Back to Basics - Insecticide Primer Part Two: Chemical Classes of Turfgrass Insecticides

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Introduction

Traditional insecticides are chemicals designed to kill or otherwise control insects. Most of the insecticides which are used widely in turfgrass management are "organic," which simply means that they contain carbon (and usually hydrogen) somewhere in the molecule. This article will attempt to explain some of the structural differences and performance characteristics of the most common chemical classes of insecticides a turf manager can expect to encounter.

Organochlorines

Background

The first class of organic insecticides to be developed commercially was the organochlorines or chlorinated hydrocarbons. A close inspection of the name reveals a great deal about the molecular structure of these compounds. "Organo" indicates there is carbon (and usually hydrogen) in the molecule, and "chlorine" indicates that at least one atom of chlorine is present. "Chlorinated hydrocarbon" is, in fact, another way of saying the exact same thing.

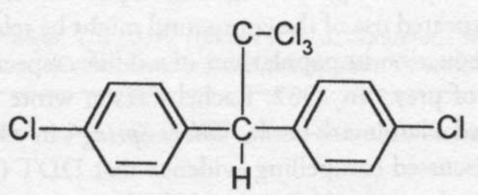
DDT was first synthesized in 1873, by a German graduate student, but he had no way of knowing about the special characteristics of the compound. In 1939, Paul Muller, a Swiss entomologist, accidentally came upon the work of the graduate student and discovered that DDT had long lasting effects against flies and mosquitoes. Several qualities of the material suited it for use in public health settings (for example, mosquito control to reduce the spread of malaria), and it quickly became the mainstay in several public health efforts. Meanwhile DDT was used in various agricultural operations to control several different kinds of insects. Farmers found that the material remained active in the soil for a long period of time (often more than a year), and they looked forward to the day when DDT would solve all of their insect pest problems.

DDT was used in agriculture, forestry, and mosquito control programs for several years. Eventually some people began to suspect that heavy and repeated use of the compound might be related to a reduction in populations of wildlife, especially birds of prey. In 1962, Rachel Carson wrote and released a landmark book, *"Silent Spring"*, in which she discussed compelling evidence that DDT (and some other organic insecticides) almost certainly was building up in the fat tissue of insects and other invertebrates. When a small fish fed on these insects, the DDT was stored in even higher concentrations in the fat tissue of the fish. At each step in the "food chain," DDT accumulated in the fat tissue of the consumer in higher and higher concentrations. Eventually birds of prey, such as eagles and falcons, fed on this highly contaminated prey and accumulated very high concentrations of DDT in their tissue. One side effect of the exposure to this contamination was that female birds produced eggs with very thin shells unable to withstand the weight of the incubating female, so the eggs collapsed or were crushed. Not surprisingly, eagle and hawk populations began to plummet.

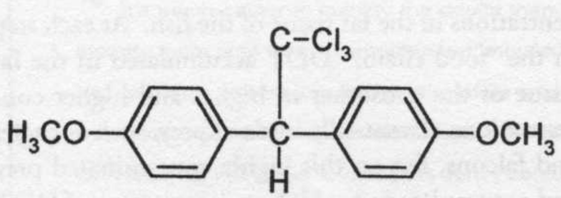
In the 1970s, soon after the Environmental Protection Agency was formed, DDT, chlordane, and several other insecticides in the same chemical class were removed from the market. Their registrations were revoked and their use is now prohibited in the United States. However, there are several other organochlorines which have strikingly different characteristics, and which are used in several agricultural and ornamental settings.

