Title: Development of Management Strategies Targeting the Brown Marmorated Stink Bug, *Halyomorpha halys* in Peppers

Project Type: Research

Project Summary:

This is a research project requesting $180,000 in P.L 89-106 funding over the next three years to develop management strategies targeting the brown marmorated stink bug (BMSB) in peppers. BMSB has spread throughout the east and portions of the Midwest and west. BMSB became a severe pest of tree fruit and vegetables in 2009 and 2010. Currently, no adequate pest management alternatives exist to prevent damage to peppers creating the potential for the illegal use of insecticides. This project proposes to develop BMSB monitoring methods, assess BMSB feeding injury in pepper, evaluate cultivar susceptibility differences to BMSB feeding, determine natural enemy species composition in different cultivars, and determines the toxicity and field efficacy of selected insecticides for BMSB control. Objectives 1 and 2 will be accomplished by sampling BMSB populations and determining damage levels caused by BMSB in unsprayed sweet bell peppers. Objectives 3 and 4 will be accomplished by sampling BMSB and natural enemy populations and determining damage levels caused by BMSB in a variety of unsprayed pepper cultivars. Objective 5 will be accomplished by spraying sweet bell peppers with different insecticides to determine efficacy in terms of BMSB toxicity and reductions in damage to fruit. We anticipate this project to safeguard human health and the environment by reducing illegal of insecticides, provide economic benefits by reducing the pepper damage caused by BMSB and promote IPM implementation by developing the tools that can be used by farmers to reduce damage caused by BMSB.

Project Description:

1. Problem, Background and Justification

Problem: The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), is an exotic stink bug (Heteroptera: Pentatomidae) that was introduced into the United States in the mid 1990's (Hoebeck and Carter, 2003). Since its initial establishment in Allentown, PA, it has spread throughout the east coast as far south as GA and as far north as NH. Additional populations occur in CA, IN, IL, KY, MS, OH, OR, and TN. In its native range of Korea, China and Japan it is an important agricultural pest in tree fruit and soybeans causing fruit and pod malformations (Kobayashi et al., 1972; Suzuki et al., 1991; Watanabe et al., 1994a; Funayama, 2002). *Halyomorpha halys* is also a public nuisance in Japan because adults enter dwellings in large numbers late in the fall (Watanabe et al., 1994a, b; Kobayashi and Kimura, 1969). In the US, this invasive insect became a public nuisance problem almost immediately. BMSB did not become an agricultural problem until 2009 when damaging populations occurred for the first time in the fruit growing regions of WV and VA. In 2010, BMSB populations exploded throughout the eastern US causing severe damage in fruit and vegetables in DE, MD, NJ and PA in addition to WV and VA with growers experiencing up to 75% damage in some (Hamilton, unpublished data). A document entitled, "Qualitative analysis of the pest risk potential of the brown marmorated stink bug (BMSB), Halyomorpha halys (Stål), in the United States" was recently released by the USDA-APHIS-PPQ-EDP in October 2010, which provides an extensive summary of potential risks posed by BMSB.

In areas where *H. halys* populations have become a problem, farmers are desperate to find ways to prevent it from causing damage. Current control measures include the use of carbamate, organophosphate and pyrethroid insecticides, which are either not highly effective or disrupt current IPM programs because of their toxicity to natural enemies. Due to the lack of viable chemical control options the potential illegal use of insecticides as a last resort by farmers exist.

To react to this situation, researchers in the northeast are attempting to develop IPM programs targeting BMSB. However, while information is available regarding BMSB behavior and life history in apples and pears (Nielsen and Hamilton, 2009a), little is known for vegetables such as peppers. Questions exist regarding when BMSB enters pepper fields to feed and how best to predict infestations, what population levels create economic damage, ability by different varieties to resist attack, parasitism levels by native parasitoids and finally what effective chemical controls exist to to manage this pest without disrupting current IPM programs. Our proposal outlines studies to address these knowledge gaps in peppers. However, much of the information gained in this project will have implications for other crops as well.

Background: In 1996, the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), was accidentally introduced into Allentown, PA from Asia (Hoebeke and Carter, 2003). Since its initial introduction, *H. halys* has established throughout most of PA. In July of 2004, a website (www.rce.rutgers.edu/stinkbug/; Hamilton, 2004) was created that allows the public to report sightings of the insect. Since its creation, over 8,000 reports have been received. As a result, we have been able to track the spread of *H. halys* in PA and NJ and in the northeast confirm its presence and spread in CT, DE, MD, NH, NY, RI, VA, Washington D.C. and WV.

Halyomorpha halys populations are also rapidly increasing wherever they have been found. For instance, in Beltsville, MD, populations have increased by over 300% since 2004 (Figure 1). In January of 2005, *H. halys* was first confirmed in Oregon (Rose 2005) and was also found in Vallejo, CA in a shipment of furniture originating in Allentown, PA in February of 2005 (Eberling 2005). In 2006, *H. halys* was first confirmed in Los Angeles and Orange County, CA. As of 2010, we have also confirmed that BMSB is present in GA, IL, IN, KY, NC, OH, SC, and TN. Unconfirmed reports have also been received from Washington and Massachusetts.

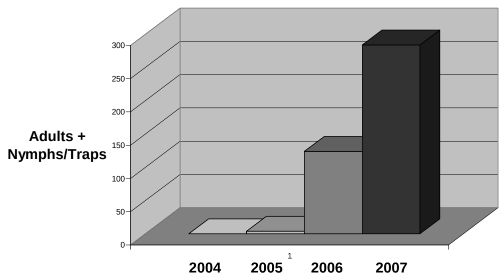

Figure 1. Number of *Halyomorpha halys* collected in Beltsville MD, 2004 – 2007 (Aldrich et al., 2009).

In Asia, *H. halys* reportedly has a very wide host range including tree fruit (Hoebeke and Carter, 2003). Watanabe (1996) discussed *H. halys* feeding damage on cherry in Japan. Funayama (1996) found that damage was heavier in early and mid-harvest apple cultivars in Japan. In Korea, *H. halys* is the dominant pest species of *Citrus junos* Sieb. ("Yuzu" or Japanese citron) causing black concave spots during the fruit enlargement and yellowing period (Choi et al., 2000). *Halyomorpha halys* has also been observed damaging apricots, peaches and plums (Watanabe 1996; NPAG 2001). In the U.S., Bernon (2004) reported that in addition to apples, peaches and pears, *H. halys* has been found feeding on at least 20 ornamental trees and shrubs including crabapple, Norway maple, empress trees (*Paulownia tomentosa*), and roses. Specimens have also been collected feeding on tomatoes, peppers, asparagus fronds, raspberry, grapes, corn, green beans, squash, pumpkins, and soybeans. Since its introduction into the U.S., *H. halys* has caused significant crop losses in fruit orchards (Figure 2, Nielsen and Hamilton, 2009a, Leskey, unpublished data).

