

PROJECT DESCRIPTION

A. PROBLEM, BACKGROUND AND JUSTIFICATION

Importance of Tree Fruit in the Northeast

Tree fruit are among the most widely grown and economically valuable crops in the Northeast. Apples are grown in all Northeast states (CT, DE, MA, MD, ME, NJ, NH, NY, PA, RI, VT, WV) and constitute the most economically valuable tree fruit crop in the region. Latest estimates show annual apple production in the Northeast to be about 46 million bushels, with a value exceeding 225 million dollars (NASS Noncitrus Fruit and Nut Summary for 2001).

Importance of Plum Curculio and Apple Maggot as Pests

The plum curculio (PC), *Conotrachelus nenuphar* (Herbst), is a key pest of tree fruit in the Northeast, Southeast, and Midwest. It is not known to occur in the Northwest or on any other continent. It is a native of the Northeast, its native host being wild plums. About 200 years ago, it expanded its host range to include apples, pears, peaches, nectarines, and cultivated plums. On unmanaged fruit trees in the Northeast, PCs annually damage a majority of the developing fruit. To illustrate, samples of fruit at harvest from unmanaged apple trees in Massachusetts taken annually from 1978 to 2001 reveal no less than 86% injured fruit in any year and an average of 95% injured fruit across all years (Prokopy 2001). Similar data were obtained in New York in the 1960s (Glass and Lienk 1971).

The apple maggot (AM), *Rhagoletis pomonella* (Walsh), is a key pest of apples throughout the Northeast as well as in the Midwest. It is less troublesome in the Southeast but has become established and poses a steadily increasing threat to apple production in all West Coast states. It is not known to occur on any other continent. It is native to the Northeast, the native host being hawthorn. About 150 years ago it expanded its host range to include apples and to a much lesser extent pears. If some form of control is not applied against AM, injury resulting from larval feeding in the fruit flesh is usually very extensive. For example, samples of fruit at harvest from unmanaged apple trees in Massachusetts taken annually from 1978 to 2001 reveal no less than 79% injured fruit in any year and an average of 91% injured fruit across all years (Prokopy 2001). Similar data were obtained in New York in the 1960s (Glass and Lienk 1971).

Grower surveys indicate the importance of PC and AM to the viability of commercial tree fruit operations. To illustrate, in 1995 an extensive survey (= the most recent survey conducted) was sent to all commercial tree fruit growers in CT, MA, ME, RI and VT as a component of the USDA National Initiative Phase I IPM Planning Grant Process. Percentages of growers responding to this survey were as follows: CT= 60%, MA= 70%, ME= 41%, RI= 65%, and VT= 52% (growers from the remaining New England state--NH--were not surveyed). Results merged across participating states showed that when growers were asked how important each of 22 insect, disease and weed pests were in their orchards, PC ranked first in importance, apple scab second, AM third and mites fourth (importance here is defined as a combination of very important and somewhat important) (Prokopy et al. 1996a, Coli 1998) (see Appendix for documentation). That PC and AM ranked first and second among insect pests is not surprising because currently the average grower annually applies 3 sprays against PC and 3 sprays against AM for control, accounting for 6 of the 7 annual insecticide sprays applied to apples in New England. Across recent (1996-2002) annual meetings of the Massachusetts Tree Fruit IPM Advisory Committee (50% of the Committee is comprised of growers), PC, AM and mites have

dominated as the arthropod pests of greatest Committee concern and of greatest expressed need for development of viable approaches to reducing or eliminating need of pesticide application as the principal means of control. Using web sites given in guidelines for NE-IPM proposal submission, we were unable to find results of grower surveys conducted in other states in the Northeast ranking the importance of different apple pests to orchard viability.

A special urgency has been expressed by many Northeast apple growers for reduced-pesticide or biologically-based alternatives against PC and AM because of EPA actions under FQPA that could severely curtail use of azinphosmethyl against PC and AM (azinphosmethyl has been and remains the most widely used insecticide against these two pests). Moreover, many apple growers in the Northeast are increasingly subjected to concerns of neighbors regarding drift of insecticides beyond orchard boundaries. This too is a motivating force toward reduced-pesticide use and bio-based alternatives to pesticides.

General Biology and Current Control of Plum Curculio

As described in reviews of the ecology and management of plum curculio (PC) by Racette et al. (1992) and Vincent et al. (1999), damage to tree fruit by PC arises when PC adults feed upon and oviposit in developing fruit, with ovipositional damage being the most important. Damage may be initiated as soon as fruit reach 6-7 mm diameter (shortly after petal fall). Feeding injury occurs as a small cavity in the fruit, whereas egg-laying injury appears as a crescent-shaped scar on the surface of the fruit. Injured fruit may (1) fall to the ground within 1-2 weeks after initial damage, (2) remain on the tree for 3-5 weeks until larvae become nearly mature and the fruit falls, or (3) remain on the tree until harvest and exhibit depressions accompanied by scars on the fruit surface, causing rejection for sale as fresh fruit. It is the fruit that fall to the ground 3-5 weeks after eggs have been laid that give rise to the next generation of adults, which emerge from pupae formed in the soil nearby infested fallen fruit.

In the Northeast there appears to exist exclusively what has been termed the northern strain of PC (Chapman 1938), which has one generation per year. Studies by Lafleur et al. (1987) and Lafleur and Hill (1987) in Quebec have shown that nearly all PC adults that arise in August from larval-infested fruit move from beneath orchard or unmanaged host trees to surrounding woods in autumn, overwinter there, and return to orchards or unmanaged host trees the following spring. Most PCs that attack orchard fruit in spring appear to originate from abandoned host trees outside the orchard.

Growers in the Northeast annually apply 3 sprays of insecticide in May and June to control PC (Prokopy et al. 1996b, Reissig et al. 1998). Much insecticide used to control PC may be wasted and applied needlessly because prior to our success in 2002 (see below), there has existed no effective, user-friendly way of monitoring the seasonal course of PC immigration and injury as a basis for determining the need to apply insecticide against PC.

Among insecticides, only the organophosphates azinphosmethyl and phosmet have a long-term proven record of providing excellent PC control when applied so as to maintain sufficient residue on treated trees. Synthetic pyrethroids are less effective and may lead to outbreaks of mites. Carbamates are even less effective than pyrethroids. Among newly registered materials for use on tree fruit, indoxacarb and thiamethoxam have proven to be about as effective as azinphosmethyl and phosmet against PC in recent single-year trials in commercial orchards (Wright et al. 2000, Prokopy et al. 2001a), but performance across several growing seasons (the true measure of the effectiveness of an insecticide) awaits future evaluation. If one

multiplies the number of acres of apples in New England, New York, Michigan and Wisconsin (states where PC is of paramount importance) by the per acre average amount of active ingredient of organophosphate annually applied to control PC (2.0 pounds) (Coli, unpublished data), then the total amount of organophosphate annually used to control PC in these states alone is about 260,000 pounds a.i.

General Biology and Current Control of Apple Maggot

As described by Dean and Chapman (1973), AM overwinter as pupae in soil beneath host trees (principally apple and hawthorn) and emerge as adults in June, July or August. After feeding for a week on bird droppings and insect honeydew, adults become mature and are ready to lay eggs. At this point, adults are highly prone to leave the area where they emerged and to immigrate into apple orchards. There, females search for fruit into which to lay eggs. AM flies rarely originate from fruit within commercial orchards. Very rarely is there more than one generation per year.

