Final Project Report to the NYS IPM Program, Agricultural IPM 2003-2004

TITLE: Development of an Improved, Integrated Management Program for the Internal Lepidopera Pest Complex Attacking Apples in Western NY.

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Type of Grant: Pheromones; biorationals; microbials; conventional pesticides

Project location(s): Results from this project can be applied throughout the Northeastern United States and also apple production regions in the midwestern United States.

Abstract: Recently, apple growers in western NY have suffered severe financial losses from unacceptable levels of fruit infestation by internal lepidoptera larvae. If this new crisis is not solved quickly, it could hasten the decline of this already beleaguered industry. Furthermore, if growers are forced to use harsh insecticides and revert to applying sprays on a calendar basis at 14-day intervals throughout the season to control these pests more than 30 years of IPM research and implementation may be subverted. The objectives of this project were : (1) Provide apple growers with effective ways of controlling internal fruit feeding Lepidoptera that are consistent with and integral to existing apple pest management systems. (2) Develop better understanding of internal Lepidoptera distribution in time and space, and susceptibility to insecticides so that control tactics can be made more robust and effective. This year's studies showed that currently available technology for timing insecticide applications against the summer generations of oriental fruit moths, developmental models based on heat unit accumulations and trap catch threshold levels are not adequate for use in NY apple orchards. Warrior, a synthetic pyrethroid insecticide, which is toxic to beneficials, was the most effective insecticide in protecting fruit, but Avaunt (Indoxacarb) provided similar levels of control. Laboratory bioassays were conducted to compare the susceptibility of field populations of oriental fruit moth in orchards in western NY to a standard organophosphate insecticide, Guthion (Azinphsomethyl) that has been widely used in the past. These studies indicated this pest has developed low levels (about 2-fold) to organophosphates. However, Imidan, another widely used standard organophosphate insecticide, provided adequate control of fruit damage from internal lepidoptera in 9 out of 10 plots in different orchards when it was applied at high rates. Mating disruption alone using sprayable formulations of oreintal fruit moth pheromones did not provide adequate control of summer damage in orchards that were subjected to high pressure from this pest. However, an integrated program utilizing sprayable pheromones and two initial applications of Avaunt provided slightly better control. Periodic sampling of fruit throughout the summer in various management programs showed that damage was very low from late July through August. Generally, higher levels of damage were observed in

all plots when fruit was evaluated in mid-late October, although fruit infestation levels were generally below 2% at harvest in most of the treatments. The overall results of this study suggest that mating disruption, and standard organophosphate insecticides as well as newer selective insecticides can provide adequate control of internal lepidoptera in problem orchards in western NY. In the future, additional work should be done to determine the optimum seasonal timing of insecticides or even pheromones (particularly sprayable formulations) for management of internal lepidoptera. Different management programs including integrated programs utilizing insecticides and mating disruption that are designed to be cost effective and IPM compatible should be compared in large scale tests in grower's orchards throughout western NY. It would also be useful if practical monitoring programs for detecting fruit infestation during the season could be developed so that growers or consultants could monitor orchards periodically to determine when and if control measures are necessary. Finally, additional monitoring of susceptibility of field populations of oriental fruit moths and perhaps codling moth to commonly used classes of compounds such as organophosphates and pyrethroids should be continued. These studies are necessary to determine if there are regional patterns of susceptibility differences throughout apple production regions in western NY and to monitor any changes during the future.

Background and justification: During the last 30-40 years, internal lepidoptera feeding in apples in NY have been controlled by broad spectrum insecticides (primarily organophosphates) applied against other insect pests feeding directly upon fruit, the plum curculio and apple maggot. These organophosphate-based management programs have been the cornerstone of apple insect management programs because they have provided excellent control of internal fruit feeders and , despite their relatively broad-spectrum activity, are now relatively benign to many important natural enemies, particularly mite predators. During the last several years, western NY apple growers have noticed increasing levels of damage from internal lepidoptera in their orchards and numerous loads of apples have been rejected by processors because of unacceptable infestations of internal worms. This escalating evidence of severe internal lepidoptera damage in NY apple orchards clearly poses a threat to the continued viability of this industry. NY growers 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.

