



Editor's note: This is the first of two articles based on a GCSAA seminar, "Turf insecticide modes of action and resistance management," which was taught by the authors for the first time at GCSAA's Education Conference in Orlando in 2008. The seminar explains the basics of insect physiology, insecticide modes of action and resistance management strategies.

Turf insecticide classes and modes of action

Products using 12 modes of action are currently available for use on golf courses, but researchers continue to look for new target areas.



A recent survey referenced in *GCM News-Weekly* reported that 92% of superintendents consider a new mode of action essential in fungicide resistance management. This is not a surprising number considering the awareness that superintendents have of the propensity for fungal turf pathogens to develop resistance when exposed to repeated applications of fungicides. It would be



Insecticide resistance has been documented in Southern chinch bug in Florida. Photos by Dave Shetlar

interesting to know the percentage of superintendents who consider new modes of action essential in insecticide resistance management. Insects typically do not develop resistance as rapidly as do pathogens because their generation time is substantially longer than that of pathogens. Turf insect pests of golf courses generally have only one to three generations per year. However, considering that the top two insecticides that are used on golf courses have been on the market for more than a dozen years, it may be time for superintendents to give more thought to incorporating products with new modes of action into their insect management programs. This is particularly true in light of recently documented cases of insecticide resistance by turf insects, including the annual bluegrass weevil in the Northeast and the Southern chinch bug in Florida.

The first step in devising an insecticide use strategy that minimizes the potential for resistance development is to recognize the different insecticide classes registered for use on golf courses and to understand the mode of action inherent to each of these classes. The Insecticide Resistance Action Committee (IRAC) was established by the crop protection industry in 1984 to promote and coordinate resistance management efforts. An integral part of this effort was to develop a classification scheme based on the physiological mode of action of insecticides. Table 1 was adapted from the IRAC classification scheme and includes those groups that contain insecticide active ingredients that are currently registered for use on golf

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Modes of action for insecticides

Group	Mode of action	Insecticide class	Insecticide common name	Original brand name	Basic manufacturer
1A	acetylcholinesterase inhibitor	carbamate	carbaryl	Sevin	Bayer
1B	acetylcholinesterase inhibitor	organophosphate	chlorpyrifos acephate trichlorfon	Dursban Orthene Dylox	Dow AgroSciences Valent Bayer
2B	GABA-gated chloride channel antagonist	phenylpyrazole	fipronil	Choice, Maxforce, TopChoice	Bayer
3	sodium channel modulator	pyrethroid	bifenthrin cyfluthrin deltamethrin lambda-cyhalothrin	Talstar Tempo DeltaGard Scimitar	FMC Bayer Bayer Syngenta
4A	nicotinic acetylcholine receptor agonist/antagonist	neonicotinoid	imidacloprid clothianidin thiamethoxam	Merit Arena Meridian	Bayer Valent Syngenta
5	nicotinic acetylcholine receptor agonist (allosteric)	spinosyn	spinosad	Conserve	Dow AgroSciences
7A	juvenile hormone mimics	juvenile hormone analogs	methoprene fenoxycarb pyriproxyfen	Extinguish Award Distance	Wellmark Syngenta Valent
7B					
7C					
11B2	microbial disruptor of insect midgut membrane	microbial	<i>Bacillus thuringiensis kurstaki</i>	Dipel	Valent
18A	ecdysone agonist/molting disruptor	diacylhydrazine	halofenozide	Mach 2	Dow AgroSciences
20	mitochondrial complex III electron transport inhibitor	hydramethylnon	hydramethylnon	Amdro	BASF
22	voltage-dependent sodium channel blocker	oxadiazine	indoxacarb	Advion, Provaunt	DuPont
28	ryanodine receptor modulator	anthranilic diamide	chlorantraniliprole	Acelepryn	DuPont

Table 1. IRAC mode of action classification for turf insecticides.

courses. (Some of these insecticides are not available in all 50 states.)