To control AM, growers annually apply an average of 3 insecticide sprays (Reissig 1988, Prokopy et al. 1990), beginning in mid-July and ending in mid-August. If sufficient pesticide residue is not present throughout the immigration and egg-laying period of AM, injury to fruit may occur. In New England, New York and Michigan in particular, and to a lesser extent in apple production areas south of these states, AM is frequently the sole fruit-injuring pest active after June against which insecticide is applied to apple orchards. Indeed, in a 1991-1994 study by Prokopy et al. (1996b) in which no insecticide was applied in 10-acre blocks after early June over 4 consecutive years in several Massachusetts apple orchards and in which AM was controlled by traps, no insect, save lesser appleworm, emerged as a significant threat to fruit production and quality. Lesser appleworm can be controlled by *Bacillus thuringiensis* or spinosad. Codling moth, oriental fruit moth and leafrollers never built to unacceptable levels.

Several studies have been conducted on toxicants most effective against AM flies (e.g. Bancroft et al. 1974, Pree et al. 1976, Reissig et al. 1980, Mohammad and Ali Niaze 1990, Duan and Prokopy 1995a, Hu et al. 2000). By far the most toxic materials at lowest doses are the organophosphates azinphosmethyl, phosmet, and dimethoate, with the organophosphate malathion of lesser toxicity. Still lesser in toxicity and of relatively poor effectiveness are the carbamates methomyl, oxamyl, and carbaryl; the chlorinated hydrocarbon endosulfan, and the synthetic pyrethroids permethrin, fenvalerate, and fenprothrin. Except for materials newly registered for application to apples, the above insecticides constitute the current array of insecticides available to apple growers for AM control. If any of the poorly-effective materials were to be used, applications would have to be very frequent, thereby defeating progress toward IPM. Among newly registered insecticides for orchard use (imidacloprid, thiamethoxam, avermectin, neem, spinosad, fenoxycarb, tebufenozide, indoxacarb, methoxyfenozide, pyriproxyfen, kaolin clay), certain of these (e.g., indoxacarb, spinosad) have proven very toxic to AM flies under laboratory conditions or performed well in small-plot field trials (e.g., Wright et al. 1999, Prokopy et al. 2001a), but none has yet proven to be as cost-effective and reliable as azinphosmethyl or phosmet for controlling AM in commercial orchards.

For decades, essentially all growers have been using an organophosphate insecticide to control AM. If one multiplies the number of acres of apples in New England, New York, Michigan and Wisconsin (states where AM is of paramount importance) by the per acre average amount of active ingredient of organophosphate annually applied to control AM (2.1 pounds)

(Coli, unpublished data), then the total amount of organophosphate annually used to control AM in these states alone is about 315,000 pounds a.i.

Approaches to Reducing Insecticide Use against Plum Curculio through Monitoring

To reduce insecticide use against PC from the current norm of 3 spray applications in May and June to an amount that is precise according to need requires an effective approach to monitoring PC. To date, 4 different approaches have been taken toward this end.

A **first approach**, practiced for decades by some growers, involves frequent examination of hundreds of fruit among numerous orchard trees for signs of PC injury; insecticide is applied upon detection of fresh injury (Racette et al. 1992). A principal shortcoming of this approach is the large number of trees and fruit that must be sampled to ensure reasonable accuracy.

A **second approach** involves use of cumulative heat unit models designed to predict the onset and termination of oviposition (Reissig et al. 1998). Although current models have not been effective for predicting the onset of oviposition, a model involving accumulation of 171 degree days (base 10°C) after petal fall has proven useful under some (but not all) conditions for predicting how long insecticide residue should be maintained on orchard trees to prevent late-season PC injury. A principal shortcoming of using this model involves uncertainty of the extent to which insecticide residue remains effective.

A **third approach** involves development of traps designed to capture PC adults and use of trap capture information as a guide for the need to spray insecticide. To date, four types of odor-baited traps have shown promise when evaluated in or adjacent to unsprayed orchards: (a) sticky clear Plexiglas panel traps placed at orchard border areas, designed to intercept adults immigrating by flight from overwintering sites in border areas (Prokopy et al. 2000b, Piñero et al. 2001); (b) black pyramid traps placed at orchard border areas or trunks of orchard trees, designed to mimic tree trunks and known to attract crawling PC adults (Tedders and Wood 1994, Mulder et al. 1997, Piñero et al. 2001); (c) Circle traps wrapped around orchard tree trunks, designed to intercept adults crawling up tree trunks into canopies (Mulder et al. 1997); and (d) vertical black cylinder traps placed in orchard tree canopies, designed to mimic vertical tree branches that are known to be visually attractive to PC adults (Leskey and Prokopy 2002). Although relatively effective in capturing PC adults under unsprayed orchard conditions, each of these trap types has proven to have shortcomings when evaluated for monitoring PC in commercial orchards.

These shortcomings became apparent in commercial orchard trials conducted under our recent three-year Northeast Region IPM (NE-IPM) Competitive Grant, active from September 1999 through August 2002. In essence, the main objectives under this NE-IPM research grant were to evaluate traps for monitoring PC abundance and characterize parameters that could affect patterns of deployment of traps for direct control of AM.

Under our objectives for PC in this recent NE-IPM grant, in 2000 we evaluated 6 synthetic components of host fruit odor (benzaldehyde, decanal, ethyl isovalerate, hexyl acetate, limonene and trans-2-hexenal) known from previous studies (Prokopy et al. 2000a, 2001d) to be attractive to PC. Each of the 6 compounds was evaluated in association with pheromone (grandisoic acid) known to be attractive to PC (Eller and Bartelt 1996) and in association with

pyramid, Circle, and cylinder traps placed in apple trees in 12 commercial orchards. Combinations of grandisoic acid (GA) with benzaldehyde, ethyl isovalerate or limonene as bait proved attractive compared with unbaited traps but none of the baited traps exhibited amounts of weekly captures that correlated significantly with weekly amounts of PC injury to fruit in corresponding plots (Prokopy et al. 2000b). **In 2001**, in the same 12 orchards, we expanded our evaluation of pyramid, Circle, and cylinder traps baited with GA plus benzaldehyde, ethyl isovalerate or limonene placed in apple trees. Pyramid and Circle traps baited with GA plus benzaldehyde captured more PCs than other baited traps, but as in 2000, neither of these baited trap types showed weekly captures that correlated significantly with weekly amounts of PC injury to fruit in corresponding plots (Prokopy et al. 2002). **In 2002**, again in the same 12 commercial orchards, we evaluated sticky clear Plexiglas panel traps and pyramid traps (both types now placed at edges of orchard border areas to capture immigrating PCs) as well as Circle traps placed in apple trees. We also evaluated an entirely new approach to monitoring PC: baiting selected perimeter-row apple trees themselves and monitoring weekly incidence of fresh ovipositional injury to fruit on such "trap trees" as a direct indication of the seasonal course of fruit injury. All traps and trap trees were baited with GA plus benzaldehyde using release rates of each that we had found to be optimal for eliciting maximum attractiveness to PC without causing repellency: 1 mg/day for GA and 40 mg/day for benzaldehyde. Again, none of the baited trap types showed weekly captures that correlated significantly with weekly amounts of PC injury to fruit in corresponding plots (Prokopy et al. 2003). Reasons for such lack of correlation and lack of ability of any of the baited trap types evaluated to date to show promise as a tool for monitoring the seasonal course of PC injury to fruit include: repellent effects of insecticide spray residue on traps (pyramid and cylinder traps placed beneath or within apple trees), bypassing of tree trunks and flight of PCs directly into tree canopies when temperatures exceed 20 C (Circle traps on tree trunks), and captures by panel and pyramid traps placed at orchard borders that do not reflect impending danger of fruit injury because of still-sufficient insecticide residue on sprayed orchard trees (Prokopy et al. 2003).

