0	Large
Oftanol	20-24	17-536	30-365	0.5	2.6	Medium
Proxol	12000-154000	2-6	3-27	1.1	3.0	Large
Sevin	32-40	79-423	6-110	0.2	1.5	Small
Triumph	69	44-143	34	4.3	3.1	Large
Turcam	40	570	3-21	0.7	0.9	Small
Fungicides						
Alliette	120000	20	1	1.3	0.0	Small
Banner	100-110	387-1147	109-123	0.1	2.0	Medium
Banol	700000-1000000	1000000	30	800.0	-1.5	Small
Bayleton	70	73	16-28	0.1	2.2	Medium
Chipco 26019	13-14	500-1300	7-30	0.03	1.3	Small
Daconil 2787	0.6	1380-5800	14-90	1300.0	1.3	Small
Dithane (Fore)	0.5	2000	35-139	13.0	1.5	Small
Dyrene	8	1070-3000	0.5-1	-	0.0	Small
Fungo	3.5	1830	10	0.01	0.7	Small
Manzate	0.5	2000	12-56	0.1	1.5	Small
Rubigan	14	600-1030	20	0.03	2.6	Large
Spotrete	30	670-672	15	1.3	1.4	Small
Subdue (Apron)	7100-8400	29-287	7-160	0.3	3.4	Large
Terraclor	0.03-0.44	350-10000	21-434	6.7	0.4	Small
Terraneb	8	1159-1653	90-180	400.0	2.0	Small
Terrazole	50-200	1000-4400	20	13.0	1.3	Small
Tersan	2-4	200-2100	90-360	1.3	1.7	Small
Herbicides						
Balan	0.1-1	781-10700	2-130	4.0	-0.05	Small
Banvel	80000	2.2	3-315	-	4.2	Large
Betason	5.6-25	740-10000	30-150	0.1	2.1	Medium
Daconate	-	-	1000	0.0	0.0	Small
Dacthal	0.05	4000-6400	13-295	0.3	0.8	Small
DSMA	254000	770	-	-	2.3	Small
Endothal	100000	8-138	2-9	1.0	2.3	Medium
Kerb	15	990	60	-	3.0	Large
MCPA	270000-866000	20	4-21	-	3.8	Large
Mecoprop	660000	20	21	0.01	3.5	Large
Prograss	51-110	340	20-30	0.6	2.2	Medium
Prowl	0.275-0.5	5000	8-480	4.0	0.6	Small
Rhonox	5	1000	8-69	0.2	1.4	Small
Ronstar	0.7	3241-5300	30-180	0.1	0.9	Small
Roundup	12000	2640	7-81	0.0	0.0	Small
2,4-D amine	200000-3000000	0.1-136	2-23	0.0	2.0	Medium
Tupersan	18	420-890	90	0.8	2.7	Medium
Turflon	2100000	1.5-27	30-90	0.2	4.5	Large

* Ground water Ubiquity Score (GUS) and leaching potential based on degradation and K_{oc}
† Potential for leaching to ground water - SCS Rankings
Data of Balogh and Walker (1992) from Kenna (1995)

Once absorbed by plant foliage, a pesticide will not readily be transported from the site to which it is applied. Also, a pesticide absorbed by plant leaves is less likely to be contacted by people in their normal use of a turf area. When absorbed by a plant, a pesticide may be metabolized and converted to an inactive chemical or, in some cases, converted into an even more toxic compound. In any event, entry into the body of plants can account for a significant portion of a pesticide applied to turf.

Wash-off by rain or irrigation: A pesticide applied to turf may be washed from the leaf surfaces by rain or irrigation. This will occur if the pesticide has not been absorbed into the surface cells of leaves, has not become firmly adsorbed (bound) to the surface cuticle of leaves, and is soluble in water. This latter property of a pesticide is important because transport by water will occur only to the extent that the pesticide dissolved in water. Many pesticides are poorly soluble in water (Table 1), thus their capacity to be washed off leaves or transported from the site of application in surface water flow is limited. Pesticides soluble in water are subject to such transport, and this may contribute to a pollution or contamination problem.

Adsorption on thatch: When washed off turfgrass leaves, a pesticide next encounters the thatch layer that accumulates on the soil surface beneath the plants. This layer of dead stems, crowns, and a few leaves provides many sites that can bind organic pesticides through surface adsorption or through internal absorption. Ad- and absorption are often combined as 'sorption,' which simply means immobilization of one material on or in another material. The thatch layer thus constitutes a highly effective trap for many pesticides, and is more or less unique to the turf environment. As a result, many pesticides do not move as readily in turf as they do in other plant communities.