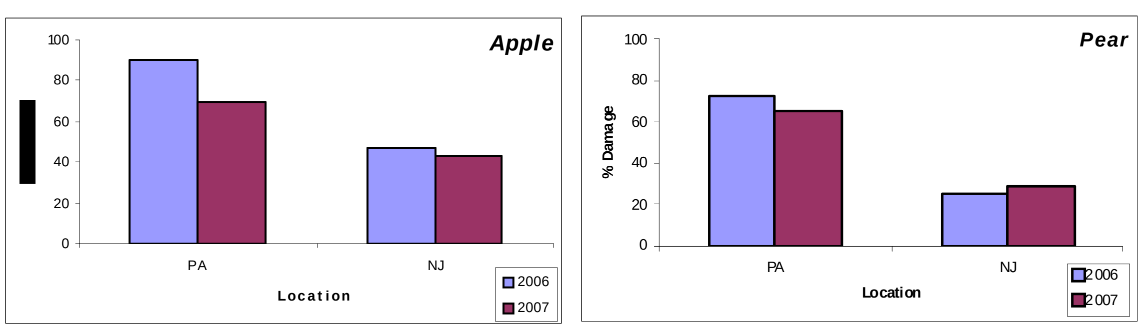

Figure 2. Damage to apples and pears in New Jersey and Pennsylvania, 2006 and 2007.

Typical methods for monitoring or trapping stink bugs include the use of pheromone traps, beat sampling and black light trapping. Cullen and Zalom (2000) used both beat sampling and pheromone trapping to create a phenology model for monitoring nymphs of *Euschistus conspersus* Uhler (Heteroptera: Pentatomidae). In low growing vegetable crops, canopy shake sampling was the most effective method to determine *Euschistus* sp. population densities along with observations of the soil surrounding the plants.

Black light traps in Japan have been used to show gradual increases in *H. halys* populations in July and August (Moriya et al., 1987) and has also been an effective way to monitor BMSB populations in the US (Nielsen and Hamilton, 2009b). Khrimian et al. (2008) showed that the aggregation pheromone of the brown-winged green bug, *Plautia stali* Scott, methyl (2*E*,4*E*,6*Z*)-decatrienoate and its isomers are attractive to *H. halys* (Figure 3). *Halyomorpha halys* is attracted not only to the *EEZ*-isomer, but also to at least two other isomers, including methyl (2*E*,4*Z*,6*Z*)-decatrienoate, a compound known to be part of pheromones of pentatomids in genus *Thyanta*. The *ZEZ*-isomer, not previously known to be attractive to *H. halys*, was moderately attractive in the field. Analyses of volatiles collected from dispensers used in field trials showed that all three compounds rapidly isomerize under daylight to form complex mixtures that seemed more attractive to *H. halys* than the individual isomers.

Traps baited with this aggregation pheromone to capture overwintering adults have been used to forecast potential *H. halys* infestations rates in the early spring (Tada et al., 2001).A similar case of cross-attraction between heteropterans within the same trophic level has recently been reported by Endo et al. (2006). Nevertheless, the search for an aggregation pheromone from *H. halys* is ongoing (J. Aldrich, pers. comm.) and, if such a pheromone can be identified and easily synthesized, it would improve our ability to utilize semiochemical-baited traps for monitoring purposes.

Other types of monitoring systems have been tested to monitor *H. halys*. In Japan, Watanabe et al. (1994a, b) showed that slit-traps were attractive to *H. halys* seeking overwintering sites, and that unpainted traps coated with a clear lacquer were more attractive than traps painted black or white.

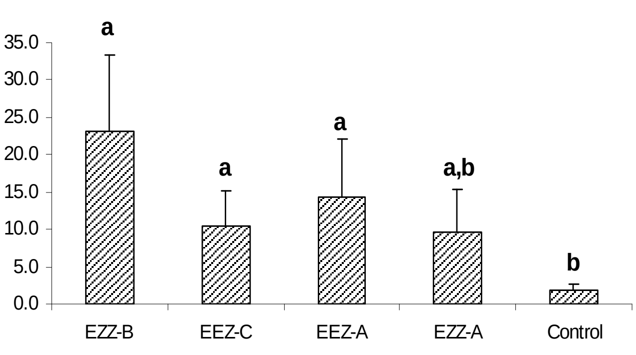

Figure 3. Cumulative number of adult *H. halys* captured in attractant baited traps from Sep. 11 Oct. 6, 2003. Each treatment contained 2.5 mg/septum and was replicated at three sites in Allentown, PA. Means followed by the same letter were not significantly different.

For monitoring using semiochemicals to be effective against a pest, trap efficiency, trap density and lure strength parameters must be understood (El-Sayed, 2006). We have addressed the issue of trap efficiency. In 2004, a three year study using rubber septa treated with 2.5 mg of attractant was begun to evaluate different traps types (pyramid, football, "smart" trap and apple trap) available to monitor stink bug populations in ornamentals and soybeans. In 2004 and 2005, significantly higher trap catches were observed in pyramid traps in both ornamental trees and soybeans (Table 1; Nielsen and Hamilton, unpublished data).

Table 1. Total mean trap catches for 2004 and 2006

	2004		2005	
Trap	Ornamentals	Soybeans	Ornamentals	Soybeans
Football	3.78 b	0.52 b	15.35 a	0.29 b
Smart	3.42 b	0.31 bc	3.04 b	0.14 b
Apple	7.31 ab	0.00 c	9.78 a	0.35 b
Pyramid	11.39 a	1.45 a	10.75 a	1.94 a

Results shown as untransformed means. For each site, means within columns followed by the same letter are not significantly different ($P \geq 0.05$).