Objectives:

1. Provide apple growers with effective ways of controlling internal fruit feeding Lepidoptera that are consistent with and integral to existing apple pest management systems.

2. Develop better understanding of internal fruit feeding Lepidoptera distribution in time and space, and susceptibility to insecticides so that control tactics can be made more effective.

Methods:

EVALUATION OF CONTROL TACTICS The following treatments were compared in 4 commercial orchards in Wayne County: (1) Imidan 70W, 4 lbs/A. (2) Avaunt 30 WDG, 5.0 oz/A. Warrior SCP, 5.0 oz/A. (3) Sprayable formulations of Oriental Fruit Moth pheromone (3M Corporation and SUTERRA) applied at 2.0 oz/A during the first spray and 1.0 oz/A in subsequent, sprays, and (4) Sprayable pheromones applied as in treatment (3), except that Avaunt 5.0 oz/A was also applied as a tank mix in the first two sprays. The original plan of this research was to let growers apply normal control programs for the control of the plum curculio during the early part of the season in the test orchards. Then a phenology model developed at Pennsylvania was going to be used to time an initial insecticide treatment at 1250 DD (base 50°) after the codling moth biofix, followed by a second application at 1600 DD followed by a third spray at a 10-14 day interval if necessary. Another treatment of Imidan was also going to be set up in which the first spray after 1250 DD was going to be applied whenever pheromone trap catches exceede thresholds of 5 codling moths/trap week or 10 oriental fruit moths/trap/week. After the plots had already been set up, we decided to apply Imidan in both plots on the same schedule based on predictions of oriental fruit moth development rather than using trap catch thresholds. Early in the season after petal fall, initial observations indicated that the phenology model for timing oriental fruit moth sprays was not accurately predicting the seasonal activity of this pest during the 2003 growing season. Therefore, initial sprays of all programs including pheromones were applied about 175-200 DD after initial trap catches increases in the plots suggested that the second flight of OFM had begun. Then, three subsequent sprays were applied in all of the insecticide plots at 10-14 day intervals. The initial spray in all plots was applied ca. on July 16 and the last sprays were applied during the last week in August. The size and relative proximity of the insecticide plots varied among all of the 4 test orchards. The insecticide plots were approximately 5A on the B and DB farms, but much smaller on the D and V farms. Whenever possible the insecticide trials were set out in adjacent plots containing the same size and cultivars. All pheromone plots were applied to 10A split plots. An initial spray of pheromones was applied at the same time the insecticide treatments began. Then the pheromone plots were sprayed three more times at 10-14 day intervals. The entire 10A pheromone plot was always treated with sprayable pheromones, but one-half was also treated with a tank mix of Avaunt (5.0 oz/A) during the first two sprays. No insecticide sprays were ever applied to the pheromone side of the plots on the B farm, but one spray of Avaunt was applied in late August in the Pheromone side of all plots on the D, DB, and V farms because fruit monitoring detected that low levels of internal lepidoptera were present later in the season in August.

Two Pherocon IIB pheromone traps were set out in the center of each insecticide plot and in the center of each half of the 10A pheromone treatments during the first week in July prior to the beginning of the second flight of oriental fruit moth. These traps were checked twice weekly throughout the season. Fruit was sampled on the trees throughout each block weekly from the last week in June until the last week in August. Each week, a total of 600 fruit was examined for internal lepidoptera (20 fruit on each of 30 trees). At harvest, 600 fruit were harvested from each plot (20 fruit on each of 30 trees), and cut to determine if any infestations of larvae were present. A total of 600 apples was also harvested in each of the two "split plots" in the pheromone treatment, but samples were stratified in different locations. A sample of 100 fruit was collected (20 apples from 5 trees) on each edge of the plots and a similar sample of 100 apples was taken from the center of each plot so that damage could be compared in different locations.

