Insights into managing annual bluegrass weevils

The annual bluegrass weevil is a prolific pest that can be troublesome on *Poa annua*, but the right timing and the right product can provide relief.

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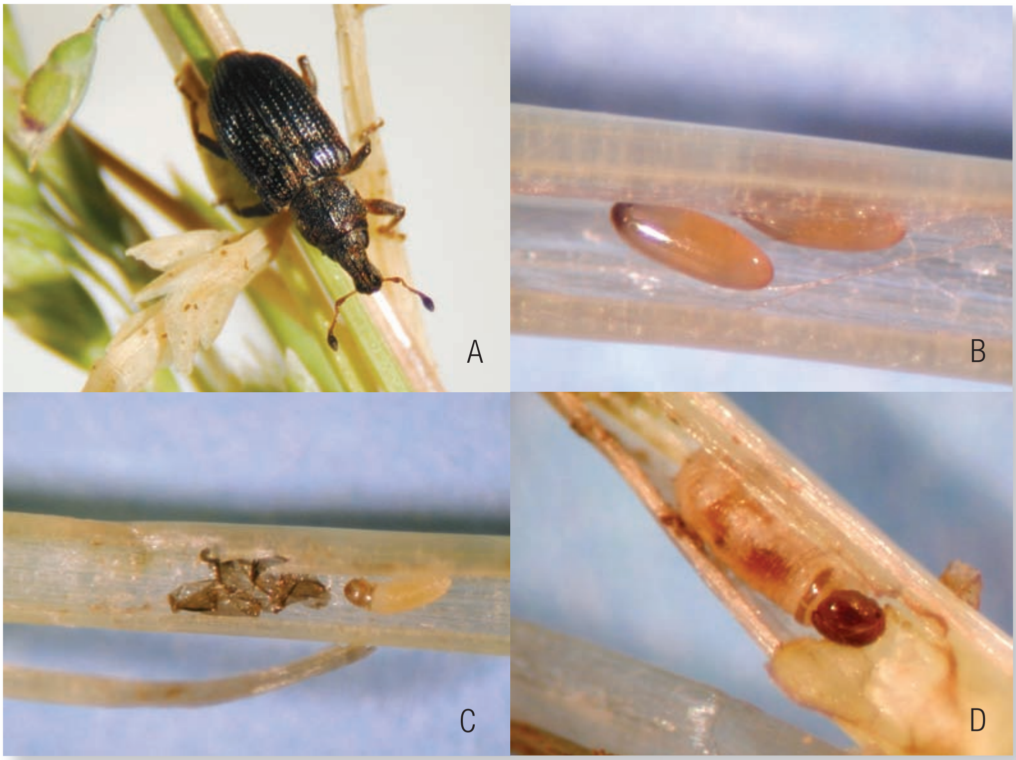
To help superintendents meet the challenges of maintaining annual bluegrass (*Poa annua*), turf scientists from across the country are collaborating in the Northeast Regional Hatch Project 1025 to study the management of two important pests of annual bluegrass — anthracnose disease and annual bluegrass weevil. The scientists authoring this article are contributing to a better understanding of annual bluegrass weevil biology and its control. This article aims to complement the review of this pest's biology as recently reported in *GCM* (5).

ABW biology

As its name implies, the annual bluegrass weevil, *Listronotus maculicollis* (formerly called *Hyperodes maculicollis*), principally feeds as larvae on annual bluegrass. Adults mostly overwinter in protected areas along the edge of woods or in the rough. During the spring, adults migrate onto golf courses, where they feed on grass blades before mating and laying eggs within the stem of *Poa annua*. Eggs hatch into the first-instar larvae, which feed within the grass stem, where they complete two additional larval stages. Third



Some development stages of annual bluegrass weevil, *Listronotus maculicollis*: **A,** adult; **B,** eggs inserted in the grass stem; **C,** newly hatched larva within the stem; **D,** second-instar larva. **Photos by R. Cowles** instars eventually exit the stem and, as fourth and fifth instars, continue feeding on *P. annua* root crowns while living at the surface of the soil. After completing this feeding, the larvae transform into pupae and then into adults.

