Management of the Internal Lepidopteran Complex in Pennsylvania

Larry A. Hull, Clayton Myers, Nicolas Ellis, and Greg Krawczyk

Fruit Research and Extension Center, Penn State University, Biglerville, PA

Presented at the 46th Annual IDFTA Conference, February 17-19, 2003, Syracuse, New York

Over the past five years (1998-2002), apple growers within Pennsylvania and throughout the mid-Atlantic region have suffered from outbreaks of the oriental fruit moth (OFM), *Grapholita molesta* Busck, and the codling moth (CM), *Cydia pomonella* (L.). Fruit processors in Pennsylvania receiving both apple and peach fruit from throughout the region have rejected 1182 loads of fruit for the presence of live larvae involving these two species. OFM larvae were responsible for over 78% of the loads rejected and 97.5% of the loads originated from apples. The peak number of loads rejected during this period for the presence of OFM larvae occurred in 2000 (464), while the peak number of loads rejected for CM live larvae occurred in 2002 (121).

REASONS FOR THE RECENT OUTBREAKS

Much speculation exists as to why both species have recently become problems for many eastern U.S. fruit growers, especially those growing apples. It is based on the following conclusions:

- OFM was seldom found as a pest of apples, thus growers were not monitoring this pest in their apple orchards.
- Resistance development by some localized populations of both OFM and CM to a number of the commonly used insecticides (i.e., organophosphate and carbamate insecticides).
- Lack of properly timed sprays of insecticides during the critical egg hatch periods for both species.
- Poor spray coverage.
- Stretching of spray intervals during critical control periods.
- Use of low rates of insecticides to promote integrated pest management.
- An increase in the use of selective insecticides (i.e., tebufenozide and spinosad) for leafroller pests that have less activity toward OFM and CM.
- Presence of bin piles infested with overwintering CM near large commercial orchards.

Since OFM is the principal species responsible for the large majority of the load rejections, much of this paper will be devoted toward the understanding and management of this pest on apples.

> *. . . OFM mating disruption is not a "stand-alone" tactic. . . limited insecticide use, either with broad-spectrum insecticides or the newer, more selective insecticides, will be essential for successful OFM mating disruption.*

BACKGROUND ON THE ORIENTAL FRUIT MOTH

The oriental fruit moth has a broad range of hosts within the family Rosaceae (Rothschild and Vickers 1991). This host range includes many economically important tree fruits such as apples, peaches, nectarines, pears, apricots, quince, almonds, plums and cherries, in addition to many wild and ornamental species. In the eastern U.S., OFM is a multivoltine pest that is present throughout the growing season. Historically, most large-scale OFM infestations have occurred on peach, and efforts at control on this crop have been extensive. With the introduction of organic insecticides during the 1940s and 1950s and their continued use to this day, the importance of OFM in commercial peach orchards had been relegated to a minor pest status as these insecticides provided excellent control for a number of decades. On apple, OFM damage was historically reported only in unsprayed orchards (Allen and Brunson 1943, Allen and Plasket 1958). Seldom was OFM ever a major problem for apple growers in this region.

Biology/Behavior

OFM adult females lay eggs singly on smooth surfaces at different locations on the tree, depending on the host. In peaches, eggs are laid on the smooth underside of leaves or on the smooth surface of a fresh terminal twig but almost never on the fruit itself. Early in the season in apple, eggs are laid on the smooth upper leaf surface (Peterson and Haeussler 1930). Later in the season when fruit are present on apples, eggs can be laid on the fruit itself, usually in the stem or calyx end (Cory and McConnell 1927). Development time for eggs is variable, usually 4-8 days from oviposition until hatch during the summer months (Garman 1918, Reichart and Bodor 1972) and generally much longer during the spring and fall.