EVALUATION OF PHENOLOGY MODELS. Understanding and being able to predict the phenology of internal fruit feeding lepidoptera is essential to their successful management. We conducted two studies that contribute towards this goal of phenological prediction. First, we determined whether historical pheromone trap catch data could be used to model phenological patterns. There are extensive pheromone trap catch records that have both temporal and spatial breadth and these data could provide a basis for answering several phenology-related questions. For example, has there been a phenological shift in populations of internal fruit feeders and might this explain, in part, increases in fruit infestation? Second, we measured the temporal progression of late-season codling moth and oriental fruit moth oviposition because we hypothesized late-season oviposition, after the cessation of pesticide applications, might be responsible for some fruit infestations in commercial orchards.

TEMPORAL AND SPATIAL DISTRIBUTION OF DAMAGE AND PATTERNS OF SUSCEPTIBILITY TO INSECTICIDES- A group of 15-20 orchards previously infested with internal lepidoptera will be identified in western NY and fruit in suspected "hot spots" will be monitored periodically for larval infestations. When an infestation is discovered, 20 fruits on each of 30 trees in the high-risk zones will be sampled to estimate larval infestations and a minimum of 100 injured fruits will be collected and brought to the laboratory so that larvae can be removed and identified. Larvae too small to immediately identify will be either held in the fruits in environmental chambers or transferred to artificial diet in individual diet cups until they grow large enough to identify.

Outbreaks in other orchards that are not monitored will be reported to us by industry cooperators and will be sampled as previously described for damage and species identification. For infestations that are not discovered until fruit has been harvested, at least 3 samples of 100 randomly selected picked fruits will be examined to determine the percent injury and 100 injured apples will be dissected to collect and identify any larvae still inside.

INSECTICIDE RESISTANCE MONITORING-In monitored orchards in which previous levels of excessive injury from internal lepidoptera have been observed, we will use assays of adult moths to estimate the relative susceptibility of codling moth and oriental fruit moth populations in these orchards to azinphosmethyl. 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 23cm) 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 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. 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°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. Resistance ratios will be tested for significance by calculating 95% confidence limits, and if the confidence limits do not bracket 1.0, then the LC_{50}s are significantly different.

Results and discussion:

EVALUATION OF CONTROL TACTICS

Fig. 1. Orchard B
Mean CM/Trap/Week Within Treatments

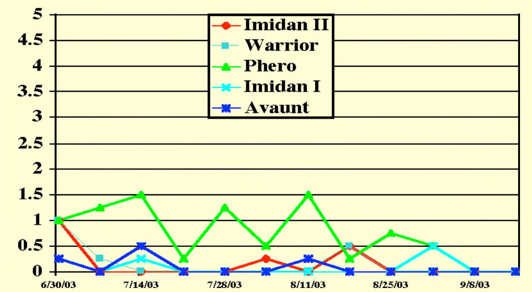


Fig. 2. Orchard B
Mean OFM/Trap/Week Within Treatments

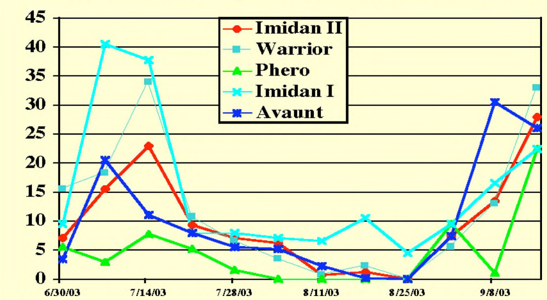


Fig. 3. Orchard DB
Mean CM/Trap/Week Within Treatments

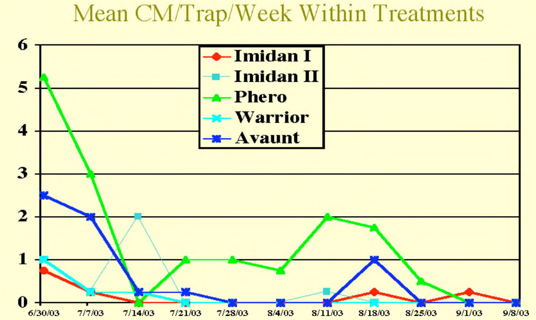


Fig. 4. Orchard DB
Mean OFM/Trap/Week Within Treatments

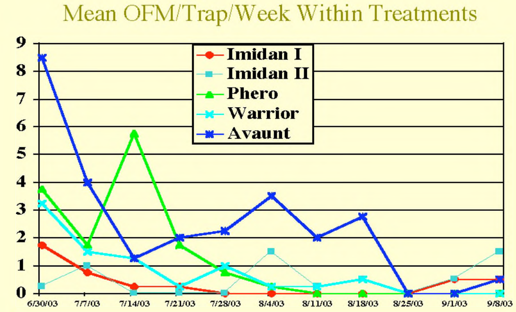


Fig. 5. Weekly Fruit Samples
Combined Farms 7/29
damaged fruit/2400

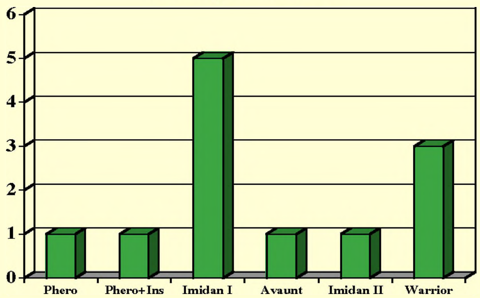


Fig. 6 Weekly Fruit Samples
Combined Farms 8/6
damaged fruit/2400

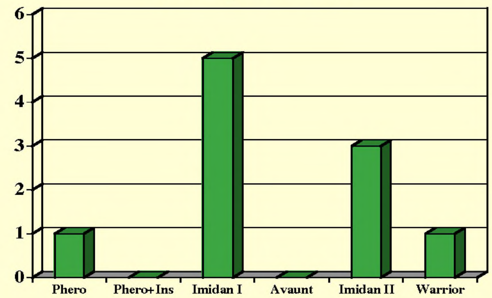


Fig. 7. Weekly Fruit Samples
Combined Farms 8/14
damaged fruit/2400

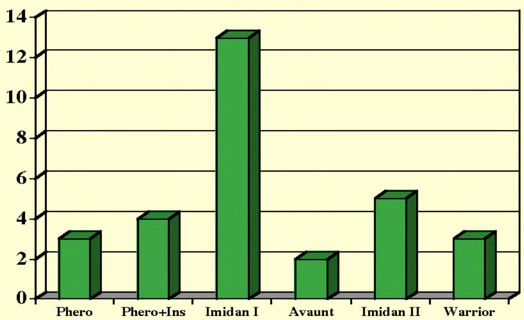


Fig. 8. Weekly Fruit Samples
Combined Farms 8/19
damaged fruit/2400

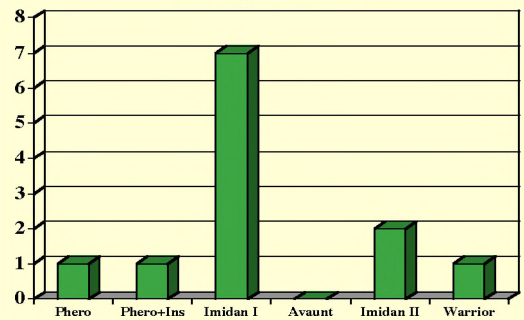


Fig. 9. Weekly Fruit Samples
Combined Farms 8/24
damaged fruit/2400

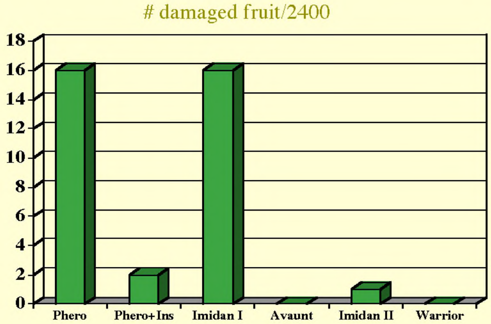


Fig. 10. Orchard B. Comparison of the average % fruit damage in different treatments at harvest.

