ENVIRONMENTAL FATE OF PESTICIDES

INTRODUCTION

While golf course superintendents try to minimize the number of pesticide applications they make, sometimes pesticides must be used to maintain the playing conditions expected by the golfer or owner or club greens committee. The purpose of this fact sheet is to describe what happens to pesticides after they are applied to the turf, and to identify conditions that can increase the likelihood that pesticides will move to local surface water or groundwater.

WHERE DO PESTICIDES GO?

Three things can happen after a pesticide application. The product might bind to organic matter or soil **(adsorption).** Some pesticides move offsite after application (**transfer / movement)**. Eventually every pesticide will break down into component parts **(degradation)**.

Each pesticide has a specific molecular structure – the organization of atoms in a variety of bonds or connections. This molecular structure determines many of the physical characteristics of the pesticide, such as solubility, half-life, affinity for soil particles, or attractiveness as an energy source for microbes. These physical characteristics, in turn, affect the environmental "fate" of the pesticide.

ADSORPTION

Adsorption refers to the binding of pesticide molecules to soil particles or to organic matter (e.g., thatch). An analogy that can be used to describe adsorption is a small magnet and iron filings. Many people remember dragging a magnet around and watching as tiny iron filings seemed to "jump" on to the surface of the magnet and stay attached.

If a pesticide binds to soil or organic matter, it is much less likely to move as a result of runoff or leaching. Insecticides that bind tightly to organic matter (e.g., pyrethroids) are excellent for controlling insects that are active in the thatch, but those insecticides usually do not reach the soil.

Conditions that increase likelihood of adsorption

- High adsorption coefficient (determined in part by molecular structure)
- Low solubility
- Soils with high clay content (the smaller clay particles provide many more possible binding sites for pesticides than do coarse sand particles)
- Soils with high organic matter content

PESTICIDE TRANSFER / MOVEMENT

There are six ways pesticides might move away from the site of application: volatilization, drift, runoff, leaching, absorption, and crop removal. In each case the original pesticide can move from the original point of application to another location. Some of these processes can result in pesticides reaching nearby surface water or groundwater. The following section defines each kind of movement ("transfer") and describes conditions that increase the likelihood of that movement occurring.

Volatilization

Volatilization refers to the transformation of a liquid or solid to the gas (vapor) phase of a chemical. For example, water is the liquid form, ice is solid, and water vapor is the gas form of H_2O. Once a chemical volatilizes, it moves into the surrounding air and may move away from the site of application on air currents.

Conditions that increase likelihood of volatilization

- High vapor pressure (physical characteristic specific to a molecule that indicates how readily that molecule can transform to the vapor phase)
- High temperature at the time of application
- Relatively low humidity at the time of application
- Light air movement at the time of application

Drift

Drift refers to the physical movement of particles of a pesticide that are released at the time of application that later move with wind to another location (Sometimes drift occurs at the time of application, but it can also occur several hours after the application if conditions are right.) There is no change in phase, so solids remain solids, liquids remain liquids, and gases (vapors) remain gases.

Conditions that increase likelihood of drift

- Small droplet or particle size
- Low density of granules
- Air movement (wind) at the time of application

Runoff

Runoff refers to the surface (lateral) movement of water, along with any pesticides or fertilizers that might be in that water. Chemical properties, soil characteristics, and local geography all play a role in determining whether runoff is likely to occur. Water molecules tend to seek the path of least resistance to move "downhill". Large soil particles and large pore spaces provide relatively easy routes for water to move into the soil profile (thereby decreasing run-off). Conversely very small soil particles or tightly compacted soils with small pore spaces will resist vertical movement of water molecules into the soil profile, and will result in more surface (lateral) movement of water.

Conditions that increase likelihood of runoff

- Pesticide is highly soluble in water

- Pesticide has a long half-life (which means it is more likely to still be in an active form when it reaches local surface water)
- Heavy clay soils or highly compacted soils
- Steep slopes (which make it easier for water to move downhill on the surface)
- Heavy precipitation or irrigation shortly after application
- Lack of surface vegetation (plant roots act as sponges absorbing water, thereby reducing the amount of water that moves off site

Leaching

Leaching refers to vertical movement of pesticides in water through the soil profile. As noted in the runoff section, water molecules tend to seek the path of least resistance to move "downhill". Soils with very small particles or tightly compacted soils with small pore spaces will resist vertical movement of water molecules into the soil profile, and will result in more surface runoff. Large soil particles and large pore spaces provide relatively easy routes for water to move into the soil profile, thereby increasing leaching. Like runoff, chemical properties, soil characteristics, and local geography all play a role in determining whether leaching is likely to occur. The primary concern with leaching is the possibility of contamination of underlying aquifers.

