UNITED STATES DEPARTMENT OF AGRICULTURE COOPERATIVE STATE RESEARCH, EDUCATION, AND EXTENSION SERVICE	OMB Approved 0524-0039 Expires 03/31/2004

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PROPOSAL TYPE

For National Research Initiative Competitive Grants Program Proposals Only

[X] Standard Research Proposal
[ ] Conference
[ ] AREA Award
[ ] Postdoctoral
[ ] New Investigator
Strengthening:
[ ] Career Enhancement
[ ] Equipment
[ ] Seed Grant
[ ] Standard Strengthening

Project Title: **Multi-Tactic Management Strategies for Internal Lepidoptera Infesting Northeast Apples**

Key Words: **Oriental fruit moth, codling moth, mating disruption, integrated control, monitoring, insecticide resistance**

For Higher Education Program Proposals Only:

Need Area: ________________

Discipline: ________________

CRITICAL/EMERGING ISSUE PROPOSAL

Apple in the eastern United States is a high value crop and a cornerstone of the region's agriculture. Apple production provides a large quantity of fresh fruit and fruit products, contributes to agri-tourism, and offers bucolic amenities to an increasingly urban and suburban landscape. During the last several years, fruit growers in New York and Pennsylvania have suffered severe financial losses because infestations by internal fruit feeding Lepidoptera have led to numerous loads of apples being rejected by fresh fruit markets and processing plants. The tree fruit industry in these states is already in an economic crisis because of depressed markets, increased production costs, changes in pesticide registrations, and foreign competition. If this new crisis is not solved quickly, it could hasten the decline of this already beleaguered industry. Furthermore, if growers are forced to revert to calendar spraying at 14-day intervals and use harsh materials such as synthetic pyrethroids to control internal Lepidoptera in these outbreak areas, more than 30 years of IPM research and implementation may be subverted. The objectives of this project are: 1) Evaluate multi-tactic management programs integrating mating disruption and improved timing of IPM-compatible insecticides in large-scale plots in grower orchards. 2) Monitor the susceptibility of field populations of internal Lepidoptera in outbreak areas to insecticides. 3) Encourage growers to adopt and implement management programs for internal Lepidoptera that are effective, sustainable, economically feasible, and compatible with existing orchard IPM programs.

LITERATURE REVIEW, PREVIOUS WORK AND RELATED EXPERIENCE:

Apple in the eastern United States is a high value crop, approaching an annual farm-gate value of $450 million with production on 6,582 farms. Management of more than two dozen arthropod pests in apple orchards in the eastern United States is a complex and difficult task (Madsen & Morgan 1970, Chapman & Lienk 1971, Howitt 1993, Hogmire 1995), and apple IPM programs are perhaps the most complex of all pest management systems. For eastern growers, the most important insects are a complex of direct pests whose larvae feed internally within fruit (internal feeders), and include the codling moth (CM), *Cydia pomonella*; oriental fruit moth (OFM), *Grapholita molesta*; lesser appleworm (LAW), *Grapholita molesta*; apple maggot (AM), *Rhagoletis pomonella*; and plum curculio (PC), *Conotrachelus nenuphar*.

During the last several years, severe outbreaks of various species of internal Lepidoptera have occurred throughout apple production regions in the eastern United States and Canada. These outbreaks have caused severe financial losses to growers throughout this region because numerous loads of apples have been rejected for the fresh or processing market. This escalating incidence of severe fruit damage in commercial apple orchards caused by internal fruit feeding Lepidoptera clearly poses a threat to the continued viability of the industry within this region. Growers in the northeastern United States are already threatened by future changes in the availability of broad-spectrum, relatively inexpensive, effective insecticides such as organophosphates, because of changes resulting from the implementation of the Food Quality Protection Act. In addition, they are faced with low commodity prices because of increased domestic and foreign competition, and higher production costs. If this new pest control crisis is not solved quickly, it could hasten the decline of this already beleaguered, important regional agricultural industry.

The Northeastern IPM Center Working groups have placed a high priority on the need for future research and extension programs to develop improved management programs for both OFM and CM utilizing softer insecticides integrated with mating disruption. More specifically, apple growers in both New York and Pennsylvania have identified an urgent need for research and extension activities to develop better technology to prevent unacceptable losses from outbreaks of internal Lepidoptera. For example, the 2003–2004 Fruit IPM Stakeholder Research Priorities for New York State identify a critical need in tree fruit for additional research in "Internal Lepidoptera biology and management", and in 2003 a research project to "Develop an Improved, Integrated Management Program for the Internal Lepidopera Pest Complex Attacking Apples in Western NY" was supported with funding from both the NYS IPM program and the NY Apple Research and Development Program. Similarly, the State Horticultural Association of Pennsylvania listed both “CM and OFM Management” as priority funding topics for both the 2003 and 2004 year funding cycle.