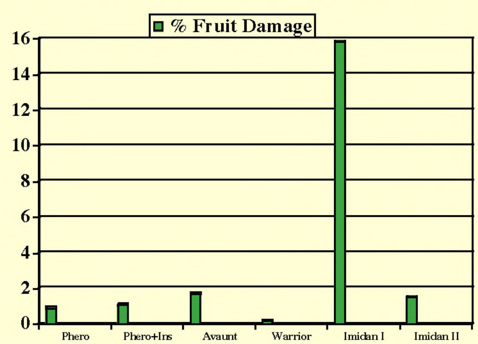


Fig. 11. Orchard D. Comparison of the average % fruit damage in different treatments at harvest.

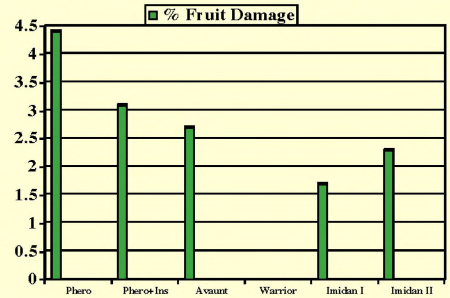


Fig. 12. Orchard DB. Comparison of the average % of fruit damage in different treatments at harvest.

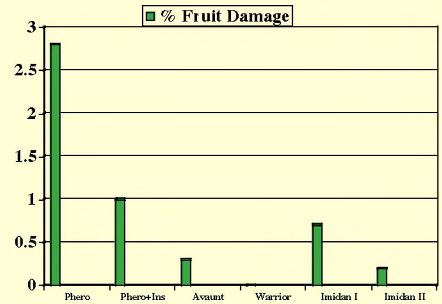


Fig. 13. Orchard V. Comparison of the average % of fruit damage in different treatments at harvest.

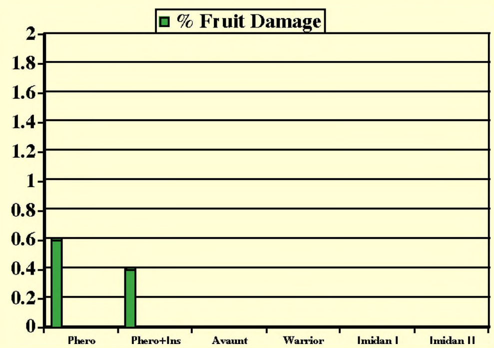
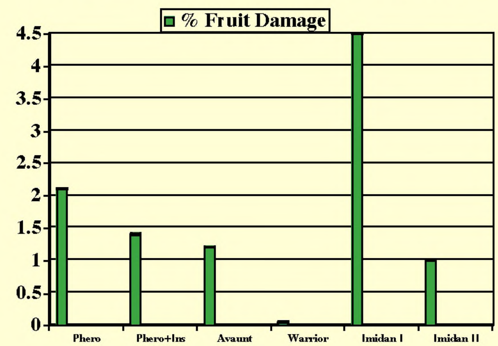


Fig. 14. Combined Farms. Comparison of the average % of fruit damage in different treatments at harvest.



A comparison of the seasonal flight patterns of codling moth and oriental fruit moth is shown for orchard B (Fig 1, 2), which had generally high population pressure from oriental fruit moths, and orchard DB (Fig. 3, 4), which had relatively low populations of both species of moths. Codling moth catches were generally low throughout the season in most of the research orchards. In contrast, trap catches of oriental fruit moth were very high early and late in the season in orchard B in all treatments except the pheromone block. Catches of oriental fruit moth were low in all treatments in the DB orchard, and never exceeded the original proposed treatment threshold level of 10 moths/trap/week.