A newly hatched OFM larva will wander on the fruit or plant surface for two or more hours and uses olfactory cues to select a feeding site on its host plant. Generally, the larva will begin feeding and enter the shoot or fruit within a few hours of hatching. Similar to a CM larva (Gilmer 1933), the first few mouthfuls of plant tissue are spit out by an OFM larva and set aside, unconsumed. The larva enters the plant tissue via feeding and becomes established inside a tunnel in the plant tissue. Due to the limited time spent on the fruit surface, the larva has a very short amount of contact time with pesticide residues; therefore timing of insecticide applications is very critical. On tree fruit species such as apple, peach, pear and quince, OFM feed at different sites on the host plant over the course of the season. Early in the season, larvae feed on fresh, growing shoots; later in the season, larvae usually feed directly on fruit. During the early season, a young larva enters a shoot near its oviposition site, often attacking at the tender junction of a leaf petiole and shoot stem (Allen 1958). Evidence of OFM shoot feeding is in the form of shoot wilting (also called "striking" or "flagging") and presence of frass. Later in the season, OFM larvae predominately feed directly on the fruit of their host plant. When larvae feed on fruit, feeding behavior is dependent upon the host plant. In apples, larvae predominantly enter in the calyx or stem ends.

After undergoing 4-5 larval generations during the growing season, OFM will overwinter in silken hibernacula as a late-stadium larva or prepupa on the tree or in the groundcover. Heat accumulation in the spring causes OFM to pupate and eventually emerge as adult moths. Moths generally mate within 24-48 hours after emergence. Female moths can deposit more than 200 eggs and are capable of multiple matings.

The dispersal capability of OFM may be an important ecological strategy in the utilization of apple as a primary host. Apple orchards commonly provide OFM with a peach postharvest resource (Hughes and Dorn 2002). Since many growers in the mid-Atlantic region have both apples and peaches on the same farm, the late season movement from peaches to apples may be partially responsible for the recent increases of OFM in apples. OFM females were shown to disperse on average 160 m while the males averaged 141 m, with a maximum distance of 2.0 and 1.3 km, respectively (Yetter and Steiner 1932). In flight-mill studies, Hughes and Dorn (2002) showed that female moths significantly outperformed males in total distance flown, distance of longest single flight, and flight velocity. These findings have important implications for adult moth movement within and certainly between various types of host orchards.

Sex Pheromone Trap Thresholds for OFM

Sex pheromone traps have long been recommended for monitoring the male adult flight periods of the various moth pests that attack tree fruits. Initially, few growers used these traps to help make orchard decisions due to the expense of purchasing the traps, the cost to service the traps on a periodic basis, and arguably because of the inability of the research community to establish a meaningful relationship between the number of moths captured in the traps and the need to treat with some control tactic (i.e., insecticides). This type of research is very difficult to conduct due to the many factors that can influence the relationship between adult trap capture and fruit injury under unsprayed and sprayed conditions. However, we have developed a set of provisional trap thresholds for OFM in both apples and peaches for Pennsylvania based on our empirical observations in both commercial and unsprayed orchards over the past 20 years (Table 1). The thresholds vary between apples and peaches, especially during the first brood, due to the effect of each host crop on the successful establishment of larvae within shoots. The interpretation of the trap catch thresholds for OFM and the resulting management decisions should be tempered by the list of factors found in Table 1.

TABLE 1

Proposed oriental fruit moth sex pheromone trap catch thresholds for apple and peach orchards in Pennsylvania. The factors listed at the bottom of the table can affect moth capture and subsequently the interpretation of trap capture.