Current studies have suggested that the development of resistance to organophosphate insecticides by codling moth and the oriental fruit moth is at least partly responsible for the development of this recent management problem. Resistance might be an important contributing factor, but at present, it is not possible to say that this is the major cause, let alone the sole responsible factor. Other potentially contributing factors are: changes or variation in pest phenology and changes in pest management practices brought on through anticipation of FQPA-mandated changes (e.g., reduced use of organophosphates late in the growing season).

The first reports of problems in controlling internal Lepidoptera feeding in apple orchards in the United States occurred in western fruit growing regions in the late 1980's and early 1990's. Research showed that populations of codling moth infesting apples and pears in commercial orchards in 4 western states were resistant to azinphosmethyl, which had been the most widely used insecticide in this region since the early 1960's (Varela et al. 1993, Knight et al. 1994). Codling moth resistance to insecticides in western fruit production regions has continued to proliferate, and subsequent studies have shown that this pest is now resistant to multiple classes of insecticides; organophosphates, carbamates, and synthetic pyrethroids (Dunley & Welter 2000). Recent studies have shown that some field populations of codling moth larvae collected from commercial orchards in Washington were also less susceptible to the benzoylhydrazine insecticides, tebufenozide (Confirm) and methoxyfenozide (Intrepid), which have yet to be widely used in commercial orchards in this region (Knight et al. 2001).

Levels of resistance observed in codling moth from commercial orchards in western apple production regions have been fairly low (usually less than 10X), and instances of complete control failure have been rare. However, in orchards with resistant populations of codling moth, growers have increased the frequencies and rates of insecticide sprays in order to obtain adequate control (Dunley & Welter 2000). In some areas of Washington and California, the technique of areawide disruption of mating by dispensing synthetic pheromones has been used successfully, but in most orchards using this tactic, applications of broad-spectrum insecticides such as organophosphates are still necessary to adequately protect fruit (Calkins 1999).

The OFM has been a major pest of stone and pome fruits in the northeastern United States and eastern Canada for many years (Pree 1985). This pest was effectively controlled with organophosphate insecticides until the late 1990's, when studies indicated that populations in peach orchards in Ontario, Canada, had become resistant to organophosphate, carbamate, and pyrethroid insecticides (Kanga et al. 1999, Pree et al. 1998).

In Pennsylvania during the last 6 years, numerous truck loads of apples have been rejected by processors because of unacceptable infestations of internal fruit feeding Lepidoptera. From 1998 to 2003, 1,103 loads of fruit were rejected by processors in Pennsylvania because of unacceptable infestations of oriental fruit moth. During the same years, 366 loads were rejected because of larval infestations of codling moth (Krawczyk, unpublished data, 2003). Bioassays conducted during the last several years have shown that adult codling moths and oriental fruit moths captured in orchards that have had severe fruit infestations are from 3–9-fold less susceptible to azinphosmethyl, methomyl and esfenvalerate than moths from other populations (Krawczyk & Hull, unpublished data, 2002).

In New York, difficulties in controlling fruit feeding Lepidoptera began later than in other states and were first manifested in peaches. Unacceptable levels of damage from oriental fruit moth were observed at harvest (5–20%) in some peach orchards in Niagara County in 1999 (D. Breth, personal observations). Subsequent trials of insecticides conducted in a peach orchard in this region in 2000 and 2001 showed that fruit damage at harvest was slightly higher when using an organophosphate than when using a pyrethroid, but the differences were not statistically significant (Reissig, unpublished data). In 2001, approximately 30 loads of apples were rejected by Cadbury Schweppes-Duffy Mott, the largest processor in western NY, because of infestation by internal fruit feeding Lepidoptera larvae. During 2002, this company rejected 113 loads of Lepidoptera-infested fruit from 42 different growers. Most larvae from these orchards that had rejected fruit were identified as oriental fruit moth, but many infested orchards also had lower percentages of codling moth or lesser appleworm larvae (Reissig & Krawczyk, unpublished data).

