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This publication includes lecture notes of papers presented at the 2000 New Jersey Turfgrass Expo. Publication of these lectures provides a readily available source of information covering a wide range of topics and includes technical and popular presentations of importance to the turfgrass industry.

This proceedings also includes research papers that contain original research findings and reviews of selected subjects in turfgrass science. These papers are presented primarily to facilitate the timely dissemination of original turfgrass research for use by the turfgrass industry.

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INTEGRATED AND BIOLOGICAL CONTROL OF WHITE GRUBS

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White grubs, the root-feeding larvae of scarab beetles, are important pests of turfgrass, pastures and many crops throughout the world. At least 10 species cause significant damage to turfgrasses in the United States. In fact, in the northeastern United States, a complex of primarily introduced white grub species is the major turfgrass insect pests. Among these, the Japanese beetle, *Popillia japonica*, has until recently been regarded as the key species, but other white grub species are becoming more important. These other species include the Oriental beetle, *Exomala orientalis*, the European chafer, *Rhizotrogus majalis*, and the Asiatic garden beetle, *Maladera castanea*. Surveys have indicated that the Oriental beetle has become the most important white grub species in New Jersey and some neighboring areas.

Entomopathogenic nematodes offer an environmentally safe alternative to chemical insecticides in the management of white grubs. Nematode efficacy in the field, however, has been variable. Improper handling of these living control agents may cause some of this variability, and only persistent education efforts by extension personnel and industry may alleviate this limitation. Nematodes are also more susceptible than chemical insecticides to environmental factors that can affect their infectivity and persistence. These factors include abiotic factors such as extreme temperature and moisture conditions, and biotic factors such as natural enemies that prey on or parasitize nematodes. A better understanding of these factors will enable us to optimize the use of entomopathogenic nematodes in pest management.

Other management tools, including pesticides, may also affect the efficacy of entomopathogenic nematodes. Understanding the potential interactions of components of an IPM program may help to prevent failures in pest control or even improve efficacy. While some pesticides have negative effects on entomopathogenic nematode infectivity, other insecticides and biological control agents interact synergistically with the nematodes. Previous studies have shown that combinations of nematodes with the milky disease bacterium (*Paenibacillus* [=*Bacillus*] *popilliae*) or the scarab specific Buibui strain of *Bacillus thuringiensis* ssp. *japonensis* can have a synergistic effect on white grub mortality. However, the combination of nematodes and milky disease is feasible only for long-term control in areas that can tolerate some damage, whereas the combination of nematodes and *Bt* Buibui is feasible only for white grub species that are sufficiently susceptible to this bacterium. A more efficient combination with wider applicability may be nematodes and the neonicotinoid insecticide imidacloprid.

BIOTIC FACTORS AFFECTING THE EFFICACY OF ENTOMOPATHOGENIC NEMATODES AGAINST WHITE GRUBS

Some of the variability in nematode efficacy may be attributable to limited knowledge about the effect of nematode species, white grub spe-

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cies, and white grub larval stages on the efficacy of nematodes to control white grubs. We have conducted laboratory (in 30-ml creamer cups filled with soil and grass) and greenhouse experiments (in 1-Liter pots with soil and grass) to determine these interactions. In laboratory experiments, the 1st and 2nd larval stage of the Oriental beetle were more susceptible to the nematode *Heterorhabditis bacteriophora* than larvae in the 3rd and last stage. For the Japanese beetle, there was only a trend for susceptibility to decrease with advancing larval development. A greenhouse experiment confirmed our observation for the Oriental beetle.

White grub species had a strong effect on efficacy of several nematode species in laboratory experiments. Generally, the Japanese beetle was the most susceptible species. A general separation of the remaining white grub species was difficult because the ranking of nematode species differed among white grub species. For example, *Steinernema* sp. (isolated from Japanese and Oriental beetle larvae in NJ), overall the most pathogenic nematode strain tested, was highly pathogenic to Japanese beetle, Oriental beetle, European chafer, and Asiatic garden beetle, but its performance in Northern masked chafer larvae was mediocre. A greenhouse trial showed a similar trend, except that Asiatic garden beetle grubs were clearly less susceptible to nematodes, including *Steinernema* sp., than all other white grub species. The discrepancy between greenhouse and laboratory observations in Asiatic garden beetle susceptibility may be due to the very high activity of these grubs in the greenhouse experiment. High activity of the grubs could interfere with nematode host attachment and subsequent infection. Future experiments will investigate the effect of larval stage of different white grub species on nematode efficacy and the potential of newly isolated and highly grub pathogenic nematode strains.