No. adult males/trap/week			
OFM (Brood 1)*		OFM (Broods 2-4)*	
Apple	Peach	Apple and peach	Recommended action
0 – 15	0 – 5	0 – 5	Not a problem
16 – 30	6 – 15	6 – 10	Usually not a problem
31 – 60	16 – 30	11 - 25	Exceeds threshold, should treat
>60	>30	>25	Potentially a serious problem**

* Based on a minimum of 2 traps/block (4 hectares or less)
** Complete sprays are recommended to control populations of this size - 1-2 sprays/brood for Broods 2-4.
The following factors affect the number of moths caught and the interpretation of moth capture:
1) number of pheromone traps per unit area of orchard
2) location of the pheromone traps in the orchard and tree
3) frequency of trap maintenance (i.e., moth removal, lure change)
4) size of trap adhesive surface area for catching moths
5) ambient temperature
6) pheromone load rate in the lure
7) distribution of moths in the orchard
8) other insecticide use in the orchard during the monitoring period

TABLE 2

Relative efficacy rating of registered and experimental insecticides for codling moth and the oriental fruit moth in Pennsylvania, USA.

Common names	Codling moth	Oriental fruit moth
Older registered insecticides*		
Azinphosmethyl	E	E
Bacillus thuringiensis	P	P
Carbaryl	F-G	F-G
Diazinon	E	E
Esfenvalerate	E	G-E
Methomyl	F-G	G
Permethrin	G	G
Phosmet	E	E
Newly registered insecticides*		
Acetamiprid	G-E**	G-E**
Fenpropathrin	G-E	G
Indoxacarb	G	G
Kaolin clay	P-F	P-F
Methoxyfenozide	G-E**	G-E**
Pyriproxifen	G**	G**
Spinosad	P-F	P-F
Tebufenozide	G-E**	P-F**

*At rates recommended in the Pennsylvania State University Tree Fruit Production Guide and not if populations exhibit resistance.
**Application timing may be different from standard OP/carbamate products due to mode of action or stage specificity of compound.
E = excellent, G = good, F = fair, P = poor, ? = unknown at this time.

OFM Egg Hatch Model Development—Apples versus Peaches

Correct timing of an insecticide application that targets the hatching OFM larva is extremely critical toward achieving successful control since larval behavior dictates how much insecticide will actually be ingested or contacted. Instinctively, following hatch, larvae quickly search for the nearest shoot or fruit to infest because they can survive outside plant tissue for only a very short time (e.g., less than 12-24 hours). One method to accurately predict the best time to apply an insecticide for this vulnerable stage is through the development of an egg hatch model based on degree-day accumulations. We have actively followed the daily hatch of OFM eggs on peaches each year since 1998 and apples since 2000 in an effort to establish a relationship between the cumulative percentage of egg hatch for each brood of OFM and the cumulative number of degree-days following the establishment of a biofix (i.e., first sustained capture of adult OFM males in a sex pheromone trap). We were able to successfully establish this relationship for the first three broods on peaches and the first brood on apples but we were not able to relate degree-day accumulation to egg hatch for the later broods on apples. Our research thus far suggests that the most likely explanation for this failure is due to the effect of host (apple versus peach) on the development and population dynamics of OFM (Myers, unpubl. data). For example, we found that OFM larvae develop faster on excised peach fruit than apple fruit.

We also found that the success of OFM establishment in peach shoots is higher than apples, but that OFM pupae that resulted from larvae feeding on apples were larger than larvae feeding on peaches. All of these factors point to the fact that the host plant plays an important role in the development of OFM. By tracking trap capture of male adults over the past few years, we have observed that cumulative OFM flight phenology and trap capture for each brood in peaches differs from that in adjacent apple blocks, especially for Broods 2-4. The flight periods on peach appear to be sharply delineated between broods, while the flight periods on apple appear to be delayed and more variable.

Efficacy and Proper Timing of Insecticides

Each year at the Penn State University Fruit Research and Extension Center in Biglerville, both registered and experimental insecticides are evaluated for their efficacy to control the various pests (e.g., OFM, CM, leafrollers, etc.) that directly attack apple. These evaluations are conducted in replicated orchard trials utilizing both small and large orchard plots and using commercial-type spraying equipment. These evaluations form the basis of Penn State's recommendations on efficacy for the various insecticides available to growers. Efficacy ratings for both the older insecticide chemistries, including organophosphates, carbamates, pyrethroids, and the newer insecticides recently registered in the U.S. for use against both OFM and CM have recently been updated (Table 2).