Infestation levels in the weekly fruit samples in all of the treatments in most of the blocks remained very low from the end of July until the last sample was taken in August, and there was no particular pattern of increasing or decreasing damage in any of the treatments (Fig. 5-9). The highest damage observed prior to harvest occurred in the last samples taken on August 24 (Fig. 9). On that date, the pheromones alone and the Imidan I treatments had the highest levels of damage in the combined samples from all orchards, but the overall average damage in these plots was still less than 1%. Most of the damage observed in the combined Imidan I treatment came from the single plot set up in Orchard B.

Damage from internal lepidoptera was considerably higher than that observed throughout the season in almost all of the treatments when fruit was evaluated just before harvest. The average percentages of fruit infestation in different treatments in the four individual orchards is shown in Figs. 10-13. These results suggest that most of this fruit damage observed at harvest occurred after labor day in September and early October, and was presumably due to late season activity of the oriental fruit moth. However, even though some infested fruit was observed in most of the treatments, except in the Warrior plots, control was generally commercially acceptable except in one Imidan plot in orchard B, which had almost 16% damage, and in the plots receiving only early sprayable pheromone treatments in the D and DB farms. Warrior, was the most effective insecticide treatment in the combined data for all orchards, followed by Avaunt, and Imidan (Fig. 14). The integrated program of Avaunt and sprayable pheromones was slightly more effective in protecting fruit than the programs using pheromones alone during the early part of the season.

EVALUATION OF PHENOLOGY MODELS- We created a model using a Bimodal Weibull Distribution to describe the relative numbers of adult Codling Moth in each of two generations from 1991 to 2002. Model parameters were estimated by fitting the model to pheromone trap catch data. Results indicate that the Bimodal Weibull Distribution is a capable of modeling the general phenological patterns, but was not capable of reproducing observed varation within a generation. Average generation length was estimated as 1090 degree-days (base 43 F), a value very similar to that reported in the literature. Generation length appeared to be unchanged over the 11 years for which there were trap catch data. However, due to the large variation in the estimate of generation length, this conclusion must be tentative.
Codling moths and oriental fruit moths oviposited through August and during much of September (Fig. 15). During September approximately 40% of the eggs hatched. Thus, infestations can occur well after growers have ceased to apply insecticides. An important question that must now be answered is whether adult moths laying eggs at this time are indigenous to the orchard in which eggs are laid, or do these adults immigrate into the orchard.

TEMPORAL AND SPATIAL DISTRIBUTION OF DAMAGE AND PATTERNS OF SUSCEPTIBILITY TO INSECTICIDES- Growers in western NY were considerably more diligent during 2003 in applying control sprays during the summer for internal lepidoptera, particularly during mid-late summer when the second generation of oriental fruit moths were active. Consequently, damage in most commercial orchards was too low to allow us to collect fruit samples to assess the relative abundance of difference species of lepidopterous larvae in the fruit either throughout the season or at harvest. For example in 2002, a major processor in western NY rejected 113 loads of fruit from 48 growers for the detection of live worms. In 2003 the same processor rejected only 17 loads from 8 growers.

INSECTICIDE RESISTANCE MONITORING-The original goal of this research was to treated 40-60 moths/dosage/flight in each orchard, but catches were too low during some times of the year in some of the research blocks. Also, during the preliminary analysis of data, some data did not fit a probit model. Therefore, data is presented only for those locations in which sufficient moths were captured to allow adequate replication and the response fit the probit model.

Table 1. Comparison of LC_{50} Values for Populations of Oriental Fruit Moths Bioassayed From Problem Commercial Orchards in Western NY in 2003.