These 2002 studies did, however, reveal the value of **odor-baited trap trees** as a new and effective approach to monitoring the seasonal course of PC injury to fruit. Apparently, this approach has never been used heretofore for monitoring any pest of tree fruit. It overcomes the shortcomings associated with reliance upon trap captures as indicators of the seasonal course of injury. In 2002, we found that baiting perimeter-row trees with GA plus benzaldehyde led to a highly significant aggregation (15-fold) of fresh ovipositional injury (Prokopy et al. 2003). In a separate set of 12 commercial orchards, we further found that addition of any of the other 5 aforementioned synthetic fruit odor attractants did not enhance PC aggregation above the 15-fold level achieved by GA plus benzaldehyde (Prokopy et al. 2003).

In addition to the above, we gained strong evidence in 2002 in Massachusetts that PCs which immigrate into orchards up to the time of petal fall (= about 60% of all immigrants) move deep into the interior of an orchard, apparently in search of fruit (not yet existent) for egg-laying. Hence, a whole-orchard spray is required at petal fall. As soon as fruit reach 6-7mm (shortly after petal fall), immigrant PCs have a strong propensity to remain on the first trees visited (=perimeter-row trees) and not move inward, a finding consistent with that of Lafleur and Hill (1987). Hence, after a petal fall spray, only perimeter-row sprays are needed to provide effective control extending to the entire orchard, as has proven to be the case in Quebec (Vincent et al. 1997). Need and timing of these perimeter-row sprays would be based on information from

perimeter-row trap trees. The challenge now becomes one of determining what segments of perimeter-row trees need treatment and when treatments should be applied to prevent economic injury.

Establishment of odor-baited trap trees on perimeter rows of apple orchards would appear to be an ideal approach to meeting the challenge of determining need and timing of post-petal-fall insecticide applications against PC. Monitoring for signs of fresh damage to fruit no longer need involve the sampling of large numbers of orchard trees, as practiced currently by some growers, but can be confined to a few trap trees spaced at appropriate intervals along perimeter rows. Before such a trap tree approach can be recommended for use by commercial growers, however, the following must be determined: (a) optimum spacing of trap trees along perimeter-rows; and (b) percent freshly damaged fruit on trap trees that would justify insecticide application to all peripheral-row trees (see 2003 research objectives below). For the future, perimeter-row trap trees, if made sufficiently attractive, might even become the sole focus of insecticide application against PC after an initial petal fall application.

Approaches to Eliminating Insecticide Sprays against Apple Maggot through Behavioral Control using Traps.

To eliminate insecticide use against AM (currently averaging 3 spray applications in July and August) requires a reliable, effective, and economical alternative approach to control. Prokopy and Mason (1996) reviewed potential alternative approaches and concluded that behavioral control using odor-baited red spheres offered far more promise than biological control, cultural control, host plant resistance, sterile male releases or creation of fly free zones.

Toward this end, Prokopy (1968) found that red spheres of 8-cm diameter are super-normal visual mimics of ripe hawthorn and apple fruit and are highly visually attractive to AM flies. When coated with sticky (e.g. Tangletrap) and hung on all trees in an apple orchard, they can provide 99% control of AM (Prokopy 1975). The problem with this approach is the very large number of traps required to achieve control. With the identification of attractive apple odors by Reissig, Averill, Roelofs and colleagues at Geneva, New York (Averill et al. 1988), the way was paved for a new approach to using the spheres: placing spheres baited with synthetic apple odor only on perimeter trees in an apple orchard. By so doing, immigrating AM flies could be attracted to the odor-baited trees and to the spheres hung on such trees, thereby denying immigration of AM into the interior of orchards.

This approach was evaluated extensively in 10-acre blocks of 6 Massachusetts commercial apple orchards from 1991-1994 using butyl hexanoate as the synthetic fruit odor attractant and sticky-coating to kill flies alighting on the spheres (Prokopy et al. 1996b). Odor attractant and spheres were used at the rate of 16 per acre (i.e., they were about 5 meters apart on perimeter orchard trees). The results were highly encouraging: an average of 1.1% injury to fruit across the 4 years using traps compared with an average of 0.7% injury to fruit across the 4 years in nearby blocks treated with 3 organophosphate insecticide sprays. Two principal shortcomings became apparent, however, regarding the feasibility of this alternative approach. First, sticky spheres proved very messy to deploy and maintain on such a large scale, with no participating grower willing to adopt this approach until an alternative to sticky was found as the fly killing agent (fortunately, red spheres are highly selective and attract few beneficial insects). Second, the decision to hang spheres 5 m apart on perimeter-row trees was somewhat arbitrary. More information was needed on factors influencing sphere effectiveness so that distance between

spheres and other aspects of sphere deployment could be optimized and tailored according to specific characteristics of each orchard.

Regarding an effective alternative to sticky as the killing agent for AM flies alighting on a sphere, we conceived the idea of coating a sphere with a mixture of insecticide, fly feeding stimulant (to induce uptake of insecticide) and residue extending agent so as to create a lethal pesticide-treated sphere (PTS). After several years of research (summarized in Prokopy et al. 2000c), we found that imidacloprid at 4% active ingredient (= the most effective insecticide at the lowest effective dose) in a mixture of sucrose (= the most effective AM feeding stimulant found) and gloss enamel latex paint (=the most effective residue-extending agent for imidacloprid found) applied to the surface of a sphere killed at least 90% of alighting AM even after 3 months of exposure to outdoor conditions, provided that sufficient sucrose was present on the sphere surface. The principal challenge to constructing an effective and durable PTS lay in developing a system for resupplying sucrose to the sphere surface after rainfall. Rain washes away sucrose, and without sufficient sucrose on the sphere surface, alighting AM do not take up a lethal dose of insecticide.

Our first approach to meeting this challenge involved constructing the entire body of the sphere from a mixture of sugar, flour and glycerin, which after drying, received a coat of latex paint containing imidacloprid (Hu et al. 1998). Sucrose continually seeped through the paint to the sphere surface. Unfortunately, when deployed in commercial orchards, such spheres have proven highly susceptible to consumption by rodents (squirrels, chipmunks and mice) foraging in apple trees and can no longer be considered as reliable (Prokopy et al. 2001b). Our second approach has involved using a wooden or plastic sphere coated with latex paint containing imidacloprid and topped with a non-insecticidal disc of a rodent-proof mixture of hardened sucrose and paraffin that re-supplies the sphere surface with needed sucrose under rainfall. When this type of sphere was evaluated in Massachusetts commercial orchards in 2001 and 2002, no spheres were consumed by rodents and 1-acre blocks of orchard trees surrounded by such spheres suffered no greater injury from AM than blocks sprayed 3 times with organophosphate insecticide (Prokopy et al. 2001b, unpub. data). Although slight refinements are still needed for optimization of sugar disc characteristics (currently taking place in Prokopy's lab under sponsorship by a USDA Pest Management Alternatives Grant), we fully anticipate that such refinements will be completed by August of 2003. For use in control of AM in orchards in 2004 and 2005, optimized sugar discs will be available from a commercial source (Pest Management Innovations, a company newly formed by 2 co-inventors of the sugar discs, S.E. Wright and B. W. Chandler) (see letter in appendix).

For the 2004 growing season and thereafter, the technology of annual grower application of latex paint (containing 4% a.i. imidacloprid) to spheres accompanied by annual replacement of sugar discs atop such spheres should be fully labeled for commercial orchard use by the manufacturer of imidacloprid (Bayer) (see enclosed letter in appendix). The anticipated annual cost per sphere would be: \$ 0.20 for the sphere itself (amortized over a 10-year expected lifetime of a durable plastic sphere available at \$2.00 from Great Lakes IPM) plus \$ 0.20 for latex paint containing imidacloprid plus \$0.15 in labor for application of such paint mixture plus \$ 1.50 for the sugar disc plus \$0.30 for the odor lure. Total = \$ 2.35 per year. For a 10-acre block of apple trees having spheres 10 m apart on perimeter trees, the total cost of the 160 spheres needed to surround the block would be \$376.00 or \$37.60 per acre.