With two to three generations per year, this weevil can build to astonishing populations (small patches may reach 1,200 larvae per square foot) that can stress or kill annual bluegrass in greens and fairways. Where *P. annua* is considered a weed as it invades other grasses, annual bluegrass weevil feeding may be perceived as beneficial because the weevil acts as a biological control agent. However, in older courses with extensive populations of *P. annua* in greens and fairways, this grass can form an acceptable playing surface and the goal is then to maintain its health. Scattered observations reveal that annual bluegrass weevil larvae also can feed on creeping bentgrass, and this complicates its status as a pest. To date, however, nothing is known about annual bluegrass weevil in association with creeping bentgrass.

Previous control strategies

Over the past few years, annual bluegrass weevil has become one of the most difficult insect pests to manage on golf courses. During the previous decade, superintendents could be assured that a well-timed pyrethroid spray in the spring would prevent damage for the remainder of the season. The strategy was to apply a pyrethroid spray to the fairways, or even just their perimeter, at the time that forsythia (*Forsythia intermedia*) reached the half-green/half-gold late stage of bloom, or when downy serviceberry (*Amelanchier arborea*) was in bloom. Adult weevils feeding at that time would encounter a lethal dose of insecticide before they started laying eggs, and the life cycle would be interrupted.

The situation has changed, and this approach no longer works on some courses. We will explain the underlying causes for control failures and ways in which superintendents may effectively respond to this challenge. Changes in strategies to combat this pest are an immediate need where control practices have failed, and may prevent similar failures in the remaining locations.

Targeting annual bluegrass weevil

Some challenges for managing annual bluegrass weevil are related to targeting. Any intervention tactic, chemical insecticide or otherwise, has to hit the target in both space and time. "In space" means understanding and predicting *where* the insect populations will reach damaging levels. One salient issue is whether perimeter applications of insecticides are sufficient because damage is most prevalent in these areas, or whether wall-to-wall fairway applications are required because potentially damaging populations are spread out over a wider area. "In time" means understanding and predicting *when* the insect appears, and *when* the life stages are present that are susceptible to control measures.

After feeding on *Poa annua* root crowns while it is living at the soil surface, a fifth-instar annual bluegrass weevil will transform into a pupa (shown) before becoming an adult weevil.

Movement on the golf course

Recent studies have described annual bluegrass weevil movement in the golf course habitat, ultimately refining our targeting ability. For instance, field studies have led to a new conceptual model

The annual bluegrass weevil is an extremely destructive pest of *Poa annua* turf on golf courses. **Photo by Stanley Swier** about how annual bluegrass weevil adults might migrate between overwintering sites (in protected areas off the course) and developmental sites (susceptible turf on golf course playing surfaces) (2). Ongoing studies will continue to test our new ideas that (a) adults may rely on walking to invade fairways in the spring, but rely on flight to disperse back to protected overwintering sites in the fall, and that (b) overwintering largely takes place in an area up to 180 feet (about 55 meters) away from the fairway, primarily along defined tree lines, to which flying adults orient in the fall.

Seasonal population fluctuations

Other studies are taking a detailed look at seasonal population fluctuations. These are revealing how much populations vary from site to site and year to year in terms of abundance, timing, synchrony and number of generations. From these studies, we will be able to gauge how much we can generalize about annual bluegrass weevil population patterns. For instance, from 2004 to 2006, annual bluegrass weevil populations in western New York completed either two or three generations, but in each case the last one was relatively small or only partially completed. Furthermore, in some years, arrival of adults to highly maintained turf is rapid and synchronous, which provides ideal circumstances for effective targeting with a well-timed insecticide application. In other years, however, adults immigrate in two waves or immigration is stretched out over a longer period of time. As a result, these populations are difficult to target effectively with a single insecticide application. Adult immigration, population development and the number of generations completed may depend on growing degree-days. A temperature-driven model is currently being developed and validated to determine how it could accompany plant phenological indicators as a tool for superintendents to time intervention tactics or scouting activities.