In 2003, most apple growers in western NY who had experienced unacceptable damage in the past began to intensify chemical control programs for control of internal Lepidoptera and consequently, fewer loads were rejected (13), from only about 11 growers. Even though western NY apple growers achieved temporary success in reducing internal Lepidoptera damage in many problem orchards in 2003, many applied frequent sprays on a calendar basis, and used materials such as synthetic pyrethroids that are incompatible with IPM programs. Some growers also experimented with using either sprayable pheromones or conventional plastic ties, primarily for mating disruption of OFM, but many of these growers also applied complete full season insecticide programs, which greatly increased their pest control costs. Although such intensive control programs are often necessary to achieve acceptable control in orchards with high levels of internal Lepidoptera infestation, more cost-effective, IPM-compatible management programs for this pest complex need to be developed and tested in the future. Initial research trials conducted in NY during 2003 have shown that field populations of OFM in problem apple orchards have low levels of resistance (1.5–2.5X) to organophosphate insecticides. The synthetic pyrethroid, cyhalothrin (Warrior) was effective in preventing damage in these types of orchards, but other materials such as indoxacarb (Avaunt), high rates of organophosphates, Avaunt, and newer materials such as acetamiprid (Assail) and novaluron (Diamond) also generally provided similar levels of control (Reissig et al., unpublished data). These trials also showed that mating disruption using sprayable formulations of OFM pheromone later in the season did not provide adequate control of OFM damage in orchards subjected to high levels of OFM pressure unless supplemented with applications of insecticides. Whereas, in Pennsylvania, researchers found that frequent applications of low doses of the sprayable pheromones applied at the start of second brood flight can supplement low doses of insecticides for successful control of OFM (Hull, unpublished data). The results from these trials suggested that additional work is necessary to determine if and when special sprays are needed to control internal Lepidoptera and to develop cost-effective, multi-tactic management programs utilizing judicious use of special insecticide control sprays integrated with mating disruption.

Pheromone-based mating disruption is another promising technique for managing lepidopteran pests, and the principal investigators of this proposal have strong research programs in this area. Pheromone deployment for pest control in fruit crops currently relies upon evaporation from polymers (ropes) impregnated or filled with pheromone. These hand-applied dispensers must be placed within orchards at relatively high densities per unit area (McDonough et al. 1992, Thomson et al. 1998.). Furthermore, because pheromones are species-specific, a different dispenser must be used for each target species. Recently though, pheromone manufacturers have developed dual or twin tube dispensers that allow for the combination of two or more pheromones from two or more species. Mating disruption has become a commercially acceptable option for control of some lepidopteran pests in apple and peach, especially for codling moth and oriental fruit moth (Cardé & Minks, 1995, Thomson et al. 1998).

To date, widespread commercial adoption of this technology has been limited to orchards in the pacific coast states of California, Washington and Oregon (Gut & Brunner 1998, Knight 1996, Thomson 1997), where a USDA sponsored area-wide project greatly facilitated the introduction of this technology. The relatively low diversity of tree fruit insect pests and the lack of surrounding alternate-host habitats were also important factors in the success of mating disruption in the western US.

Although there have been successful uses of codling moth and oriental fruit moth mating disruption programs in localized areas in the eastern region, a more diverse pest complex and alternate host habitat surrounding orchards has hindered more widespread adoption of this technology. A major barrier to the more widespread adoption of mating disruption in the east is the need to hand-apply pheromone dispensers. Application is labor-intensive and needs to be done in the early spring when field labor is not readily available.

New mating disruption technology does offer an opportunity to overcome these barriers in the eastern region. Microencapsulated sprayable pheromones (Gut et. al 2000), low density dispensing systems (Shorey et al., 1996, Mafra-Neto & Baker, 1996, Isaacs et. al, 1999), and paraffin emulsions (Delwiche et al. 1998) represent alternative approaches to labor-intensive hand applied matrices. The microencapsulation process creates 10–20-µm diameter membrane spheres around pheromone, and this acts as a reservoir of pheromone that gradually releases the compound into the air. The capsules are formulated in water, so they can be mixed in a spray tank and applied to the crop in a water carrier. Super low-density approaches have been referred to as 'puffers' (Shorey et al., 1996), 'misters' (Mafra-Neto & Baker, 1996) or 'mircrosprayers' (Isaacs et al., 1999). The release of pheromone is controlled mechanically by the various units to provide a constant pre-determined release rate and a stable environment for the large volume of pheromone prior to its release. In recent years, this method has been tested using such devices for disruption of some insect pests in fruit crops (Shorey & Gerber, 1996a, b; Shorey et al., 1996, Baker et al., 1997, Isaacs et. al, 1999, Ellis, 2002). Another novel method of pheromone delivery is the use of a sprayable biodegradable carrier material. Paraffin emulsions containing insect pheromones sprayed on the trunk and scaffold limbs of fruit trees show promise for disrupting some pest species, including OFM (Delwiche et al. 1998). The pheromone emulsions can be quickly applied to the upper portion of the canopy using various manually operated field-portable sprayers, such as a forestry paint gun.