The U.S. EPA has recently developed voluntary insecticide resistance management guidelines based on the IRAC mode of action classification scheme. Figure 1 provides an example of the approved EPA symbol that pesticide manufacturers may elect to place on their product labels to assist end-users in determining the mode of action. Although the use of these symbols is not mandatory, the EPA believes that this approach to resistance management is sound and that the use of these symbols would be highly beneficial because the symbols are easily recognizable and should help superintendents select treatment options based on modes of action. This should make it easier for superintendents to implement one of the most important pesticide resistance management strategies, which is to avoid the repeated use of pesticides with the same mode of action.

In this article, we will use the IRAC classification scheme for modes of action to review the active ingredients in insecticides that are currently available for use by superintendents.

Group 1A Insecticide Acetylcholinesterase inhibitor: carbamates

Development history

Carbamate insecticides are derivatives of car-

Mode-of-action symbol



Figure 1. EPA insecticide target mode of action symbol

bamic acid and were first introduced in 1951 by Geigy Chemical Co. of Switzerland. The first products developed in this class were N, N-dimethyl carbamates, which were generally less effective than the N-methyl carbamates that were developed later. The first N-methyl carbamate introduced was carbaryl in the late 1950s. Most carbamates were developed during the roughly 30-year period from the mid-1950s until the mid-1980s.

Mode of action: acetylcholinesterase inhibition

During normal nerve impulse transmission, an impulse is passed from one nerve cell to another by the neurotransmitter substance acetylcholine. After the impulse is transferred, the acetylcholine must be destroyed to prevent additional impulses from being initiated. Acetylcholinesterase is an enzyme that catalyses the degradation of acetylcholine into a pair of benign compounds. Carbamate insecticides inhibit acetylcholinesterase,



which causes acetylcholine to remain at the receptor site where it induces repetitive impulses, eventually paralyzing the insect's nervous system and ultimately causing its death.

Current products registered for use on golf courses

Carbaryl (Sevin, Bayer Environmental Science) is the only carbamate insecticide that remains registered for use on golf courses in the U.S. Carbaryl was introduced by Union Carbide Corp. in 1956. It is estimated that more carbaryl has been used worldwide than all of the remaining carbamates combined. The two characteristics that are most responsible for its success are its very low mammalian toxicity and its broad spectrum of activity toward insect pests.

**Group 1B insecticide
Acetylcholinesterase inhibitor:
organophosphates**

Development history

Organophosphate insecticides are derivatives of phosphoric acid that evolved from nerve gas research in Germany during World War II. Research into organophosphate insecticides was initiated to identify substitutes for nicotine, which was used as an insecticide at the time and was in critically short supply in Germany. The first organophosphate insecticide TEPP (tetraethyl pyrophosphate) was introduced in 1946. Many insecticides in this class were developed in the 1950s as substitutes for the organochlorine insecticides. Although most organophosphates were much more acutely toxic than the organochlorines, they soon dominated the market based on their relatively quick speed of action and shorter persistence in the environment. As with the carbamates, the greatest period of development for the organophosphate insecticides occurred during the 1950s and 1960s. However, new products continued to be launched until the 1980s.

Mode of action: acetylcholinesterase inhibition

As with the carbamate insecticides discussed above, organophosphate insecticides inhibit acetylcholinesterase.

Current products registered for use on golf courses

Three organophosphate insecticides remain registered for use on golf courses. Acephate (Orthene, Valent U.S.A. Corp.) was first registered by Chevron in 1972. On golf courses, its primary use is mole cricket control in the Southeast. Chlorpyrifos (Dursban, Dow AgroSciences) was first registered in 1965 and at one time was one of the lead-

ing insecticides in the turf market. This changed drastically in 2000 as reregistration of the active ingredient by the EPA resulted in the elimination of many uses. At that time, chlorpyrifos remained registered for use on golf courses, but the higher application rates were removed from the label. Its primary use was for caterpillar and annual bluegrass weevil control. Recently, nonagricultural uses (including use on golf courses) have been removed from chlorpyrifos product labels. Existing end-use chlorpyrifos products may be used until stocks are depleted. Trichlorfon (Dylox, Bayer Environmental Science) was first registered in 1957. On golf courses, it is primarily used for curative control of white grubs and annual bluegrass weevil larvae.