We have addressed the issue of lure strength. In 2007, we completed a two year study examining the response of *H. halys* to traps baited with different trap loading rates. This work showed that the 25 mg/trap load caught significantly more individuals than all other treatments each year (Table 2; Khrimian, Hamilton and Shearer, unpublished data). In addition, the use of a trap loaded with 7.5 mg lure attracted significantly more *H. halys* than did the 2.5, 0.5 and 0 mg treatments. These results indicate that traps baited with a 25 mg/septum attractant may have potential for use in a mass trapping effort.

Table 2. Total mean trap catches using traps baited with 0, 0.5, 2.5, 7.5 and 25 mg attractants, 2006 and 2007.

	Number/Trap	
Loading Rate	2006	2007
0.0 mg	0.04 c	0.51 d
0.5 mg	0.35 c	2.22 cd
2.5 mg*	0.64 c	5.31 c
7.5 mg**	3.76 b	10.71 b
25 mg***	9.41 a	16.51 a

* 2.5 mg per rubber septum; ** 2.5 mg septum x 3; ***2.5 mg septum x 10. Means within columns followed by the same letter are not significantly different ($P \geq 0.05$).

Stink bugs have historically been managed using organophosphorus insecticides, however, changes in insecticide chemistries and U.S. Environmental Protection Agency decisions that limit or prohibit the use of this class of insecticides has led researchers to investigate other management options. Currently, materials to control stink bugs include various pyrethroids (cyfluthrin, λ-cyhalothrin, esfenvalerate, fenpropathrin and permethrin), carbamates (oxamyl and methomyl), and neonicotinoids (imidacloprid, thiamethoxam, dinotefuran, clothianidin) (Ward, 2010). Nielsen et al. (2008) demonstrated in the laboratory that pyrethroids were toxic to BMSB, but to date, none have been field tested against BMSB.

Another potential option for managing BMSB is biological control. Relatively little information exists regarding BMSB's natural enemies in Asia, although a few natural enemies have been recorded in the literature. Several egg parasitoids, *Trissolcus mitsukurii*, *T. plautiae*, *T. itoi*, (Arakawa & Namura 2002) and *Gryon japonicum* (Noda 1995) have been reported in Japan. Recent studies in Japan have reported one or more new species of *Trissolcus* from BMSB (M. Toyama, pers. comm.). Until very recently there were no published studies for natural enemies in China, but a new species, *T. halyomorphae*, was recently described (Yang et al. 2009). A parasitic tachinid fly, *Bogosia* spp., is reported to attack the adult BMSB in Japan (Kawada & Kitamura, 1983b). Studies conducted through a cooperative agreement with Seoul National University identified a tachinid fly, *Pentatomophaga latifascia,* attacking adult BMSB in Korea, but evidence to date suggests it has a wide host range and little specific impact. No nymphal parasitoids are reported from pentatomids.

In the U.S., Bernon (2004) reared two egg parasitoids, *Telenomus podisi* Ashmead (Hym.: Scelionidae) and *Anastatus* sp. (Hym.: Eupelmidae), from an early survey of eggs of *H. halys* on *Paulownia*. The former is a well-known parasitoid of southern green stink bug, *Nezara viridula*, and many other stinkbugs (Jones 1988), whereas *Anastatus* spp. are broadly polyphagous within their search habitats and attack eggs of many different insect families and orders. Bernon (2004) noted an unidentified tachinid fly stalking *H. halys* on *Paulownia* and collected dead adult BMSB with apparent tachinid exit holes. Tachinids were found in pheromone-baited traps being tested to attract the bug (Aldrich et al. 2006), but inspection of nearly a thousand wild adults at ARS BIIR laboratory in Newark over the past several years showed that only about 5% contained tachinid eggs, and no adult flies were reared from any of these (Hoelmer, unpublished data). This suggests that at least some indigenous tachinids will recognize and attack BMSB as a potential host, but are not physiologically suited to complete development in this host stink bug. ARS BIIR surveys identified two species of *Anastatus* and two or three species of *Trissolcus* (Hym.: Scelionidae) from wild-collected and sentinel egg masses. A majority of the low levels of parasitism seen was due to the *Anastatus* species. Although *Trissolcus* sps. are typically restricted to pentatomids, and are capable of high levels of parasitism (e.g., Koppel et al 2009), these species parasitized only 1-2% of BMSB eggs. Much higher levels of BMSB parasitism are reported in Asia (Toyama, unpublished data). Surveys to date have focused solely on *Paulownia* as a host plant of BMSB egg masses. Additional surveys need to be conducted to determine whether levels of parasitism vary among different host plants in different crop environments, as there may well be unknown differences in regional and habitat-specific composition of parasitoid species that will search for and attack BMSB in tree fruits, on vegetables, and in native and introduced ornamental species. This information will be very important in evaluating the need for a classical biological approach. Screening for egg parasitoids in soybeans and ornamentals has been initiated in DE, NJ and PA with limited success (Hoelmer et. al., 2008).

Justification:

In 2008, 16.7 million cwt of bell peppers were grown in the U.S., valued at nearly $672.3 million. New Jersey ranks third in the country in pepper production (1.1 million cwt worth $32.9

million) (NASS 2009). U.S. consumption of all peppers has increased, moving from an average of 13 pounds per person in 2000 to 16 pounds per person in 2008 (ERS 2009).
Pepper production costs can be quite high (~$9662/acre), but this is offset by a high profit potential with gross returns reaching almost $13,000/A (NASS 2003). Smaller producers report that pepper is one of the most valuable products they can grow, particularly in specialty types and organic markets. Peppers are estimated to be grown on nearly 3,000 farms in the Mid-Atlantic States.

Currently, there are no adequate pest management alternatives to prevent *H. halys* from damaging peppers and as a result, farmers are desperate to find ways to prevent damage from occurring. Current control measures include the use of carbamate, organophosphate and pyrethroid insecticides, which are either not highly effective or disrupt current IPM programs because of their toxicity to natural enemies. Due to the lack of viable chemical control options, the potential illegal use of insecticides as a last resort by farmers exists.