Pyrethroid resistance in annual bluegrass weevil

Recent studies have demonstrated dramatic differences in the susceptibility to pyrethroid insecticides of annual bluegrass weevil populations found in Connecticut and the greater New York metropolitan area (DR, unpublished data). Whereas susceptible weevils succumb when exposed to 0.8 nanogram (one-billionth of a gram) of the active ingredients of Talstar (bifenthrin) or Scimitar (λ-cyhalothin), weevils from courses that have experienced intensive prior use of pyrethroids are killed only when they are exposed to 30 to 200 times that amount of insecticide. These results point to the evolution of resistance to pesticides, a problem also commonly encountered with fungicides. Repeated use of effective pesticides selects for individuals with genetic traits that allow them to survive. Their offspring, in turn, will be more difficult to kill than the previous generations.

Cross-resistance

In the case of annual bluegrass weevil, selection by pyrethroids has left many courses with adult weevils that are now virtually impossible to kill with any pyrethroid. What has occurred is called cross-resistance, in which selection with one product allows the insect to withstand another insecticide that is usually closely related. Recent investigations into the genetics and biochemistry of insecticide resistance in other insects have demonstrated that a large suite of traits can simultaneously evolve to cause insecticide resistance whereby each trait contributes different yet complementary roles, allowing the insect to cope with toxic chemicals (1,4). As we have no reason to believe that the genetics or physiology of annual bluegrass weevil is different from that of other insects, superintendents should be aware that the physiological changes caused by pyrethroid resistance may also make some other insecticides less effective. Although insecticides with new modes of action may provide additional options for managing pyrethroid-resistant weevils, new and old chemistries alike are jeopardized by the development of pyrethroid resistance.

Metabolic detoxification

Metabolic detoxification is a resistance category in which enzymes degrade insecticide molecules before they reach target sites such as the nervous system. Several families of these enzymes exist, the most important of which are the cytochrome P450 system, carboxyesterases, and glutathione transferases, all of which confer some general detoxification capabilities. Laboratory tests with adult annual bluegrass weevil have demonstrated that the cytochrome P450 system is involved with resistance to pyrethroids. Unfortunately, other resistance traits are also involved, but these other traits have not yet been characterized (DR, unpublished data).

The cytochrome P450 and to some extent the carboxyesterase enzymes can be blocked with a synergist called piperonyl butoxide (PBO), commonly found in household insecticide aerosols and available in registered products (for example, Exponent and Prentox PBO-8) intended for use in tank-mixes. Although nontoxic by itself, PBO enhances the toxicity of the pyrethroid. When pyrethroid-resistant annual bluegrass weevil adults are exposed to PBO, their susceptibility to pyrethroids is restored. This capability can be exploited for diagnosing pyrethroid-resistant weevils in the laboratory or with diagnostic test kits (see below).

Although PBO restores pyrethroid toxicity in the laboratory, it decomposes quickly when exposed to sunlight. Therefore, we do not know how well it might perform against populations of annual bluegrass weevil in the field. Field trials are under way to determine the potential for synergists such as PBO to restore the toxicity of pyrethroids to annual bluegrass weevil.

Target-site insensitivity

Approach with caution the continued use of pyrethroids, even when combined with PBO, as additional mechanisms could allow annual bluegrass weevil to circumvent insecticides. Besides metabolic degradation (which currently is taking place), the most important is target-site insensitivity. Pyrethroids bind to sodium channels of nerves, which are their target site, like a key fitting into a lock. If the shape of the lock changes so the key no longer fits, the insect gains resistance to that class of insecticide. A few years of intensive selection with pyrethroid + PBO combinations could result in resistance because of target-site modification, which could even make synergized pyrethroids ineffective. Continuing studies will determine whether target-site insensitivity (along with detoxification) is contributing to poor performance of pyrethroids against adult annual bluegrass weevil.