Regarding optimization of distance between spheres and sphere deployment patterns, we had found previously that (a) neither abundance of AM food nor addition of synthetic attractive food odor (e.g., ammonium acetate) to spheres had any influence whatsoever on the probability of capturing feral AM using sticky spheres baited with synthetic attractive fruit odor (butyl hexanoate) (Reynolds and Prokopy 1997, Rull and Prokopy 2000), and (b) among orchard blocks of large, medium, or small trees surrounded by sticky spheres (baited with butyl hexanoate) at 1 sphere every 5 m along perimeter-row trees, more feral AM penetrate into blocks of large trees (M.7 rootstock) than medium (M.26 rootstock) or small (M.9 rootstock) trees (Rull and Prokopy 2001a, Prokopy et al. 2001c).

Under our objectives for AM in our recent NE-IPM Grant (September 1999-August 2002), in 2000 we evaluated 13 apple cultivars for attractiveness to AM. Certain common cultivars (e.g., Jersey Mac, Gala, Fuji) proved highly attractive to AM flies whereas other common cultivars (e.g., McIntosh, Cortland), proved much less attractive (Rull and Prokopy 2001b). **In 2000, 2001 and 2002** we conducted a large scale trial of varying deployment patterns (on perimeter-row trees) of odor-baited sticky spheres in 2-acre blocks of apple trees (mostly M.26) in each of 12 commercial orchards. Six blocks had perimeter-row cultivars that were comparatively susceptible to AM (Gala, Fuji, Jonagold), and 6 blocks had comparatively tolerant perimeter-row cultivars (McIntosh, Cortland, Empire). Blocks were divided into 4 square plots, each having about 50 m of perimeter-row trees. Three of the 4 plots received only spheres (no insecticide spray) for AM control; the 4th received 3 organophosphate insecticide sprays. Penetration of plots by feral AM and lab-reared color-marked AM (released 10 m outside of plots) was assessed via captures of AM by unbaited sticky spheres placed on interior trees and bi-weekly sampling of apples for AM injury. Over these 3 years, we found that (a) 50-70% more AM were captured by perimeter-row spheres baited with a new 5-component blend of synthetic fruit odor attractant (Zhang et al. 1999) than by the former best attractant (butyl hexanoate), (b) blend-baited spheres were more effective than spheres baited with butyl hexanoate in preventing fly penetration of plots, especially plots containing susceptible cultivars, (c) blend-baited spheres placed 10 m apart on perimeter-row trees were just as effective as insecticide sprays in preventing AM penetration of plots when perimeter-row trees were comprised of comparatively tolerant cultivars but were slightly less effective than sprays and than 5 m-apart blend-baited spheres in preventing penetration of plots of comparatively susceptible cultivars, and (d) orchard blocks bordered by woods or hedgerows as adjacent habitat consistently were subject to greater AM pressure than blocks bordered by open field (Hoffmann et al. 2002). Finally, in 2002 we found that blend-baited spheres hung in the outer third of the tree canopy and having 50 cm of space between them and surrounding fruit and foliage captured more AM than blend-baited spheres having less than 25 cm of space or greater than 50 cm of space and were comparatively unaffected by increasingly competitive visual attractiveness of nearby apples (visual competition increases toward harvest as fruit grow larger and redder) (Hoffmann and Prokopy unpub. data).

These findings from our 2000-2002 studies have led us to conceive of a ranking system for assigning distance between blend-baited perimeter-row spheres. The system is based on a combination of tree size, perimeter-row cultivar and nature of adjacent habitat (see below section on approaches and procedures). Our findings also indicate that whatever the distance between spheres, optimum placement within a tree canopy should be toward the outer third and devoid of visually-competing fruit within 50 cm.

Justification

Apples are an important crop in the Northeast. Grower responses to extensive formal surveys in New England indicate that PC and AMF are the two most important insect pests attacking apples. The most recent information from EPA (August 2002) indicates that the most effective and the most frequently used insecticide to control PC and AMF (azinphosmethyl) very likely will be prohibited from use in apple orchards after 2005. The second most effective and the second most frequently used insecticide to control PC and AMF (phosmet) may also be under threat of loss of label for apple orchard use after 2005.

At this point in time, no one can predict how the future course of action under FQPA will unfold in regard to phosmet. If phosmet remains legal, most growers undoubtedly will adopt it as their first choice against PC and AM because of its effectiveness and relatively low cost. If it is cancelled, growers will be obliged to turn to one of the newer insecticides against PC and AM. These cost at least 3 times more per acre than phosmet to achieve effective control. Therefore, there will be high priority to minimize the amount of these pesticides used. In the case of PC, this translates into need for an effective system of monitoring PC so that need and timing of application can be optimized. In the case of AM, this translates into an opportunity for use of an economical and reliable alternative to pesticides: deployment of odor-baited pesticide-treated spheres. Even if phosmet were to continue to be labeled for apple orchard use beyond 2005, there is strong environmental justification for minimizing its use: reduction of impact on orchard laborers, reduction of impact on beneficial arthropods in orchards, and reduction of drift onto neighboring properties bordering orchards. The latter is especially important in the face of increasing urban and suburban encroachment on orchard property in the Northeast.

Through research to be conducted in MA in 2003, this proposal aims to refine and finalize a simple and effective approach to monitoring PC (an odor-baited trap tree approach) and a simple and effective approach to directly controlling AM (deployment of odor-baited spheres). Through extension activity to be carried out in CT, MA, ME, NH, NY, RI and VT in 2004 and 2005, this proposal aims to validate and demonstrate in commercial orchards the value of using a trap tree approach to monitoring PC and a sphere-deployment approach to directly controlling AM. By so doing, extension personnel, private consultants and apple growers (all of whom would participate in the planned extension activity) should be well prepared to face whatever future actions are taken by EPA that could impact on the management of PC and AM. Planned extension activity would also involve multiple forms of delivery of information to apple growers on the effectiveness of these new approaches to managing PC and AM.

B. OBJECTIVES

Research in 2003 in commercial orchards in MA

For **Plum Curculio**, optimization of an odor-baited trap tree approach to monitoring PC.

- Determine the distance over which attractive odor (benzaldehyde plus grandisoic acid) placed in a perimeter-row trap tree acts to aggregate PC adults. This in turn will determine how many meters of perimeter-row apple trees can be effectively served by sampling a single perimeter-row trap tree for fresh PC injury.
- Determine the action threshold for spraying perimeter-row apple trees based on percentage of freshly-injured sampled fruit on designated trap trees.

For **Apple Maggot**, optimization of the pattern of deployment of odor-baited spheres for direct control of AM.

- Determine what distance between perimeter-row traps provides an optimal balance between deploying fewest numbers of traps and achieving effective control. To be accomplished using a ranking system for assigning distance between traps according to the orchard architecture parameters of tree size, tree cultivar and nature of surrounding habitat.

Extension in 2004 and 2005 in commercial orchards in CT, MA, ME, NH, NY, RI and VT.

For **Plum Curculio**, validation and demonstration in 25 commercial orchards of the effectiveness of an optimal trap tree approach to determining need and timing of insecticide use against PC in comparison with existing approaches based on calendar-driven sprays or heat-unit-accumulation models.

For **Apple Maggot**, validation and demonstration in 25 commercial orchards of the effectiveness of an orchard-architecture-based ranking system for deploying odor-baited pesticide-treated spheres for direct control of AM in comparison with existing approaches to AM control based on calendar-driven sprays or monitoring-trap-capture-driven sprays. For both **plum curculio** and **apple maggot**, delivery of information to all apple growers in these states on advantages of these new approaches compared with existing approaches to management.

C. APPROACH AND PROCEDURES

I. Research in 2003 on Plum Curculio. All research on PC will be carried out in 12 commercial apple orchards in MA. Each of the 12 orchard owners or managers has agreed to be a full cooperater in this research (see letter from growers in appendix).