**Group 2B insecticide
GABA-gated chloride-channel
antagonists: phenylpyrazoles**

Development history

Fipronil is the only insecticide in the phenylpyrazole chemical class that is currently being marketed. Other phenylpyrazoles are currently under development. Fipronil was discovered by Rhone-Poulenc in 1987. It was first registered in France in 1993 and was registered by the U.S. EPA in 1996.

Mode of action: GABA-gated chloride-channel antagonist

Phenylpyrazoles interfere with gamma-aminobutyric acid (GABA). During normal transmission of nerve impulses, GABA is released from the presynaptic nerve terminal and binds to a postsynaptic receptor protein. The receptor protein contains an intrinsic chloride-ion channel. When GABA binds to the receptor, the channel is opened, and chlorine ions flow into the postsynaptic neuron. This chloride permeability hyperpolarizes the membrane potential and dampens the nerve impulse. Phenylpyrazoles bind to the receptor and block chloride channel activation by GABA. The lack of synaptic inhibition by GABA leads to hyperexcitation of the central nervous system, which eventually paralyzes the system and ultimately results in the death of the insect.

Current products registered for use on golf courses

Bayer Environmental Science markets three products that contain fipronil and are registered for use on golf courses. Chipco Choice is applied with slit-application equipment for mole cricket control and as a broadcast application primarily for imported fire ant control. TopChoice is used



Annual bluegrass weevil causes the most damage in the larval stage, when it does most of its feeding.



primarily for imported fire ant control. Maxforce FC is registered for imported fire ant control.

Group 3 insecticide Sodium-channel modulators: pyrethroids

Development history

Pyrethroids are synthetic analogs of natural pyrethrum and have been extensively developed for insect control based on their high insecticidal activity, low mammalian toxicity and favorable environmental characteristics. Natural pyrethrum is extracted from the flowers of a chrysanthemum plant (*Chrysanthemum cinerariaefolium*), and its insecticidal properties have been known for hundreds of years. The chemical composition of pyrethrum was elucidated during the 1920s and 1930s. The first pyrethroid insecticide, allethrin, was developed by the USDA, and its insecticidal activity was first reported in 1949. The most significant advance in pyrethroid chemistry was the discovery of structural modifications that yielded photostability, a characteristic that was lacking in earlier pyrethroids and limited their use in agriculture and other outdoor applications. The first photostable pyrethroid was permethrin, which was discovered during the mid-1970s. Subsequent pyrethroids were based on the addition of an alpha-cyano group, including cypermethrin, cyfluthrin, lambda-cyhalothrin and deltamethrin. The biphenyl pyrethroid bifenthrin was developed during the mid-1980s.

Mode of action: sodium-channel modulators

Pyrethroids, like many of the other major classes of insecticides, interfere with the normal functions of the insect nervous system. Pyrethroids interfere with the sodium-channel gating mechanism that underlies the generation and conduction of each nerve impulse. Pyrethroids act by disrupting the sodium/potassium ion equilibrium along the nerve cell membrane by prolonging sodium ion influx. This creates excess sodium in the cell, which causes an electrical imbalance that results in excessive and repetitive firing of the neurons and leads to paralysis and ultimately the death of the insect.

Current products registered for use on golf courses

Pyrethroids have become a major group of insecticides in the turf industry, and many products are currently registered for use on golf courses. These include bifenthrin (Talstar, FMC Corp.), lambda-cyhalothrin (Scimitar, Syngenta) and cyfluthrin (Tempo, Bayer Environmental Sci-



Fipronil can be used to control the fire ant and the tawny mole cricket (an adult female is shown).

ence). The primary target pests of pyrethroids on golf courses include caterpillars, annual bluegrass weevil and mole crickets. All pyrethroids registered for use on golf courses are classified as Restricted Use Pesticides based on their acute toxicity to fish and aquatic organisms. These products also require a 25-foot buffer zone for applications near bodies of water (ponds, streams, etc.).