OBJECTIVES:

1. Evaluate a multi-tactic management program that integrates mating disruption and improved timing of IPM-compatible insecticides in large-scale plots in grower orchards.

2. Monitor the susceptibility of field populations of internal Lepidoptera in outbreak areas to insecticides.

3. Encourage growers to adopt and implement management programs for internal Lepidoptera that are effective, sustainable, economically feasible, and compatible with existing orchard IPM programs.

PROCEDURES:

1. Evaluation of integrated management programs: Lepidoptera that feed internally on apple fruits are difficult to control because: 1) Relatively low rates of infestation can have severe economic consequences (i.e., rejected loads of fruit). 2) These pests are difficult to monitor and rescue treatments, even if possible, require long lead times. 3) Pest phenology can be quite variable, and at times, difficult to predict. 4) The efficacy of some of the newer insecticides is lower than that for older insecticides. At present, the best strategy for controlling these pests is hypothesized to be an integrated program of mating disruption and insecticide applications. In terms of efficacy, these two tactics should have an additive effect because they target entirely different control mechanisms. However, employing both tactics is expensive, and in some instances, may not be warranted. We propose to evaluate an integrated management program that makes use of pheromone disruption and insecticide applications on an as-needed basis, which should reduce the cost of the program and minimize unneeded pesticides.

The general structure of the management program is illustrated in Figure 1. The first step of the program is to rank the risk of internal Lepidoptera infestation so that a decision regarding the need for pheromone disruption can be made. This risk rating will have two categorical levels, high and moderate risk. By default, those orchards not ranked as high risk will have a moderate risk. High-risk orchards are those in which infested fruit were detected at harvest the previous year. Orchard blocks classified a high risk would be scheduled to receive the integrated pheromone and insecticide program. Blocks rated a moderate risk would be scheduled to receive an insecticide-only management regime. The logic for this distinction, is that the integrated program is more stringent, and hence needed, when infestation pressure is high. Otherwise, a rational insecticide program should suffice.

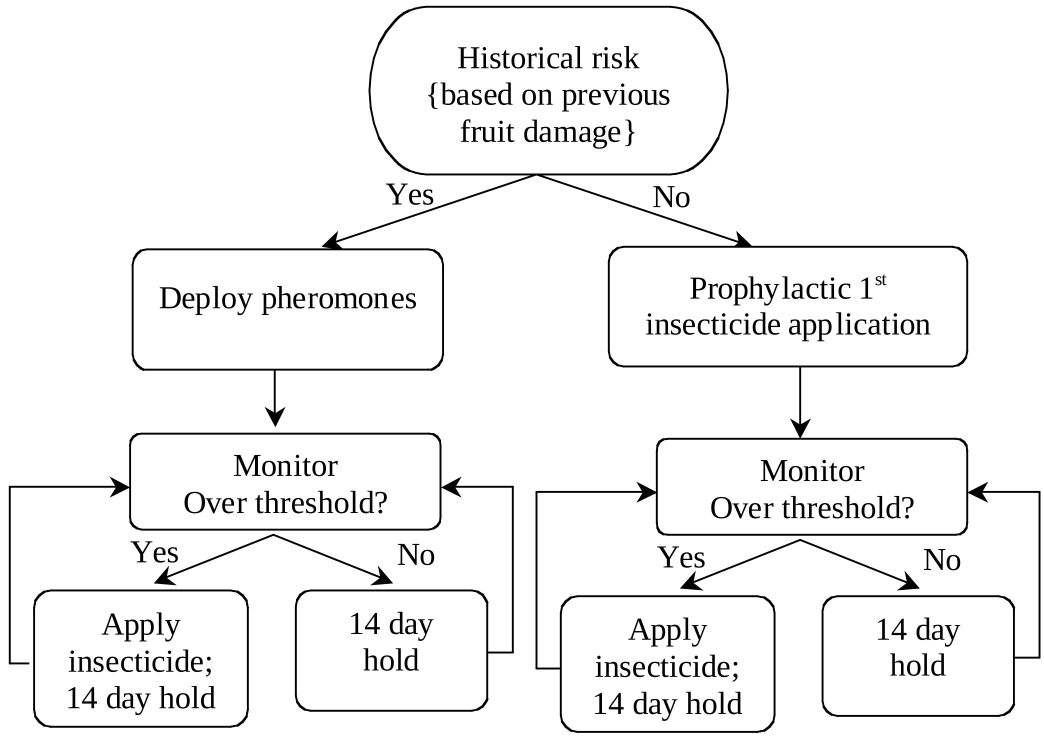

Figure 1. Flow diagram for an integrated management program for internal fruit feeding Lepidoptera.