The odor used to bait all trap trees will be a combination of benzaldehyde (BEN= synthetic attractive fruit odor) and grandisoic acid (GA= synthetic attractive pheromone). The release rate of each odor in each trap tree will be 40 mg per day of BEN and 1 mg per day of GA. Our studies in unsprayed and commercial orchards in 2002 showed that these release rates in a blend of BEN and GA were optimum for attracting PCs (Prokopy and Piñero unpublished data). Irrespective of release rate of GA, a lesser release rate of BEN attracted fewer PCs and a greater release rate of BEN attracted no more PCs. Irrespective of release rate of BEN, a lesser release rate of GA attracted fewer PCs and greater release rate of GA attracted no more PCs.

Four dispensers of BEN, each releasing 10 mg per day, are needed to achieve 40 mg per day of release. In 2002, we introduced 6 ml of BEN (obtained from Sigma-Aldrich, Milwaukee, WI) into each of four 15 ml capped polyethylene vials (white dropping bottles; black phenolic rubber-lined caps) (PGC Scientific Corp, Gathersburg, MD) and achieved in total a release rate of 40 mg per day of BEN averaged over a 7-week period of deployment in orchard trees. Each vial was suspended by wire inside of a plastic drinking cup (266 ml) to minimize the potential negative impact of ultraviolet light on the stability of BEN. This approach to deploying BEN at 40 mg per day of release is relatively inexpensive (total cost for 4 cups, 4 vials, 4 vial caps, and BEN= \$4.40), safe for the user, and proved very effective in 2002. We plan to adopt it in 2003. We will also adopt it for 2004-2005 unless a commercial dispenser of BEN at desired release rate (40 mg per day) and longevity (7 weeks) becomes available (to date there is none) at a competitive price and absolves us from the need to prepare our own dispensers of BEN.

Only one dispenser of GA is needed to achieve a release rate of 1 mg per day over a 7-week period of deployment. In 2001, we evaluated 3 types of GA dispensers and found the best type to be produced by Chem Tica International, San Jose, Costa Rica. This type was used in our 2002 studies and proved to be very satisfactory, releasing an average of 1 mg of GA per day over a 7-week period. The cost for a 50 mg dispenser of GA will be \$8.75 per dispenser. We will again use the Chem-Tica dispenser unless a better alternative becomes available.

For 2003 and succeeding years, all dispensers will be deployed at petal fall, just before fruit reach 6-7 mm diameter and become susceptible to PC. All dispensers need to remain effective for a period of 6 weeks after petal fall, by which time PC immigration has ended (Piñero and Prokopy, unpub. data).

A. Determining the distance over which BEN plus GA in a trap tree attracts PCs will involve use of 4 perimeter-row segments of apple trees in section A in each orchard. Each perimeter-row segment will constitute a plot and involve assessment of a different distance over which a trap tree might elicit aggregation of PC injury to perimeter-row fruit. A perimeter-row trap tree releasing 40 mg of BEN plus 1 mg of GA per day will be the center tree of each plot. The length of each perimeter-row plot will be as follows: 25, 50, 100 or 200 m. Thus, the distances over which PCs will be tested for aggregation on central trap trees will be 12.5, 25, 50 and 100 m, respectively. All 4 plots within the same orchard will be (a) bordered by same-type habitat (woods, hedgerow or open space) and (b) comprised of same-size and same-cultivar apple trees so as to minimize the potential influence of variation in these factors on experimental outcome. PCs will be controlled by 3 grower-applied organophosphate insecticide sprays: one at petal fall and two thereafter. Within an orchard, the same insecticide will be delivered at the same time to each of the 4 plots of perimeter-row trees.

Each week for 6 weeks (beginning when fruit reach 6-7mm), we will visit each of the 48 plots (4 plots x 12 orchards). For each visit, we will examine fruit for signs of fresh PC egg-laying scars: 100 fruit on each trap tree and 10 fruit on each of 10 other perimeter-row trees in the plot (5 evenly-spaced trees to the right and 5 evenly-spaced trees to the left of the trap tree). From experiments and photos made in 2002, we are confident that we can categorize ovipositional injury as being fresh (occurring within past 7 days) or old (initiated more than 7 days ago) (see figure in appendix).

By calculating the average amount of fresh injury on the trap tree as a proportion of the average amount on other sampled trees in a plot, we will be able to determine the distance over which a trap tree functions to aggregate PCs. For example, in 2002 using plots 30 m long, we found that total fresh ovipositional injury by PC across all perimeter-row trees in a plot was the same for plots which did and did not have a trap tree. However, average percent fresh injury was 15 times greater on central trap trees than on other perimeter-row trees in trap tree plots, whereas it was evenly distributed among perimeter-row trees in non-trap-tree plots.

The outcome of this experiment will tell us how far apart we need to place trap trees to gain an indication of which segments of perimeter-row trees in an orchard require insecticide application after the first whole-orchard spray and which do not.

B. Determining the action threshold for spraying perimeter-row apple trees against PC based on information from traps trees will involve use of 4 plots of apple trees in section B in each orchard. Each plot will be 50 m long (i.e., have 50 m of perimeter-row apple trees) and 9 rows of trees deep. A trap tree releasing 40 mg of BEN and 1 mg of GA per day will be the center perimeter-row tree of each plot. We anticipate that findings under part A (above) will

show that a single trap tree can serve to monitor well more than 50 m of perimeter-row apple trees, but we will adopt 50 m for the purpose of this experiment. All 4 plots within the same orchard will be bordered by same-type habitat (woods, hedgerow or open space) and consist of same-size and same-cultivar apple trees so as to minimize the potential influence of variation in these factors on experimental outcome.

PCs will be controlled by grower-applied spray of phosmet at petal fall (in May), delivered to the entirety of each of the 4 plots plus follow-up sprays of phosmet (in May/June) delivered by us (using our own existing equipment) to perimeter-row trees only. For this purpose, we have available a 2-year old tractor, a 2-year old tractor-mounted mist blower plus a truck and trailer for hauling the tractor and mounted mist blower to commercial orchards within MA. In 2001 and 2002, using this equipment, we successfully made insecticide applications at precise times and amounts in several MA orchards cooperating in other experiments. For purposes here, we believe it is important that we ourselves apply the phosmet to achieve precise timing and minimize variation in mode of delivery and amount applied (label-recommended rate of 16 ounces of formulated 70 WP per 100 gallons water). As indicated in the above section on Justification, there are several reasons why phosmet should be the insecticide of choice for this experiment.

Each of the 4 plots will be devoted to a different action threshold for triggering an application of a perimeter-row spray to the plot. The threshold will be 1, 2, 4 or 8 percent of freshly injured fruit on the trap tree. The rationale for selecting these percentages is as follows. For each of the past 20 years, we have sampled thousands of apples at harvest in MA commercial orchards and found the average amount of injury by PC to be 0.5% (see Prokopy et al. 1996b for examples). This amount appears to be acceptable to commercial growers. As indicated in the above section on Background, information from our recent studies and from studies in Quebec indicates that following a whole-orchard spray at petal fall, sprays applied only to perimeter-row apple trees effectively prevent immigration of PCs into interior rows and effectively prevent injury to interior-row fruit. Hence, the focus on perimeter-row trees. In a preliminary study in 2002, 2% of fruit injured by PC on perimeter-row trap trees was associated with an average of 0.5% injured fruit across all perimeter-row trees (including trap trees) in plots 30 m long. Hence, 2 or 4% freshly injured fruit on a trap tree might be expected to translate into plot-wide injury in the vicinity of 0.5% or less. Action threshold values of 1 and 8 % freshly injured fruit on a trap tree would represent outer limits embracing an expected action threshold.