Eventually a pesticide will be carried to the soil surface and then down into the soil profile. For some pesticides, for example those intended to inhibit soil insects or pathogens and those that are absorbed primarily by roots, transfer into the soil is essential for effective pest control. However, the soil environment provides many obstacles to pesticide survival and effectiveness. These include adsorption on soil colloids, metabolism by microorganisms, chemical degradation, root absorption, animal ingestion, and leaching out of the root zone.

Sorption on soil colloids: The same sorption phenomena that can occur in thatch can also bind pesticides in the soil. Soils contain many organic and mineral colloids, which can attract and bind organic molecules such as pesticides. When bound to colloids, a pesticide is removed from solution and is no longer capable of exerting its toxic properties. This is demonstrated by the fact that in the highly organic soils (muck soils) of the upper Midwest, several preemergence herbicides must be applied at double the normal rate to provide adequate weed control. So much of these herbicides is removed from the soil solution by the profusion of organic colloids, that more must be used to obtain a concentration toxic to plants.

The soil under most well established turfs contains more than the normal amount of organic matter. This additional organic matter rarely compromises the effectiveness of pesticides, but can significantly restrict their movement through the soil profile. The tendency of a pesticide to bind with organic colloids is characterized by its organic carbon partition coefficient, abbreviated K_{oc}. A large K_{oc} (Table 1) indicates a strong tendency for a pesticide to bind with organic colloids. Such a pesticide will be less available and is less likely to leach in a soil relatively high in organic matter.

Absorption and metabolism by soil microbes: Once in the soil, a pesticide can be absorbed by the microorganisms present there. Once inside microbe cells, unless it is metabolized into a different chemical compound, a pesticide is no longer free to exert its toxic action (kill pests) or to be lost from the turf-soil environment. There are many ways in which an organic pesticide can be acted upon by microorganisms, but they all have the effect of changing the pesticide into a non-pesticide molecule. Soils high in organic matter normally are rich in soil microbes, and consequently have a high capacity to inactivate a pesticide.

Chemical degradation in soil: Soils provide a chemically active environment that can bring about the destruction of some pesticides. Soil water not only dissolves pesticides, but places

Table 2. Properties of Pesticides that Indicate a High Potential for Surface and Ground Water Contamination

Pesticide property	Value indicating probable contamination
Water solubility	30 ppm or greater
K_{oc}	300 or less
Half-life: Hydrolysis	175 days or more
Half-life: Photolysis	7 days or more
Half-life: Field dissipation	21 days or more
GUS*	3.00 and higher

* Ground Water Ubiquity Score
Modified from Kenna 1995

them in contact with the chemically active surfaces of colloids in the presence of metallic ions. When this occurs, some pesticide molecules may react chemically and change into inactive compounds. This process does not depend on soil microorganisms or organic colloids and can occur in mineral soils of low organic content. It requires only water and a suitable ionic environment, which is present in most soils.

While most pesticides will be degraded by microbial activity, the chemical structure of many pesticides is sufficiently stable not to succumb to chemical degradation.

Absorption by roots: A pesticide dissolved in soil solution can be absorbed by microbes or roots. In the case of root absorbed herbicides or systemic insecticides and fungicides, this may be part of its intended toxic pesticidal action. The fate of a pesticide within a plant can be similar to that of a pesticide absorbed by soil microbes, however. Many pesticides are chemically degraded by metabolic processes within plant cells. Others absorbed into roots can be carried to the shoots where they can be lost when animals graze on the plant or when shoot tissues are removed in mowing. Thus absorption by roots can contribute to the loss of a pesticide applied to turf.

Ingestion by soil animals: Specific research is scarce on this, but the macro- and microfauna in soil can also participate in the loss of turf pesticides. Worms, grubs, nematodes, and the entire galaxy of soil animals will consume pesticide molecules as they ingest soil organic residues, microorganisms, roots and each other. Once in an animal's body, a pesticide can be metabolized or stored in fatty tissues. In either case it is removed from active participation in the turf-soil environment.