Combining insecticides

Another approach to managing existing resistant populations is using insecticides in combination with each other. Insecticides affecting different functions of nerves sometimes synergize each other. Essentially, it's like hooking up two amplifiers in series: each toxin causes the nerves to fire more often, so the combination of two poisons will multiply their effects. Two companies are introducing insecticides containing a pyrethroid (bifenthrin) in combination with a neonicotinoid. Aloft (Arysta) combines clothianidin with bifenthrin, while Allectus (Bayer) combines imidacloprid with bifenthrin. Neither clothianidin nor imidacloprid by themselves have reliable activity against annual bluegrass weevil; however, they do work together with bifenthrin to provide better results (RSC, unpublished data). Ongoing studies will further test prospects for these synergistic combinations, as well as those that do not include pyrethroids.

Testing for pyrethroid resistance

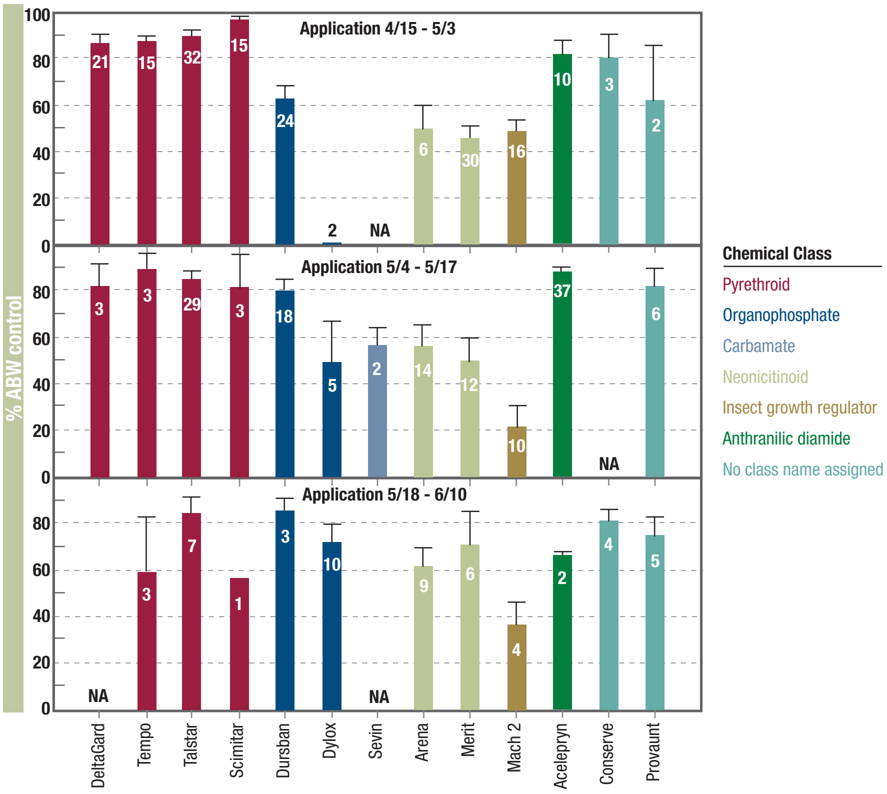
The basis for making intelligent pest management decisions is accurate information. A simple diagnostic test kit is now available that allows a superintendent to determine whether annual bluegrass weevil populations on a course are resistant to pyrethroids (RSC, unpublished data). The test requires at least 24 adult weevils, which can be obtained with a soapy irritant drench or can be picked directly off the turf.

Those adults are added to four disposable plastic dishes or zippered plastic bags along with a piece of moistened filter paper that was previously dosed with the field rate (on an area basis) of a pyrethroid insecticide and kept at room temperature. Two days after the beetles have been dropped on the treated filter paper, they are rated as alive or dead. The kits usually provide an easily interpreted all-or-nothing response: weevils from susceptible populations all die on exposure to pyrethroid or pyrethroid + PBO, whereas weevils from resistant populations only die when exposed to the pyrethroid + PBO. Although 24 weevils can provide statistically valid results, using twice as many weevils is advisable.

