

PROJECT DESCRIPTION

1 THE PROBLEM, BACKGROUND AND JUSTIFICATION

1.1 Introduction

Current white grub control scenarios in turfgrass of the Northeast have essentially closed the door to successful IPM. Not only is there widespread reliance on early season preventive applications of imidacloprid, there is a lack of biologically-based control alternatives. In practical terms this means that turfgrass managers have no quantitative way to decide when not to spray, other than making localized applications that target areas highly susceptible or traditionally affected by these pest. And those seeking non-chemical options are stymied by biological alternatives that are relatively difficult or expensive to apply, or yield such inconsistent results that they are impracticable. Part of the solution are curative alternatives that would permit sampling and better decision-making, and biological alternatives that could supplant reliance on chemical insecticides.

Among white grubs and other soil-borne insect pests, there is broadening evidence that synergistic interactions between chemical and biological insecticides hold promise for new management opportunities. For instance, separate laboratory studies have shown that the susceptibility of white grubs to entomopathogenic nematodes can be enhanced by other stressors, including endophyte infection of the host plant, Bt (*Bacillus thuringiensis*) and milky spore disease (*Paenibacillus popilliae*) application, and the insecticide imidacloprid. This suggests that there is promise in carefully evaluating and exploiting the susceptibility of insects to control tactics while they are being challenged under other conditions.

To date, however, this approach has not been undertaken in a comprehensive fashion for any turfgrass pest, nor has it been adapted to or evaluated under field conditions. The “critical step” we propose to take in this proposal, is to conduct a series of laboratory bioassays that will launch a systematic and cohesive approach to advance biologically-based management in turfgrass systems. Results from these detailed laboratory studies will guide greenhouse and field studies, and in turn integration of new approaches into existing management scenarios. In essence, we seek to understand under what circumstances biologically-based pest management can be effective, whether those conditions are widespread or reproducible, and how to overcome the limits to adoption of these technologies. We will end up with the best recommendations for how synergisms between combined chemical and biological control products can be exploited and best incorporated into IPM programs for white grubs and other troublesome soil insect pests.

1.2 Scope of the Problem

Turfgrass is a valuable and rapidly expanding component of our urban and rural landscape. In 1990, it was estimated that turfgrass covered 12 million hectares in the U.S. (Potter & Braman 1991) and today that includes 60 million lawns and 16,000 golf courses (Emmons 2000). In NY, the estimated expenditure of the turfgrass industry two decades ago was \$1 billion (Gruttadaurio et al. 1982). The NY Agricultural Statistics Survey has just published results compiled from a 2003 statewide survey revealing that this industry has ballooned to \$5.1 billion annually for the

maintenance of 3.43 million acres (NASS 2004). In addition to its significant economic contribution, turfgrass provides important recreational, ecological and visual functions in our society. Recreational uses include lawns around homes, businesses and institutions, athletic fields, golf courses and parks. Ecological roles include soil stabilization, erosion control, reduction and filtering of runoff, and cooling of the local atmosphere - especially in urban areas. Turfgrass is visually pleasing as an alternative to concrete or pavement in urban and suburban areas, and provides textural contrast in rural and otherwise vegetated areas.

As managed ecosystems, these extensive and diverse turfgrass habitats require decision-making strategies to maintain them for their intended uses. To IPM practitioners, better management of pests and diseases across this area and over this sector means opportunities for great gains in the improvement of human and environmental health and welfare.

White grub species are the most injurious and widespread pest complex in turfgrass of the U.S. (Vittum et al. 1999). In the Northeast, four of the eight species are introduced exotics, including the Asiatic garden beetle, European chafer, Japanese beetle and Oriental beetle. Since its introduction in 1917 (NJ) the Japanese beetle has expanded its range to the Mississippi and beyond (Alsopp 1996); it is currently one of the most ubiquitous and injurious pests of turfgrass and ornamentals in the eastern U.S., resulting in economic losses of >\$460 million/year (USDA-Aphis 1998). California deploys some 10,000 traps annually in their Japanese beetle monitoring and detection program as part of efforts to prevent Japanese beetle establishment on the West Coast; this complements the U.S. Domestic Japanese Beetle Harmonization Plan that regulates the movement of nursery plants from infested to non-infested states (Klein et al. 2002).

Our focus on white grub control in turfgrass thereby represents the major pest complex in one of the most extensive and rapidly expanding components of our urban and rural landscape. Better managing this vast area will have huge positive impacts especially considering that this habitat is intimately associated with human populations and that home owners can spray lawn chemicals with little regulation. Under this scenario, our modern challenge is not to promote more conversion of wild and agricultural lands to turfgrass, but to better protect and steward the land already dedicated to that use.

At least in the Northeast, current white grub management scenarios have essentially closed the door to successful IPM because of dependence on early season preventive applications of imidacloprid (Merit). This neonicotinoid pesticide has largely replaced several other insecticides that were less effective, had higher mammalian toxicity, were withdrawn from registration, or are currently under FQPA review. Imidacloprid is not effective against late instar grubs yet early instars are too difficult to target in sampling programs. As a result, imidacloprid is applied early in the season before sampling can assess thresholds. On Long Island, NY, where local legislation has severely curtailed the use of certain insecticides, imidacloprid has now been detected in groundwater, sparking discussion about best management practices for its continued use (Gilrein & Yeh 2004). Best management practices should discourage wall-to-wall applications and promote localized treatments that target areas highly susceptible or traditionally affected by this pest (Rossi 2003).

In addition to dwindling chemical control options, the practice of IPM is also compromised by lack of biologically-based control alternatives. Many natural enemies have been studied, and a few have been commercialized, but no real non-pesticide options are available with proven effectiveness and practicality for white grubs in turfgrass. The major commercial products, based on entomopathogenic nematodes and *Paenibacillus popilliae* (the causal agent of milky disease), are generally regarded as ineffective or too costly for any real role in white grub management. Overall, IPM of white grubs in turfgrass would benefit immensely from (i) curative alternatives that would permit sampling and better decision-making, and (ii) biological alternatives that could supplant reliance on chemical insecticides.

1.3 Background

1.3.1 White grub biology and ecology

White grubs are the immature stages of scarab beetles (Coleoptera: Scarabaeidae) and are among the most important soil insect pests found in U.S. and international agriculture (Jackson & Glare 1992, Vittum et al. 1999, Bellotti & Peck 2000). In the northeastern U.S., turfgrass is subject to intense feeding pressure from a complex of at least eight scarab species. These include four native and four introduced species (Table 1). This pest complex is very widespread throughout the region although the distribution of each particular species is limited by geography and local site conditions.