It is well known that the older, broad-spectrum insecticides, especially the organophosphates, are much more efficacious against OFM and CM, whereas the more recently registered insecticides such as acetamiprid, methoxyfenozide, and tebufenozide are more selective in their activity against this pest group. In addition, these newer products may have to be timed somewhat differently for a given pest because of their mode of action. It is known that insect growth regulators—namely methoxyfenozide and pyriproxifen—are more effective as ovicides than larvicides against OFM and CM.

As alluded to earlier in this paper, successful control of OFM and CM larvae depends on the correct timing of an insecticide application. Based on experiments conducted at the Penn State University Fruit Research and Extension Center where various insecticide applications were timed according to the stage of the crop or the egg hatch degree-day model for OFM, we have developed a list of insecticide timings for controlling the first three broods of OFM on either apple or peach (Table 3, Fig. 1A—apple only).

These timings (for both OFM and CM) are based on using an insecticide (e.g., organophosphate, carbamate, pyrethroid, indoxacarb) that kills the larva soon after egg-hatch but prior to shoot or fruit entry. Timings against OFM and CM for other products (e.g., acetamiprid, methoxyfenozide, pyriproxyfen, etc.) may need to be 50-100 degree-days earlier since they possess both adult and ovicidal activity (Fig. 1B). Depending on the density of OFM and the choice of insecticide and rate, only one application may be needed per brood. However, under high pest pressure, and when using insecticides with short residual activity, two or more applications per brood may be necessary.

Sex Pheromone Mating Disruption for OFM

Whereas the larval behavior of OFM sometimes prevents its successful control, OFM adult behavior—namely, the reproductive behavior—has been manipulated with sex pheromones to achieve successful control in many regions of the U.S. There are a number of dispenser technologies now commercially available to growers for mating disruption of OFM in the eastern U.S. These include hand-applied polyethylene twist-tie dispensers (Isomate-M100® and Isomate OFM Rosso®), sprayable microencapsulated pheromones (3M Canada and Suterra LLC) and electronically controlled aerosol dispensers (Paramount Puffers™, Suterra LLC).

Researchers in New Jersey and Pennsylvania have reported that hand-applied dispensers are comparable to conventional insecticides for preventing OFM injury to fruit (Atanassov et al. 2001, Hull and Felland 1999, Robertson and Hull 2002). Ellis (2002) showed that sprayable pheromones and Puffers™ could be used successfully in conjunction with reduced rates of insecticides to reduce high populations of OFM to low levels. In New York, sprayable pheromones and hand-applied dispensers were shown to keep incidence of OFM injury relatively low, although not lower than that in conven-