It's unknown whether larvae from populations

Figure 1. Efficacy of insecticides targeting annual bluegrass weevil as immigrating adults (applications April 15-May 3, forsythia full to late bloom/dogwood full bloom); early-stage larvae feeding within the grass stem (application May 4-May 17, forsythia late bloom/dogwood full to late bloom/first anthesis of *Poa annua*);or late-instar larvae feeding on the crown within the soil (application May 18-June 10, *Rhododendron catawbiense* full to late bloom). Insecticides are grouped by chemical class, which is indicated by color (see the legend). The trials were conducted over the geographical range of all the collaborating authors, over the past several years. Dates are adjusted to the New York metropolitan area. The number of trials from which the mean and standard errors were calculated is shown within each bar. Percent control is the percent reduction of larvae and pupae recovered relative to untreated check plots.

Insecticide efficacy



Experimental studies involving the use of entomopathogenic nematodes as biological controls of annual bluegrass weevil targeted early fourth instars of the weevil (shown). **Photo by R. Cowles**

with resistant adults are also resistant. Based on insecticide tests (Figure 1), pyrethroid applications not only kill annual bluegrass weevil adults, but they also kill larvae traveling from stem to stem or feeding as late instars on the plant crowns. Therefore, pyrethroids have been effective if they were applied when many life stages of weevils were present. If adult weevils are resistant to pyrethroids but the larvae are not, a change of application date — from targeting the adults to targeting the third, fourth and fifth instars — may still allow these products to be useful.

Nonpyrethroid alternatives

The results of several years of insecticide trials targeting annual bluegrass weevil are summarized in Figure 1, in which the efficacy of many newer insecticides is contrasted with that of pyrethroids and older chemicals. Research trials conducted by most of the authors have confirmed that effective alternatives to pyrethroids do exist for combating annual bluegrass weevil. Rather than relying on pyrethroids to intercept and target adults immigrating onto the fairway from overwintering sites, more emphasis may have to be placed on targeting the larvae slightly later in the season. An advantage of this approach is the opportunity to spot-treat areas in a curative fashion; that is, once scouting has indicated where populations are localized and determined whether thresholds have been surpassed. That degree of fine-tuning isn't possible with the standard preventive approach.

Along with savings from unnecessary insecticide applications, spot-treatments could reduce the total area treated and the proportion of the weevil population being selected with insecticides, thereby reducing selection for resistance.

Among the nonpyrethroid products being confirmed as effective against annual bluegrass weevil are Dylox (trichlorfon, Bayer Crop Science), Conserve (spinosad, Dow AgroSciences), Acelepryn (chlorantraniliprole, DuPont) and Provaunt (indoxacarb, DuPont). Although we know the optimal timing for using Dylox, we need more studies to make reliable suggestions for the use of the other chemistries.

Researchers have had the longest experience with Dylox because it is an older chemical. Dylox is a contact insecticide and is most effective when used as a curative or rescue treatment that targets larvae after they have exited the grass stem. Younger (smaller) larvae live within their host as stem borers, but as they mature and get larger, they move out of the stem and reside at the soil surface where they feed externally on crowns. Superintendents must be aware that Dylox is an organophosphate with heightened human and environmental toxicity relative to other available products.

Acelepryn operates as a systemic, entering the plant and being ingested by the insect. Based on our findings, this insecticide can be applied from peak emergence of adults to the appearance of the first young larvae in the stems. After eggs are laid and larvae emerge, the insecticide is in place within the plant to target the young larvae feeding within the stem. However, more trials are necessary to study the efficacy of earlier applications and especially of curative applications.

Provaunt and Conserve have each demonstrated some activity against both annual bluegrass weevil adults and larvae. Intriguingly, indoxacarb is made more toxic to the insect through the action of one family of enzymes (carboxyesterases) implicated in resistance to pyrethroids. Therefore, Provaunt may have special value for targeting pyrethroid-resistant annual bluegrass weevil populations. Both Conserve and Provaunt are known from agricultural systems to be less toxic to beneficial predators and are overall much less toxic to the applicator, golfers and the environment than Dylox or pyrethroids.