Group 4A insecticide Nicotinic acetylcholine receptor agonists/antagonists: neonicotinoids

Development history

The previous section described how the pyrethroid insecticides evolved from research into the insecticidal properties of the natural pyrethrum. In much the same manner, the neonicotinoid insecticides evolved from research into the insecticidal properties of the naturally occurring compound nicotine. Nicotine had been used for centuries to control sucking pests of many crops, despite its relatively low efficacy to pests and high toxicity to mammals. The first step toward commercialization occurred when Shell Chemical Co. began researching heterocyclic nitromethylenes during the 1970s. A major breakthrough occurred in 1985 with the discovery of imidacloprid by Nihon Bayer Agrochem. Imidacloprid was launched in the mid-1990s and is currently the top-selling insecticide worldwide. Additional neonicotinoids have been launched since the year 2000, including clothianidin and thiamethoxam.

Mode of action: Nicotinic acetylcholine receptor



Pyrethroids are one type of insecticide that superintendents can use to control annual bluegrass weevil adults.



agonists/antagonists

Neonicotinoids are acetylcholine mimics. Acetylcholine is released by presynaptic cells and it binds to the post-synaptic nicotinic acetylcholine receptor. This binding activates an intrinsic cation channel, which depolarizes the post-synaptic cell due to an influx of sodium and calcium. Synaptic activation is terminated by acetylcholinesterase, which degrades acetylcholine. Neonicotinoids bind to the nicotinic acetylcholine receptor and are insensitive to acetylcholinesterase. Persistent activation leads to overstimulation of cholinergic synapses, which results in hyperexcitation, convulsions, paralysis and death of the insect.

Current products registered for use on golf courses

Neonicotinoids have become the top-selling insecticides in the turf industry, and many products are currently registered for use on golf courses. Imidacloprid (Merit, Bayer Environmental Science) was registered by the U.S. EPA in 1994, and it quickly became the leading insecticide in the turf market, primarily based on its outstanding activity against white grubs. Imidacloprid changed the way superintendents controlled white grubs. Before its introduction, white grubs were controlled almost exclusively with curative applications targeting larvae in August and September. Imidacloprid was the first insecticide to provide excellent preventive white grub control from applications made before egg laying. Clothianidin (Arena, Valent U.S.A. Corp.) was registered by the EPA in 2003. Thiamethoxam (Meridian, Syngenta) was introduced to the turf market in 2007.



For the past 15 years, neonicotinoids have been the primary insecticides used for controlling white grubs, such as the masked chafer grub shown here.



Black cutworm larvae (caterpillars) cause extensive damage to golf courses by feeding on cool-season turfgrasses.

**Group 5 insecticide
Nicotinic acetylcholine receptor
agonists (allosteric): spinosyns**

Development history

During the 1980s, Eli Lilly Research Laboratories initiated a program to discover new natural products for the pharmaceutical and agricultural industries. The spinosyns, a group of natural products produced by the bacterium *Saccharopolyspora spinosa*, were first discovered in the Caribbean in 1982. Culturing in fermentation broths generated a range of compounds suitable for agricultural use. The first products of this class were commercialized during the late 1990s.

Mode of action: nicotinic acetylcholine receptor agonists (allosteric)

The mode of action of spinosyns is the allosteric activation of insect nicotinic acetylcholine receptors and a prolongation of acetylcholine responses. "Allosteric" is defined as "of or relating to a change in the shape and activity of a protein/enzyme that results from combination with another substance at a point other than the chemically active site." Spinosyns excite the insect nervous system, which leads to involuntary muscle contractions and paralysis. Note that the physiological mode of action is different for spinosyns than for neonicotinoids. A body of evidence suggests that the spinosyns also affect GABA receptor function, which may contribute to their insecticidal activity.

Current products registered for use on golf courses

Spinosad (Conserve, Dow AgroSciences) has been registered for use on golf courses since 1997. It is primarily used to control caterpillars and annual bluegrass weevil larvae.