INTERACTIONS BETWEEN NEONICOTINOID INSECTICIDES AND NEMATODES

Efficacy of neonicotinoid-nematode combinations

Imidacloprid, a broad-spectrum insecticide, with relatively low vertebrate toxicity, low application rates, long residual activity, and a relatively small effect on beneficial invertebrates, is one of the most widely used agents for white grub control. Imidacloprid belongs to the subgroup of chloronicotinyls within the neonicotinoid insecticides. Because its efficacy declines with advancing white grub development, it has to be applied preventively, preferably before the presence of the first instar. However, white grub outbreaks are difficult to predict because they are localized and usually sporadic and because of the difficulty in sampling for white grubs in general and their eggs and first instars in particular. Therefore, the preventive approach involves treating large turf areas that otherwise may need only partial or no treatment at all. Curative spot applications against the easier to detect later white grub stages using the synergistic combination of imidacloprid and entomopathogenic nematodes could reduce cost and environmental impact, and offer an alternative to the more hazardous organophosphate and carbamate insecticides threatened by the Food Quality Protection Act of 1996.

In a series of greenhouse and field experiments, we tested the effect of application timing, imidacloprid rate, white grub species, and nematode species on the efficacy of imidacloprid-nematode combination for white grub control. We showed that imidacloprid interacted synergistically with the entomopathogenic nematodes *Heterorhabditis bacteriophora*, *H. marelatus*, *H. megidis*, and *Steinernema glaseri* in 3rd instars of the Japanese beetle, the Oriental beetle, and the masked chafers, *Cyclocephala borealis*, *C. pasadenae*, and *C. hirta*. The degree of interaction varied with nematode species. The strongest and most consistent synergism occurred between imidacloprid and *S. glaseri*. Synergism between imidacloprid and *H. bacteriophora* was weaker and less consistent. Combinations of imidacloprid and *Steinernema kushidai* only resulted in additive white grub mortality. We observed synergistic interaction whether nematode were applied at the same time as imidacloprid or 14 days later. Although our study suggested that the synergistic interaction could occur at imidacloprid rates as low as 10 to 25% of the recommended field rate, the extent to which the chemical can be reduced seems to depend on a number of conditions including timing of application (earlier better) and white grub species.

We have expanded our observations on nematode-neonicotinoid interactions to include thiamethoxam, a new neonicotinoid with very similar characteristics as imidacloprid that belongs to the subgroup of thianicotinyls. In a series of greenhouse experiments, we observed only occasional synergism between thiamethoxam and various *Heterorhabditis* species in Oriental beetle 3rd instar larvae; only *S. glaseri* showed strong synergism with thiamethoxam. Imidacloprid showed consistent synergism with all nematode species in the same experiments. In a field experiment with Oriental beetle 3rd instars, we also observed synergism between the nematode *H. bacteriophora* and imidacloprid and no synergism between thiamethoxam and this nematode.

The combination of nematodes and imidacloprid could be used for effective curative treatments of white grub infestations. The compatibility of nematodes and imidacloprid in tank mixes increases the feasibility of this approach. In addition, imidacloprid has no negative effects on nematode reproduction in infected white grubs and fitness of the emerging nematode progeny. Rather, the increased number of hosts succumbing to nematode infection in combinations with imidacloprid should improve nematode recycling that may lead to additional white grub mortality and longer persistence of nematode populations.

Mechanism of the imidacloprid-nematode interaction

To successfully infect a host, the infective juvenile stage nematodes have to locate a potential host, attach to its cuticle, penetrate, and become established in the host's body cavity. However, during their coevolution with soil pathogens such as entomopathogenic nematodes, white grubs have developed a series of behavioral, morphological, and physiological barriers to infection. To elucidate the mechanism of interaction between entomopathogenic nematodes and imidacloprid, we conducted a series of experiments testing the effect of imidacloprid exposure on various white grub defensive mechanisms.

In vials with soil and grass, mortality, speed of kill, and nematode establishment were positively affected by imidacloprid exposure of the grubs with *S. glaseri* and *H. bacteriophora*. Imidacloprid had a similar effect for both nematode species on various factors important for the successful nematode infection in white grubs. Nematode attraction to grubs was not affected by imidacloprid treatment of the grubs. Establishment of nematodes injected into the grub body cavity was always higher in imidacloprid-treated grubs but the differences were small and in most cases not significant. The major factor responsible for synergistic interactions between imidacloprid and entomopathogenic nematodes appears to be the general disruption of normal nerve function due to imidacloprid resulting in drastically reduced grub activity. This sluggishness facilitates host attachment of infective juvenile nematodes. Grooming and evasive behavior in response to nematode attack was also reduced in imidacloprid-treated grubs. The degree to which different white grub species responded to entomopathogenic nematode attack varied considerably. Untreated *P. japonica* grubs were the most responsive to nematode attack among the species tested. Untreated *C. borea-*

lis grubs showed a weaker grooming and no evasion response, and untreated *C. hirta* grubs showed no significant response. Chewing/biting behavior was significantly increased in the presence of nematodes in untreated *P. japonica* and *C. borealis* but not in *C. hirta* and imidacloprid-treated *P. japonica* and *C. borealis*.

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