By developing baseline data that can be used to develop a management program in peppers, the citizens in the Northeast will directly benefit from this project. In addition, farmers in other areas of the US (Southeast, Midwest, Oregon and California), where *H. halys* is currently known to occur will also benefit. Future benefits may be seen by farmers in other states as *H. halys* populations expand into these areas. Specific benefits include reduced crop losses to this new devastating pest, and potentially a reduction in illegal pesticide use to control this insect, a reduction in potential environmental problems, reductions in exposure to pesticides by farmers and their workers thereby improving their health. This project focuses on a species that is becoming an increasing agricultural problem wherever it is found and thus, addresses the IPM roadmap. This importance is highlighted by the Northeast IPM Center to fund a grant to form a BMSB working group charged with characterizing the pest status and identifying current abilities and critical research needs. This group includes federal and university researchers, extension personnel and stakeholders from seven states and met June 15 and 16, 2010. A report outlining critical research needs is available at http://www.northeastipm.org/work_bmsb.cfm.
Further, a document entitled, "Qualitative analysis of the pest risk potential of the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), in the United States" was recently released by the USDA-APHIS-PPQ-EDP in October 2010, which provides an extensive summary of potential risks posed by BMSB.

Our proposed research project spans state boundaries and involves collaborators from several areas. It involves research and extension personnel from DE, MD, NJ and VA with the expertise to conduct the proposed research and develop/deliver the outreach program that will be created if the project is successful.

Finally, this project addresses the need to develop IPM tactics for pest problems of regional or national magnitude such as a newly discovered invasive species that could have a significant impact on the economies of the Northeast as identified by the Pest Management Alternatives Program.

2. Objectives and Anticipated Impacts

Objectives: For the reasons outlined above, we propose to accomplish the following research objectives.

1. Develop monitoring methods for brown marmorated stink bug in peppers,
2. Assess the extent and nature of feeding injury to pepper by adult and nymphal brown marmorated stink bug in peppers,
3. Evaluate susceptibility of different pepper cultivar types to brown marmorated stink bug feeding,
4. Determine species composition of parasitoids and predators and rate of egg parasitization and predation for the BMSB in different pepper cultivars,
5. Determine the toxicity and field efficacy of selected insecticides for BMSB control in peppers.

Anticipated Impacts: We anticipate this project to have the following impacts:

Safeguarding human health and the environment – The IPM tactics we propose to develop will be adopted by farmers in 23 states thereby potentially impacting hundreds of thousands of people through reductions in pesticide residues on harvested peppers. It would result in the cessation of illegal pesticide applications to control *H. halys* by farmers. Adoption of this program over large areas also has the potential to reduce the spread of this invasive insect to agricultural areas in other states not currently impacted by BMSB.

Economic benefits – This project will result in economic benefits in the form of decreased monetary looses due to yield reductions caused by this insect. It will also result in increased time being available for marketing of the crop that would otherwise be spent managing this insect. Finally, this project will ultimately result in fewer costs in managing this pest due to reductions in pesticide use.

Implementation of IPM – This project will document the development and evaluation of several IPM tactics including monitoring, resistant varieties and targeted use of pesticides. Information about the tactics will be discussed by each of the PI's at state and regional grower meetings and will result in information being made available at www.rce.rutgers.edu/stinkbug/. Placing this information on the web will allow distribution to growers throughout the US.

3. Approach and Procedures

Objective 1: Develop monitoring methods for brown marmorated stink bug in peppers – To evaluate monitoring methods, sweet bell pepper (Aristotle or Paladin) plots will be established at several locations in DE, MD, NJ and VA. Plants will be grown from transplants on black plastic mulch and drip irrigation. Standard fertility practices and fungicide programs will be used. No insecticides will be applied. The plot will consist of eight rows 30 ft long. Adult BMSB will be monitored in three ways: weekly trap counts from a single blacklight trap placed at each location; weekly direct visual counts; and biweekly trap counts from four small yellow colored vein pheromone traps containing *Platia stali* aggregation pheromone. Monitoring by each method will commence after transplanting. Nymphal populations will be monitored using weekly direct counts only. Blacklight and pheromone trap counts will be correlated with the first presence of adults and nymphal BMSB in plots.

Objective 2: Assess the extent and nature of feeding injury to pepper by adult and nymphal brown marmorated stink bug in peppers – This objective will be done using the same pepper plot discussed under objective 1 at the NJ and MD locations. Beginning with the first appearance of adults, eggs or nymphs in plots, weekly damage evaluations will be conducted by removing all fruit from 20 sentinel plants evenly distributed throughout the plot. At harvest, 100 different plants will be selected, strip harvested and evaluated for damage. Data will be recorded on the number of marketable fruit, number, shape, and developmental stage of fruit damaged by stink bugs, and number of feeding sites (cloud spots) per fruit.

At the MD location, a larger plot will be established for addition space to accommodate several manipulative studies. One study will determine if nymphal feeding only on foliage affects fruit development. Stink bug nymphs will be manually introduced into small plots (one row sections of 5 plants) prior to fruiting and allowed to feed on plants until fruit development commences, at which time weekly treatments of a pyrethroid insecticide will be applied to prevent further feeding. Paired plots without nymph introductions will also be treated weekly to serve as undamaged controls. The size, shape, and weight of marketable fruit will be recorded to assess whether the physiological stress of foliage feeding will indirectly affect fruit development. Another study will examine the yield and quality impacts of direct fruit feeding by nymphal and adult BMSB. Replicate sets of undamaged developing fruit will be enclosed using fine-mesh bags and manually infested with varying densities of either nymphs or adults. Similar fruit will be bagged but not infested. After a 7-day infestation period, insects will be removed but the bags will remain intact until the fruit reaches marketable size. Data will be recorded on number and nature of feeding sites (cloud spots) per fruit, and the internal tissue disruption below each feeding site will be characterized.

Objective 3: Evaluate susceptibility of different pepper cultivar types to brown marmorated stink bug feeding – To evaluate the susceptibility of different pepper cultivar types, study plots will be established in year 1 in DE, MD, NJ and VA using a single popular cultivar of sweet bell (Aristotle or Paladin), sweet banana (Bounty), and hot Chile (Sparky) pepper. All three cultivars will be grown from transplants on black plastic mulch and drip irrigation. Standard fertility practices and fungicide programs will be used. No insecticides will be applied. Plots will be arranged in a Latin-square design to allow equal colonization of stink bugs across treatments in all directions. Each plot will consist of four rows 15 ft. long replicated three times. Depending on year 1 results, additional cultivars within each pepper type will be evaluated in years 2 and 3 to provide a relative ranking of BMSB susceptibility among the most common cultivars grown in the Mid-Atlantic Region.