Diphenyl aliphatics

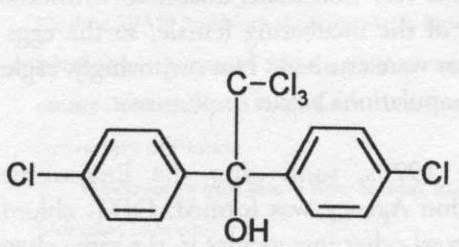
Several compounds have a striking similarity to DDT and are described as diphenyl aliphatics. "Phenyl" is a term used to describe a ring of six carbon atoms, usually represented as a hexagon when sketching a molecule. "Diphenyl" simply means that there are two such rings in the molecule. "Aliphatic" means that the chains of atoms attached to the rings are "straight," with no additional rings or branches. Three examples of diphenyl aliphatics are given here:



DDT



methoxychlor



Dicofol

The chemical structures of each of these compounds look remarkably similar. For example, methoxychlor appears identical to DDT except that the chlorine atoms which are attached to the rings in DDT are replaced by methoxy "OCH3," groups which consist of an oxygen atom attached to a carbon atom which has three hydrogens linked to it. Such a seemingly simple difference results in a tremendous change in physical characteristics. DDT tends to be very persistent in the environment, sometimes remaining active for several years, while methoxychlor is much less persistent, usually remaining active for a few weeks. DDT tends to accumulate in fat tissue of animals as they move through the food chain, while methoxychlor is much less likely to do so.

However, most organochlorine compounds which fall into the "diphenyl aliphatic" class do have certain characteristics in common. They tend to be relatively low in acute toxicity to mammals and other vertebrates. (Note: a subsequent article will discuss acute vs. chronic toxicity in more detail.) In addition, they tend to be less water soluble and mobile than many other insecticides, and so are not as likely to leach into groundwater or run-off into surface water.

Examples: DDT (no longer available), methoxychlor, dicofol (Kelthane™, used as a miticide)

Cyclodienes

Cyclodienes are organochlorine compounds that have a relatively complicated structure which often includes two or more carbon rings interconnected to each other. These compounds were developed in the late 1940's and 1950's and were used as soil insecticides for several years because they were very persistent in the soil. One such compound most familiar to turf managers was chlordane, which was used in turf settings until about 1975 and was a very effective material against termites as well as turf insects. However, because of concerns about the persistence of chlordane in the soil and the development of resistance to chlordane by several insects, its registration was phased out - by 1982, it was no longer legal to use chlordane in the United States.

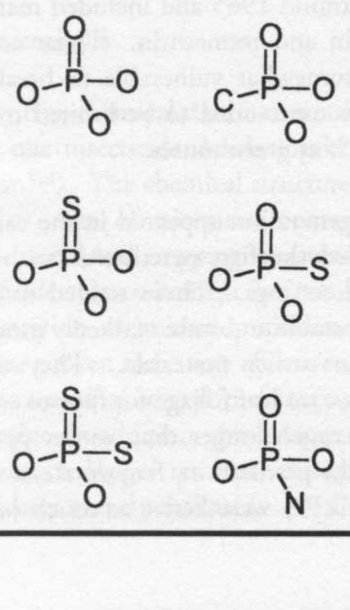
Examples: aldrin, chlordane, dieldrin (none of which is still available)

Organophosphates

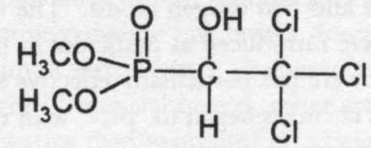
Organophosphates (OPs) contain carbon and hydrogen, but also have at least one atom of phosphorus and either oxygen or sulfur attached to that phosphorus atom. Chemists would say that organophosphates are derived from phosphoric acid. There are six possible variations, each of which is considered a different type of organophosphate (or, more accurately, organophosphorus) compound.

The first organophosphorus insecticides were developed in the late 1940's and early 1950's, in part in response to concerns voiced about the persistence of DDT and other organochlorines. Just as with the organochlorines, there are several different kinds of organophosphates, some are relatively simple and some are very complicated molecules.

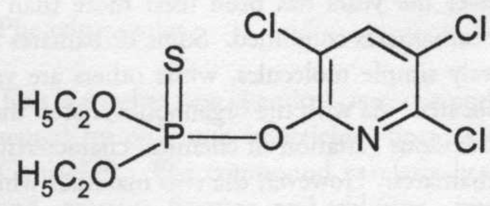
The chemical characteristics depend on the length and shape of the chain of atoms attached to the phosphorus, oxygen, and/or sulfur located at the central part of the molecule. Some OPs have fairly simple chemical structures, while others are quite complex, with long or complicated chains attached to the central structure.