Table 1. White grub pests of turfgrass in the northeastern U.S.

Common name	Scientific name	Origin
Asiatic garden beetle	<i>Maladera castanea</i>	Exotic
Black turfgrass ataenius	<i>Ataenius spretulus</i>	Native
European chafer	<i>Rhizotrogus majalis</i>	Exotic
Green June beetle	<i>Cotinis nitida</i>	Native
Japanese beetle	<i>Popillia japonica</i>	Exotic
May and June beetles	<i>Phyllophaga</i> spp.	Native
Northern masked chafers	<i>Cyclocephala borealis</i>	Native
Oriental beetle	<i>Exomala orientalis</i>	Exotic

With two exceptions, these white grubs have a one-year life cycle in the Northeast. The black turfgrass ataenius completes one to two generations per year, while May or June beetles require one to three years to complete a generation. The life cycle varies slightly depending on species, geographic location, and seasonal weather. Typically, eggs are laid in late June or early July, and grubs hatch in late July or early August. Larvae feed on grass roots, weakening individual plants. As grubs persist and grow larger in the late summer and fall, more roots are consumed and individual grass plants die. Low to moderate levels of grub infestation can thin turf stands, whereas high populations (>100 grubs/m²) usually result in large patches of dead turf. Severe damage is common, and entire lawns, athletic fields and golf course fairways can be rendered unusable. Damaged turf peels back easily from the soil (often when raking) because the root systems have been disrupted or devoured. The soil surface will feel spongy, not firm. Unlike other species, larvae of the green June beetle cause damage by their active tunneling through the root zone, not by direct feeding on roots.

Because the Japanese beetle is a high-profile and abundant pest throughout the Northeast, many products and practices for white grub management have only targeted this species. However, the Japanese beetle has been displaced as the most damaging scarab pest in turf in many areas on a local or regional basis. For example, the European chafer is the predominant insect pest of lawns across much of upstate NY and is expanding its impact into MA and NH. The European chafer is considered the most difficult of all grubs to control using traditional insecticides and biological control agents, and is more damaging to turf than the Japanese beetle. Oriental beetles have become the predominant pest in some areas, and have spread throughout the Northeast (Alm et al. 1999). Other species such as the Asiatic garden beetle, northern masked chafer, green June beetle and *Phyllophaga* beetles are increasing in importance as well.

1.3.2 Insecticide history and management

Traditionally, turf care specialists manage scarab grubs with one or two annual insecticide applications. They seldom assess grub population levels and species composition before making treatment decisions, and usually apply insecticides preventively or in direct response to turf damage. Prophylactic treatments have increased tremendously since the introduction of imidacloprid (which is applied before beetles oviposit and grub populations can be assessed), and the loss of several curative compounds.

As recently as five years ago, at least ten insecticides were labeled for use against white grubs. Those included bendiocarb, carbaryl, chlorpyrifos, diazinon, ethoprop, fonofos, halofenozide, imidacloprid, isofenphos and trichlorfon. The wide array of products varied in their speed of efficacy, persistence, species-specific efficacy, ability to penetrate the thatch layer, and a variety of environmental impact factors. Choice is important in grub control products because of the long duration of the damaging stage of the insect (>3 months), the variety of grub species that may be encountered, and the diversity of sites and settings where grubs are pests. However, options are now limited because many of the previously available insecticides have been eliminated or severely restricted from the turf market, as a direct result of FQPA.

Several materials were voluntarily removed from the turf market (e.g., bendiocarb, ethoprop, fonofos and isofenphos) within the last four years. These materials became effective within three to six days after application and provided residual activity for three to six weeks. Comparable curative compounds of intermediate speed of efficacy and persistence are no longer available.

Additional restrictions have resulted from label changes that significantly reduced application rates to ineffective levels for grub control, thereby functionally removing more insecticides from the turf market (e.g. diazinon and chlorpyrifos). Of the remaining compounds, carbaryl and trichlorfon are in the group of cholinesterase inhibitors that is still undergoing review, and they may eventually be removed from the turf market as well. Carbaryl has been inconsistent at best when used against white grubs (Shetlar 1995), but trichlorfon is a critical part of any integrated pest management system, because it is the only fast-acting material remaining that can be used to reduce grub populations after damage becomes apparent (Heller & Walker 2000, Vittum et al. 2000a).

Throughout the 1990s, turf managers had many options when facing the need to manage a white grub infestation. They had access to materials that would take a couple weeks to become active but remained effective for three to five months (e.g. imidacloprid), intermediate materials as described above, or fast-acting compounds that would degrade within a few weeks after application. But since FQPA was promulgated, the list has dwindled to one curative fast-acting material and two products that are most effective when applied preventively (imidacloprid and halofenozide). The application of preventive materials before sampling to assess damage potential is counter to good IPM practices, but is chosen by many managers now because of the lack of options.

To further complicate matters, the eight important pest species of grubs occurring in the Northeast vary widely in their susceptibility to insecticides (Alm et al. 1999). For example, halofenozide (an insect growth regulator) is effective against Japanese beetles, but not against Oriental beetles and European chafers (Cowles & Villani 1996) that predominate in many parts of southern New England and NY. Therefore, many turf managers hesitate to use halofenozide, even though it is much less toxic to vertebrates and poses fewer problems in the environment than the curative option (trichlorfon) (Cowles & Villani 1996, Vittum et al. 2000b).

Coupling the direct loss of insecticides (as a result of FQPA decisions) with the complications of multiple grub species, the investigation of non-chemical alternatives for grub management is critical.

1.3.3 Biological and cultural management

Among professional turf managers, prophylactic treatments predominate despite extensive multiyear research showing that insecticide treatment is only warranted 20% of the time on both lawns and golf courses in NY (Grant 1995, Nyrop et al. 1995, Grant et al. 1996). Therefore, insecticide applications directed at scarab grubs in turfgrass could be greatly reduced if turfgrass managers learned and implemented sampling plans. Scarab grub sampling has been shown to be an economical and efficient decision tool for determining the need for treatment of scarab grubs in turf.