TABLE 3

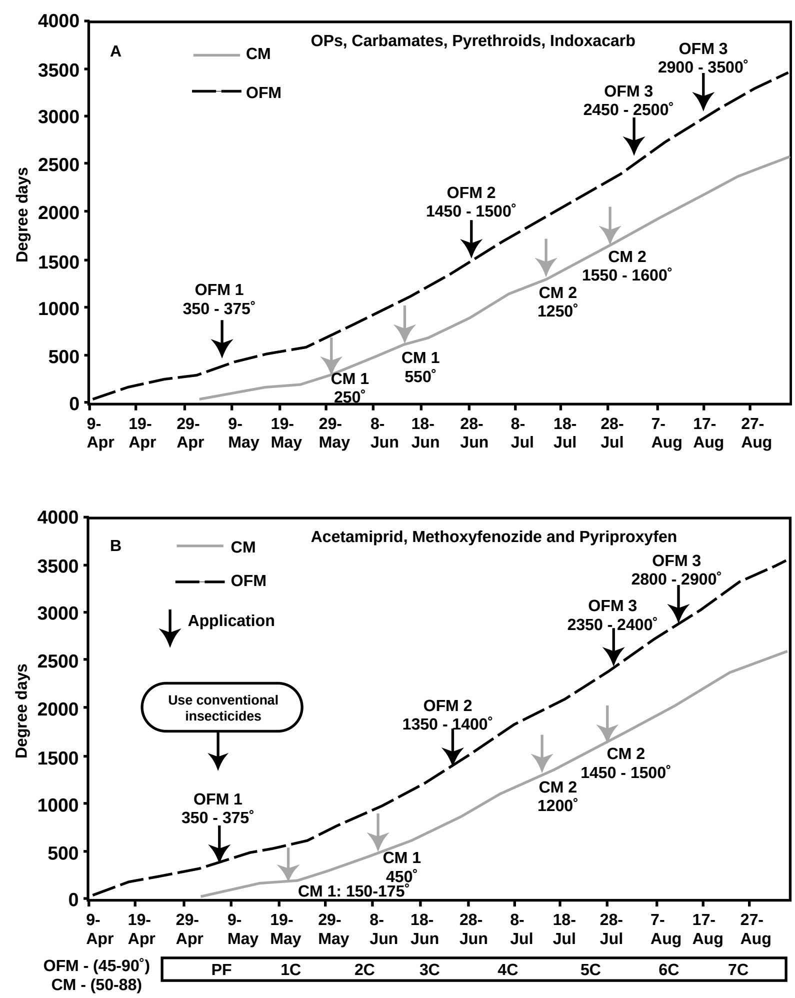
Timing of insecticide applications for organophosphates, carbamates and pyrethroids on apples and peaches to control the oriental fruit moth based on crop stage or degree days from biofix in Pennsylvania.

Crop	OFM brood	Application timing[1]: Crop stage or DD (F°)	Application timing[1]: Approximate % egg hatch	Comments[2]
Apple (A)	1	Pink	0	to kill adult moths
	1	350-375	55-60	most important spray on apple for 1st brood
Peach (P)	1	170-195	10-15	most important spray on peach for 1st brood
	1	350-375	55-60	depends on pest density if second applic. needed
P	2	1150-1200	15-20	most important spray for peach second brood
Both (A & P)	2	1450-1500	65-72	only spray recommended for apple, second spray for peach
P	3	2100-2200	10-20	very important if trap threshold exceeded and/or fruit injury found
	3	450-2500	50-60	very important if trap threshold exceeded and/or fruit injury found
A	3	2450-2500	?	important if trap threshold exceeded
	3	2900-3000	?	and/or fruit injury found
Both (A & P)	4	?	?	important if trap threshold exceeded and/or
	4	?	?	fruit injury found

[1]Application timings for more selective products (e.g., acetamiprid, methoxyfenozide, pyriproxifen, tebufenozide) may be earlier (i.e., 50-100 DD) than those specified due to their mode of action.
[2]Pheromone trap catches and monitoring for pest injury (i.e., flagging and fruit injury) should also be used to determine the need to spray.

FIGURE 1

Proposed degree-day (F°) timings for applications of various insecticide chemistries for OFM and CM control on apples in Pennsylvania. Degree-day accumulations and calendar dates are based on 2002.



tionally insecticide treated orchards (Agnello et al. 2001). Walgenbach (2000) observed elimination of injury to apples caused by internal-feeding larvae (including OFM) when Isomate-M100 dispensers (timed for the first and third broods of OFM) were used in conjunction with insecticides applied at petal fall in North Carolina. His results, and those of Ellis (2002), support the assertion that OFM mating disruption is not a "stand-alone" tactic. That is, limited insecticide use, either with broad-spectrum insecticides or the newer more selective insecticides, will be essential for successful OFM mating disruption.