There is tremendous variation in characteristics within the class. For example, some OP insecticides are very persistent, while others break down



Trichlorfon



Chlorpyrifos

very quickly. Some OPs are virtually insoluble in water and therefore quite immobile, while others are extremely soluble (and mobile) in water. Some of these materials are extremely toxic to mammals and other vertebrates, while others are much less toxic. It is virtually impossible to generalize about the environmental characteristics of organophosphate insecticides, because there is so much variation within the class.

Most OP insecticides are "broad spectrum," which means that they are effective on many different kinds of insects, and therefore may have harmful effects on beneficial insects and other arthropods. Most OPs do not accumulate in the food chain.

Typical application rates - 1 to 8 pounds active ingredient per acre

Examples: acephate (Orthene™), chlorpyrifos (Dursban™), diazinon (**not on golf courses**), fonofos (Crusade™, Mainstay™), isazofos (Triumph™), isofenphos (Oftanol™), trichlorfon (Proxol™, Dylox™)

Carbamates

Carbamate insecticides are derived from carbamic acid, which means they contain at least one atom of nitrogen and two oxygen atoms. The first carbamates were introduced as pesticides in the early 1950's but were not particularly effective as insecticides. As chemists began to "play" with the molecule, adding some things here and taking away things there, they found ways to improve the effectiveness of these compounds against insects.

Carbaryl (Sevin™) was the first truly successful carbamate insecticide to be introduced, in 1956, and over the years has been used more than all other carbamates combined. Some carbamates are relatively simple molecules, while others are very complicated. As with the organophosphates, there is tremendous variation in chemical characteristics of carbamates. However, the two materials which are currently available for use by turf managers in the United States (carbaryl, or Sevin™, and bendiocarb, or Turcam™) are intermediate in mobility, persistence, and toxicity. Both of these materials are broad spectrum, and tend to be quite toxic to earthworms, honey bees, and certain other non-target arthropods.

Typical application rates - 2 to 8 pounds active ingredient per acre

Examples: bendiocarb (Turcam™), carbaryl (Sevin™, Sevimol™)

Synthetic Pyrethroids

Pyrethrum/Pyrethrin

There are several compounds which occur naturally in plants and have insecticidal properties. One of these is pyrethrum, a compound produced by some kinds of chrysanthemums native to Africa. Pyrethrum refers to the crude flower dust, while pyrethrin refers to six closely related compounds which occur in the blend. Some of these pyrethrins are quite toxic to insects. Pyrethrins act very quickly against target insects and cause a virtually immediate "knockdown" effect, in which the insect is paralyzed. However, many insects are able to metabolize (break down) pyrethrins quite quickly, so some insects survive after a brief period of paralization. Pyrethrins as a group are less acutely toxic to mammals than are several other classes of insecticides, but they usually are quite toxic to fish. Pyrethrins tend to be less stable than several other kinds of insecticides and break down in ultraviolet light quite quickly.

Synthetic Pyrethroids

As with so many other kinds of insecticides, chemists looked at some of the naturally occurring pyrethrins and began to experiment with the structure of the basic molecules. They found that as they added atoms to different parts of the original molecule, they could "improve" the insecticidal properties of the compound. These new pyrethroids are not natural compounds, but they are directly based on the structure of natural compounds. The chemical "tweaking" has resulted in the development of materials which last much longer than the natural pyrethrins (several weeks instead of a few hours or days) and are more toxic to insects.

Pyrethroids have gone through several levels of development. The first generation was developed around 1950 and included materials like allethrin, which essentially was a synthetic duplicate of one of the natural pyrethrins. The second generation appeared around 1965 and included materials like tetramethrin and resmethrin. These compounds were still somewhat vulnerable to breakdown in sunlight, so use tended to be limited to enclosed settings such as greenhouses.

The third generation appeared in the early 1970's and included the first pyrethroids to be used in agricultural settings. These tended to be much more photostable and were markedly more toxic to insects than earlier materials. They tended to remain active on leaf foliage for four to seven days, which was much longer than earlier pyrethroids. Materials like permethrin, fenvalerate, and fluvalinate (Mavrik™) were active at much lower rates than other classes of insecticides, and were applied at 0.1 to 0.2 lb active ingredient per acre.