Direct visual and beat counts of all life stages on five plants in each of the two center rows will be made semi-weekly in a non-destructive way starting one week after planting until harvest. Multiple fruit harvests will be conducted according to commercial practices. At each picking, the number of marketable fruit, number of fruits damaged by stink bugs, and number of feeding sites (cloud spots) per fruit will be recorded.

Data will be analyzed using the SAS ANOVA model procedure with adjustments made for lack of normality and repeated measurements. The Tukey option will be used to test for significance among multiple mean comparisons.

Objective 4: Determine species composition of parasitoids and predators and rate of egg parasitization and predation for the BMSB in different pepper cultivars – This objective will be done using the same pepper plots discussed under objective 3. To compare predation and parasitism of *H. halys* eggs among the different pepper cultivars, study plots will be established in DE, MD, NJ and VA. Sentinel egg masses will be outsourced on a minimum of eight randomly selected pepper plants in each pepper plot. This will be initiated when naturally colonizing adults are observed in the plots and will be repeated every other week throughout the growing season. The number of eggs per egg mass will be determined before eggs are taken to study sites but will be in the normal range for stinkbug egg masses (i.e., 20 to 30 eggs). Egg masses will be placed near the most recently mature leaf or just below the fruit when present and directly pinned onto the bottom side (Tillman 2007) of the 8 selected test plants in each plot and examined 24 h later to detect predation (as measured by damaged or disappeared eggs). After a 48-h exposure time, egg masses will be collected from the various plants, brought back to the laboratory, examined for predation of individual eggs, and then, if appropriate, held for emergence of adult parasitoids. The frequency of egg parasitization by a single parasitoid or combination of parasitoids will be calculated for the sentinel egg masses. Eggs attacked by chewing predators will be distinguished from those attacked by sucking predators.

Because objective 3 is to determine whether there are difference in the susceptibility of the three pepper cultivars to damage imposed by naturally occurring BMSB, naturally laid eggs will not be removed from the plants, but if found, at least five pepper plants from each plot containing naturally oviposited BMSB egg masses will be marked by placing a flag next to the plant and dotting the upper surface of the leaf with a permanent marker. The mark will not be made directly opposite the egg mass or directly adjacent to it. The selected egg masses will be checked daily for a week. Egg masses will be classified as (1) hatched, in which a BMSB nymphs emerged; (2) missing, in which eggs were entirely gone from the surface of the leaf; (3) mortality unknown, in which eggs did not hatch, yet they showed no sign of predation or parasitism; or (4) mortality by predator, in which the eggs appeared shrunken or collapsed or egg chorion was torn. This test will be conducted every other week until crop completion.

Arthropod predators will be censused during periods when plants are being sampled for BMSB adults, nymphs, and eggs. As such whole plant counts will be conducted at 7 DAP and continued at 10 day intervals. During each sampling occasion, 12 plants will be randomly selected from each treatment plot. The number of beneficial arthropods (e.g., lady bugs, damsel bugs, spined soldier and assassin bugs, ants, minute pirate bug, spiders, etc) encountered on pepper plants, through direct sampling will be identified to species, counted, and recorded on each sampling occasion. Predator numbers will be recorded according to their stage (i.e., egg, larva, adult).

All data will be analyzed using the SAS mixed model procedure with adjustments made for lack of normality and repeated measurements. The Tukey option will be used to test for significance among multiple mean comparisons.

Objective 5: Determine the toxicity and field efficacy of selected insecticides for brown marmorated stink bug control in peppers – Small-plot field experiments will be conducted in DE, MD, NJ and VA where heavy infestations of BMSB occurred in 2010. Separate trials on organic materials and conventional insecticides will be conducted during each of the three years. A suite of conventional insecticides including foliar contact, foliar systemic and soil-applied systemic products will be tested. Preliminary observations indicate that BMSB adults invade vegetable crops over an extended period and are less susceptible to contact-type insecticides, so residual activity, precise timing, and systemic activity are critical factors for successful control. For this reason, systemic treatments will involve chemigation applications through the drip irrigation system and timed at the most vulnerable life stages of the insect. Suggested conventional products include: oxamyl (Vydate L, drip), acephate (Orthene 97S, drip), dinotefuran (drip, foliar) (Venom 70SG), thiamethoxam (Actara 25WDG, foliar), pyriproxyfen (Knack 0.86E) + acephate (foliar), spirotetramat (Movento, drip, foliar), cryolite (Krocide 96W or Prokill 96, foliar), indoxacarb (Avaunt 30WDG, foliar), methomyl (Lannate LV, foliar), flonicamid (Beleaf foliar), acetamiprid (Assail 30SG, foliar), imidacloprid (Provado 1.6F, foliar; Admire Pro, drip), clothianidin (Belay, drip), and endosulfan (Thionex 3EC, foliar). Based on previous efficacy studies on squash bug and native stink bug, organic trials will include organically-certified materials that have the best chance of achieving control. Suggested organic products (all foliar) include: AzaDirect, Pyganic, Entrust (Koppel et al. 2009), Surround at 12.5 lbs, Azera at 32 oz, Surround at 12.5 lbs + Trilogy at 30 oz, Surround at 12.5 lbs + Neemix at 8 oz, Surround at 12.5 lbs rate + Azera 16 oz).

In all trials, sweet bell peppers will be grown from transplants on black plastic mulch with drip irrigation and fertility inputs applied according to commercial practices. Treatments plus the untreated controls will be arranged in a randomized complete block design with four replicates. Insecticide drip and foliar treatments will be initiated at the first sign of adult stink bug activity (based on visual plant counts and nearby pheromone traps). Decisions to apply additional applications will be made on a treatment by treatment basis, so the commercial value of each formulation-combination will be evaluated by the immediate control efficacy as well as residual activity to keep stink bugs below economic levels. Drip treatments will be applied either by a CO_2 driven injection of diluted solution through a second drip line in each plot or as a side-dress dose directed at the base of individual plants. Foliar insecticides will be applied using a CO_2 backpack sprayer with one hollow cone nozzle directed on each side of the foliage and one over the top. Marketable-sized fruit will be examined and counted during multiple harvests. The total number and weight of marketable fruit, number of fruits damaged by stink bugs, and number of feeding sites (cloud spots) per fruit will be recorded. Data will be summarized as marketable yield (based on average number of boxes), percent stink bug damaged fruit, average number of cloud spots per fruit, and percent control (based on the reduction in the number of damaged fruit relative to the control).