Leaching in percolate water: Pesticide molecules that escape all the fates described above and remain dissolved in soil water can leach through the soil profile, beneath the root zone, and into ground water. Once in the ground water, where organic and microbial activities are low, the pesticide can stabilize and may last for a long time. However, the chemical and biological activity of soil under turf is so intense that most pesticides do not survive long enough to leach into ground water. This will be discussed in more detail later.

The likelihood that a pesticide will be transported from the site to which it is applied and contaminate ground or surface water depends on how long it remains in a form, and at a location in the turf-soil system, that makes it subject to transport. This in turn depends to a large extent on the physical and chemical properties of the pesticide and the environment in which it is present. Table 2 outlines the values for several pesticide properties which have been identified as favoring transport to surface or ground water. It all comes down to residence time and opportunity. The longer a pesticide remains in the turf-soil environment the greater are its chances of being transported from the site of application to water bodies. However, the turf environment is such that transport from it is less likely than from most other environments where pesticides are used.

Direct contact of people with pesticides: Are people at risk of coming in contact with pesticides if they use a turf area shortly after chemical application? This question can be answered. The amount of research addressing it is limited, however. Human contact following pesticide application can occur via two routes: inhalation of volatilized material and contact of skin with residues present on the grass surfaces, or on clothing that has contacted grass surfaces.

Pesticide inhalation: As outlined earlier, following application, a pesticide can volatilize into the atmosphere. When air containing the pesticide is inhaled, the pesticide can be absorbed through the lungs and enter the blood-stream. Caution dictates applying pesticides such that volatilization is restricted and atmospheric contamination is minimized.

A study reported by Cooper, Clark, and Murphy at the University of Massachusetts showed that volatility of pesticides is not uniform: most volatilization occurs within the first four to five days following application. Volatilization is much reduced after that, and declines to nothing within a week or two.

Volatility losses can also be much reduced if turf is irrigated shortly after pesticide application (Figure 2). Of course, irrigation must be compatible with the action and intent of the pesticide. This is true for materials which act primarily through the soil. Materials which must be absorbed by leaves (i.e. postemergence herbicides used to control broadleaved weeds) would be rendered ineffective if washed off the grass soon after application. In some cases, the Massachusetts researchers found volatilization increased during days two and three following irrigation, and that this resulted in slightly increased exposure by inhalation over an application not followed by irrigation. In general, however, irrigation reduces pesticide losses due to volatility.

As noted earlier, volatility is increased by high temperatures, so it is not surprising that most pesticides exhibit their greatest vapor loss during midday. Increased midday volatilization may accentuate inhalation exposure, especially on golf courses where midday use is heavy. However, when the Massachusetts researchers measured the quantity of vaporized pesticide in the air and calculated the exposure resulting from that level of atmospheric contamination, it was in most cases well below established permissible exposure levels. Only the insecticide isazofos (Triumph) provided inhalation exposure calculated to exceed safe levels.

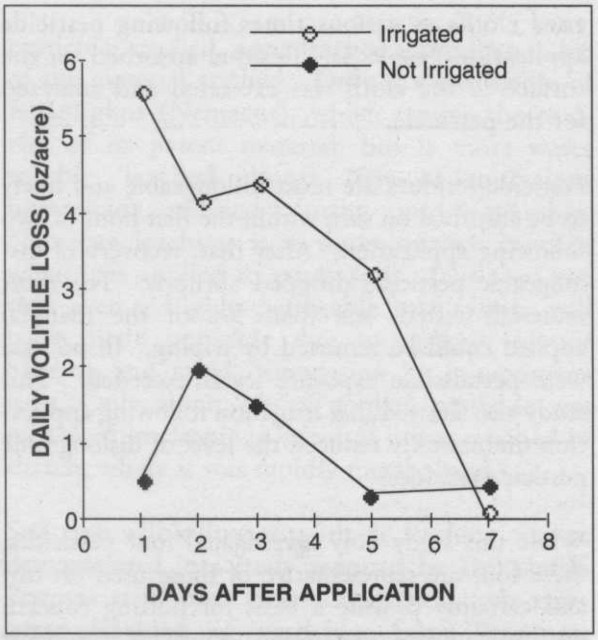

Figure 2. Volatility Losses of Trichlorfon (Proxol) Applied to Turf With/Without Irrigation (based on Cooper, et al. 1995)

All such results must be considered in the context of the estimating models' assumptions, however. In this case, the model assumed a person playing a four hour round of golf would be exposed to insecticide contaminated atmosphere throughout that period. This is unlikely. In real life, inhalation exposure would probably be much less than that estimated.