**Group 7 insecticide
Juvenile hormone mimics: 7-A:
Juvenile hormone analogs, 7-B:
Fenoxycarb, 7-C: Pyriproxyfen**

Development history

Insect growth regulator (IGR) research was initiated in the late 1960s in response to growing concerns about the toxicological and environmental characteristics of the chlorinated hydrocarbon, organophosphate and carbamate insecticides that were in use at the time. Interest in developing IGRs was based largely on their much more favorable toxicity and environmental profiles. IGR activity is very specific to the target pests, which makes them ideal candidates for inclusion in Integrated Pest Management programs. The



major types of insect growth regulators include juvenile hormone mimics, chitin synthesis inhibitors and ecdysone agonists/molting disruptors. Juvenile hormone mimics are compounds that bear a structural resemblance to naturally occurring insect juvenile hormone. The first juvenile hormone mimic registered by the U.S. EPA was methoprene in 1975.

Mode of action: juvenile hormone mimics

Insect juvenile hormones are lipophilic sesquiterpenoids that contain an epoxide and methyl ester groups. Commercial juvenile hormone analogs mimic the action of the juvenile hormones on a number of physiological processes, including molting and reproduction. When insects are exposed to these compounds at a vulnerable stage of development, individuals are produced that have mixed larval/pupal or larval/adult characteristics. The effectiveness of juvenile hormone mimics is greatest when the normal levels of juvenile hormone are low, such as the final larval instar or early pupal stage. Thus, application timing may be critical for successful control.

Current products registered for use on golf courses

Methoprene (Extinguish, Wellmark International), fenoxycarb (Award, Syngenta) and pyriproxyfen (Distance, Valent U.S.A. Corp.) are all active ingredients in fire ant baits registered for use on golf courses.

**Group 11B2 insecticide
Microbial disruptors of insect
mid-gut membranes: *Bacillus
thuringiensis kurstaki***

Development history

The insecticidal bacterium *Bacillus thuringiensis* was discovered in Japan in 1901. It was first used as a microbial insecticide in 1938. Commercial products were registered in the U.S. in 1961. *Bacillus thuringiensis* has become the most commercially successful microbial insecticide. Commercial products containing *B. thuringiensis* are available to control caterpillars (*B.t. kurstaki* and *B.t. aizawai*), mosquitoes and black flies (*B.t. israelensis*) and beetles (*B.t. san diego* and *B.t. tenebrionis*).

Mode of action: microbial disruptors of insect mid-gut membranes

Bacillus thuringiensis is a soil-inhabiting, gram-positive bacterium that produces one or more very small crystals within its sporulating cells. These crystals are composed of large proteins called

delta-endotoxins. When the crystals are eaten by an insect, they are dissolved in the mid-gut and the delta-endotoxins are released. The delta-endotoxins bind to specific receptor sites on the mid-gut epithelium membrane. Cation channels are formed in the membrane, and ion movement through these channels disrupts critical potassium and pH gradients, which ruptures the epithelium leading to gut paralysis and death of the insect.

Current products registered for use on golf courses

Bacillus thuringiensis kurstaki (Dipel, Valent U.S.A. Corp.) is registered for sod webworm control on golf courses.

**Group 18 insecticide
Ecdysone agonists/molting
disruptors: diacylhydrazines**

Development history

Prototypes of diacylhydrazines were discovered by Rohm and Haas in the early 1980s. Products were introduced to the market in 1993 and



Because of their painful sting and large mounds, fire ants are a nuisance to golfers.



A microbial insecticide, *Bacillus thuringiensis kurstaki*, is registered for sod webworm control on golf courses.



On average, fire ant mounds are 10 to 24 inches (25-61 centimeters) in diameter and 18 inches (46 centimeters) high and can extend as deep as 6 feet (1.8 meters) underground.

marked the only major contribution to the insect growth regulator group in nearly 20 years. Four compounds in this class have been commercialized: tebufenozide, halofenozide, methoxyfenozide and chromafenozide. Halofenozide was introduced to the turf market in 1997.

Mode of action: ecdysone agonists/molting disruptors

Ecdysone receptor agonists are also known as molting accelerating compounds. They mimic the natural function of the molting hormone ecdysone, which is released at strict physiologically defined times before molting. Its release initiates a cascade of biochemical reactions that lead to the formation of a new cuticle and shedding of the old cuticle at the end of the molting process. Diacylhydrazines bind to the ecdysone receptor complex and initiate a precocious and lethal larval molt.