Data will be analyzed using the SAS mixed model procedure with adjustments made for lack of normality and repeated measurements. The Tukey option will be used to test for significance among multiple mean comparisons.

Timetable:

Obj	Task	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Year 1													
1-5	Plant peppers (all studies)										x	x	x
	Trap monitoring	x	x	x	x	x						x	x
	Plant sampling	x	x	x	x							x	x
2	Fruit inspections	x	x	x									
	Manipulative studies	x	x	x									
3	Plant sampling	x	x	x								x	x
	Fruit inspections	x	x	x									
4	Introduce egg masses	x	x	x								x	x
	Sample plants	x	x	x									
	Rear egg masses	x	x	x									x
5	Monitor plots	x	x										
	Apply treatments	x	x										
	Sample plots	x	x	x									
1-5	Analyze data				x	x	x	x					
1-5	Write progress reports								x	x	x		
Year 2													
1-5	Plant peppers (all studies)										x	x	x
	Trap monitoring	x	x	x	x	x						x	x
	Plant sampling	x	x	x	x							x	x
2	Fruit inspections	x	x	x									
	Manipulative studies	x	x	x									
3	Plant sampling	x	x	x								x	x
	Fruit inspections	x	x	x									
4	Introduce egg masses	x	x	x								x	x
	Sample plants	x	x	x									
	Rear egg masses	x	x	x									x
5	Monitor plots	x	x										
	Apply treatments	x	x										
	Sample plots	x	x	x									
1-5	Analyze data				x	x	x	x					
1-5	Write progress reports								x	x	x		
Year 3													
1-5	Plant peppers (all studies)										x	x	x
	Trap monitoring	x	x	x	x	x						x	x
	Plant sampling	x	x	x	x							x	x
2	Fruit inspections	x	x	x									
	Manipulative studies	x	x	x									
3	Plant sampling	x	x	x								x	x
	Fruit inspections	x	x	x									
4	Introduce egg masses	x	x	x								x	x
	Sample plants	x	x	x									
	Rear egg masses	x	x	x									x

Obj	Task	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Year 3 continued													
5	Monitor plots	x	x										
	Apply treatments	x	x										
	Sample plots	x	x	x									
1-5	Analyze data				x	x	x	x					
	Write final report								x	x	x	x	

4. Evaluation Plans

Results of the insecticide efficacy experiments will be evaluated each year to determine which products and application strategies have the most potential to achieve effective control. Selection of candidate insecticides to be recommended or screened for further testing will also be based on potential environmental and worker exposure risks, economic benefits, and how well specific products fit into existing IPM practices in pepper production. In particular, each insecticide and application method will be evaluated for its potential to disrupt the beneficial arthropod community and trigger secondary pest problems on peppers. Once certain products and application strategies have been proven effective, we will actively participate in a group effort with industry, state regulatory agencies, and partner institutions to seek approval of special local needs registrations and/or supplements to existing labels if necessary. Steps have already been taken by Members of Congress and the USDA Office of Pest Management Policy working with EPA to facilitate the registration and/or emergency use of efficacious insecticides. This immediate action is needed as a short-time solution for pepper growers and will enable participating states to make management recommendations after the first year.

Pepper growers need immediate information on the potential for crop losses caused by BMSB, what infestation levels warrant management actions, and whether certain cultivars are less susceptible to injury. Data from the proposed studies across participating states will be pooled and analyzed to address these needs. The impacts of stink bug damage on fruit quality and associated infestation levels determined by plant inspections and trap monitoring will be evaluated together in terms of expected economic losses and cultivar susceptibility in order to establish provisional thresholds for implementing management actions. The potential for biological control will also be factored into these thresholds if levels of egg parasitism contribute significantly to stink bug population suppression.

Recommendations based on these evaluations will be developed during years 1 and 2 and discussed with growers at state and regional vegetable meetings during the fall and winter of years 2 and 3. The aim is to increase grower knowledge about BMSB and its potential for damage to various pepper cultivars, provide information about monitoring and when to apply management actions, assess the potential for native natural enemies to help manage BMSB, and provide growers with effective insecticide options. The final results of the overall project will be discussed in a similar fashion during the winter of year 3. In addition, the information developed will be incorporated into a current website (www.rce.rutgers.edu/stinkbug/) and a regional grower recommendation manual developed jointly by DE, NJ, MD and VA during the fall and winter of year 3. Our intent is to provide growers with information in a staged manner throughout the project with short term goals of increasing awareness of potential economic losses, pesticide impacts, effective insecticide options; medium term goals of reducing the amount of high risk pesticides used in the pepper crop system and further adoption of the tools developed; and ultimately long term goals of reducing human health risks caused by insecticide use (see logic model below).

5. Key Personnel

Dr. Galen Dively, Entomologist – Dr. Dively will serve as co-study director and will assist in the design, set-up and implementation of studies to address objectives 1, 2, 3 and 5 in MD.

Dr. Gerald Ghidiu, Entomologist - Dr. Ghidiu will serve as co-study director and will assist in the design, set-up and implementation of studies to address objective 5 in NJ.

Dr. George Hamilton, Entomologist – Dr. Hamilton will serve as co-study director and will assist in the design, set-up and implementation of studies to address objectives 1, 2, 3 and 4 in NJ. Dr. Hamilton will also develop a project outcomes website at www.rce.rutgers.edu/stinkbug/ and generate yearly project reports.

Dr. Cerruti Hooks, Entomologist - Dr. Hooks will serve as co-study director and will assist in the design, set-up and implementation of studies to address objective 4 in MD.

Dr. Thomas Kuhar, Entomologist - Dr. Kuhar will serve as co-study director and will assist in the design, set-up and implementation of studies to address objectives 1, 3, 4 and 5 in VA.

Ms. Joanne Whalen, IPM Specialist – Ms. Whalen will serve as co-study director and will assist in the design, set-up and implementation of studies to address objectives 1, 3, 4 and 5 in DE.