Biological control options are highly sought by homeowners as well as professionals who manage lawns, school grounds, parks, athletic fields and golf courses. However, currently available biological controls for scarab grubs are extremely inconsistent in their results and vary greatly by target species. The two major biological control agents commercially available for management of white grubs in turf are entomopathogenic nematodes and the bacteria that cause milky spore disease.

Entomopathogenic nematodes have proven to be one of the most successful biological strategies, often providing control comparable to insecticide treatments when environmental conditions were ideal (Shetlar et al. 1988, Klein 1990, Shanks & Agudelo-Silva 1990, Georgis & Gaugler 1991, Kaya et al. 1993, Gaugler 1999). However, there has been great variability in efficacy based on biotic factors such as matching nematode strains with the appropriate target species (Gaugler 1999) and abiotic factors such as soil moisture and temperature (Koppenhöfer et al.

1995, Fujiie et al. 1996, Grant 2001).

Milky spore disease powder is produced by grinding up living, diseased Japanese beetle grubs infected with the bacterial complex *Paenibacillus popilliae* and *P. lentimorbus* (formerly known as *Bacillus*). The bacterial population can build up over several years to become suppressive to Japanese beetle grubs but only if very high populations of the grubs are tolerated. Commercial preparations of milky spore powder have performed poorly in recent tests, leading to questions about the usefulness of this biological control agent for white grub management (Redmond & Potter 1995, Koppenhöfer et al. 2000a, DCP unpublished data). Many formulations applied according to conventional procedures are not efficacious in the field. Another limitation is that the bacteria is most infective to Japanese beetle grubs and of no value against other common grub species infesting turfgrass in the Northeast. Finally, because milky disease bacteria only multiplies within living bodies of grubs, one must be willing to tolerate a period of relatively high grub populations to obtain disease levels sufficient to control grubs.

1.4 New Opportunities for Biologicals

We feel that new opportunities for biologically-based management of white grubs in turfgrass are on the horizon. First, new products are still being actively developed by the commercial sector, and these require rigorous laboratory and field testing to gauge their potential. Measuring that potential should not overlook how effective the product is across different turfgrass management systems and across the variety of white grub species that pose problems.

Second, there is new broad evidence from the scientific literature that synergisms between chemical and biological agents is a promising approach for management of soil insects and turfgrass pests. For example, third instar white grubs are more susceptible to nematodes when challenged by reduced rates of imidacloprid or by endophytic host plants (Grewal et al. 1995, Koppenhöfer & Kaya 1998, Koppenhöfer et al. 2000b, Koppenhöfer & Fuzy 2003a). Neither imidacloprid, endophytes nor nematodes alone are efficacious against this robust life stage. In addition, other studies have confirmed that reduced rates of imidacloprid can enhance pathogenicity of fungal entomopathogens in other beetle larvae such as root weevils and Colorado potato beetle (Quintela & McCoy 1998, Furlong & Groden 2001). This justifies the need to evaluate how combined approaches could open curative options for white grub management.

Third, there is an increasing demand for more limited use of chemical pesticides in turfgrass systems. This means that we need to understand under what circumstances biologically-based pest management can be effective, whether those conditions are widespread or reproducible, and how to overcome the limits to adoption of these technologies. A major point of entry is to systematically investigate the additive and synergistic effects of combined control tactics, such as reduced rates of pesticides in tandem with biologicals. Limiting the economic and environmental costs of pesticides may depend on new management approaches such as this.

Although the barriers to biologically-based pest management in turfgrass may be formidable at present, there is most certainly a potential for future implementation. This potential is based on aggressive pesticide regulation in certain counties of NY, demand for reduced-pesticide control

alternatives by stakeholders, and the high value and management intensity of the affected commodity. The white grub system thereby offers an opportunity for serious scrutiny and evaluation of alternative approaches, warranting a comprehensive analysis of how control tactics can be combined, and how synergisms could be exploited, to achieve more effective pest management while reducing our reliance on chemical insecticides.

1.5 Relationship to Stakeholder Priorities

In the Northeast, scarab grubs are the primary insect pests of turfgrass (Vittum et al. 1999) and are of particular concern in lawn, golf course and athletic field turf. As soil insect pests, white grubs are particularly troublesome because of how difficult it is to monitor, interpret and manipulate interactions that are being played out below the soil surface. Compared to above-ground foliar feeding insects, below-ground root feeding insects are harder to sample and the products used to control them are harder to accurately deliver. Another challenge is the number of exotic pest species. Unintentionally introduced to the Northeast, these species have arrived without the natural enemies, competitors or other factors that might have checked populations in their native regions. Therefore they have a great capacity to outbreak and cause highly damaging infestations. In addition to their species diversity, and widespread distribution, these reasons are why white grubs are overwhelmingly considered by stakeholders to be the most injurious pests in turfgrass of the Northeast.

The 2003 New York Turfgrass Survey is the most recent statewide survey in the Northeast to assess the value of this industry (NASS 2004). In this report, data are compiled that show total annual expenditures for insecticides exceeding \$12.7 million, the majority of this attributed to the activities of lawn care professionals (Table 2). Across major turfgrass areas, 15-40% of respondents regarded insect pests as a leading problem in turf management.

Table 2. Importance of insect pests and their control in turfgrass of NY (NASS 2004).

	Golf courses	Sod	Lawn care	Schools
Proportion of turf maintenance expenses for insecticides	5.8%	6.0%	11.6%	0.6%
Total expense for insecticides	\$3,653,111	\$143,640	\$8,876,088	\$51,719
Respondents reporting insects as leading problem in turf	15%	40%	24%	10%

The Northeast Working Group on IPM for Golf listed seven research priorities that must be addressed in order to improve and expand implementation of IPM on golf courses in the Northeast region (http://northeastipm.org/priority/turf_2001.html). Of the four highest ranking, one was “Alternatives to current pesticides including new (non-pesticide) IPM techniques,” an area directly addressed by our proposed study. This group met in January 2001, and was a broad-based group of participants interested in golf course IPM, including superintendents, university personnel, environmental and public health advocates, and representatives from the US Golf Association and the US EPA.

In the National Roadmap for Integrated Pest Management (May 17, 2004) prepared by stakeholders across the nation (http://northeastipm.org/regu_regional.cfm), residential and public

areas is listed as one of three IPM focus areas. Turfgrass systems are more intimately associated with where people “live, work, and play” than any agricultural commodity. Therefore expanding and improving IPM programs in these managed habitats will contribute to overall human and environmental health. Our studies also directly address one of the report’s three Future Directions, “Minimize adverse environmental effects from pest and related management strategies.” Among the eight research needs listed for the national IPM Program, our studies address “Develop new generation low-risk suppression tactics including biological control and products of traditional breeding and biotechnology.”