Probably the most effective way to counteract insecticide resistance is to rely more on biological control and less on insecticides. Predators and pathogens are the perfect countermeasure to insecticide resistance because they kill the survivors of insecticide treatments. Older insecticide chemistries such as pyrethroids and Dylox are highly toxic to predators and parasitic insects. Newer chemistries such as Conserve, Provaunt and Acelepryn will probably cause less collateral damage to populations of natural enemies and thereby move us closer to an integrated system where insecticides and predators can work in concert. Because annual bluegrass weevil often is continuously present from mid-summer to autumn, superintendents need to be aware that insecticide applications targeting other turf pests (for example, white grubs and cutworms) can cause inadvertent selection of annual bluegrass weevil populations. Adoption of newer insecticides with reduced impact on beneficial insects will help the overall turf insect management system.

Biological control with nematodes

We are currently investigating entomopathogenic nematodes (EPNs) as a biological control option to suppress annual bluegrass weevil populations. Entomopathogenic nematodes are microscopic roundworms found in the soils of most ecosystems. They attack insects by entering through natural openings or, in some instances, directly through the insect's cuticle. Once inside the insect's body cavity, entomopathogenic nematodes release symbiotic bacteria that assist in killing the insect (usually within 48 hours). The bacteria break down the insect's internal tissues and provide a substrate for entomopathogenic nematode reproduction. After one to three reproductive cycles within the insect (usually one to two weeks), thousands to hundreds of thousands of juvenile nematodes exit the insect cadaver in search of new hosts. Their ability to cause rapid death to the insect and their high reproductive capabilities make them ideal candidates for biological control of soil-dwelling turfgrass pests.

A study conducted over a 3-year period on untreated fairways of three golf courses in New Jersey demonstrated that two species of entomopathogenic nematodes (*Steinernema carpocapsae* and *Heterorhabditis bacteriophora*) regularly infect annual bluegrass weevil stages from the third larval instar through newly hatched adults (3). The impact of entomopathogenic nematodes on annual bluegrass weevil was variable, ranging from 0% to 50% mortality within annual bluegrass weevil generations. Entomopathogenic nematodes were found during all months that annual bluegrass weevil stages were detected on fairways (early April to mid-October), yet their densities were shown to fluctuate dramatically with annual bluegrass weevil densities and environmental conditions. Entomopathogenic nematodes are sensitive to extreme moisture and temperature conditions. Not surprisingly, entomopathogenic nematode populations crashed during excessively hot conditions in the summers of 2005 and 2006.

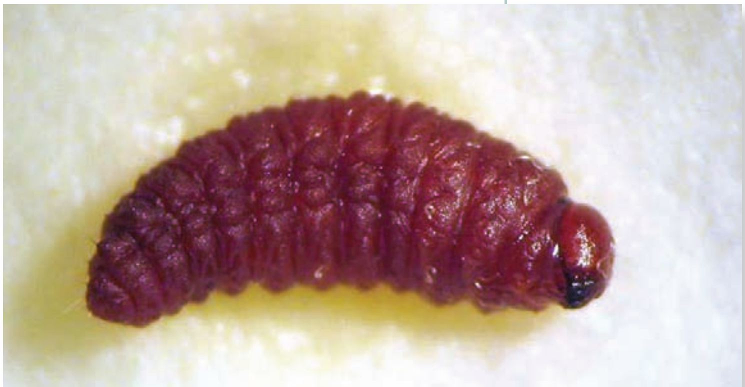
The variable mortality and sensitivity of annual bluegrass weevil to environmental extremes suggest that resident populations of entomopathogenic nematodes are unlikely to consistently reduce annual bluegrass weevil populations to the low thresholds for damage imposed by most golf course operations. However, the ability of natural populations to infect a wide range of annual bluegrass weevil stages and cause moderate generational mortality suggests that there is potential in using entomopathogenic nematodes as inundative, curative controls against the damaging soil-dwelling stages of annual bluegrass weevil.