These results suggest that inhalation of volatile pesticides can occur, even if infrequently. The wise turf manager will exercise caution in using such materials and take measures to limit their volatilization.

Pesticide contact to skin and clothes: Following application, a pesticide can make skin contact. This is most likely if the turf is used immediately after spraying, before the liquid has dried. Even after drying, some pesticide residue may be dislodgeable and can make contact with skin and clothing. Shoes and hands are the most common sites of residue contact, except with children who when playing on a lawn can make residue contact pretty much on any part of their bodies. The Massachusetts researchers recognized this possibility and wiped turf with moistened cloths at various times following pesticide application (Table 3). Residue adsorbed on the surface of the cloth was extracted and analyzed for the pesticide.

Pesticide residues are most dislodgeable and likely to be adsorbed on skin within the first hour or two following application. After that, recovery of dislodgeable pesticide dropped abruptly. For most materials tested, less than 5% of the material applied could be removed by wiping. In no case were permissible exposure levels exceeded. This study also showed that irrigation following application dramatically reduced the level of dislodgeable pesticide residues.

While this study only investigated four pesticides, these four are representative of those used on turf and certainly provide a basis for putting concern over human exposure in perspective. If reasonable management precautions are taken, significant exposure to pesticides used on turf, either from vapor inhalation or through skin contact, is not likely to even approach, let alone exceed, established acceptable levels. Because exposure can occur, however, the use of signs to discourage turf use following pesticide application should be encouraged, whether required or not.

Transport with water: The major environmental concern over pesticide use on turf is its movement from the site of application and eventual contamination of surface and ground water. Water is the principal vehicle by which pesticides are transported from a site. This can occur through surface runoff. It can also occur by percolation through the soil.

The likelihood of a pesticide being washed off a site or leached through the soil profile is estimated with computer models. These mathematical models consider the physical and chemical properties of the pesticide and its probable interaction with a soil. For very large projects, site-specific models might be constructed, but for most turf managers a reasonable estimate of pesticide transport potential can be obtained from published values derived from model determinations using standard conditions.

Pesticide leaching potential: For reasons presented below, you will find no values for pesticide losses due to runoff in Table 1. Leaching potential can be estimated from Ground Water Ubiquity Scores (GUS), derived by matching pesticide properties with characteristics of a 'normal' soil. These values provide a basis for estimating the leaching potential of a given pesticide. GUS values of less than 2.0 indicate a non-leaching material; values between 2.0 and 3.0 denote intermediate leaching potential; a GUS value above 3.0 normally indicates a pesticide with a strong leaching potential.

The USDA Soil Conservation Service (SCS) has established a similar system for judging the leaching potential of pesticides. SCS rankings are also given in Table 1. In this system, 'small' indicates little leaching potential, 'medium' signifies intermediate leachability, and 'large' indicates a material which is highly leachable.

Table 3. Dislodgeable Residues on Leaves of Turf Following Pesticide Application

Time after spraying	MCPP (Mecoprop)	Triadimefon (Bayleton)	Isazophos (Triumph)	Trichlorfon (Proxol)	
	— % of pesticide applied —				
Day 1					
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

* Non-irrigated
** Application followed by 0.5" irrigation
Based on Cooper et al. 1995

Table 4. Organophosphate Pesticides Recovered in Clippings and Present in Percolate Water from a Sand Green in Florida

Pesticide	Dates applied	Total recovery (% of that applied) in Clippings	Percolate
Fenamiphos (Nemacur)	13 Nov 91	-	0.06
	27 Jan 92	0.38	0.04
Metabolite of fenamiphos	13 Nov 91	-	17.69*
	27 Jan 92	0.14*	1.10*
Fonophos (Dyfonate)	13 Nov 91	-	<0.01
	27 Jan 92	1.17	0.02
Chlorpyrifos (Dursban)	27 Jan 92	7.87	0.15
	21 Apr 92	0.52	0.08
Isazophos (Truimph)	21 Apr 92	0.43	0.09
	15 Sep 92	0.38	0.02
Isofenphos (Oftanol)	21 Apr 92	0.79	0.02
	15 Sep 92	0.89	0.01
Ethoprop (Mocap)	15 Sep 92	0.44	0.05

* Metabolites expressed as % of parent compound applied. From Snyder and Cisar 1995

A study of Table 1 shows that leachability is a balance between water solubility, adsorption on soil colloids (K_{oc}), and the half-life of a pesticide in the soil (DT_{50}). Half-life is estimated on a compound's tendency to be immobilized and degraded by microorganisms. Thus some very soluble compounds may leach little if they have a high K_{oc} or a short DT_{50}. For example, the fungicide propamocarb (Banol) is highly water soluble but also has a very high affinity for organic soil colloids (K_{oc} = 1,000,000) and a relatively short half-life in soil (DT_{50} = 30 days) which gives it a negative GUS value and an SCS leaching potential ranking of "small."