The “Survey of Current Pest Management Practices of New York State Schools” was developed as a collaborative effort among the NY State Department of Health, NY State Department of Education, and the NY State IPM Program (<http://www.nysipm.cornell.edu/comm/school.pdf>). From results published in 2004, statewide an average of 17% of the districts cited white grubs in school grounds and athletic fields as one of their most frequent pest problems, and 10% said grubs were among the most troublesome. The greatest concern about grubs was expressed on Long Island, where 31% of schools cited grubs as a frequent problem, and 16% as a very troublesome problem.

2 OBJECTIVES

2.1 Project Purpose

The purpose of this project is to reduce the economic and environmental costs of insecticide dependence in turfgrass systems by evaluating and promoting new approaches to pest management.

2.2 Overall Objective

The main objective of this project is to evaluate and promote biologically-based management options for white grubs in turfgrass, with an emphasis on the synergistic interaction between combined biological and chemical control products.

2.3 Specific Objectives

- Screen the efficacy of 15 different registered and experimental bioproducts and curative chemical insecticides to larvae of European chafer in controlled laboratory bioassays.
- Quantify and compare the efficacy of the same products to four white grub species: European chafer, Japanese beetle, Oriental beetle and Asiatic garden beetle.
- Evaluate and compare the efficacy of different combinations of select bioproducts with three rates of curative chemical insecticides to larvae of European chafer in controlled laboratory bioassays.
- Quantify and compare the efficacy of select chemical/biological combinations to four white grub species: European chafer, Japanese beetle, Oriental beetle and Asiatic garden beetle.
- Identify the most promising combinations for future greenhouse and field trials by characterizing the interactions as synergistic, additive or antagonistic, and ranking their efficacy and compatibility.

2.4 Anticipated Accomplishments

In these studies we will launch a systematic and cohesive approach to determine which combinations of chemicals and biologicals are most efficacious and how efficacy may vary across four major white grub species in the Northeast. It will lead to specific recommendations for biologicals and biopesticides registered in NYS. Our work will not end there. With additional funding (as is currently being solicited from NYSTA) we will continue to seriously evaluate perspectives for biologically-based management of white grubs in turfgrass systems of the Northeast by moving on to greenhouse and field-based trials. We will end up with the best recommendations for how the approach of exploiting synergisms between combined chemical and biological control products can best be incorporated into IPM programs for white grubs and other troublesome soil insect pests.

Our specific expected results include:

- Known efficacy of biologicals, biopesticides and chemical insecticides for four white grub species under controlled laboratory conditions
- Identification of the most promising combinations of chemical and biological control products for white grub control
- Characterization of the interactions among biological and chemical control products for white grubs as synergistic, additive or antagonistic
- Quantification of how the efficacy of control products varies across the predominant white grub species
- Critical information generated on how to most successfully scale out results by conducting greenhouse pot trials, microplot field trials with artificially infested populations, and small plot field trials with natural populations
- Documentation of a comprehensive and systematic approach to advance biologically-based pest management for soil insect pests in turfgrass
- Trade journal article written and submitted
- Scientific journal article written and submitted

3 APPROACH AND PROCEDURES

3.1 Overall Strategy

We propose a one-year “critical step” study to focus on bioassays under controlled laboratory conditions. These studies are structured so as to give us opportunities to seriously advance to evaluation in pot trials in the greenhouse, and then in the field under both artificially infested and natural populations. In Phase 1 of the proposed studies, we will screen 15 bioproducts and potential chemical synergists to four white grub species. In Phases 2 and 3, we will combine chemical insecticides with select bioproducts and evaluate them against the European chafer as a model species. Based on the response of grubs, these combinations will be characterized as additive or synergistic. In Phase 4, we will gauge the variation in the effectiveness of the best combinations simultaneously across four predominant white grub species in the Northeast.

3.2 Selection of Biological and Chemical Treatments

The biologicals will be represented by entomopathogenic nematodes, fungal entomopathogens and the milky spore disease bacteria; the biopesticides by *Bacillus thuringiensis*, spinosad, and diatomaceous earth; the chemicals by imidacloprid, clothianidin, thiamethoxam, and trichlorfon (Table 3).

The three biologicals have demonstrated highly positive results for white grub control based on laboratory studies, nevertheless their field results are inconsistent and failures are too common for them to represent real options for pest management practitioners in turfgrass. Reasons for poor field results include bad formulations of commercial products, unsuitable environmental conditions, improper storage and handling, and improper selection of strains to match the target species.

Among the three biopesticides, Bt and spinosad have shown some potential in field trials. Diatomaceous earth (DE) will be included as another biological. The high silica content of this material breaks down the protective waxy coating of the cuticle, rendering insects highly susceptible to desiccation (Arthur & Throne 2003). We know of no studies that have examined the effects of DE on turfgrass insects. Nevertheless, this material will be included because it is a known synergist with biologicals (Lord 2001).

Imidacloprid, thiamethoxam and clothianidin are all neonicotinoid (nitroguanidine) insecticides that are effective against white grubs when applied as preventive treatments during the time of egg laying. Their efficacy declines drastically with growth of the insect so they are considered ineffective against third instars. At least imidacloprid and thiamethoxam have been shown to be synergists with nematodes against white grubs (Grewal et al. 2001, Koppenhöfer et al. 2002). Clothianidin has been chosen because it falls into the same class of chemicals. Of these, only imidacloprid is currently registered for turfgrass in NY.

Trichlorfon is a fast-acting, short-residual insecticide recommended for spot treatments. It is used as a late-season curative, applied once grubs (usually third instar) have been located, up to as late as mid September.

Table 3. Summary of biological and chemical agents to be tested for efficacy alone and in combination for white grubs.