In the high-risk blocks, synthetic pheromones will be deployed to allow for season-long mating disruption. After pheromone deployment, the orchard block will be monitored to verify that the mating disruption is preventing fruit infestation from occurring. The monitoring will be done in two stages: First, beginning at the end of July and then every two weeks until harvest, 1000 fruit will be examined for infestation. This sample size provides a relatively high probability of detecting at least one infested fruit when the true infestation is 0.25% or higher. Finding a single infested fruit would trigger an insecticide application, scheduled to coincide (using a phenology model) with a high proportion of susceptible individuals (eggs and first instar larvae). The second monitoring tactic will be to deploy four pheromone traps in the center of the disrupted block. Any trap captures would also trigger an insecticide application. Fourteen days following a monitoring bout or application of an insecticide, the monitoring and decision-making process would be repeated (of course, pheromone traps are continuously deployed). This is an admittedly ad-hoc procedure, but one we feel confident in testing based on our extensive experience in this pest-crop system.

Blocks designated a moderate risk would be assigned to the rational insecticide management scheme (Figure 1). In this scheme an insecticide is always applied to control first generation larvae. This prophylactic application is made because numbers during the first generation set the stage for the abundance of subsequent stages and given the gated phenology of the first generation, it is the easiest to control. Thus, this first prophylactic application is worthwhile insurance against subsequent infestation. Following the first insecticide application, the monitoring program previously described will be used to determine the need for subsequent insecticide applications. When insecticide applications are determined to be necessary, they will be timed using a degree-day based phenology model to coincide with a high proportion of susceptible individuals.

We will evaluate this management strategy using an experiment conducted in New York and Pennsylvania orchards. In this experiment we will test three specific hypotheses:

1. Risk of infestation by internal fruit feeding Lepidoptera can be based on the history of infestation the prior year.
2. In orchard blocks designated as high risk, the integrated pheromone disruption – insecticide program will provide cost effective control.
3. In orchard blocks designated as moderate risk, as-needed insecticide applications will be sufficient to provide acceptable control.

Each replicate of the experiment will be conducted in a 7-acre or larger orchard block (Fig. 2). In these blocks, three plots will be established; 1) a plot of at least 5 acres in which the integrated pheromone and insecticide management program will be deployed, 2) a plot of approximately 1 acre in which the rational insecticide program will be deployed, and 3) a plot of approximately 1 acre in which a prophylactic insecticide program will be deployed. This latter treatment will provide a measure of the best control that can be achieved in the block. In the two blocks in which only insecticides are used, there will also be two sets of 4 trees to which no insecticides will be applied. These unsprayed trees will provide a measure of infestation pressure in the block. The level of infestation in the untreated controls will be used to test the first hypothesis. Contrasting the infestation rates in the prophylactic insecticide treatment with the integrated program and the rational insecticide program will allow for tests of the second and third hypotheses. The experiment will be replicated 8 times in each state. Half of these replicateswill be orchard blocks that had detectable fruit infestations the prior year. Details for each state are provided below.