Pesticide leaching from turf has been measured in field studies. Snyder and Cisar (1995) compared leachability of several pesticides through a sand green in Florida (Table 4). This system is prone to high water infiltration rates, so pesticide leaching would be expected. However, of the six pesticides studied, none leached more than 0.2% of the material applied. Only the metabolite of fenamiphos (Nemacur), which retains the toxicity of its parent material, but is more water soluble, leached almost 20% of equivalent nematicide applied during mid-November. Nemacur leaching is a water quality concern when it is applied to sandy soils. It is apparent that even a highly permeable turf system will leach little pesticide due to organic matter binding and rapid degradation by microorganisms. Only about 1% of applied pesticide was recovered in clippings. Most of it was retained in thatch, where it was rapidly metabolized.

Soil type will influence pesticide leaching, as was demonstrated in a study reported by Dr. Martin Petrovic at Cornell University (1995). He measured leaching of pesticides from Penncross

Terms to Know

Absorption - the process by which a chemical is transported into a plant cell or the matrix of a soil colloid. **Adsorption** - the process by which a chemical binds to plant or soil particle surfaces. **Sorption** - collective reference to both absorption and adsorption. **Desorption** - the release of previously absorbed or adsorbed materials.

Colloid - a particle of small size (< 2 μ diameter) that remains suspended in water - will not settle out. Soil colloids contain electrical charges and have chemically active surfaces.

Degradation - breakdown (biological or chemical) of a chemical into simpler compounds or elemental components.

Half-life - time required for half the quantity of a compound to degrade.

Leaching - movement through the soil profile of a chemical carried by water. **Leachate** - the chemical transported in this process.

Metabolism - processes by which a chemical is changed (into tissue, energy, and waste) through the action of living organisms.

Percolation - movement of water through a soil profile.

Vapor Pressure - a measure of the tendency of a solid or liquid to volatilize or evaporate.

Volatilization - process by which a solid or liquid changes to its gaseous state.

creeping bentgrass turf managed as a fairway under two precipitation levels (Table 5). Pesticide recovered in the water table 15 inches beneath the turf was used to estimate leaching. While this system was somewhat artificial, it did show that under a worst case scenario, pesticides applied to turf can leach to a substantial extent. The highly soluble Mecoprop leached more than 60% of that applied to a sand based turf under 9.6 inches of rainfall occurring during an eight day period following application. However, even under these extreme conditions, most pesticides leached less than 5% of the amount applied. This study makes the case as well as any for the limited propensity of turf to leach pesticides into ground water.

Pesticide runoff potential: Runoff is not normally a major problem in turfgrass management. Studies at Pennsylvania State University and the University of Rhode Island have shown that water, even during a heavy rain, will not normally run off a well established dense turf. Dr. Tom Watschke at Pennsylvania was forced to create a rainfall intensity comparable to a once per hundred year storm (6 in./hour rainfall) before he could measure significant runoff. In Rhode Island, runoff was only recorded during the winter, when rainfall occurred on frozen ground. Because of this limited capacity for runoff, it is generally considered unlikely that surface movement of pesticides from turf will normally be a problem.

In the southeastern states, however, surface flow of water from turf is more commonly observed. The greater frequency of very heavy summer storms creates more opportunities for high intensity precipitation events. Also, the sandy clay soils common to much of the Southeast have lower infiltration rates than the sandy loams of the Northeast. For these reasons, researchers in this region have become more concerned with pesticide runoff and recognize it as a potential problem. Al Smith (1995), working at the Georgia Station in Griffin, GA, studied pesticide runoff from Bermudagrass turf growing on a 5% slope. Following an application of three herbicides to simulated fairways, runoff was measured for a 25-day period during which time seven artificial and natural precipitation events occurred. Of the total water received by the turf during this period, 42% left the plots as runoff and approximately 8% of the herbicides applied were lost with this water. Eighty percent of this herbicide

