

## **Area-wide mating disruption for improved control of Oriental fruit moth *Grapholita molesta* in Victoria, Australia**

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**Abstract:** Area-wide mating disruption had been applied to improve the protection of orchards against migration, edge damage and outbreaks of oriental fruit moth. Experiment started in the 1997-98 season, when the area over 800 hectares of 18 orchards in northern Victoria was treated with mating disruption and continued in the 1998-99 season in the extended area over 1,100 hectares of 40 orchards in the same region. Mating disruption dispensers were applied to all fruit trees including not only peaches and nectarines treated before, but also pears, apples, apricots and plums where growers did not apply mating disruption normally. Detailed monitoring of oriental fruit moth population and regular shoot tip and fruit damage assessments were conducted. The results indicated that application of area-wide mating disruption during 2 consecutive seasons demonstrated an outstanding success in control of oriental fruit moth. The area-wide mating disruption application in the first year helped growers to reduce the number of insecticide sprays by half and in the second year, most of the growers did not spray against oriental fruit moth at all.

**Key words:** area-wide mating disruption, *Grapholita molesta*, oriental fruit moth, sex pheromone, stone and pome fruit orchard.

### **Introduction**

Oriental fruit moth *Grapholita molesta* Busck, (Lepidoptera: Tortricidae) (OFM) is one of the most important pests of commercial orchards in the northern Victoria, Australia. OFM is able to severe damage, not only peaches and nectarines, but also pears, apples, apricots and plums.

Identification of the OFM female sex pheromone structure (Carde et al., 1979) has made new methods for control of this pest possible. The method based on the release of large amounts of sex pheromone, restricting the ability of males to locate virgin females, was called mating disruption (MD) (Rothschild, 1975). Rothschild (1979) also demonstrated that MD treatments could be as effective in controlling OFM as insecticides. Later research (Vickers et al., 1985) suggested that MD may become even more effective, when all orchards in a district are treated, so as to reduce the likelihood of mated OFM females migrating from untreated areas.

First area-wide MD treatment for OFM control was initiated during 1991-92 in the Tulbagh Valley in South Africa (Barnes and Blomefield, 1997). MD treatment in this experiment was only applied as five-row borders in adjacent fruit around 1200 hectares (ha) of peaches and nectarines previously treated with MD. This project had an outstanding success after two seasons, but later when MD applications were stopped, OFM population quickly increased and started to cause severe damage again. This experiment suggested that the success of area-wide MD treatment depended on effective management of borders of MD treated orchards and blocks.

Mating disruption is now a corner stone of Integrated Pest Management in Australian orchards. OFM has been successfully controlled by MD for many years in Victoria, but recently some farmers reported that shoot tip and fruit damage has occurred on the border of MD peach blocks adjacent to fruit blocks under insecticide treatments (Sexton and Il'ichev, 2000). Studies of OFM movement have indicated that most adults do not disperse over distances greater than 200 m, although a few individuals may cover distances exceeding 1 km (Rothschild and Vickers, 1991). Later observations (Il'ichev *et al.*, 1998) indicated that migration of mated OFM females from pear blocks under insecticide treatment to adjacent peach MD blocks resulted in damage at the edge of the peach blocks.

Our experiment with area-wide MD treatment in Victoria (Il'ichev *et al.*, 1999a) aimed to demonstrate that the OFM population would be reduced with the use of MD on the whole orchards in the designated area. The expectation was that this approach would be more reliable and cost effective than combination of MD and insecticide treatments. The significant reduction of insecticide use will be an environmental benefit from this project. This paper reports the initial results of the area-wide MD experiment in northern Victoria, Australia.

## **Materials and methods**

*Description of the study area and monitoring technique.* The orchard area located on south of Cobram, northern Victoria, was chosen to conduct area-wide MD experiment because most of the growers have had experience in managing MD. The most severe OFM damage in this area was typically found at the edge of peach blocks under MD, adjacent to pear blocks under insecticide treatments. This pattern of damage is known as an 'edge effect'. When the severe damage spread around MD treated stone fruit blocks to adjacent pome fruits and the outbreak of higher level of OFM population was recorded in the entire area, such area was called "hot spot".