Conditions that increase likelihood of leaching

- Pesticide is highly soluble in water
- Pesticide has a long half-life (which means it is more likely to still be in an active form when it reaches underlying groundwater)
- Sandy soils or soils with large pore spaces (water can penetrate more easily)
- Presence of animal burrows (e.g., earthworm burrows) in the upper soil layers
- Little or no slope (little or no surface movement of water)
- Heavy precipitation or irrigation
- Lack of surface vegetation (plant roots act as sponges absorbing water, thereby reducing the amount of water that moves off site
- Vertical fractures in underlying rock layers (which can speed the vertical movement of water below the subsoil)
- Depth to water table

Absorption

Absorption refers to the movement of a pesticide into a plant or an animal. A sponge is a useful analogy when considering absorption. If you place a dry sponge in a bowl of colored water, you can see the water move into the sponge tissue. Some pesticides are absorbed into plant or animal vascular tissue, and some of these products are further distributed through the organism.

Conditions that increase likelihood of absorption

- Chemical characteristics of the pesticide (*systemic* pesticides are absorbed into the vascular system of the plant while *contact* pesticides are not absorbed into the plant)
- Physiology of the plant (if a plant is not growing vigorously, it is less likely to absorb the pesticide)

Crop removal

Crop removal usually is of concern only when harvesting food crops. (The EPA establishes "days to harvest" for pesticides used on food crops, establishing limits for the number of days that must occur after the last application before a crop can be harvested. This ensures that the crop will have residues that are well below the health advisory level for that pesticide.)

A golf course superintendent must remember that when clippings are collected after a pesticide application and tossed into a pile, some pesticide residue may remain on those clippings. Ordinarily this is not a problem, but if 2,4-D is applied and then clippings are used as a mulch for a garden, tomatoes and other crops will show evidence of herbicide injury.

DEGRADATION / BREAKDOWN

Fortunately, pesticides do not persist forever. Each pesticide has a specific molecular structure, which includes bonds ("connections") between many different atoms. Lots of things can happen to break one or more of these bonds in the original molecular structure. Some of these processes involve living organisms, some involve chemical reactions, and some occur as a result of energy introduced to the system in the form of sunlight. If at least one of the bonds of the original pesticide molecule is broken, the molecule "breaks down" into two or more smaller molecules. These breakdown products usually are less toxic than the original ("parent") compound, but sometimes the breakdown products are more toxic than the original compound.

Microbial degradation

Many pesticides can serve as food sources for various microorganisms in the soil or thatch. When we use such pesticides that provide nutrients for a given species of microorganism, it flourishes. Often the population increases significantly and quickly. The increasing population continues to feed on the pesticide, rendering it ineffective against the target pest.

An example of this "enhanced degradation" occurred in the 1980s, when isofenphos (Oftanol™) was introduced for the control of various soil insects, including corn earworms in corn and white grubs in turf. A species of bacterium occurred naturally in soils in the US Corn Belt broke down the insecticide (and reproduced) very quickly. Bacterial populations increased by an order of magnitude during the growing season, and within a year or two, the product was no longer effective against corn earworms because the microbe broke down the insecticide almost the moment it was applied.

Conditions that increase likelihood of microbial degradation

- Repeated applications of the pesticide at the same site
- Soil or thatch conditions that favor the microbe (specific conditions depend on the biological needs of the microorganism), including:
  - Temperature
  - Moisture

- Soil or thatch pH
- Presence (or absence) of oxygen
- Presence of organic matter

Chemical degradation

Chemical degradation refers to breakdown of pesticides by chemical processes that do not involve living organisms. One example that occurs with many pesticides is hydrolysis, where water molecules assist in the breakdown of a pesticide molecule. Alkaline hydrolysis (breakdown of a pesticide in water with a high pH) is a common problem with certain insecticides, like trichlorfon and carbaryl. If pesticides that are subject to alkaline hydrolysis are applied in water with a high pH (7.3 or higher), some of those products can breakdown in the spray tank in less than an hour.

There are many different kinds of chemical reactions that can break molecular bonds, thereby degrading a pesticide. These include oxidation, reduction, isomerization, hydrolysis, and many more. Each of those reactions is driven by physical conditions, such as moisture level in the soil, soil or air temperature, and pH of the soil or thatch. Each molecule has a particular set of conditions under which it is vulnerable to degradation. If those physical conditions are present, the molecule will eventually be broken down through one of those reactions.

Conditions that increase likelihood of chemical degradation

- molecular structure of the pesticide (some are more vulnerable to breakdown than others)
- water pH
- air and water temperature
- many other possible reactions and conditions

Photodegradation

Photodegradation refers to breakdown of pesticides by sunlight. The UV rays of the sun deliver a form of energy that can break certain molecular bonds.

Conditions that increase likelihood of photodegradation

- Intensity of sunlight at the time of application (sunlight is more intense in summer, at midday, and at lower latitudes)
- Molecular characteristics of the pesticide