In Pennsylvania, growers have traditionally applied the majority of their pesticide applications to tree fruits as alternate row middle (ARM) applications where every other row middle is treated each time the sprayer passes through the orchard (Hull et al. 1983). In order to successfully control their pest problems with this method of application, growers typically reduce the interval between applications from the traditional 14-16 days for complete sprays to a 7-9 day interval depending on pest pressure. Since 2000, we have conducted a number of studies using various formulations of 3M Canada's OFM sprayable pheromone and applying them as ARM applications.

In a two-year study (2000-2001) in large commercial apple orchards, OFM sprayable pheromone formulations (Phases 1 and 3) were applied as either ARM sprays at one site or as complete sprays (both sides) at the other site. The applications started in early to mid-June each year before the start of the second brood flight of OFM. The number of sprayable applications per season varied by year and grower with the number of ARM applications ranging from 2 to 7 (18.5 g a.i./ha/side/application) and the number of complete applications from 4 to 6 (37 g a.i./ha/application).

Excellent cumulative trap shutdown of monitoring traps was achieved in the sprayable pheromone blocks in each season on the two commercial farms regardless of whether the pheromones were applied as ARM or as complete applications. At each site, there was no difference in the number of apples showing entries from OFM between the sprayable pheromone treatment and the blocks treated with conventional insecticides.

In another series of experiments conducted during the 2002 season, we continued our efforts to evaluate applications of OFM sprayable pheromone formulations using the ARM approach but with reduced rates of sprayable pheromones. Again, we set up studies at two large commercial orchard sites. Growers 1 and 2 made a total of 7 and 6 ARM applications of both Phase 1 and 5 OFM sprayable pheromones starting with the first application in mid-June and ending with the last application in mid-August (Fig. 2).

Both growers continued to apply a reduced program of insecticides in all pheromone treated blocks. The mean numbers of OFM adults captured per trap per week and mean cumulative adult captures were highest in the conventional orchards at both sites (Figs. 2). Suppression of trap capture was evident for 3-4 consecutive weeks following the final sprayable pheromone applications, regardless of the formulations or rates applied. There was a 94.6% and 87.0% reduction in cumulative adult captures observed between the Phase I and conventional plots at both the Grower 1 and 2 sites, respectively (Table 4). In addition, there was an approximate 98.1% and 97.7% reduction in cumulative adult captures between the lowest ARM rate (3.0 g a.i./ha/side/application—Phase 5) and the conventional plots at both Grower 1 and 2 sites, respectively. No fruit injury was found in any of the mating disruption plots at the Grower 1 site, while 0.3% of the fruit in the standard insecticide block had evidence of internal larval feeding from OFM (Table 4). At the Grower 2 site, there was no difference among the treatments in the percentage of apples showing evidence of OFM injury.

We concluded from these studies that the Phase 5 formulation is effective for preventing OFM capture in pheromone traps and has a longer residual time than the Phase 1 formula-