	(LC_{50} (μg ai/ml)		
Orchard	1st Flight (23°C)	2nd Flight (25°C)	3d Flight (25°C)
Bartleson	25.6	21.6	19.8
Datthyn	16.6	27.5	26.5
Verbridge	43.8	25.4	-.-
Check (Orchard 12	32.4	10.6	11.4

Table 2. Comparison of LC_{90} Values for Populations of Oriental Fruit Moths Bioassayed From Problem Commercial Orchards in Western NY in 2003.

	(LC_{90} (μg ai/ml)		
Orchard	1st Flight (23°C)	2nd Flight (25°C)	3d Flight (25°C)
Bartleson	63.4	72.5	58.8
Datthyn	113.4	58.6	53.4
Verbridge	123.9	71.9	-.-
Check (Orchard 12	94.2	28.4	42.7

Table 3. Comparison of Resistance Ratios for $LC_{50's}$ of Populations of Oriental Fruit Moths Bioassayed From Problem Commercial Orchards in Western NY in 2003.

	(RR=LC_{50} WNY/LC_{50} Standard		
Orchard	1st Flight (23°C)	2nd Flight (25°C)	3d Flight (25°C)
Bartleson	-.-	2.0	1.7
Datthyn	-.-	2.6	2.3
Verbridge	1.4	2.4	-.-

Table 4. Comparison of Resistance Ratios for $LC_{90's}$ of Populations of Oriental Fruit Moths Bioassayed From Problem Commercial Orchards in Western NY in 2003.

	(RR=LC_{90} WNY/LC_{90} Standard		
Orchard	1st Flight (23°C)	2nd Flight (25°C)	3d Flight (25°C)
Bartleson	-.-	2.6	1.4
Datthyn	1.2	2.1	1.3
Verbridge	1.3	2.5	-.-

During the first flight of oriental fruit moths, only the Verbridge orchard had a higher LC_{50} value (Table 1) than the susceptible standard, Orchard 12 and the LC_{90} values of moths from this orchard and from the Datthyn blocks were only slightly larger than that of the standard (Table 2). In contrast, resistance ratios for the $LC_{50's}$ of the second flight of adults ranged from 2.0 in the Bartleson orchard to 2.6X at Datthyn's (Table 3). Resistance ratio's for $LC_{90's}$ of the second flight among the various orchards were also similar, ranging from 2.1 to 2.6X (Table 4). Resistance ratio's for the third flights were lower and ranged from 1.7 to 2.3 for the $LC_{50's}$ and 1.3 to 1.4X for the $LC_{90's}$. The LC_{50} and LC_{90} values remained fairly constant during the different flights of moths from the commercial orchards, but values were much lower for the later flights of moths from the susceptible standard orchard. The reasons for this variation in response among generations of moths in the standard research orchard are not known.

Most apple growers in western NY that had severe infestations of internal lepidoptera at the end of the 2002 growing season achieved adequate control during 2003. However, many of these growers applied cover sprays of insecticides very frequently during the summer and some also used multiple sprays of harsh materials such as Warrior and other synthetic pyrethroids. Even growers who used mating disruption for control of the summer generations of oriental fruit moth often applied intensive schedules of insecticides almost on a calendar basis throughout the summer. These types of intensive schedules were probably necessary to reduce initial high populations of these lepidopterous pests in orchards that were severely infested in 2002. However, if growers in western NY and other parts of the state continue to utilize these types of control programs it will have serious implications for the future of IPM program. These programs are so expensive that eventually it will put an increasing financial burden on NY apple producers. Also the frequent use or even a single annual application of harsh materials such as synthetic pyrethroids will upset integrated biological control programs for mites and may cause outbreaks of such secondary pests as mealybugs and woolly apple aphids.