Our 1996-99 experiments investigated whether applying MD to all orchards in an area-wide basis would improve the effectiveness of MD in the OFM "hot spots" and "edge effects" area.

Food traps were used to monitor the population of both male and female of OFM in fruit blocks under MD. These food traps are not specific to OFM, but capa-

ble to indicate the level of OFM population. Each trap (Efecto-fly trap, Avond Pty.Ltd., Western Australia) was filled with 1 litre of 10% brown sugar solution and 12 drops of terpinyl acetate solution (48.5 mL of terpinyl acetate with 1.5 mL of non-ionic wetting agent and 50 mL of warm water). The food traps were monitored weekly by collecting moths and changing the sugar and terpinyl acetate solutions.

To monitor the whole area-wide MD experiment at least one food trap was placed in all blocks of each fruit variety inside each orchard that was part of the area-wide MD. Additional food traps were placed into blocks larger than 3 ha and overall the average trap density was one trap per 4 ha.

The identified hot spot in property 2 was monitored with 21 food traps distributed in 3 lines of 7 traps through the interface of pears and peaches. The hot spot in property 1 was much bigger than in property 2 and had additional set of 21 food traps to cover whole area infested. There was a distance of 5 trees between traps. The weekly monitoring of area-wide MD experiment and hot spots each season usually started in August, before the first flight of OFM after winter and was continued until two weeks after the last OFM flight finished in April.

*Application of the area-wide MD treatment and monitoring the OFM population (1996 - 97 season).* This season, before the start of area-wide MD experiment, approximately 550 ha of separated peach and nectarine blocks were treated with MD. The Cobram growers treated such stone fruit blocks inside of the orchards with 4 dispensers of 'Isomate OFM Plus' (Shin-Etsu Chemical Co. Ltd., Japan for Biocontrol Ltd., Australia) per tree or 1000 dispensers per ha. 'Isomate OFM Plus' is a controlled release formulation of OFM sex pheromone that contains Z-8-dodecenyl acetate (130.3 mg/dispenser), E-8-dodecenyl acetate (8.4 mg/dispenser) and Z-8-dodecenol (1.3 mg/dispenser). The blocks of pears, apples, plums and apricots in these orchards were under the insecticide treatment with spray application of parathion-methyl and/or azinphos-methyl. MD in stone fruits was usually applied before the end of September and insecticide treatments were applied about 7-14 times during the season. Food traps were placed in the stone fruits under MD. The monitoring data was used to identify the initial level of OFM in properties with edge damage effect and hot spots before the area-wide MD application. Such preliminary information was very important in the future experimental planning and design process.

*1997 - 98 season.* The area-wide MD experiment was established in September-October, in over 800 ha on 18 orchards to the south of Cobram region. The area included 550 ha of peaches and nectarines, which had been treated with MD in previous season. The balance of 250 ha under area-wide MD included pears, apples, plums and apricots that had not been treated with MD previously. Area-wide MD was achieved by treating every tree in the entire experimental area with OFM pheromone at the recommended rate of 4 dispensers of 'Isomate OFM Plus' per tree or 1000 dispensers per ha. The whole area was considered to be extensive enough to ensure that, within it, any edge effects and OFM migration problems in hot spots would be greatly reduced.

More than 230 food traps were placed in the area for monitoring. Three sites without MD treatment were designated as control. Two were separate orchards, adjacent to the north and south borders of the area-wide MD experiment and one was a block of pears left under insecticide treatment opposite to peaches under MD within the area-wide MD.