Agent	Product	Formulation/Description
Biologicals	Entomopathogenic nematodes	1) Commercial nematode formulations of <i>H. bacteriophora</i> with <i>H. marelatus</i> , or <i>Steinernema carpocapsae</i> ; products to be selected 2) <i>Steinernema scarabaei</i> , a highly virulent strain not yet commercialized, isolated from white grubs in NJ (Koppenhöfer & Fuzy 2003b) 3) <i>Heterorhabditis</i> spp. strain, naturally occurring strain collected in 2003 and maintained in laboratory culture at NYSAES
	Fungal	4) <i>Beauveria bassiana</i> , commercial product to be selected

	entomopathogens	5) <i>Metarhizium anisopliae</i> , commercial product to be selected 6) <i>Metarhizium anisopliae</i> strain F52, registered in 2003 with EPA, to be marketed as “Gro-Well Pro-tek for Grubs”
	Milky spore	7) <i>Paenibacillus popilliae</i> and <i>P. lentimorbus</i> , the causal agents of milky spore disease, commercial product
Biopesticides	Bt tenebrionis	8) Novodor, microbial insecticide based on <i>Bacillus thuringiensis</i> var. <i>tenebrionis</i> 9) SDS502, microbial insecticide based on Bt, registration pending with EPA
	Spinosad	10) Conserve SC, fermentation product derived from a soil actinomycete
	Diatomaceous earth	11) Commercial product to be selected
Chemicals	Imidacloprid	12) Merit, neonicotinoid insecticide, a common and effective curative control agent, registered for turfgrass
	Clothianidin	13) Neonicotinoid insecticide (e.g. “Poncho”) not yet registered in NY.
	Thiamethoxam	14) Neonicotinoid insecticide (e.g. “Cruiser”) not yet registered in NY.
	Trichlorfon	15) Dylox, an organophosphate with curative uses against white grubs, effective against third instars

3.3 Collection and Maintenance of White Grubs

All studies will be conducted on third instar white grubs collected from the field. We choose this life stage because they can be maintained in the laboratory for several months, they are the most difficult to control, and they are the target for curative control in the field. Our laboratory has very successful protocols for collecting, maintaining and handling third instars. This life stage is collected in late fall before they descend in the soil profile for overwintering. Through our network of collaborators in Cornell Cooperative Extension and the golf course industry, we will locate and collect from areas with high infestations. Last season in NY we were successful at collecting a few thousand each of Japanese beetle (*AgWay Shady-Green*) as a food source. Cup diameter is 4.0 cm with a surface area of 12.56 cm². Soil is screened field soil raised to 10.5% moisture and added at approximately 27.6 g per cup.

Applications will be made in 1 ml of water applied over the soil surface after the grub has successfully burrowed into the soil. Cups are then capped. In each experiment, treatments will include an untreated control and a chemical control (trichlorfon) and there will be five repetitions. Each repetition will consist of 10 cups (10 grubs) per treatment. The insects will be maintained in an environmental chamber under controlled climate conditions (darkness, high humidity, 77°F). All cups will be evaluated 3 weeks after treatment application to measure mortality rates.

We will calculate mean mortality rates for each treatment based on five repetitions of 10 grubs. For each species, an overall effect of treatment will be tested with analysis of variance. If detected, differences among treatments will be assessed with a multiple means separation tests.

Experiments will be conducted in four consecutive phases. In Phase 1 we will evaluate all 15 treatments plus the two controls (Table 2) against grubs of European chafer, Japanese beetle, Oriental beetle and Asiatic garden beetle in one concurrent experiment. This will require 850 grubs per species. Relative to the control, we expect 100% mortality in the trichlorfon treatment, 0% in the neonicotinoid treatments, and somewhere in between for the bioproducts (with the exception of milky spore which is specific to Japanese beetle).

In Phase 2 we will compare the interaction of select bioproducts with potential synergists against grubs of European chafer in one concurrent experiment. The synergists (diatomaceous earth and the three neonicotinoids) will be applied at full recommended field rates. Based on the results of Phase 1, five bioproducts will be selected from among those that produced the lowest overall mortality rates across the four grub species. There will be a total of 27 treatments consisting of two controls, five bioproducts applied singly and in combination with each of the four synergists. This will require 1350 grubs. The combinations will be characterized as synergistic, additive or antagonistic based on how mortality in the combined treatment compares to the sum of the single component treatments.

In Phase 3, we will compare the effect of reduced rates of chemical synergists. The four combinations that represent the best synergies will be chosen. These will be crossed with the synergists at 1/4 and 1/2 and full field rates. There will be a total of 18 treatments consisting of two controls, four bioproducts applied singly and in combination with their synergists at three rates. This will require 900 grubs. Once again the combinations will be characterized as synergistic, additive or antagonistic.

In Phase 4 we will conduct a final trial to evaluate a select group of synergistically combined chemical/biological combinations across four species of white grubs concurrently: European chafer, Japanese beetle, Oriental beetle, Asiatic garden beetle. We will evaluate the six best combinations that feature reduced rates of chemical synergists. With the two controls, this yields eight treatments and requires 400 grubs of each species.

3.5 Anticipated Outcomes

The specific measurable results are described previously (section 2.4 Anticipated Accomplishments).

These experiments are designed to test how sublethal doses of preventive neonicotinoid insecticides influence susceptibility of third instar white grubs to biologicals and biopesticides that might otherwise not be effective against that life stage. Therefore one major outcome is identification of the most promising combinations of biological and chemical tactics for suppressing white grubs under laboratory conditions. We anticipate finding one or more truly synergistic combinations that will open the door for biologically-based curative control options. These options will set the stage for other studies that will be necessary to move this new

approach toward real field application, namely (i) pot trials in the greenhouse, (ii) microplot field trials with artificially-infested populations, and (iii) small plot field trials with natural populations.

These experiments will also quantify how the efficacy of control products (applied singly and in combination) varies across the four most damaging grub species in the Northeast. We know that insecticide efficacy varies depending on species and it is expected that biologically-based options will perform the same given the relatively wide taxonomic diversity represented by the white grub complex. The most promising overall result will be a curative chemical/biological combination that is equally viable as a control option for all grub species in the Northeast.

This system has been chosen as a model so we can document the process of how to identify the most promising combinations of biological and chemical tactics under laboratory and field conditions, and how synergistic interactions can be explored and manipulated to offer new approaches to pest management. Therefore a second major outcome is the documentation of this process and how it can guide the development of biologically-based pest management options for soil insect pests in other turfgrass and horticultural systems. There are certainly future hurdles – such as the relatively high cost of biologicals – that will need to be addressed during a field implementation phase. But given the environmental, economic and human health costs associated with insecticide use, increasing restrictions, and broadening public concern, new opportunities for biologically-based pest management must be approached with all the energies we can muster.