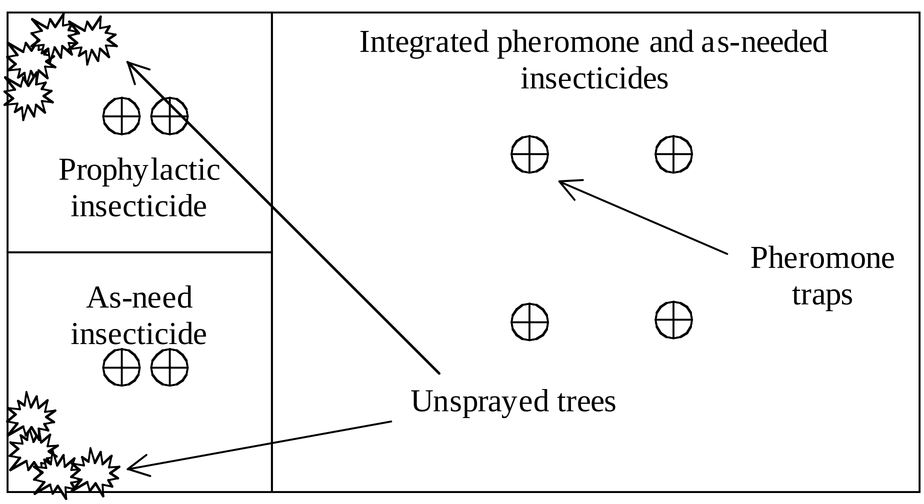

Figure 2. Plot layout to evaluate an integrated management program for internal fruit feeding Lepidoptera in apples.

New York - Recent studies have shown that oriental fruit moth (OFM) is the primary cause of unacceptable fruit damage due to internal Lepidoptera in most commercial, western NY orchards. Therefore, the management program will be designed to optimize control of this species, although populations of lesser appleworm and codling moth will be monitored and the program will be modified to manage these species if necessary.

Insecticides applied against OFM will be timed using pheromone trap catch data a phenology model based on degree day (DD) accumulations. Two pheromone traps will be deployed in each plot and checked weekly throughout the season. Oviposition by OFM will also be predicted using DD phenology models developed at Pennsylvania State University. The first treatment will be applied either to coincide with the first estimated hatch of OFM eggs or at the pink bud stage if the initial egg hatch is predicted during bloom. Growers will apply normal control sprays for plum curculio at petal fall, and if necessary, during early season cover sprays. A second control spray will be applied during the summer to coincide with the estimated first hatch of eggs of the first summer generation of OFM (175–200DD, base temp 45°F). A third and final spray will be applied during late August to coincide with the estimated first hatch of eggs of the third flight of OFM. In the prophylactic insecticide treatment, organophosphates or synthetic pyrethroids will be used. In the other plots Assail, Avaunt, Calypso, Guthion, Imidan or Intrepid will be used, depending on availability. The trap threshold for OFM used to trigger insecticide applications is 10 moths/trap/week.

Mating disruption will be accomplished by deploying Isomate Rosso pheromone ties prior to the first flight of OFM. Growers will apply normal insecticide sprays as needed over the entire block for other insect pests such as plum curculio, leafrollers, mites, aphids, and apple maggot.

Pennsylvania: Recent surveys have shown that depending on the orchard locale, high populations of either codling moth or oriental fruit moth exist, and in some orchards, infestations by both species have resulted in rejection of harvested fruit. Therefore, management programs in PA are designed to optimize control of either species depending upon the nature of the problem. In orchards with primarily an OFM problem, procedures will be identical to those described for New York. In blocks where CM is the primary problem, insecticides will be timed using a DD phenology model; approximately 250, 550, 1250 and 1550 DD after biofix. Timings will be earlier if Intrepid is used. The trap threshold for CM used to trigger insecticide applications is 5 moths/trap/week. In blocks with mixed populations of OFM and CM, synthetic pheromones for both species will be deployed and degree day timings for insecticide applications will be based either on a DD model or a trap threshold (OFM – 10 moths/trap/week, CM – 5 moths/trap/week). in this program.

Assessment of infestations - Periodically throughout the season, fruit will be monitored on the tree (20 apples on each of 25 trees) to compare the effectiveness of different management programs in all research plots. At harvest, a sample of 600 fruit (20 apples on 30 trees) will be picked and examined for damage from internal Lepidoptera in the research plots. Data will be analyzed using linear models.