Current products registered for use on golf courses

Halofenozide (Mach 2, Dow AgroSciences) became available to superintendents in 1997. It may be used to control a range of white grub and caterpillar species.

Group 20 insecticide
Mitochondrial complex III
electron transport inhibitors:
hydramethylnon

Development history

Hydramethylnon was discovered by American Cyanamid in 1977. It was first registered by

the U.S. EPA in 1980. Commercial products have been developed to control ants, cockroaches and termites.

Mode of action: mitochondrial complex III electron transport inhibitors

Mitochondrial electron transport, coupled with oxidative phosphorylation, is an essential process in many organisms. The electrons are transferred by several different enzyme complexes to produce ATP, which is the energy source of all cells. Compounds that disrupt energy metabolism have been identified from both natural and synthetic sources. Hydramethylnon disrupts energy metabolism by inhibiting the electron transport system and blocking the production of ATP, resulting in a slowly developing toxicity. Symptoms include inactivity, followed by paralysis and ultimately the death of the insect.

Current products registered for use on golf courses

Hydramethylnon (Amdro, BASF) is available as a fire ant bait for use on golf courses.

Group 22 insecticide
Voltage-dependent sodium-channel
blockers: oxadiazines

Development history

Initial research on the voltage-dependent sodium-channel blockers was conducted by Phillips-DuPhar in the early 1970s. This research led to the discovery of a new family of pyrazoline insecticides. Some of these compounds had excellent insecticidal activity, but they were plagued by serious problems, including acute toxicity, bioaccumulation and environmental persistence. DuPont began researching pyrazolines in 1986, and their mode of action was described by Rohm and Haas in 1988. Compounds were discovered during the late 1980s that had improved insecticidal activity. However, other issues such as persistence (both too much and too little), bioaccumulation and metabolic fate precluded their commercialization. In 1990 DuPont researchers found that oxadiazines are viable alternative structures that can target the voltage-dependent sodium channel and are more susceptible to metabolic and soil degradation. Further research led to the discovery of indoxacarb, which retained high insecticidal activity combined with favorable environmental and metabolic profiles.

Mode of action: voltage-dependent sodium-channel blockers

The sodium channel is an ionic pore in nerve



cell membranes. It allows sodium ions to flow into the nerve cell via selective permeability. The movement of sodium through the nerve cell membrane is a critical component of normal nerve-impulse transmission. Oxadiazines block the flow of sodium into the nerve cell. This results in the rapid impairment of nerve-impulse transmission and ultimately leads to paralysis and death of the insect.

Current products registered for use on golf courses

Three formulations of indoxacarb, all from DuPont Professional Products, are currently registered for use on golf courses. Provaunt is used for annual bluegrass weevil, caterpillar and mole cricket control. Advion mole cricket bait is used to control large nymphs and adult mole crickets, and Advion fire ant bait is used to control imported fire ants and the turfgrass ant (*Lasius neoniger*).

**Group 28 insecticide
Ryanodine receptor modulators:
anthranilic diamides**

Development history

The insecticidal properties of the water-soluble plant extract ryania were first discovered in the 1940s. Researchers from Rutgers University and Cornell University found that extracts from the stems of *Ryania speciosa* contain several structurally related compounds, including ryanodine, that could be used to control insects. The agricultural use of ryania-containing products peaked in the early 1950s and then declined as synthetic chemicals became more available and less expensive. EPA registrations of ryania-containing products were voluntarily cancelled in 1997. Initial attempts to develop synthetic compounds that would target the ryanodine receptor were unsuccessful. This changed in 2008 when the U.S. EPA registered the anthranilic diamide, chlorantraniliprole.