Project Logic Model

Inputs

- Project leaders/staff
- In-kind resources
- Funding
- Materials
- Stakeholders' needs
- Extension base

Outputs

Activities

- Establish research plots at education ctr (DE, NJ, MD & VA)
- Attend stakeholders' meetings
- Demonstrate results and information on new IPM strategies
- Train stakeholders how to integrate biological, cultural, and chemical control
- Develop & distribute educational material
- Upload information to IPM & other web

Participants & audience

Participants

- Program leader/staff
- Education center crew
- Extension Partners
- Graduate students
- Interns

Audience

- Vegetable growers (sustainable, organic & conventional, IPM practitioners)
- Grower Agencies
- Crop Advisors
- Extension educators

Outcomes

Short

- Participants & audience learn viable low risk chemical option
- Obtain baseline info for developing an IPM plan
- Participants start to integrate newly learned tactics into their current production scheme
- Pepper growers learn new ways to monitor BMSB
- Reduce crop lost and illegal pesticide usage
- Lower pesticide usage and production cost
- Pepper growers and other stakeholders have easy access to new information

Medium

- Develop control tactics that are not disruptive to current IPM program
- Increased number of vegetable growers use IPM tactics
- Increased number of farmers adopt best management practices to protect crops from BMSB
- Pepper and other growers adopt practices that are environmentally and economically feasible
- Decrease use of high risk (health hazard) pesticides
- Broad spectrum chemicals replaced by more softer compounds
- Growers interest in alternative BMSB control tactics reach an all time high.
- Pepper growers gain confidence in their new skill sets, teach others
- Pepper growers make better production decisions.

Long

- Significant boost in environmental health in Northeast communities
- Notable reduction in insecticide use in peppers & other vegs
- Permanent stakeholder involvement in BMSB research & extension program
- Increased role of bio-logical control in pepper growers IPM programs
- Overall increase in yields at lower operational and environmental cost
- Reduce spread of BMSB to other states
- Organic growers and others who stopped growing peppers return and prosper
- IPM program become a model for other crops impacted by BMSB

Assumptions: Pepper growers are aware of the economic losses and increased production costs associated with the BMSB, and are interested in alternative methods of control. Short and medium outcomes will be realized through feedback from farmers at various outreach events.

External Factors: Pepper growers willing to change practices to protect their crops and lower production costs. Grower associations such as the Maryland Vegetable Grower Association promote adoption of a more integrated IPM program for BMSB management.

Situation: The brown marmorated stink bug, *H. halys* has become a widespread destructive pest of several vegetable cropping systems including peppers in the Northeast; and farmers are desperate to prevent it from causing them more economical hardship. Current control measures which include the use of broad spectrum insecticides are ineffective and/or disrupted to current IPM programs instituted to manage other pepper pests. Due to the lack of viable control options and desperation, the potential illegal uses of insecticides by farmers exist. We propose to establish the foundation for a novel, biorational IPM strategy to address these and associated problems.

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Relevance Statement

Institutions and Project Directors:

Rutgers University	Dr. George C. Hamilton, Dr. Gerald Ghidiu
University of Delaware	Ms. Joanne Whalen
University of Maryland	Dr. Galen Dively, Dr. Cerruti Hooks
Virginia Polytechnic Institute	Dr. Thomas Kuhar

Project Title: Development of Management Strategies Targeting the Brown Marmorated Stink Bug, *Halyomorpha halys* in Peppers

Project Type: Research

Project Summary:

This is a research project requesting $180,000 in P.L 89-106 funding over the next three years to develop management strategies targeting the brown marmorated stink bug (BMSB) in peppers. BMSB has spread throughout the east and portions of the Midwest and west. BMSB became a severe pest of tree fruit and vegetables in 2009 and 2010. Currently, no adequate pest management alternatives exist to prevent damage to peppers creating the potential for the illegal use of insecticides. This project proposes to develop BMSB monitoring methods, assess BMSB feeding injury in pepper, evaluate cultivar susceptibility differences to BMSB feeding, determine natural enemy species composition in different cultivars, and determines the toxicity and field efficacy of selected insecticides for BMSB control. Objectives 1 and 2 will be accomplished by sampling BMSB populations and determining damage levels caused by BMSB in unsprayed sweet bell peppers. Objectives 3 and 4 will be accomplished by sampling BMSB and natural enemy populations and determining damage levels caused by BMSB in a variety of unsprayed pepper cultivars. Objective 5 will be accomplished by spraying sweet bell peppers with different insecticides to determine efficacy in terms of BMSB toxicity and reductions in damage to fruit. We anticipate this project to safeguard human health and the environment by reducing illegal of insecticides, provide economic benefits by reducing the pepper damage caused by BMSB and promote IPM implementation by developing the tools that can be used by farmers to reduce damage caused by BMSB.

Problem:

The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål), is an exotic stink bug (Heteroptera: Pentatomidae) that was introduced into the United States in the mid 1990's. Since its initial establishment in Allentown, PA, it has spread throughout the east coast as far south as GA and as far north as NH. Additional populations occur in CA, IN, IL, KY, MS, OH, OR, and TN. In its native range of Korea, China and Japan it is an important agricultural pest in tree fruit and soybeans causing fruit and pod malformations. *Halyomorpha halys* is also a public nuisance in Japan because adults enter dwellings in large numbers late in the fall. In the US, this invasive insect became a public nuisance problem almost immediately. BMSB did not become an agricultural problem until 2009 when damaging populations occurred for the first time in the fruit growing regions of WV and VA. In 2010, BMSB populations exploded throughout the eastern US causing severe damage in fruit and vegetables DE, MD, NJ and PA in addition to WV and VA with growers experiencing up to 75% damage in some.

In areas where *H. halys* populations have become a problem, farmers are desperate to find ways to prevent it from causing damage. Current control measures include the use of carbamate, organophosphate and pyrethroid insecticides which are either not highly effective and/or disrupt current IPM programs because of their toxicity to natural enemies. Due to the lack of viable chemical control options the potential illegal use of insecticides as a last resort by farmers exit. To react to this situation, researchers in the northeast are attempting to develop IPM programs targeting BMSB. However, while information is available regarding BMSB behavior and life history in apples and pears, little is known for vegetables such as peppers. Questions exist regarding when BMSB enters pepper fields to feed and how best to predict entry, what population levels create economic damage, ability by different varieties to resist attack, parasitism levels by native parasitoids and finally what chemical controls exit, if any, to manage this pest without disrupting current IPM programs. Our proposal outlines studies to address these knowledge gaps in peppers.