The fourth, and most recent, generation was first developed in the 1980's and continues to undergo further refinement. These compounds are much more stable in sunlight and can remain active on leaf surfaces for a few weeks. They are applied at even lower rates than third generation pyrethroids, which may become a significant factor for turf managers in years to come. Materials like bifenthrin (Talstar™), lambda-cyhalothrin (Battle™, Scimitar™), and cyfluthrin (Tempo™) are sometimes effective at 0.01 to 0.05 lb active ingredient per acre.

Most of the synthetic pyrethroids which are currently being used on turf are of the fourth generation group. In many cases, the acute toxicity (to mammals and other vertebrates) and environmental characteristics (such as mobility and persistence) depend on the kind of solvent which is used in a given formulation. While most of the pyrethroids tend to be less toxic to vertebrates than other classes of insecticides, there are some exceptions.

Typical application rates - 0.01 to 0.5 pound active ingredient per acre

Examples: bifenthrin (Talstar™), lambda-cyhalothrin (Battle™, Scimitar™), cyfluthrin (Tempo™), fluvalinate (Mavrik™)

Chloronicotinyls

This very new chemical class is currently represented by only one insecticide, imidacloprid (Merit™ or Marathon™). The chemical structure is somewhat related to that of nicotine, containing several nitrogen atoms and two ring structures. There has been considerable excitement in the turf world since the registration of imidacloprid because the compound has proven to be very effective at low rates of application against several turf insects, particularly white grubs. In addition, the compound appears to provide much longer residual activity than other insecticides currently available.

Imidacloprid, the only representative of this chemical class, is relatively low in acute toxicity to mammals and most other vertebrates. It appears to be quite persistent in the soil, sometimes remaining active for three or four months after application. It is relatively mobile but breaks down quickly if it ends up in surface water. It appears to be less toxic to several beneficial insects, other arthropods, and earthworms than many turf insecticides.

Typical application rates - 0.2 to 0.4 pound active ingredient per acre

Example: imidacloprid (Merit™)

Phenylpyrazoles

This is another new chemical class, currently represented by only one insecticide, fipronil (Chipco Choice™). The compound is relatively complex and contains fluorine and chlorine, among the usual atoms. This compound has generated considerable excitement in the turf world because it appears to be very effective against mole crickets at low rates of application. In addition, it appears to provide much longer residual activity against mole crickets than other insecticides currently available.

At this point, fipronil must be applied sub-surface (using high pressure liquid injection or a slicing technique). This is in part because the product is relatively immobile in soil, so even heavy irrigation following an application may not be sufficient to move a surface application of the material through the thatch. While fipronil is moderately toxic to mammals and other vertebrates, it does not appear to be as disruptive to beneficial insects as most other turf insecticides.

Typical application rates: 0.02 to 0.05 pound active ingredient per acre

Example: fipronil (Chipco Choice™)

Resistance Issues

Most insects have the ability to break down, or otherwise detoxify, many of the chemicals with which they come in contact during their daily activity. Some of these chemicals are natural products produced by plants as a form of natural defense, while others are insecticides applied by humans in an effort to suppress an insect population.

Just as no two people are alike, most insect populations have considerable variation, with some individuals being particularly talented at finding new food sources and others being especially able to break down chemicals. If an insecticide is used in such an area, the insects which are already inherently better able to break down chemicals will survive exposure to an insecticide which is applied, while other insects which had other innate abilities but were not as efficient at breaking down chemicals will be more likely to be killed by exposure to the material.