We ultimately expect positive impacts for IPM of other turfgrass and soil insect pests, in other urban and rural landscapes and managed ecosystems. Locally and near-term, benefits will include reduced pesticide reliance, environmental contamination, control costs and nontarget effects for pest control in turf systems of the Northeast. Regionally and mid-term, benefits will include new options to support and promote the transition to biologically-based and reduced-insecticide pest management in turfgrass. Globally and long-term, benefits will include a new comprehensive approach to pest management that is based on innovative ways to combine biological and chemical control tactics as a component of IPM. This will allow us to achieve more effective and durable pest management strategies in major agroecosystems throughout the temperate and tropical zones.

3.6 Time Table

Proposed start date: 1 July 2005
 Proposed termination date: 30 June 2006

Activity	2005						2006					
	J	A	S	O	N	D	J	F	M	A	M	J
Obtain products for experimental treatments												
Collect third instar larvae from field sites and establish in laboratory												

Conduct screening of individual products against EC, JB, OB and AGB (Phase 1)													
Conduct bioassays on combined products against EC (Phase 2, Phase 3)													
Conduct bioassays on select combinations against EC, JB, OB and AGB (Phase 4)													
Analyze data to characterize combinations as synergistic, additive or antagonistic													
Summarize results and write manuscripts													
Present terminal report at NE IPM conference													

EC = European chafer; JB = Japanese beetle; OB = Oriental beetle; AGB = Asiatic garden beetle

4 COOPERATION AND INSTITUTIONAL UNITS INVOLVED

4.1 Lead Institution

State: New York
 Institution: Cornell University
 Unit: Soil Insect Ecology and Turfgrass Entomology research group,
 Department of Entomology, NYSAES, Geneva, NY
 Project Director: Daniel C. Peck, Ph.D.
 Cooperator: Anuar Morales

4.2 Available Research and Field Facilities

The Soil Insect Ecology and Turfgrass Entomology Lab at Cornell has continual access to facilities that are critical for the successful execution of this project, including (1) recently renovated laboratory with modern microscope and computing equipment, (2) five walk-in controlled environmental chambers for maintaining white grubs and conducting experiments, (3) greenhouse space for rearing and conducting experiments, (4) laminar flow hood for working with fungal entomopathogens and other biologicals, and (5) dedicated rooms for soil handling, insect specimen preparation, and cold storage of overwintering grubs. To conduct field collections, we have a long list of contacts throughout the state for identifying abundant and collectible populations of four white grub species (European chafer, Japanese beetle, Oriental beetle and Asiatic garden beetle).

5 IMPLEMENTATION AND EVALUATION PLANS

5.1 Probability of Success

Given our experience in efficacy trials, evaluation and manipulation of biologicals and white grub ecology, our probability of successfully conducting the proposed research is high. Preliminary trials conducted last year have confirmed the appropriateness of these protocols by

(i) demonstrating 100% mortality in chemical controls (trichlorfon) across three species (European chafer, Japanese beetle and Oriental beetle), (ii) demonstrating acceptable low level mortality (0-15%) in absolute controls, and (iii) establishing the evaluation period at 3 weeks, the window after the effect of the slowest biocontrol agents and before the insect pupates. Those trials also confirmed our ability to manipulate all classes of biological control agents against white grubs of the Northeast.

The proposed research is opportune because very recent studies have shown how certain stressors can make biologicals more effective for the suppression of soil insect pests in the laboratory. Based on this foundation, we are confident that we will identify combinations of chemical and biological products that operate in a truly synergistic fashion, opening opportunities for their use as curative controls and consequently opening opportunities for improved IPM of white grubs in turfgrass.

The overall success of this project will be measured in the short-term as:

- Identification of the most promising combinations of chemical and biological control products for white grubs under laboratory conditions, and how efficacy varies across the taxonomic diversity of grub species that occur in the Northeast

The overall success of this project will be measured in the mid-term as:

- Documentation of a comprehensive and systematic approach to advance biologically-based pest management for soil insect pests in turfgrass

The overall success of this project will be measured in the long-term as:

- Initiation of collaborative greenhouse and field-based projects with regional partners at Rutgers University (Albrecht Koppenhöfer) and University of Connecticut (Ana Legrand) to further advance this line of research
- Inclusion of biologically-based approaches to white grub control in regional summaries of best management practices, particularly practical curative options that involve reduced pesticide inputs and implementation of IPM decision tools (i.e. sampling and action thresholds)
- Reduced reliance on pesticides for turfgrass management

5.2 Stakeholder Impetus

Success of this project is partially founded on, and depends on, broad-based stakeholder support. White grubs are perceived as the most damaging insect pest complex in turfgrass of the Northeast. Some of these same scarab species are injurious to other horticultural crops of the region (Polavarapu et al. 2002), and some are burgeoning pests to the west as their geographic distribution expands.

On top of this high pest status, specific counties in the Northeast (e.g. Westchester and Suffolk, NY) are confronting increased restrictions due to public health perceptions. These hot spots, in this regional milieu, are kindling a broad-based demand for reduced pesticide or pesticide free control strategies for insect pests of turfgrass.

5.3 Coalescing a Multi-State Partnership

The studies proposed here are a first comprehensive step to achieve a possible solution. Results must be built upon with greenhouse and field studies that move this approach closer to implementation and adoption. This will be done via a multi-state partnership in order to (i) harness the expertise and input of various scientists that are uniquely committed to confront issues of biologically-based pest management of white grubs and (ii) ensure that the results will be as broadly applicable as possible across the Northeast region where white grub pests are so devastating. It is hoped that once additional funding is secured, collaborators from other institutions can be galvanized, a partnership solidified, and our expertise synergized to achieve real solutions for this widespread and injurious pest.

5.4 Leveraging Biologicals into Turfgrass

Biological control is a fundamental tool of the IPM practitioner, yet there are very few examples of practical and effective application in turfgrass systems. This means that we need to understand under what circumstances biologically-based pest management can be effective, whether those conditions are widespread or reproducible, and how to overcome the limits to adoption of these technologies.

Golf course are among the most highly managed and highly valued turf habitats. If biologically-based pest management practices for turfgrass are ever to be developed, transferred and adopted, it would be in a system such as this that features a specific pest on a high value commodity in a regional milieu of public demand for reduced pesticide options. Therefore, we believe that this system is a productive place to begin to see how biological control might be leveraged into the turfcape. In tandem with new information on pest biology and ecology, new potential for certain biologicals, and a growing understanding of how synergistic interactions among chemical and biological products holds promise for the management of soil-borne pests, biologically-based management of white grubs warrants serious scrutiny.