*1998 - 99 season.* The area-wide MD experiment was continued over a larger area of more than 1,100 ha on 40 orchards. All fruit trees were treated with 'Isomate OFM Rosso' (Shin-Etsu Chemical Co. Ltd., Japan for Biocontrol Ltd., Australia) at the recommended rate of 2 dispensers per tree or 500 dispensers per ha. 'Isomate OFM Rosso' is a controlled release formulation of OFM sex pheromone that contains Z-8-dodecenyl acetate (223 mg/dispenser), E-8-dodecenyl acetate (14.5 mg/dispenser) and Z-8-dodecenol (2.5 mg/dispenser). The new 'Isomate OFM Rosso' dispensers replaced 'Isomate OFM Plus' because of the longer life time and lower application rate (Sexton and Il'ichev, 2001).

More than 280 food traps for OFM monitoring and mapping of the hot spots were placed in area-wide MD. Weekly monitoring of the area-wide MD experiment in this particular season started early in the middle of August 1998, before the start of the first flight of OFM after winter and continued longer than two weeks after the last OFM flight finished in April 1999. The long period of monitoring was useful for better analysis of the monitoring data across two seasons.

Five control sites were designated this season. Four were separate orchards without MD, adjacent to the north, west and south borders of the area-wide MD experiment and one was a property on the western part of experimental area, inside the expanded area-wide MD and surrounded by orchards under MD.

*Shoot tip and fruit damage assessments.* The OFM larvae damage actively growing shoot tips of peach trees by tunneling into the shoot for 8-10 cm. This causes the tip to die or wilt. Larvae can also damage developing peach fruits, causing them to exude gum. Larvae enter the fruit and burrows to the stone, filling the tunnel with brown particles of excreta. But unlike the damage caused by codling moth (*Cydia pomonella* L.) in apples and pears, this excreta is not usually conspicuous on the outside of the peach. OFM damage to pome fruit looks like codling moth damage but when the fruit is cut open the damage does not usually include the pips.

The detailed shoot tip damage assessments were carried out in the hot spot of the property 1 on the following dates: 16.12.96, 27.02.97, 16.12.97, 21.01.98, 3.01.99 and 24.02.99. Fifty shoot tips (twenty-five at random on both the east and west sides of the canopy) were counted on each of the 21 peach tree in the 6 rows where food traps had been placed across the pear and peach interface. Property 2 had no visible tip damage after the 1-st year of area-wide MD experiment and no assessments were taken.

Fruit damage assessments were also carried out only in the property 1. There was no damaged fruit in property 2 after the 1-st year of area-wide MD experiment. The assessments were made prior to the first colour picking on 24.02.97, 28.01.98

and 3.03.99 and at the time of harvest on 3.04.97, 17.03.98 and 22.03.99. A random sample of 25 peaches was taken from the same trees that were assessed for shoot tip damage.

Shoot tip and fruit damage assessments were taken to investigate the distribution of the damage throughout the interface of the MD peach block adjacent to the pear block under 3 different treatments. First was MD on the whole pear block called 'Pear MD', second was MD on a 10 pear tree barrier adjacent to the peach block called 'Pear Barrier', and third was pear block under insecticide chemical spray program called 'Pear Chem'. Shoot tips and fruits were assessed from each of 21 peach trees making up the 6 rows where food traps had been placed in the hot spot.

*Management and analysis of data.* The number of damaged shoot tips and fruits was recorded and the percentage of damaged shoot tip and fruit in each tree was calculated. The percentage of shoot tip and fruit damage down 6 rows of peach trees in each experiment was analysed for the trends and autocorrelation using AS-REML (NSW Agriculture) and GENSTAT 5. Release 4.1 (Lawes Agricultural Trust, Rothamsted Experimental Station).

A geographic information system (GIS) was used for the management, visualisation and analysis of the monitoring and damage assessment data from the area-wide MD experiment. The location of orchard blocks and traps were entered into the GIS using sketch maps of each property in conjunction with satellite imagery and digital cadastral information for the area-wide MD experiment. Once all of the monitoring data had been entered, a desktop GIS package *ArcView 3.1* (ESRI Inc. USA) was used to locate and interpret the data with respect to cadastre of the Cobram area and the road network. The zooming functionality of *ArcView 3.1* enabled the mapping scale of the data to be easily manipulated, and could range from the entire study area to individual orchards. The GIS data base was also used to provide all participating growers with weekly reports of OFM numbers monitored on their property and regularly inform them about the situation with outbreaks and hot spots on the whole experimental area.