Every 3-4 days for 6 weeks (beginning when fruit reach 6-7 mm), we will visit each of the 48 plots (4 plots x 12 orchards). For each visit, we will examine 100 fruit on each trap tree for signs of fresh PC egg-laying scars. When the level of fresh injury reaches the threshold value assigned to that plot (1, 2, 4, or 8%), a perimeter-row spray of phosmet will be applied to the plot within 24 hours. No plot, however, will receive more than 2 such sprays (= the average number applied against PC by MA growers after a petal fall spray). During the 7th week (after end of PC season), we will examine 200 fruit on the perimeter row (= row 1) and 200 fruit on each of rows 3, 5, 7 and 9 in each plot for evidence of PC injury (total= 1000 fruit per plot). Correlation analysis will be conducted to relate action thresholds to percent plot-wide injured fruit. Whichever threshold corresponds to 1% plot-wide fruit injury will be the chosen threshold.

II. Research in 2003 on Apple Maggot. All research on AM will be carried out in the section B area of the same 12 commercial apple orchards in MA involved in the PC research in 2003 (see letter from growers in appendix). Each section B area will be divided into 2 plots for

AM research rather than the 4 plots for PC research. PC and AM do not overlap in appearance in commercial orchards. Each plot will be 100 m long and 9 rows deep. We recently characterized the architecture of the section B area in each cooperating orchard and found the following: 4 orchards have large (M.7 rootstock) trees, 4 have medium (M.26 rootstock) trees, and 4 have small (M.9 rootstock) trees; 4 orchards have perimeter-row cultivars comparatively highly susceptible to AM, 4 have cultivars comparatively moderately susceptible and 4 have cultivars comparatively tolerant to AM; 4 orchards have woods, 4 have hedgerow, and 4 have open space adjacent to section B plots. Such among-orchard variation in architectural characteristics is highly conducive to evaluation of a ranking system for assigning distances between traps for AM control.

One plot in each orchard will receive 3 grower-applied sprays of phosmet in July and August to control AM. The other plot will receive sticky red spheres baited with attractive 5-component blend to control AM. In early July, such spheres will be placed 5, 10 or 15 m apart on perimeter trees on all 4 sides of the plot so as to completely envelop the plot with spheres. Spheres will be placed in optimal position within trees (see Background section). No insecticide will be applied to such trapped plots for AM control. Each sprayed and trapped plot will receive 8 unbaited sticky red spheres on interior trees to monitor the degree of AM penetration into the plot interior.

For each plot, distance between spheres will be assigned according to the following ranking system built from information gained under our recent (1999-2002) NE-IPM award. Values of 1, 2 and 3 represent descending order of probability that enough AM would penetrate the barrier of traps to pose an economic threat to the crop. A value of 1= large trees, highly susceptible cultivars or woods. A value of 2= medium-size trees, moderately susceptible cultivars or hedgerow. A value of 3= small trees, comparatively tolerant cultivars or open field. For a given plot, values totaling 3-4, 5-7 and 8-9 would receive traps 5, 10 and 15 m apart, respectively.

Every 2 weeks after sphere deployment, perimeter and interior spheres will be cleaned of AM and others insects (to maintain trap capturing power) and numbers of captured AM recorded. At harvest, we will sample 200 fruit on each of rows 1, 3, 5, 7 and 9 in each plot for evidence of AM injury. Using information from AM captures on unbaited monitoring traps on interior trees and amounts of AM injury to fruit, we will evaluate the effectiveness of our ranking system for assigning distances between spheres for control of AM versus control by 3 sprays of phosmet.

III. Extension in 2004 and 2005 on Plum Curculio and Apple Maggot. Validation and demonstration in 25 commercial orchards will be the main focus of extension in 2004 and 2005. Additional focus will be on delivery. The number of cooperating orchards per state will be as follows: CT= 1, MA= 12, ME= 1, NH= 3, NY= 3, RI= 2, VT= 3. University-employed personnel having a substantial appointment in cooperative extension will carry out validation, demonstration and delivery in CT, MA, ME, NY and RI. Independent private consultants will carry out validation and demonstration in NH and VT, with delivery carried out by such consultants plus university-employed extension personnel.

There will be one validation/demonstration block of apple trees in each of the 25 orchards. Each block will have 300 m of perimeter-row apple trees and be 9 rows of trees deep. Each block will be divided into 3 same-size plots of about 1 acre (100 m long x 9 rows deep). Tree size, cultivar arrangement and adjacent habitat will be the same for all 3 plots within an

orchard but will vary substantially among orchards. PC and AM will be managed as follows: Plot A= calendar-driven insecticide sprays (= conventional approach); Plot B= insecticide sprays driven by monitoring information (= current IPM approach); Plot C= trap-tree (for PC) and trap-out (for AM) approach to reducing/eliminating insecticide sprays (= bio-based approach).

Specific validation/demonstration protocols will be as follows:

Plot A: For PC, petal fall application of phosmet to entire plot in May followed by 2 more applications of phosmet to entire plot (10-14 and 20-28 days after petal fall). For AM, 3 applications of phosmet to entire plot (mid-July, early August, mid-August).

Plot B: For PC, petal fall application of phosmet to entire plot followed by 2 more applications of phosmet to entire plot (1st= 10-14 days after petal fall and 2nd = based on heat-unit-accumulation model of Reissig et al (1998) that calls for last spray against PC to have sufficient residual activity for control until 171 degree days (base 10°C) have accumulated since petal fall. For AM, application of phosmet to entire plot driven by accumulation of AM on unbaited sticky red sphere monitoring traps placed on interior trees (Agnello et al. 1994) (phosmet applied when fly captures reach 2 per sphere).

Plot C: For PC, petal fall application of phosmet to entire plot followed by application of phosmet only to perimeter-row apple trees driven by action threshold based on percent fruit having fresh PC injury on 1 or 2 perimeter-row trap trees per plot (as determined by 2003 research). For AM, deployment of odor-baited pesticide-treated spheres on perimeter trees of all 4 sides of plot as a substitute for insecticide use (distance between perimeter-row spheres will be unique to each plot as determined by results of ranking-system research in 2003).

All phosmet would be provided to growers via funds from this grant. Growers would make all phosmet applications as dictated by above protocols. Each extension/consultant cooperator will have responsibility for communicating to the grower when insecticide should be applied based on monitoring results. All materials needed to monitor PC (high-low thermometers for heat unit accumulation, dispensers of BEN and GA, colored pictures of 1-4 day old PC egg-laying scars) and all materials needed to monitor and control AM (unbaited sticky spheres for monitoring, odor baits and pesticide-treated spheres for control) will be provided to extension/consultant cooperators via funds from this grant and delivered to them by MA personnel.

For PC, the BEN and GA will be deployed on trap trees in plot C at petal fall. Each orchard will be visited every 3-4 days thereafter for 6 weeks (12 such visits). On each visit, 100 fruit will be sampled on each trap tree (requiring 10 minutes per tree) for fresh PC injury. During week 7, 200 fruit on each of rows 1, 3, 5, 7 and 9 in each plot will be sampled for PC injury.

For AM, all odor-baited pesticide-treated spheres in Plot C and 4 unbaited sticky spheres on interior trees in each plot will be deployed in early July. Each orchard will be visited every 7 days thereafter for 12 weeks (through harvest). On each visit, AM will be counted and removed from unbaited spheres on interior trees in each plot and such spheres will be cleaned of AM and other large insects to maintain capturing power. Pesticide-treated spheres will be checked to insure none has disappeared (if so, each would be replaced). At harvest, 200 fruit on each of rows 1, 3, 5, 7 and 9 in each plot will be sampled for AM injury plus injury by leafrollers and internal lepidoptera (e.g., codling moth, oriental fruit moth, lesser appleworm).