Once this approach is developed there would be various incentives to adoption. Pesticide restrictions and phase outs are rapidly curtailing chemical control options. There is even discussion that given detection of imidacloprid in ground water of Long Island, that this widely used product may also be on its way out as well. Therefore more golf course superintendents, lawn care providers and others have incentive to adopt this approach to biologically-based pest management. The approach would lead to improved IPM, replacing preventive use of imidacloprid with a late season curative application of reduced rates of imidacloprid as a synergist for a biological, allowing for sampling and the opportunity to decide NOT to apply. By allowing golf courses to improve their IPM practices, there might also be incentive from those courses seeking registration with the Audubon Sanctuary program.

As we advance options for a solution to white grubs in turfgrass systems of the Northeast, we will look ahead to how positive impact can be scaled-out to broader horticultural and agricultural systems. We intend to garner the lessons, protocols and approaches that this model system offers

by documenting this research process and making it accessible to researchers advancing biologically-based management of other turfgrass pests and of other soil insect pests.

REFERENCES

- Alm, S.R., M.G. Villani & W.L. Roelofs. 1999. Oriental beetles (Coleoptera: Scarabaeidae): current distribution in the United States and optimization of monitoring traps. *J. Econ. Entomol.* 92:931-935.
- Allsopp, P. 1996. Japanese beetle, *Popillia japonica* Newman (Coleoptera: Scarabaeidae): rate of movement and potential distribution of an immigrant species. *Coleopterists Bull.* 50:81-95.
- Arthur, F.H. & J.E. Throne. 2003. Efficacy of diatomaceous earth to control internal infestations of rice weevil and maize weevil (Coleoptera: Curculionidae). *J. Econ. Entomol.* 96:510-518.
- Bellotti, A. & D.C. Peck. 2000. Scarab larvae – a worldwide pest problem. Symposium presentation (Biology and Management of Scarab Pests). In: Abstract Book I. XXI International Congress of Entomology, Foz do Iguassu, Brazil. p. 21.
- Cowles, R.S. & M.G. Villani. 1996. Susceptibility of Japanese beetle, oriental beetle and European chafer to halofenozide, an insect growth regulator. *J. Econ. Entomol.* 89:1556-1565.
- Emmons, R.D. 2000. *Turfgrass Science and Management*, 3rd ed. Delmar, Albany. 528 pp.
- Fujiie, A., Y. Takata, M. Tachibana & T. Yokoyama. 1996. Insecticidal activity of an entomopathogenic nematode, *Steinernema kushidai* (Nematoda: Steinernematidae), against *Anomala cuprea* (Coleoptera: Scarabaeidae) larvae under different soil moisture conditions. *Appl. Entomol. Zool.* 31:453-454.
- Furlong, M.J. & E. Groden. 2001. Evaluation of synergistic interactions between the Colorado potato beetle (Coleoptera: Chrysomelidae) pathogen *Beauveria bassiana* and the insecticides imidacloprid and cyromazine. *J. Econ. Entomol.* 94:344-356.
- Gaugler, R. 1999. Matching nematode and insect to achieve optimal field performance, pp. 9-14. In S. Polavarapu [ed.], *Optimal Use of Insecticidal Nematodes in Pest Management*. Rutgers University, New Brunswick, NJ.
- Georgis, R. & R. Gaugler. 1991. Predictability in biological control using entomopathogenic nematodes. *J. Econ. Entomol.* 84:713-720.
- Gilrein, D & T. Yeh. 2004. Best management practices for professional turf uses of Merit on Long Island. Unpublished draft brochure.
- Grant, J.A. 1995. Implementing IPM on New York State golf courses, 1994. In 1994 New York State Ornamentals Project Reports Relating to IPM. NYS IPM Publication #408, pp. 55-58.
- Grant, J.A., J. Nyrop & M. Villani. 1996. Validation of a scarab grub sampling plan for home lawns. In 1995 New York State Ornamentals Project Reports Relating to IPM. NYS IPM Publication #409, pp. 56-63.
- Grant, J.A. 2001. Soil Moisture Effects on Entomopathogenic Nematodes. Dissertation, Cornell University, Ithaca, NY.
- Grewal, S.K., P.S. Grewal & R. Gaugler. 1995. Endophytes of fescue grasses enhance susceptibility of *Popillia japonica* to an entomopathogenic nematode. *Entomol. Exp. Appl.* 74:219-224.
- Grewal, P., K.T. Power & D.J. Shetlar. 2001. Neonicotinoid insecticides alter diapause behavior and survival of overwintering grubs (Coleoptera: Scarabaeidae). *Pest Management Sci.* 57:852-857.