## Results

Monitoring the OFM population in the area-wide MD experiment (1996 - 97 season). According to our observations of shoot tip damage distribution and monitoring data 4 properties with edge damage effect were identified at the end of the 1996-97 season. Also during this season 2 properties in the experimental area were designated as hot spots according to our monitoring data. In these areas, shoot tip and fruit damage was also high and more than 10-15 OFM in average during the season were caught per week in food traps.

The average weekly catch of OFM per trap from the food traps showed three distinct peaks of OFM flights (first, second and fourth generations), especially in the

pear blocks under insecticide treatments, where the peak of the first generation reached average of 35 OFM per week per trap (OFM w/t) (Figure 1). The OFM numbers decreased after the first flight in all peach MD blocks. The population of OFM in the Pears MD barrier remained low after second flight whereas, in the rest of pear block under insecticide treatments, the population showed two distinct peaks at the second and fourth generations. The peak of the second generation flight was higher under insecticide treatment and reached average of 50 OFM w/t. These results indicated that the MD worked effectively in almost all peach blocks, decreasing the initial level of OFM population compared with pears under insecticide treatments (Pear Chem.) (Figure 1).

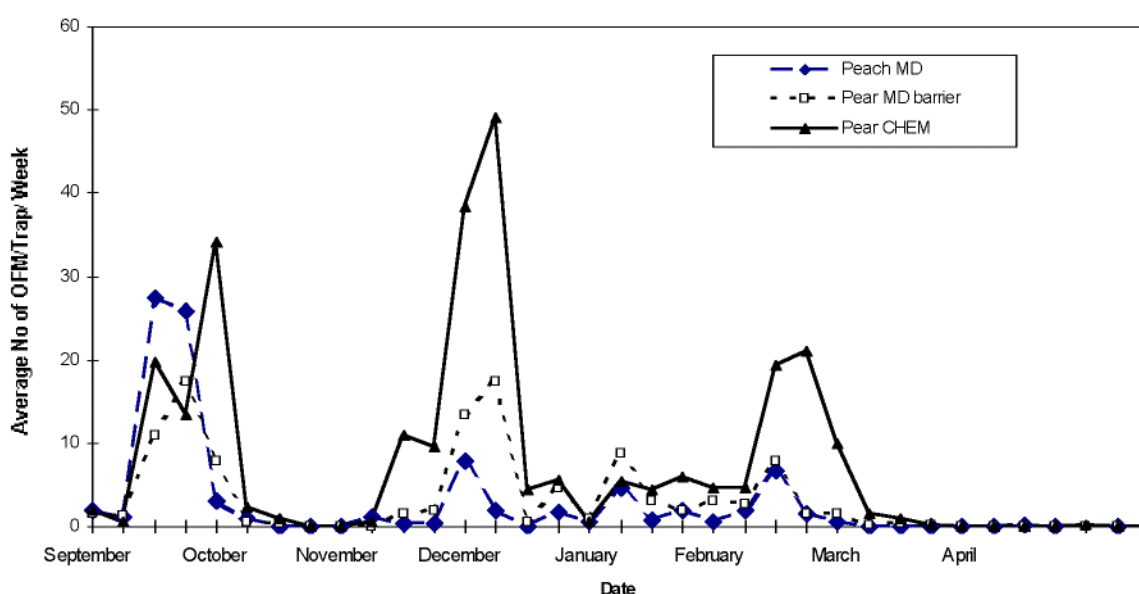


Figure 1. Average number of OFM in pear and peach blocks under different treatments. Monitoring by food traps was conducted during the 1996-97 season in the hot spot area of property 1 in Cobram before application of area-wide MD.