Laboratory studies

We are testing the virulence of five commercially available entomopathogenic nematodes (*S. carpocapsae, S. feltiae, S. kraussei, H. bacteriophora, H. megidis*) and two entomopathogenic nematode isolates collected from naturally infected annual bluegrass weevil cadavers (*S. carpocapsae, H. bacteriophora*) against different annual bluegrass weevil stages. In laboratory assays, adults collected as they emerged on fairways in April 2007 and fall-collected adults had similarly low susceptibility to entomopathogenic nematodes. *Steinernema carpocapsae*, the top-performing species, only provided 50%–60% mortality after 12-day exposure of 250 nematodes per weevil. No differences were observed between our locally isolated entomopathogenic nematodes and their commercial counterparts. The low susceptibility of adults even under ideal laboratory conditions suggests that entomopathogenic nematodes are not likely to replace preventive chemical pesticides for adult control.

Field studies

Virulence of entomopathogenic nematodes to annual bluegrass weevil fourth- and fifth-instar larvae was assessed in field-infested turf cores in the laboratory. Control of fourth instars ranged from 65% to 100%, with 97% for *S. feltiae* and 100% for the field-isolated *S. carpo-*



White string-like nematodes can be seen on the surface of this annual bluegrass weevil larva that shows the characteristic red coloration caused by infection with *Heterorhabditis bacteriophora.* **Photo by B. McGraw** *capsae*. Control of fifth instars was lower overall but reached 90% for *S. feltiae*. This suggests that entomopathogenic nematode applications should be targeted against the early fourth instars to maximize control and minimize the potential for turf damage.

Field trials using one endemic and five commercial entomopathogenic nematode strains at two rates indicate that high levels of control can be achieved with well-timed applications against first-generation soil stages of annual bluegrass weevil. Our applications have been timed to follow the peak in third-instar densities (the last stage typically found boring within the plant), before a majority of the annual bluegrass weevil stages have entered the soil.

In 2006, entomopathogenic nematodes provided 62% to 92% control of annual bluegrass weevil when applied to moderate infestations (~ 25 annual bluegrass weevils/square foot) at the rate of one billion entomopathogenic nematodes/acre. *Steinernema feltiae* (92% control) and the endemic strain of *H. bacteriophora* (85% control) provided the greatest benefit. More-variable control (0%–87%) was observed in the 2007 field trials and is likely attributable to high annual bluegrass weevil densities in the plots (>70 annual bluegrass weevils/square foot in the untreated controls). *Steinernema carpocapsae* (one billion/acre) provided the most consistent control (70%). However, split applications of *H. bacteriophora* (87%) and a mixed-species treatment (*H. bacteriophora* + *S. carpocapsae*) (82%) provided the greatest reductions in annual bluegrass weevil densities. Both these treatments were able to reduce densities below damaging threshold in the field (<40 annual bluegrass weevils/square foot).

We will continue to investigate the potential of entomopathogenic nematodes for annual bluegrass weevil management with the most consistent candidates (*S. feltiae, S. carpocapsae, H. bacteriophora*). In particular, in 2008 experiments we will address the effect of timing and application rates on the level of annual bluegrass weevil control.

The research says

- ➔ Annual bluegrass weevil (ABW) has become one of the most difficult pests on golf courses.
- ➔ Control strategies that have worked well in the past (well-timed pyrethroid sprays) are no longer effective in some cases, and new control methods must be found.
- ➔ Researchers are trying to determine how ABW migrate and where they overwinter and why ABW populations experience fluctuations in abundance, timing, synchrony and number of generations.
- ➔ Where ABW populations have developed resistance to pyrethroids, using a pyrethroid plus a synergist could provide effective control.
- ➔ Some nonpyrethroid chemistries have been found to be effective; using entomopathogenic nematodes as a biological control has not been effective on adults, but greater success has been shown with fourth instars in the laboratory and in the field.

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