Table 5. Pesticide Leaching from Experimental Fairways with Three Soil Types and Two Precipitation Levels

Pesticide	Precipitation amount	Soil type: Sand	Sandy loam	Silt loam
	inches/8 days	% of applied pesticide leached		
Isazophos	4.4	10.4	0.04	0.68
(Triumph)	9.6	5.6	0.09	0.30
MCPP	4,4	51.0	0.79	0.44
(Mecoprop)	9.6	62.1	0.46	1.25
Trichlorfon	4.4	1.2	1.13	0.63
(Proxol)	9.6	3.4	4.41	3.33
Triadimefon	4.4	1.0	0.06	0.24
(Bayleton)	9.6	2.4	0.01	0.28

Based on Petrovic 1995.

References Cited

Balogh, J. C. and W. J. Walker (eds.). 1992. *Golf Course Management & Construction: Environmental Issues.* Boca Raton, FL: Lewis Publishers (ISBN: 0873717422)

Cooper, R. J., J. M. Clark and K. C. Murphy. 1995. Volatilization and Dislodgeable Residues are Important Avenues of Pesticide Fate. *Green Section Record* 33(1):19-22.

Kenna, M. P. 1995. What Happens to Pesticides Applied to Golf Courses? *Green Section Record* 33(1):1-9.

Petrovic, A. M. 1995. The Impact of Soil Type and Precipitation on Pesticide and Nutrient Leaching from Fairway Turf. *Green Section Record* 33(1):38-41.

Smith, A. 1995. Potential Movement of Pesticides Following Application to Golf Courses. *Green Section Record* 33(1):13-14.

Snyder, G. H. and J. L. Cisar. 1995. Pesticide Mobility and Persistence in a High-Sand-Content Green. *Green Section Record* 33(1):15-18.

loss occurred during the first simulated rainfall following pesticide application (2 in./hour). It appears that wherever soils and rainfall are heavy, turf managers must consider runoff as a route of pesticide loss and probable vehicle for surface water contamination.

Several turf researchers (Kenna 1995) noted that both leaching and runoff of pesticides applied to turf was significantly less than that predicted by models designed to estimate pesticide fluxes in agricultural cropping systems. This may indicate that the GUS values and SCS rankings cited in Table 1 overestimate pesticide transport rates from turf. If so, this is undoubtedly due to the greater intensity of metabolic activity in the thatch and soil of a turf-soil ecosystem. The generally higher organic content of soils under turf promotes increased microbial activity; and this in turn speeds the metabolism of pesticides and facilitates their degradation. As a result, the potential for pesticides escaping from turf and contaminating surface or ground water is probably below that of any other managed land use.

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Erratum

On page 7 of the May 1995 issue of TurfGrass TRENDS, Metalaxyl was inadvertantly included in Table 3 as increasing the severity of red thread and Rhizoctonia diseases. Metalaxyl is not known to enhance these diseases. We regret the error.

Relationships among Soil Insects, Soil Insecticides, and Soil Physical Properties

by Michael G. Villani

Insecticides are applied to the soil for the control of Japanese beetle and other scarab grub species in areas where these pests damage the roots of turfgrass and landscape ornamentals. A noted chemist researching the use of insecticides for controlling soil insects once commented that, the more we learn about the interaction of the soil environment, insect behavior, and insecticide properties, the more we recognize it is a wonder that soil insecticides are ever effective in controlling insects.

Controlling soil insects in turfgrass is especially difficult because, in contrast to agricultural and garden uses, turf insecticides are not usually incorporated directly into the soil. We must rely on the movement of insecticide down into the soil where grubs are feeding to provide sufficient coverage for control.

Although many studies have been carried out to determine how specific insecticides act in the field, there is little information available on soil-insecticide-insect interactions that accurately predict insecticide performance in controlling this pest complex.

With this rather pessimistic starting point, I would like to discuss several reasons why soil insecticides should not be expected to kill white grubs in turfgrass and suggest how turfgrass managers might mitigate the impact of these factors, thereby increasing insecticide activity. Following this, I will present a case study undertaken by Dr. Rich Cowles (Connecticut Agricultural Research Station, New Haven) and myself in which we determined the impact of soil physical properties on the performance of several turfgrass insecticides labeled for use against Japanese beetle grubs. This study was carried out in several California soils.