2. Monitoring adult susceptibility to insecticides: We will use assays of adult moths to estimate the relative susceptibility to azinphosmethyl of codling moth and oriental fruit moth populations in these orchards. These data will allow us to better determine the extent to which resistance to organophosphates plays a role in this pest control problem. The procedure to be used is the topical pheromone trap assay described by Riedl et al. (1985). Briefly, Pherocon 1C traps will be baited with *G. molesta* or *C. pomonella* dispensers (Pherocon® Cap). The polybutene adhesive Tangletrap (Tanglefoot, Grand Rapids, MI) will be evenly applied at 1–1.4 mg adhesive/cm^2 with a spatula as a thin coat to an area (12.5 by 23 cm) on a 1C trap bottom. These coated inserts are placed on non-adhesive trap bottoms inside pheromone traps and held in place with two paperclips. Male moths will be collected during pre-peak and peak flights of each generation by placing traps in orchards during evening hours and removing them early the next morning and bringing the traps with moths back to the laboratory. Traps will not be placed in orchards for at least five days after insecticides are applied to a particular block. Trapped moths that are extremely undersized or appear old because of worn wing scales will be discarded. Moths in good condition will be treated topically on their thoracic dorsum with a microsyringe mounted on a repeating dispenser with 1.0 μl of acetone only (controls) or 1.0 μl of an acetone solution of insecticide only. Only moths attached to the adhesive on their ventral surface will be used in the tests. Treated moths will be held in rearing chambers at 25^{o}C, 70% RH, and a photoperiod of 16:8 (L:D) h. Mortality will be assessed 24 h after treatment. Collected moths will be counted and then assigned in approximately equal numbers to a treatment concentration or control. At least five different concentrations will be used per insecticide. To determine mortality, insects will be prodded with a soft brush. Moths are scored as dead when there is no movement at all. A moth will be scored as alive if it is able to move its antennae, legs, wings, or head every time it is prodded. Moths whose legs and wings are immobilized by the trap adhesive will also be scored as alive if they exhibit some movement at the base of each wing each time they are prodded. Moths are classified as moribund if they display one or more of the following movements: rapid and continuous fluttering of wings in response to prodding, rapid uncontrolled twitching of abdomen, wings, or antennae; extension of claspers with little movement; movement of body scales only. Categories of dead and moribund will be combined for mortality analysis. Dosage-mortality regressions will be analyzed by probit analysis and resistance ratios estimated by dividing the LC_{50} values by the lowest LC_{50} value obtained (probably from the Experiment Station sites). Resistance ratios will be tested for significance by calculating 95% confidence limits, and declaring them significant if they do not bracket 1.0 (Robertson & Preisler 1992).

3. Encourage growers to adopt and implement management programs for internal Lepidoptera: A group of 15–20 western NY apple growers that have expressed an interest in testing new management programs for internal Lepidoptera will be recruited to conduct an adaptive research trial on their farms. These growers will be asked to choose one of the management programs described under Objective 1, and set up a block on their farm so that the results obtained in this trial can be compared with their standard programs utilized in other blocks. Growers will be responsible for applying sprays, but will be given advice on proper timing and the need to implement sprays based on either monitoring sites set up on their own farms (if they choose to use pheromone trap catch thresholds) or from data collected in nearby research sites. The effectiveness of these grower-adaptive trials will be compared with other research plots monitored by Cornell personnel, and their own standard programs on their individual farms will be compared by sampling fruit at harvest as described in Objective 1. These trials will allow more widespread testing of the single research protocols described in Objective 1, and will also facilitate more widespread adoption of internal Lepidoptera management programs. The effectiveness and acceptance of these programs will subsequently be evaluated at meetings between growers and Cornell research and extension personnel, held during the winter after the 2004 growing season. These meetings will also allow growers to provide input to help modify programs tested during 2004 for future evaluation in western NY.

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PROBABLE DURATION:

This project will continue for one year and most of the research work will be conducted during the growing season from April 1-October 31, 2004. Data from field trials will be analyzed during the months of November and December, and results of the study will be transmitted to the general community of growers during winter and spring months (Jan-March 2005). Also, during the early part of January and February of 2005, individual meetings and interviews will be held with growers who had research and extension trials on their farms to obtain their input and suggestions for future modification of management trials for testing during subsequent years.

EVALUATION PLANS:

Management strategies will be developed to be appropriate for integration into the overall pest management plans for the entire complex of arthropod pests, and will be tailored to fit the particular distribution of different internal Lepidoptera species and their biology and seasonal activity plans in both New York and Pennsylvania. Although the fundamental approaches underlying these strategies will be similar in all cases, the specific ways in which they will be constructed and implemented will naturally differ according to each state's crop, pest complex, and market situations. The benefits of evaluating comparable management programs in different states of the eastern fruit region will derive not only from the minor biological differences in the respective systems, but also from the distinct extension/audience interactions that operate in each of these areas. Each of the participating investigators fulfills a specific role in their state's extension education process, and the diversity of scenarios represented by this range of efforts will create a valuable opportunity to assess the value and effectiveness of this project's activities in a range of extension settings.

Because multiple farm sites will be involved in the implementation of these management programs in each growing region, it is possible that a significant number of key growers will be participants in each state. In addition, individual conferences will be scheduled with each of the cooperators before and after the growing season, to assess their individual management strategies and program successes and weaknesses at the end of the season. These conferences will include any private consultants, fieldmen, or orchard managers that normally work with each grower to oversee their pest management program.