The insects which survive in such a situation are almost certainly the ones which had an inherent ability to break down chemicals. There are several ways by which insects can break down chemicals, so there are many variations which can show up in an insect population. The main point, however, is that the insects which survive the first exposure to an insecticide will pass on their genetic makeup to subsequent generations. The gene which enables an insect to break down an insecticide will be passed on from generation to generation (especially if the insecticide is used at least once during each generation of that insect), because the gene provides a competitive advantage to the insects which

Figure 1. How resistance develops in an insect population. (S = susceptible, R = resistant)

NORMAL POPULATION	S S S R S S S R S S S R
	R S S S R S S S R S S S
	S R S S S R S S S R S S
INSECTICIDE APPLIED	S R R S R
(many susceptible insects die)	R S R R S
	R R S R S
SURVIVORS REPRODUCE	R S R R R S R R R S R S
	S R R R S R R S R R S R
	R R S R S R R R S R R S
INSECTICIDE APPLIED	
(many susceptible insects die)	R R R R R
	R S R R R
	R R R S R

EVENTUALLY MOST SUSCEPTIBLE INDIVIDUALS DIE, AND SURVIVORS ARE RESISTANT possess it. Eventually the gene will become so prevalent in the population that most insects will not be affected by an application of that insecticide. When this happens, scientists say that the population of insects has become resistant to the insecticide.

Figure 1 demonstrates the concept visually. If we start with a population of insects in which most individuals are susceptible to an insecticide ("S" in the diagram) but a few individuals are inherently resistant to that insecticide ("R" in the diagram), and allow those insects to interbreed, the overall percentage of individuals which are susceptible and resistant remains constant in the absence of the insecticide. However, if the insecticide is applied, most of the susceptible individuals will be killed, while the resistant individuals will survive. Over time, the percentage of individuals which are resistant to the insecticide increases, because the resistant ones are the ones which survive and pass on their genes.

As it happens, the mechanisms which an insect uses to detoxify an organophosphate insecticide are often the same, regardless of the OP to which it is exposed. If an insect develops resistance to one organophosphate, it usually becomes resistant to other organophosphates at the same time. The same is true for most other classes of insecticides, as well.

There are several things a turf manager can and should do to reduce the likelihood of resistance developing in an insect population. The most important suggestion is to **avoid using the same insecticide or insecticides in the same chemical class repeatedly in the same location.** If you do use the same material over and over, some insects invariably will develop resistance to that material and pass on their resistant genes to their offspring. Eventually the "normal" insecticide application will have no noticeable effect on the population because most individuals will be unaffected by it.

If possible, **avoid treating "wall to wall"**. Monitor the turf areas and determine which areas are most heavily infested. Concentrate control efforts in those areas and leave other areas, with lower populations (and likely non-damaging) untreated. Any time a turf insecticide is applied, the chance exists that some individuals will already be or will develop resistance to the material. To delay the inevitable, **treat only when absolutely necessary.**

Selecting an Insecticide

If you determine that the insect population on your turf warrants the use of an insecticide, consider several factors before deciding which material to use. There are many kinds of insecticides, with a wide range of characteristics (for example, how quickly they work; how long they last; how mobile they are in surface water or ground water; toxicity to humans, target insects, and beneficial insects; and chemical structure). Take the time to review the information available and determine which ones are best suited to your needs. Note that a good choice in one instance will not necessarily be an appropriate choice in a different set of circumstances. As a guide, consider each of the following items before deciding which inseciticide would be "best."

1. Identify any environmental conditions (nearby ponds or streams, sandy soils, compacted soils) which should be considered. Choose materials which will not leach or run-off in those conditions.
2. Identify any toxicity issues which should be considered. Are you treating athletic fields? Is there a playground nearby - or are children likely to play on the treated area? Will pets or wildlife have access to the area after application? Choose materials which have lower levels of toxicity to humans and other vertebrates.
3. Can you irrigate the area after application? If you are unable to irrigate, you must select materials very carefully. Do not use a material which must be watered in unless you are equipped to do so!
4. Are there any particular beneficial insects which you must be careful to protect? Several insecticides are extremely toxic to honey bees. Follow label instructions carefully and do not use such materials when bees are foraging. There are several other insects which are beneficial but not necessarily

obvious. Avoid using broad spectrum insecticides whenever possible, to reduce the detrimental effects on these beneficial insects.

5. Determine whether you need a fast acting material (are the insects already causing damage?) or whether you can use a slower but longer lasting material. (Sometimes there is considerable variability within a chemical class, but the chemical class often provides a clue to "speed of efficacy" and residual activity.)

6. Do not use insecticides in the same chemical class repeatedly in the same location. Alternate chemical classes so that insect populations are less likely to become resistant to the insecticides being used.