Mode of action: ryanodine receptor modulators

Anthranilic diamides disrupt calcium homeostasis, which plays a key role in multiple cell functions, particularly muscle control. Coordinated muscle contraction involves the activation of two different types of calcium channels. Voltage-gated channels are activated by a nerve impulse, which causes them to open and allow calcium entry into the muscle fiber. Ryanodine receptor channels regulate the movement of calcium from the sarcoplasmic reticulum. Anthranilic diamides bind to the ryanodine receptor and lock it in a partially opened state, which results in the uncontrolled release of calcium and the disruption of normal

muscle contraction, which leads to the death of the insect.

Current products registered for use on golf courses

Chlorantraniliprole (Acelepryn, DuPont Professional Products) was registered for use on golf courses in May 2008. It is effective against the entire spectrum of turf-damaging white grubs as well as annual bluegrass weevil, billbugs and turf-infesting caterpillars.

Conclusions

A fundamental principle of insecticide resistance management is to minimize dependence on a single product or multiple products that share the same mode of action. This article has reviewed the



The turfgrass ant disrupts play on the golf course when it builds mounds on greens and tees.



The bluegrass billbug can cause severe damage to its preferred host, Kentucky bluegrass, as well as fescues and perennial ryegrass.



The research says

→ Insects are relatively slow to develop resistance to insecticides, but cases of resistance have recently been documented in annual bluegrass weevil and Southern chinch bug.

→ A fundamental principle of insecticide resistance management is to minimize dependence on a single product or multiple products that share the same mode of action.

→ Superintendents currently have 12 modes of action available for insect control.

→ The most recent addition to the superintendent's arsenal is the anthranilic diamide, chlorantraniliprole, which is a synthetic compound that targets the ryanodine receptor. It was approved by the U.S. EPA in 2008.

12 modes of action that superintendents currently have available for insect control. Close examination of insecticide development history provides reason for great optimism regarding our ability to sustain insect pest management programs well into the future.

Figure 2 shows a timeline for the development of the major synthetic insecticide classes. It is interesting to note that the compounds developed during roughly the first 50 years of the synthetic insecticide age attacked only three target sites/modes of action. However, in the past 15 years, insecticides have been developed that attack an additional five target sites/modes of action. This clearly shows that the agricultural chemical industry is committed to discovering insecticides that have novel modes of action, and these new insecticide classes also have much more favorable toxicological and environmental characteristics. On the other hand, most insecticide products have a relatively limited spectrum of activity, so the options available to control a specific pest species are usually quite limited. In our next article, we will address insecticide resistance and how it may be managed by focusing on the different modes of action that may be used in control programs for the major turf insect pests.

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Synthetic insecticides

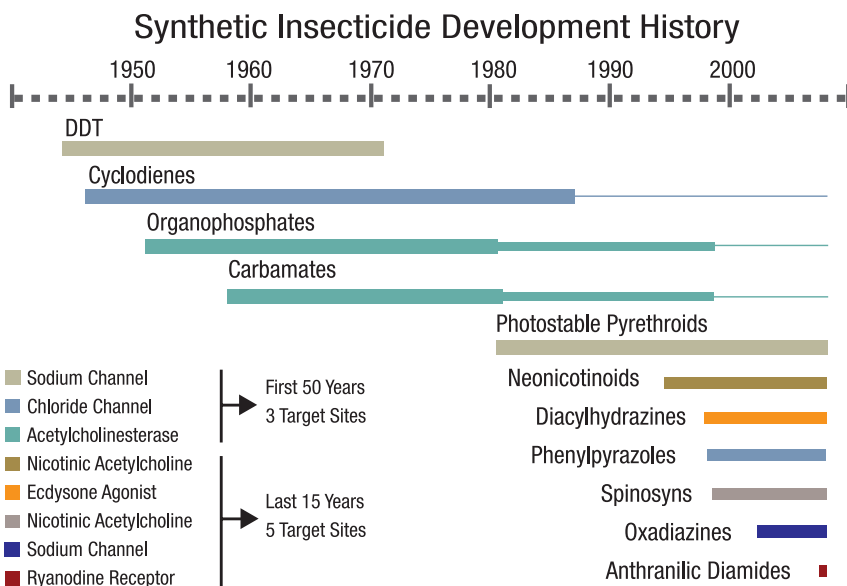


Figure 2. Synthetic insecticide development history

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