Justification:

Currently, there are no adequate pest management alternatives to prevent *H. halys* from damaging peppers and as a result, farmers are desperate to find ways to prevent damage from occurring. Current control measures include the use of carbamate, organophosphate and pyrethroid insecticides which are either not highly effective and/or disrupt current IPM programs because of their toxicity to natural enemies. Due to the lack of viable chemical control options the potential illegal use of insecticides as a last resort by farmers exit.

By developing baseline data that can be used to develop a management program using mass the citizens in the Northeast will directly benefit from this project. In addition, farmers in other areas of the US (Southeast, Midwest, Oregon and California) where *H. halys* is currently known to occur will also benefit. Future benefits may be seen by farmers in other states as *H. halys* populations expand into these areas. Specific benefits include a reduction in illegal pesticide use to control this insect, a reduction in potential environmental problems, reductions in exposure to pesticides by farmers and their workers thereby improving their health. This project focuses on a species that is becoming an increasing agricultural problem wherever it is found and thus addresses the IPM roadmap. This importance is highlighted by the Northeast IPM Center's willingness to fund a grant to form a BMSB working group charged with characterizing the pest status and identifying current abilities and critical research needs. This group includes federal and university researchers, extension personnel and stakeholders from seven states and met June 15 and 16, 2010. A report outlining critical research needs is available at http://www.northeastipm.org/work_bmsb.cfm.

This project spans state boundaries and involves collaborators from several areas. It involves research and extension personnel from DE, MD, NJ and VA with the expertise to conduct the proposed research and develop/deliver the outreach program that will be created if the project is successful.

Finally, this project addresses the need to develop IPM tactics for pest problems of regional or national magnitude such as a newly discovered invasive species that could have a significant impact on the economies of the Northeast as identified by the Pest Management Alternatives Program.

Objectives:

We propose to accomplish the following research objectives:

1. Develop monitoring methods for brown marmorated stink bug in peppers,
2. Assess the extent and nature of feeding injury to pepper by adult and nymphal brown marmorated stink bug in peppers,
3. Evaluate pepper cultivar susceptibility differences to brown marmorated stink bug feeding,
4. Determine species composition of parasitoids and predators and rate of egg parasitization and predation for the BMSB in different pepper cultivars,
5. Determine the toxicity and field efficacy of selected insecticides for brown marmorated stink bug control in peppers.

Anticipated Impacts: We anticipate this project to have the following impacts:

Safeguarding human health and the environment – The IPM tactics we propose to develop will be adopted by farmers in 23 states thereby potentially impacting hundreds of thousands of people through reductions in pesticide residues on harvested peppers. It would result in the cessation of illegal pesticide applications to control *H. halys* by farmers. Adoption of this program over large areas also has the potential to reduce the spread of this invasive insect to agricultural areas in other states not currently impacted by BMSB.

Economic benefits – This project will result in economic benefits in the form of decreased monetary looses due to yield reductions caused by this insect. It will also result in increased time being available for marketing of the crop that would otherwise be spent managing this insect. Finally, this project will ultimately result in reduced expenses managing this pest because reductions in pesticide use.

Implementation of IPM – This project will document the development and evaluation of several IPM tactics including monitoring, resistant varieties and targeted use of pesticides. Information about the tactics will be discussed by each of the PI's at state and regional grower meetings and will result in information being made available at www.rce.rutgers.edu/stinkbug/. Placing this information on the web will allow distribution to growers throughout the US.

Project Logic Model - Development of Management Strategies Targeting the Brown Marmorated Stink Bug in Peppers

Inputs	Outputs: Activities	Outputs: Participants & audience	Outcomes: Short	Outcomes: Medium	Outcomes: Long
• Project leaders/staff • In-kind resources • Funding • Materials • Stakeholders' needs • Extension base	• Establish research plots at education ctr (DE, NJ, MD & VA) • Attend stakeholders' meetings • Demonstrate results and information on new IPM strategies • Train stakeholders how to integrate biological, cultural, and chemical control • Develop & distribute educational material • Upload information to IPM & other web	*Participants* • Program leader/staff • Education center crew • Extension Partners • Graduate students • Interns *Audience* • Vegetable growers (sustainable, organic & conventional, IPM practitioners) • Grower Agencies • Crop Advisors • Extension educators	• Participants & audience learn viable low risk chemical option • Obtain baseline info for developing an IPM plan • Participants start to integrate newly learned tactics into their current production scheme • Pepper growers learn new ways to monitor BMSB • Reduce crop lost and illegal pesticide usage • Lower pesticide usage and production cost • Pepper growers and other stakeholders have easy access to new information	• Develop control tactics that are not disruptive to current IPM program • Increased number of vegetable growers use IPM tactics • Increased number of farmers adopt best management practices to protect crops from BMSB • Pepper and other growers adopt practices that are environmentally and economically feasible • Decrease use of high risk (health hazard) pesticides • Broad spectrum chemicals replaced by more softer compounds • Growers interest in alternative BMSB control tactics reach an all time high. • Pepper growers gain confidence in their new skill sets, teach others • Pepper growers make better production decisions.	• Significant boost in environmental health in Northeast communities • Notable reduction in insecticide use in peppers & other vegs • Permanent stakeholder involvement in BMSB research & extension program • Increased role of bio-logical control in pepper growers IPM programs • Overall increase in yields at lower operational and environmental cost • Reduce spread of BMSB to other states • Organic growers and others who stopped growing peppers return and prosper • IPM program become a model for other crops impacted by BMSB

Assumptions: Pepper growers are aware of the economic losses and increased production costs associated with the BMSB, and are interested in alternative methods of control. Short and medium outcomes will be realized through feedback from farmers at various outreach events.

External Factors: Pepper growers willing to change practices to protect their crops and lower production costs. Grower associations such as the Maryland Vegetable Grower Association promote adoption of a more integrated IPM program for BMSB management.

Situation: The brown marmorated stink bug, *H. halys* has become a widespread destructive pest of several vegetable cropping systems including peppers in the Northeast; and farmers are desperate to prevent it from causing them more economical hardship. Current control measures which include the use of broad spectrum insecticides are ineffective and/or disrupted to current IPM programs instituted to manage other pepper pests. Due to the lack of viable control options and desperation, the potential illegal uses of insecticides by farmers exist. We propose to establish the foundation for a novel, biorational IPM strategy to address these and associated problems.