- Gruttadaurio, J., E.E. Hardy & A.S. Lieberman. 1982. Turfgrass in New York State: a billion dollar agricultural production and service industry. 1982 Update. Cornell University Department of Floriculture and Ornamental Horticulture, Ithaca, NY.
- Heller, P.R. & R.G. Walker. 2002. Annual bluegrass weevil management comparing registered pyrethroids, 2001. *Arthropod Management Tests* 27: G15.
- Jackson, T.A. & T. R. Glare. 1992. *Use of Pathogens in Scarab Pest Management*. Intercept Press, Andover, Hampshire, UK.
- Kaya, H., R. Bedding & R. Akhurst. 1993. An overview of insect-parasitic and entomopathogenic nematodes, pp. 1-10. *In* R. Bedding, R. Akhurst and H. Kaya [eds.], *Nematodes and the Biological Control of Insect Pests*. CSIRO, Canberra, Australia.
- Klein, M.G. 1990. Efficacy against soil-inhabiting insect pests, pp. 195-214. *In* R. Gaugler and H. Kaya [eds.], *Entomopathogenic Nematodes in Biological Control*. CRC Press, Boca Raton.
- Klein, M.G., J.B. Oliver, J.J. Moysenko & M.E. Reding. 2002. Insecticidal dips and other strategies for the elimination of Japanese beetle larvae from balled and burlapped nursery stock. *Proceedings, SNA Research Conference*, vol. 47.
- Koppenhöfer, A.M., H.K. Kaya & S. P. Taormino. 1995. Infectivity of entomopathogenic nematodes (Rhabditida: Steinernematidae) at different soil depths and moistures. *J. Invert. Path.* 65:193-199.
- Koppenhöfer, A.M. & H.K. Kaya. 1998. Synergism of imidacloprid and entomopathogenic nematodes: a novel approach to white grub control in turfgrass. *J. Econ. Entomol.* 91:618-623.
- Koppenhöfer, A.M., M. Wilson, I. Brown, H.K.Kaya & R. Gaugler. 2000a. Biological control agents for white grubs (Coleoptera: Scarabaeidae) in anticipation of the establishment of the Japanese beetle in California. *J. Econ. Entomol.* 93:71-80.
- Koppenhöfer, A.M., P.S. Grewal & H.K. Kaya. 2000b. Synergism of imidacloprid and entomopathogenic nematodes against white grubs: the mechanism. *Entomol. Exp. Appl.* 94:283-293.
- Koppenhöfer, A.M., R.S. Cowles, E.A. Cowles, E.M. Fuzy & L. Baumgartner. 2002. Comparison of neonicotinoid insecticides as synergists for entomopathogenic nematodes. *Biological Control* 24:90-97.
- Koppenhöfer, A.M. & E.M. Fuzy. 2003a. Effects of turfgrass endophytes (Clavicipitaceae: Ascomycetes) on white grub (Coleoptera: Scarabaeidae) control by the entomopathogenic nematode *Heterorhabditis bacteriophora* (Rhabditida: Heterorhabditidae). *Environ. Entomol.* 32:392-396.
- Koppenhöfer, A.M. and E.M. Fuzy. 2003b. *Steinernema scarabaei* for the control of white grubs. *Biological Control* 28:47-59.
- Lord, J. 2001. Desiccant dusts synergize the effect of *Beauveria bassiana* (Hyphomycetes: Moniliales) on stored-grain beetles. *J. Econ. Entomol.* 94:367-372.
- NASS (NY Agricultural Statistics Service). 2004. 2003 New York Turfgrass Survey. 80 pp (http://www.nass.usda.gov/ny/special_surveys.htm).
- Nyrop, J.P., M.G. Villani & J.A. Grant. 1995. A control decision rule for European chafer (Coleoptera: Scarabaeidae) larvae infesting turfgrass. *Environ. Entomol.* 24:521-528.
- Polavarapu, S., M. Wicki, K. Vogel, G. Lonergan & K. Nielsen. Disruption of sexual communication of oriental beetles (Coleoptera: Scarabaeidae) with a microencapsulated

- formulation of sex pheromone components in blueberries and ornamental nurseries. *Environ. Entomol.* 31:1268-1275.
- Potter, D.A. & S.K. Braman. 1991. Ecology and management of turfgrass insects. *Ann. Rev. Entomol.* 36:383-406.
- Quintela, E.D. & C.W. McCoy. 1998. Synergistic effect of imidacloprid and two entomopathogenic fungi on the behavior and survival of *Diaprepes abbreviatus* (Coleoptera: Curculionidae). *J. Econ. Entomol.* 91:110-122.
- Redmond, C.T. & D.A. Potter. 1995. Lack of efficacy of in vivo- and putatively in vitro-produced *Bacillus popilliae* against field populations of Japanese beetle (Coleoptera: Scarabaeidae) grubs in Kentucky. *J. Econ. Entomol.* 88:846-854.
- Rossi, F.S. 2003. Is pesticide reduction a numbers game? *Cornell University Turfgrass Times.* 14:6-7.
- Shanks, C.H.J. & F. Agudelo-Silva. 1990. Field pathogenicity and persistence of heterorhabditid and steinernematid nematodes (Nematoda) infecting black vine weevil larvae (Coleoptera: Curculionidae) in cranberry bogs. *J. Econ. Entomol.* 83:107-110.
- Shetlar, D.J., P.E. Suleman & R. Georgis. 1988. Irrigation and use of entomogenous nematodes *Neoplectana* spp. and *Heterorhabditis heliothidis* (Rhabditida: Steinernematidae and Heterorhabditidae) for control of Japanese beetle (Coleoptera: Scarabaeidae) grubs in turfgrass. *J. Econ. Entomol.* 81:1318-1322.
- Shetlar, D. 1995. White grubs in turfgrass. The Ohio State University Extension Fact Sheet, HYG-2500-1995, 4 pp.
- USDA-APHIS. 1998. Managing the Japanese beetle: a homeowner's handbook. Program Aid No. 1599, 16 pp.
- Vittum, P.J., M.G. Villani & H. Tashiro. 1999. Turfgrass Insects of the United States and Canada, 2nd edition. Cornell University Press, Ithaca, NY.
- Vittum, P.J. & N.L. Rothwell. 2000a. Field efficacy of bifenthrin, alone or in tank mix with chlorpyrifos, against annual bluegrass weevil on golf course fairway, 1999. *Arthropod Management Tests* 25: G44.
- Vittum, P.J. & N.L. Rothwell. 2000b. Field efficacy of deltamethrin against annual bluegrass weevil on a golf course fairway, 1999. *Arthropod Management Tests* 25: G46.

KEY PERSONNEL

Daniel C. Peck, Principal Investigator, is Assistant Professor of Entomology, area of soil insect ecology and turfgrass entomology, at Cornell University's New York State Agricultural Experiment Station in Geneva, NY. DCP is a specialist in applied insect ecology and grass-feeding insect pests. His research program at Cornell focuses on (1) biology and management of major turfgrass pests, (2) influence of the soil environment on the behavior and ecology of subterranean insects and their natural enemies, (3) discovery and exploitation of scarab pheromones, and (4) effect of control tactics on nontarget microarthropod communities. Previous to coming to Cornell (1996-2002) he was a Senior Research Fellow in the Forage Grass and IPM Projects at the International Center for Tropical Agriculture (Cali, Colombia).

Anuar Morales, Cooperating Researcher, is a Visiting Scholar in the Department of Entomology, NYSAES, Cornell University. AM is a specialist in insect pathology with 10 years experience in basic and applied biological control, most recently with scarab larvae and other soil insect pests of Neotropical cassava, forage grasses and onions. He comes to Cornell from the International Center for Tropical Agriculture (CIAT), located in Cali, Colombia. He has advanced technical expertise in manipulating and evaluating biological control agents (including entomopathogenic nematodes, entomopathogenic fungi and milky spore) as well as experience in rearing and maintaining soil insect and grass-feeding pests. AM has been a collaborator in the Soil Insect Ecology and Turfgrass Entomology laboratory since September 2003.