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Terms to Know

Biomagnification- occurs when a material is not metabolized by an animal, but instead is stored in fat tissue. If that animal is consumed by another animal, the material is stored in the fat tissue of the consumer at even higher concentrations than it was present in the original animal.

Inorganic - does not contain carbon.

Metabolize - break down from a complex chemical structure into numerous simpler structures (refers to break down of an insecticide into a usually less toxic form)

Molecule - a collection of atoms which bond together, retaining a particular and specific structure.

Natural - produced by a plant or an animal.

Organic - containing carbon and hydrogen (and usually oxygen).

Organochlorine (Chlorinated Hydrocarbon) - a synthetic insecticide which contains chlorine and carbon, among other things.

Organophosphate (Organophosphorous Compound) - a synthetic insecticide which contains carbon and phosphorus (as well as oxygen and/or sulfur).

Photostable - stable in sunlight

Synthetic - produced by humans (may be organic or inorganic).

Synthetic Pyrethroid - a synthetic insecticide whose complex chemical structure is derived from pyrethrins (naturally occurring compounds found in some chrysanthemums)

Interpreting Chemical Structures

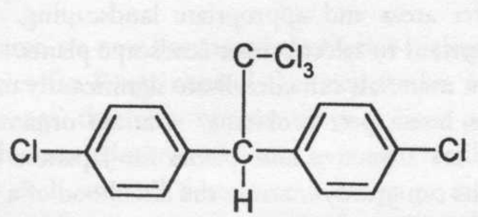
Chemists use a kind of shorthand to sketch the shape of molecules, which are made up of two or more atoms.

Abbreviations:

C = carbon
Cl = chlorine
H = hydrogen
O = oxygen
P = phosphorus
S = sulfur

Bonds:

Many atoms are connected to their neighbors by "single bonds," which are usually relatively stable and are represented by a single dash between the atoms. Sometimes atoms are connected by double bonds, which tend to be less stable and are represented by two dashes between the atoms.



DDT

The center of the molecule is a carbon atom, which is attached to two hexagonal rings. These are rings of carbon connected by alternating single and double bonds (actually it is not quite that simple!). The central carbon also has another carbon atom attached to it (at the top of the sketch), which in turn has three chlorine atoms attached to it. Finally, there is a chlorine atom attached at the "far" end of each of the hexagonal rings.

Chemical Characteristics:

The molecular structure of an insecticide will determine its persistence, solubility in water, acute toxicity (to people or to insects), and other characteristics.

Genetic Resistance to Mole Crickets in Turf Bermudagrass

by Wayne Hanna, U.S. Department of Agriculture
Will Hudson, University of Georgia

Mole crickets can quickly ruin beautiful turf if a plan to manage and/or control them is not in place. It seems that this pest is becoming more serious each year. Insect management procedures are usually continuous and must be repeated. Genetic resistance to pests is usually permanent and can greatly reduce and simplify (and possibly eliminate) some management procedures.

Development of turf cultivars with genetically controlled pest resistance is an important objective in the U.S. Department of Agriculture-ARS turf bermudagrass breeding program at the University of Georgia Coastal Plain Experiment Station in Tifton, GA. Pesticides (including insecticides) are rarely applied to the plots with experimental cultivars so that insects will infest the research area and new plant types with resistance to insects can be identified. 1996 has been an exceptionally good year to screen for genetic resistance to the tawny mole cricket (Scapteriscus vicinus) in our research plots.

In 1996, we rated mole cricket activity in 497 experimental turf bermudagrass hybrids growing in 4 x 4 meter plots replicated twice. These were selected for close mowing tolerance from over 27,000 hybrids produced in 1993. Ratings ranged from 1 (no mole cricket activity) to 9 (severe mole cricket activity) indicating at least that the mole crickets preferred some cultivars more than others. Differential feeding by the mole crickets on the experimental hybrids was dramatic. Where the lowest and highest rated plots were adjacent to each other, the crickets would not invade the non-preferred plots. Tift 94, a fine-textured cultivar introduced at Midiron at Tifton, GA, which should be