The results of this initial study suggest that western NY growers have several more IPM-compatible options that using pyrethroids for management of oriental fruit moth and perhaps other internal lepidoptera: high rates of conventional organophosphates, Avaunt and perhaps other newer more selective materials, and integrated management programs of mating disruption supplemented by judicious applications of selective insecticides. Clearly, since this study also showed that current phemology models are inaedquate for predicting the activity of oriental fruit moths in apples, additional work needs to be done to determine the optimum seasonal timing of insecticides or even pheromones (particularly sprayable formulations) for management of internal lepidoptera. Different management programs including integrated programs utilizing insecticides and mating disruption that are designed to be cost effective and IPM compatible should be compared in large scale tests in grower's orchards throughout western NY. It would also be useful if practical monitoring programs for detecting fruit infestation during the season could be developed so that growers or consultants could monitor orchards periodically to determine when and if control measures are necessary. Finally, additional monitoring of susceptibility of field populations of oriental fruit moths and perhaps codling moth to commonly used classes of compounds such as organophosphates and pyrethroids should be continued. These studies are necessary to determine if there are regional patterns of susceptibility differences throughout apple production regions in western NY and to monitor any changes during the future.

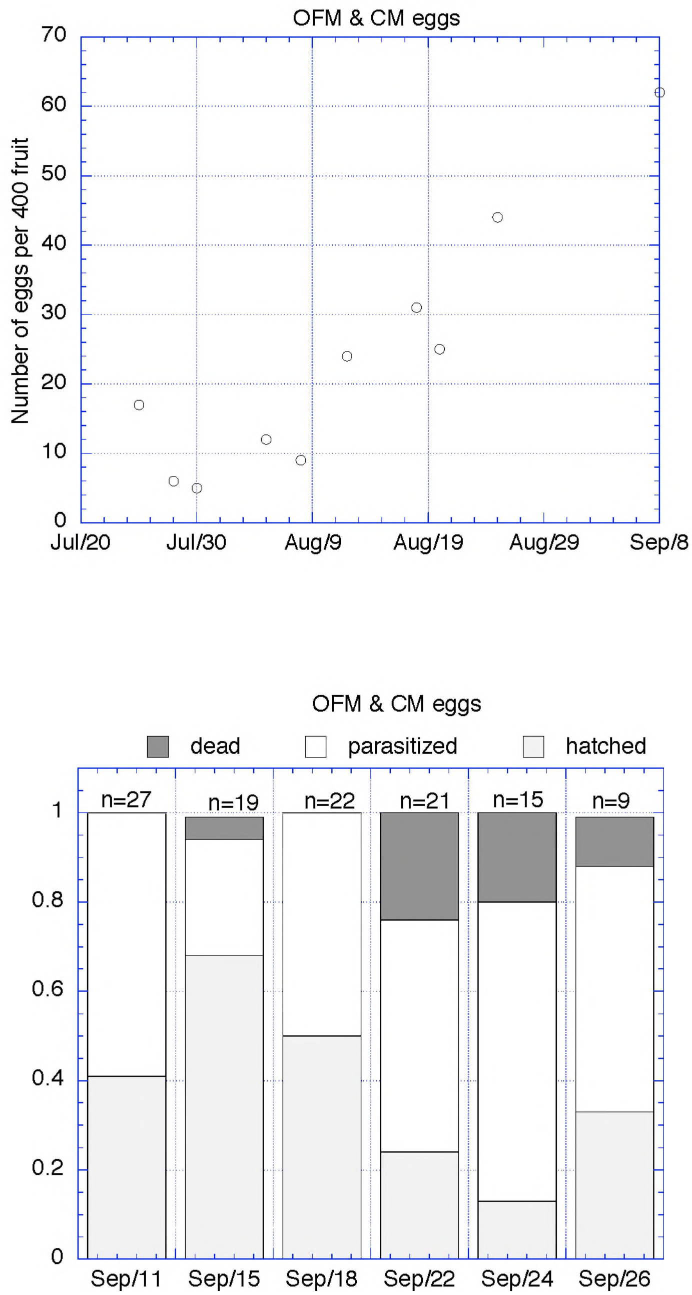


Figure 15. Patterns of oriental fruit moth and codling moth late-season oviposition in apple. A) Numbers of un-hatched, viable eggs found on 400 fruit from late July through early September. B) Proportion of eggs laid during September that subsequently, hatched, were parasitized or died.