TABLE 4

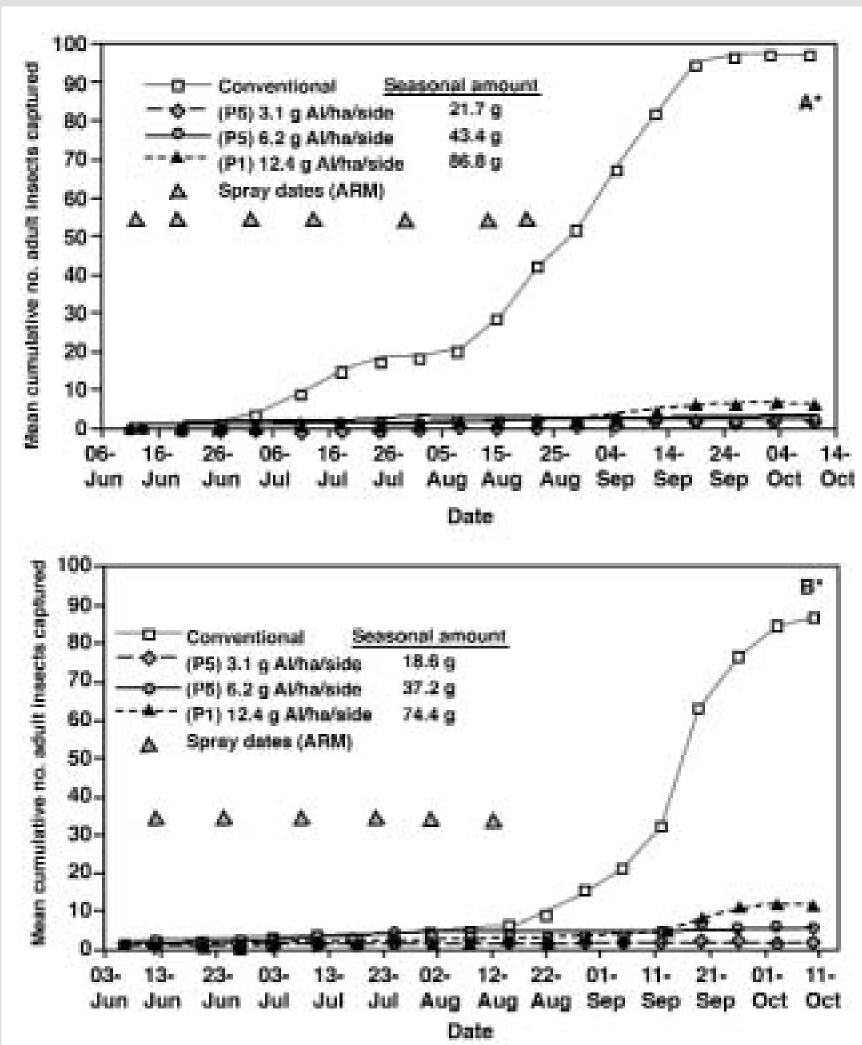
Evaluation of two formulations (P1 and P5) of OFM Sprayables (3M Canada) applied as alternate row middle (ARM) applications on the prevention of fruit injury and pheromone trap capture, Biglerville, PA, 2002.

Grower	Treatment	g a.i./ha (each applic.)	No. ARM applic.	Seasonal g a.i./ha	% Apples-frass	Cum. no. OFM moths caught[1]
1	OFM Sprayable - P5	3.1	7	21.7	0.00 a	7
1	OFM Sprayable - P5	6.2	7	43.4	0.00 a	9
1	OFM Sprayable - P1	12.4	7	86.8	0.00 a	20
1	Std. Insecticide	- -	- -	- -	0.30 b	372
2	OFM Sprayable - P5	3.1	6	18.6	0.08 a	6
2	OFM Sprayable - P5	6.2	6	37.2	0.00 a	16
2	OFM Sprayable - P1	12.4	6	74.4	0.08 a	34
2	Std. Insecticide	- -	- -	- -	0.04 a	261

*Means followed by the same letter(s) are not significantly different, (Fisher's Protected LSD, P <0.05).
[1]Cumulative number of male adults caught in 3 pheromone traps per treatment from 13 Jun - 10 Oct (Grower 1) and 6 Jun - 10 Oct (Grower 2).

FIGURE 2

Comparison of two formulations of 3M Canada OFM Sprayables (P1 and P5) applied using the alternate row middle application technique on oriental fruit moth cumulative trap capture, Grower 1 (A) and Grower 2 (B), Biglerville, PA, 2002.



tion—even at rates 50 and 75% lower than the Phase 1 rates. Also, the addition of sprayable pheromones to a reduced program of insecticides can significantly contribute to the prevention of fruit injury from OFM. In addition, these data show that the ARM technique of spraying can be used to successfully apply sprayable pheromones and still achieve reduced adult capture and prevention of fruit injury. This finding may have valuable utility during seasons of normal or above average rainfall. In such seasonal situations, the pheromone deposit is renewed more often with the ARM method than when full applications are made to both row middles.