Fruit injury and trap capture data for each orchard will be compiled by the extension/consultant cooperator associated with the orchard and given to MA personnel for coalescence across orchards. In addition, each extension/consultant cooperator will record the amount of on-site time spent: monitoring day-degree information in Plot B for PC; deploying

odors and monitoring trap trees for fresh PC injury in plot C; deploying, monitoring and cleaning unbaited spheres for AM in plot B; and deploying pesticide-treated spheres for controlling AM in plot C. Using combined data for all 25 orchards, MA personnel will compare the effectiveness of PC and AM control in plots A, B and C. Also, MA personnel will conduct a cost/benefit analysis for each of plot types A, B and C based on amount of phosmet applied, time and equipment cost for phosmet application, cost of other materials for PC and AM management, and time devoted by extension/consultant cooperators to plot management. Final data for each orchard and combined data across all orchards will be provided to each cooperator for use in delivery to growers.

Delivery to growers in each of the 7 states will be accomplished via (a) twilight meetings held at cooperating orchards (extension in each state annually conducts several twilight meetings at grower orchards), (b) field days organized by consultants (an annual event of New England Fruit Consultants), (c) findings presented in weekly pest-management messages (from April through August, extension in each state composes and delivers weekly messages to apple growers on current, new and timely pest management practices – e.g., Healthy Fruit in MA, Orchard Radar in ME, Scaffolds in NY, web sites in CT, NH, RI and VT) (d) findings presented by extension and consultants at fruit schools for growers (e.g., annual New England tree fruit pest management school in January, periodic fruit schools in NY), (e) extension and consultant publications for fruit growers (e.g., Fruit Notes of New England, New York Fruit Quarterly), (f) extension and consultant visits to individual non-participating grower orchards, and (g) last but not least, word of mouth from cooperating growers (often this is the most compelling of all means of delivery; hence one of the principal reasons why growers in so many different states will be involved).

D. COOPERATION AND INSTITUTIONAL UNITS INVOLVED

The following institutional units and corresponding personnel with extension appointments will be involved:

For CT: University of Connecticut (Lorraine Los) (1 orchard in CT)

For MA: University of Massachusetts (Ronald Prokopy) (12 orchards in MA)

For ME: University of Maine (Glen Koehler) (1 orchard in ME)

For NY: Cornell University (Arthur Agnello) (3 orchards in NY)

For RI: University of Rhode Island (Heather Faubert) (2 orchards RI)

The following independent private consultants will be involved:

For NH and VT: New England Fruit Consultants (Glen Morin and Robin Spitko) (2 orchards in NH, 2 orchards in VT).

For NH and VT: Polaris Orchard Management (Kathleen Leahy) (1 orchard in NH, 1 orchard in VT).

The lead state will be MA.

The PD will be Ronald Prokopy from MA and the CO-PD will be Heather Faubert from RI. Specific responsibilities of each cooperator listed above are given in Section C (Approach and Procedures) under “Extension in 2004 and 2005 on Plum Curculio and Apple Maggot” and in the section on KEY PERSONNEL.

E. IMPLEMENTATION AND EVALUATION PLANS

A detailed plan for the conduct of research in 2003 is given in Section C: Approach and Procedures. A detailed plan for the conduct of extension in 2004-2005 involving validation, demonstration and delivery likewise is given in Section C: Approach and Procedures.

Evaluation of research results in 2003 will be based on careful examination and analysis of the data collected. Findings will be applied to the protocol for validation/demonstration in 2004 and 2005.

As given in Section C, a cost/benefit analysis will be conducted separately for 2004 and 2005 comparing the expected net income from fruit production in Plot A (conventional) vs. Plot B (IPM) vs. Plot C (bio-based), averaging inputs and outputs across all 25 orchards. A “partial budget analysis” approach will be used, with the following components:

- Cost of phosmet for treatments against PC and AM
- Cost of labor and equipment for phosmet treatments
- Cost of baits and traps for monitoring/controlling PC and AM
- Cost of labor to monitor/control PC and AM using baits/traps
- Value of fruit lost (assuming yield of 600 bushels/acre) due to PC and AM injury
- Value of fruit lost (assuming yield of 600 bushels/acre) due to injury by all other insects (this will be included because plots treated conventionally might have less (or more) injury from leafrollers and internal lepidoptera than bio-based plots.

The results of this analysis will be transmitted to each extension/consultant cooperator and each grower cooperator. The total number of acres involved (3 acres per orchard x 25 orchards) is not huge but the impact of the validation/demonstration effort is bound to influence the practices of many apple growers in each cooperating state because of the extensive nature of planned delivery (given in Section C). If the outcome of the cost/benefit analysis for the bio-based approach used in Plot C shows this approach to be competitive insect-management-wise and cost-wise with conventional approaches and current IPM approaches, then one can expect that our bio-based approach to management of PC and AMF will be adopted by many more growers than the 25 who will cooperate here and will potentially impact upon the 10,000 or so acres of apples in the Northeast. More difficult to measure is the long-term benefit of our bio-based approach to managing PC and AMF to the health of the orchard (buildup of beneficials under reduced insecticide in May and June and total absence of insecticide in July and August) and to the health of the surrounding environment (fewer non-target effects and less impact on the well-being of neighbors).

F. POTENTIAL PITFALLS

- Choice of phosmet as the sole insecticide throughout rather than choosing to use azinphosmethyl or one of the newer materials (thiamethoxam, indoxacarb, spinosad) is based on the presumption that azinphosmethyl has a dim future for continued apple orchard use, that phosmet will in fact be allowable for future use, and that the newer materials are too expensive to compete with phosmet. One or more of these presumptions could prove wrong but they represent our best estimate.
- Ideally, it would be best if sprays in the demonstration plots in each orchard in each state in 2004 and 2005 were to be applied using equipment and personnel under direct control of the extension or consultant cooperator carrying out the demonstration. Except for MA and NY, such cooperators don't have the necessary equipment for spraying. Even in MA and NY, the

number of needed trips to orchards is beyond reach. Hence, our reliance on growers to apply the phosmet in an accurate and timely manner that we will carefully supervise.

- Lack of whole-orchard sprays after the petal fall spray in the plot C treatment could invite buildup of leafrollers, codling moth, oriental fruit moth and lesser appleworm, all of which can injure fruit in apple orchards. Under similar circumstances, such buildup did not reach economically injurious proportions over 4 years of study (1991-1994) in several MA orchards (Prokopy 1996b) nor over a 20-year period (1981-2000) in Prokopy's own commercial orchard (Prokopy 2001). But we can not be certain that such would remain true for the future.
- We do include a letter from all 12 MA growers indicating their willingness to collaborate in our proposed research in 2003 in their orchards. We did not ask for letters from prospective grower collaborators for 2004 and 2005 demonstration studies because none of us felt confident at this time (1 ½ years in advance) that prospective plots would remain intact and not be altered by grower practices that can not be predicted this far in advance. Each of us as an extension person or consultant has performed demonstration studies in several commercial orchards in the past. Each of us feels very confident that there will be more growers interested in collaborating than we can accommodate.

REFERENCES

- Angello, A.M. et al. 1994. Extension and evaluation of a simplified monitoring program in New York apples. *Amer. Entomol.* 40: 37-49.
- Averill, A.L. et al. 1998. Specificity of olfactory responses in the apple maggot fly. *Entomol. Exp. Appl.* 47: 211-222.
- Bancroft, R.P. et al. 1974. Comparative toxicities of some insecticides to apple maggot. *J. Econ. Entomol.* 67: 481-483.
- Chapman, P.J. 1938. The plum curculio as an apple pest. *N.Y.S. Agric. Exp. Sta. Bull.* 684: 1-75.
- Coli, W.M. 1998. Preliminary report on multi-state phase of IPM planning grant. *Ann. Mtng. of Northeast Research and Extension Committee (NEREC)*. June 3-5, Hartford, CT.
- Dean, R.W. & P.J. Chapman. 1973. Bionomics of the apple maggot fly in Eastern New York. *Search Agriculture Entomology (Geneva, New York)* 3 (10): 1-61.
- Duan, J.J. and R.J. Prokopy. 1995. Development of pesticide-treated spheres for controlling apple maggot flies: pesticides and residue extending agents. *J. Econ. Entomol.* 88: 117-126.
- Eller, F.J. and R.J. Bartelt. 1996. Grandisoic acid, a male-produce aggregation pheromone from plum curculio. *J. Nat. Prod.* 59: 421-453.