During the off-season periods of this project, the overall strategies, strengths and failings of these programs will be evaluated using several different feedback methods in each state. Overviews of the program histories, preferably representative of each state's affected growing region, will be discussed at roundtable discussions with all the participating consultants and orchard managers, to compare notes and make plans for any changes identified for subsequent seasons. Similarly, grower panels will be held at winter fruit meetings and in-depth schools, as discussion forums on selected aspects of these programs.

Finally, larger trends and consequences of the transition in control practices being examined by this project will be assessed within the context of meetings conducted by each state's fruit extension program committee, which include not only university extension faculty and county-based staff, but also industry representatives, grower group members and other stakeholders. In this way, the broadest possible exposure is ensured to those in the fruit industry who need to be kept informed of progress and limitations in this area.

Our results will be incorporated into existing pest management programs in several ways, but will rely primarily on traditional Cooperative Extension education program methods. The fastest way to provide updates to extension personnel and growers is through newsletter articles and web-based information resources. Both states involved with this project send out timely newsletters and/or maintain current online information sites. All of the investigators participating in this proposal provide significant input into their individual states' Tree Fruit Production Guides. These guides, which are made available to growers, are updated annually (NY) or biennially (PA), and will have the greatest day-to-day impact on grower practices because they are routinely consulted during the growing season to assist in the process of management decision-making. These production guides are also exchanged with representatives from most other states that have similar tree fruit production regions.

All of the participating investigators present information to grower and industry groups in their states, at venues that include winter schools, field meetings, in-depth schools and short courses. As the tree fruit entomology and insect pest management arbiters in their respective region, they give numerous grower-oriented presentations each year. Results obtained from this project will be presented to growers in meetings throughout the region as well as those in other production areas of the country. Results will also be presented at professional meetings and conferences with colleagues, which will facilitate adoption of project findings and recommendations in other states. In addition, results from this research will be published in refereed journals that have wider audiences.

The most significant and influential index of successful implementation of the recommendations developed from this project will be grower and industry feedback. We expect that growers successfully adopting improved management programs will be able to maintain effective, sustainable and economic control of internal Lepidoptera pests of apple without the recurrent control failures stemming from either resistance to conventional classes of insecticides that have lost efficacy through overuse, or improperly timed programs of newer selective materials that require a closer correspondence of application with specific stages of pest development. Enhanced fruit quality will be easily determined on the fruit packing line, and fruit growers may not have to struggle every year to maintain the competitive edge that allows them to remain in business.

COOPERATION AND INSTITUTIONAL UNITS INVOLVED:

This proposal is a team effort involving two of the leading fruit production states in the northeastern United States joining together to solve a problem of importance to the whole region. Prior to the start of the grant, the researchers will meet to finalize common protocols to be used in each state. Both states will conduct studies on all three objectives of the project. The specific amount of work done on each species of the pest complex—codling moth, oriental fruit moth, and lesser appleworm—will be designed to meet the specific needs of each state. The institutions involved in the proposal are:

- Cornell University, New York State Agricultural Experiment Station - Lead institution, responsible for overall project management.
- The Pennsylvania State University

KEY PERSONNEL:

New York:

W. H. Reissig, Principal Investigator: Will oversee the applications and evaluation of the multi-tactic management programs compared in the high pressure orchards and coordinate and design the laboratory resistance bioassays.

A. M. Agnello, Co-Principal Investigator: Will coordinate the establishment and subsequent data collection in the pheromone trap catch threshold trial trials and the adaptive research trials set up as single programs on individual farms. He will also set up formal and informal extension meetings to disseminate information to growers and develop plans to evaluate the impact of the project on grower practices.

J. P. Nyrop, Co-Principal Investigator: Will set up protocol for data analysis, and provide advice on experimental design of field and laboratory research.

Pennsylvania:

L. Hull & D. Biddinger, Co-Principal Investigators: Will coordinate the establishment and subsequent data collection for the multi-tactic management programs compared in the high pressure orchards and will also oversee the evaluation of the trap catch thresholds and adaptive research trials set up as single programs on individual farms.

G. Krawczyk, Co-Principal Investigator: Will coordinate and design the laboratory and field resistance bioassays. He will handle the identification of the internal larvae collected from problem blocks and those collected routinely from processing plants in Pennsylvania and New York. In addition, he will also set up formal and informal extension meetings to disseminate information to growers and develop plans to evaluate the impact of the project on grower practices within Pennsylvania.

COLLABORATIVE ARRANGEMENTS:

None