As discussed earlier, mating disruption is seldom a "stand-alone" technology for either OFM or CM, especially where targeted pest populations are high or there is a diversity of other pests present. In those situations where pest populations are high, mating disruption should be used in conjunction with insecticides to reduce high pest populations to a level where the mating disruption technology can be successful.

REFERENCES

Agnello, A.M., W.H. Reissig and D.I. Breth. 2001. Pheromone disruption of oriental fruit moth in New York State. In Proceedings of the 76th Cumberland-Shenandoah Fruit Workers Conference. pp. 47-53.

Allen, H.W. 1958. The oriental fruit moth. USDA, Agriculture Information Bulletin no. 182.

Allen, H.W. and M.H. Brunson. 1943. The effect of proximity to apple on the extent of oriental fruit moth injury in peach orchards. J. Econ. Entomol. 36:879-82.

Allen, H.W. and E.L. Plasket. 1958. Populations of the oriental fruit moth in peach and apple orchards in the eastern states. USDA Technical Bulletin No. 1182.

Atanassov, A., P.W. Shearer, G. Hamilton, D. Polk and F. de Lame. 2001. Reduced risk peach arthropod management program. In Proceedings of the 76th Cumberland-Shenandoah Fruit Workers Conference. pp. 88-96.

Cory, E.N. and H.S. McConnell. 1927. *Laspeyresia molesta* as an apple pest. J. Econ. Entomol. 20:190-3.

Ellis, N.H. 2002. Efficacy and integration of two novel mating disruption technologies and biorational insecticides for the oriental fruit moth [*Grapholita molesta* (Busck)] and leafrollers in apples and the response of oriental fruit moth to delayed mating. M.S. thesis, The Pennsylvania State University.

Garman, P. 1918. Comparison of several species of lepidopteran pests infesting peach and apple in Maryland, with additional notes on the oriental peach moth. The Maryland State College of Agriculture. Agricultural Experiment Station Bulletin No. 223.

Gilmer, P.M. 1933. The entrance of codling moth larvae into fruit, with special reference to the ingestion of poison. J. Kansas Entomol. Soc. 6(1):19-25.

Hull, L.A., K.D. Hickey and W.W. Kanour. 1983. Pesticide usage patterns and associated pest damage in commercial apple orchards of Pennsylvania. J. Econ. Entomol. 76:577-583.

Hull, L.A. and C.M. Felland. 1999. Mating disruption for peach insects—will it work? Penn Fruit News 79(4):50-54.

Hughes, J. and S. Dorn. 2002. Sexual differences in the flight performance of the oriental fruit moth, *Cydia molesta*. Entomol. Exp. et Applic. 103:171-182.

Peterson, A. and G.J. Haeussler. 1930. Life history of the oriental peach moth at Riverton, N.J., in relation to temperature. USDA technical bulletin no. 183.

Reichart, G. and J. Bodor. 1972. Biology of the oriental fruit moth (*Grapholita molesta* Busck) in Hungary. Acta Phytopathologica Academiae Scientarum Hungaricae 7:279-95.

Robertson, S. and L.A. Hull. 2002. Areawide mating disruption of the oriental fruit moth, *Grapholita molesta*, in Pennsylvania apples and peaches. Penn Fruit News 82:(in press).

Rothschild, G.H.L. and R.A. Vickers. 1991. Biology, ecology, and control of the oriental fruit moth. In van der Geest, L.P.S., and H.H. Evenhuis, eds. Tortricid pests: their biology, natural enemies, and control. New York, Elsevier, 1991.

Walgenbach, J.F. 2000. Evaluation of codling moth and oriental fruit moth mating disruption systems. In Proceedings of the 75th Cumberland-Shenandoah Fruit Workers Conference.

Yetter, W.P. and L.F. Steiner. 1932. Efficiency of bait traps for the oriental fruit moth as indicated by the release and recapture of marked adults. J. Econ. Entomol. 25:106-116.