- Glass, E.H. and S.E. Lienk. 1971. Apple insect and mite populations developing after discontinuation of insecticides: 10 year record. *J. Econ. Entomol.* 64: 23-26.
- Hoffman, S. et al. 2002. Influence of odor-bait, cultivar type and adjacent habitat composition on performance of perimeter traps for controlling apple maggot flies. *Fruit Notes* 67 (2): 20-24.
- Hu et al. 1998. Controlled release of sugar and toxicant from a novel device for controlling pest insect. *J. Cont. Ref.* 50: 257-265.
- Hu, X.P., et al. 2000. Toxicity and residual effectiveness of insecticides on insecticide-treated spheres for controlling apple maggot flies, *Rhagoletis pomonella*. *J. Econ. Entomol.* 93: 403-411.
- Lafleur, G., and S.B. Hill. 1987. Spring migration, within-orchard dispersal, and apple tree preference of plum curculio in Southern Quebec. *J. Econ. Entomol.* 80: 1173--1187.
- Lafleur, G. et al. 1987. Fall migration, hibernation site selection, and associated overwinter mortality of plum curculio in a Quebec apple orchard. *J. Econ. Entomol.* 80: 1152-1172.
- Leskey, T.C., and R.J. Prokopy. 2002. Developing a branch-mimicking trap for adult plum curculios. *Entomol. Exp. Appl.* 102: 253--259.
- Mohammad, A.B. and M.T. Ali Niازه. 1990. Toxicity of foliar residues of phosmet to the apple maggot. *J. Ent. Soc. Brit. Col.* 87: 55-58.
- Mulder, P.G. et al. 1997. Monitoring adult weevil populations in pecan and fruit trees in Oklahoma. *Oklahoma St. Univ. Extension Fact Sheet* 9447: 8 p.
- Piñero, J.C. et al. 2001. Response of plum curculio to odor-baited traps near woods. *J. Econ. Entomol.* 94: 1386-1397.
- Pree, D.J. et al. 1976. Persistence of foliar residues of dimethoate and azinphosmethyl and their toxicity to the apple maggot. *J. Econ. Entomol.* 69: 473-476.
- Prokopy, R.J. 1968. Visual response of apple maggot flies: orchard studies. *Entomol. Exp. Appl.* 11: 403-422.
- Prokopy, R.J. 1975. Apple maggot control by sticky red spheres. *J. Econ. Entomol.* 68: 197-198.
- Prokopy, R.J. 2001. Twenty years of apple production under an ecological approach to pest management. *Fruit Notes* 66: 3-10.
- Prokopy, R.J. and J.L. Mason. 1996. Behavioral control of apple maggot flies. p. 555-559 in B. McPherson and G. Steck, eds. *Fruit Flies*. St. Lucia Press, Fl.

- Prokopy, R.J. et al. 1990. Transitional steps toward second-stage integrated management of arthropod pests of apple in Massachusetts orchards. *J. Econ. Entomol.* 83: 2405-2410.
- Prokopy et al. 1996a. 1995 tree fruit survey: insect management. *Fruit Notes* 61(3): 10-12.
- Prokopy et al. 1996b. Arthropod pest and natural enemy abundance under second-level versus first-level integrated pest management practices in apple orchards: a 4-year study. *Agric. Ecosyst. Environ.* 57: 35-47.
- Prokopy, R.J. et al. 2000a. Evaluation of host-odor compounds for attractiveness to plum curculio adults: 2000 results. *Fruit Notes* 65: 30-31.
- Prokopy, R. J. et al. 2000b. Comparison of traps for monitoring plum curculio adults (Coleoptera: Curculionidae) in apple orchards. *J. Entomol. Sci.* 35: 411-420.
- Prokopy, R.J. et al. 2000c. Attracticidal spheres for controlling apple maggot flies: commercial orchard trials. *Entomol. Exp. Appl.* 97: 293-299.
- Prokopy, R.J. et al. 2001a. Comparison of Avaunt versus Guthion in every-row versus perimeter-row sprays against key apple pest. *Fruit Notes* 66: 14-18.
- Prokopy, R.J. et al. 2001b. Commercial orchard evaluation of pesticide-treated spheres for apple maggot control in 2001. *Fruit Notes* 66: 30-34.
- Prokopy, R.J. et al. 2001c. Size of orchard trees as a factor affecting behavioral control of apple maggot flies by traps. *J. Appl. Entomol.* 125: 371-375.
- Prokopy et al. 2001d. Compounds from host fruit odor attractive to plum curculios. *J. Entomol. Sci.* 36: 122-134.
- Prokopy et al. 2002. Commercial orchard evaluation of traps for monitoring plum curculios: 2001 results. *Fruit Notes* 17-22.
- Prokopy, R.J. et al. 2003. Odor-baited trap trees: a new approach to monitoring plum curculio. *J. Econ. Entomol.* (Submitted).
- Racette, G., G. Chouinard, C. Vincent, and S. B. Hill. 1992. Ecology and management of plum curculio (Coleoptera: Curculionidae) in apple orchards. *Phytoprotection* 73: 85-100.
- Reissig, W.H. et al. 1980. Laboratory and field tests of insecticides against the apple maggot. *J. Econ. Entomol.* 73: 752-754.
- Reissig, W.H. 1988. Management of apple maggot in the eastern United States. p. 56-71 in M.T. Ali Niaze (ed.). *Ecology and Management of Economically Important Fruit Flies.* Oregon State Univ. Agric. Exp. Sta. Special Rept. 830.

- Reissig, W.H. et al. 1998. Oviposition model for timing insecticide sprays against plum curculio in New York State. *Environ. Entomol.* 27: 1053-1061.
- Reynolds, A.H. and R.J. Prokopy. 1997. Evaluation of odor lures for use with red sticky spheres to trap apple maggot. *J. Econ. Entomol.* 90: 1655-1660.
- Rull, J. and R. Prokopy. 2000. Attraction of apple maggot flies of different physiological states to odor-baited traps in the presence and absence of food. *Bull. Ent. Res.* 90: 77-86.
- Rull, J. and R. Prokopy. 2001a. Effect of apple-orchard structure on interception of *Rhagoletis pomonella* flies by odor-baited traps. *Can. Entomol.* 133: 355-361.
- Rull, J. and R. Prokopy. 2001b. Cultivar preferences affect apple maggot fly distribution in orchards. *Fruit Notes* 66: 19-21.
- Tedders, W.L., and B.W. Wood. 1994. A new technique for monitoring pecan weevil emergence. *J. Entomol. Sci.* 29: 18-30.
- Vincent, C., et al. 1997. Peripheral zone treatments for plum curculio management: validation in commercial apple orchards. *Entomol. Exp. Appl.* 84: 1-8.
- Vincent, C., et al. 1999. Progress in plum curculio management: a review. *Agric. Ecos. Environ.* 73: 167-175.
- Wright, S.E. et al. 1999. Comparison of Provado and Actara as toxicants on pesticide-treated spheres. *Fruit Notes* 64(4): 11-13.
- Wright, S.E. et al. 2000. Small plot trials of Surround and Actara for control of common insect pests of apples. *Fruit Notes* 65: 22-27.
- Zhang, A. et al. 1999. Identification of a new blend of apple volatiles attractive to the apple maggot. *J. Chem. Ecol.* 25: 1221-1232.