There were two main hot spots found in two properties within the experimental area in the 1996-97 season. The average trap catch in the whole area designated for area-wide MD experiment during this season was between 5-10 OFM w/t, but in hot spots it was much higher between 20-30 OFM w/t. MD was applied only on peaches in these hot spots, and severe damage occurred on the edges of MD peach blocks adjacent to pear blocks under insecticide treatments.

*1997 - 98 season.* Monitoring data of the first OFM flight in 1997-98 from the food traps placed on 18 properties under area-wide MD confirmed two distinct hot spots in properties 1 and 2.

In the hot spot at property 1, the initial population level on peaches was higher and the peak of the first generation flight was about 85 OFM w/t in 1996-97, when

adjacent pears were treated with insecticides, and 45 OFM w/t in 1997-98, when adjacent pears were treated with MD (Figure 2). In 1997-98 under area-wide MD treatment, the OFM numbers dropped during the second generation and did not show any increase up to the end of the season, although the numbers continued at a level of 10-20 OFM w/t.

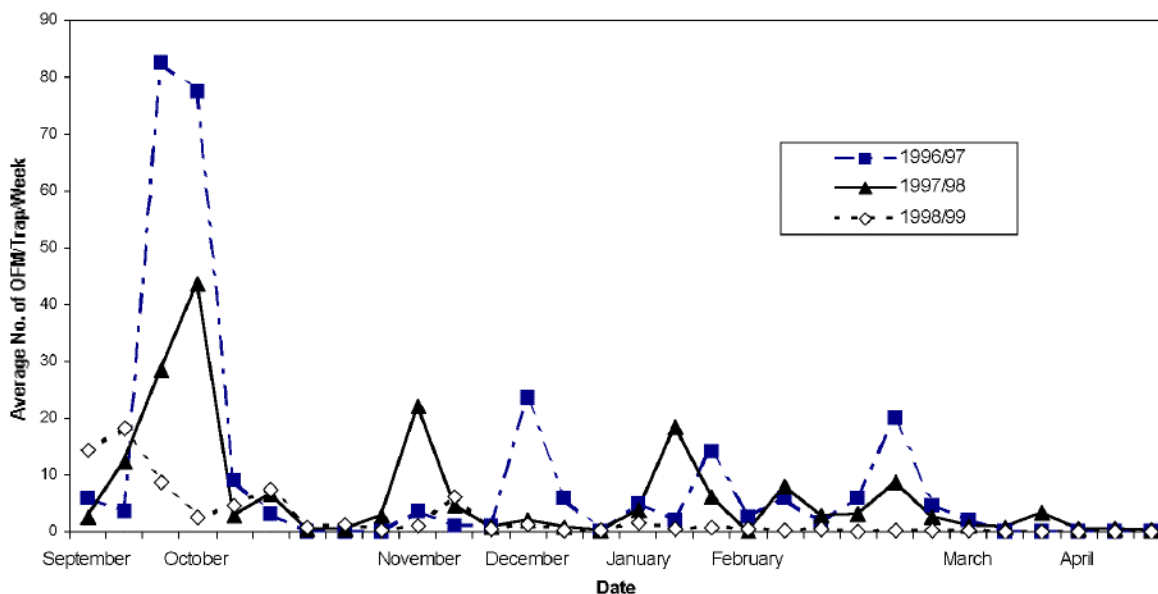


Figure 2. Average number of OFM in peach block under MD in the hot spot area of property 1. Monitoring by food traps was conducted during the 1996-97, 1997-98 and 1998-99 seasons.

In the hot spot at property 2, after area-wide MD application, the OFM population was greatly reduced and it continued to be low till the end of the season. The initial level of the first OFM generation in property 2 was much lower (10-15 OFM w/t) than in property 1 (about 85 OFM w/t). In subsequent generations, the OFM number became insignificant in property 2 and there was no visible shoot tip and fruit damage in this property. Therefore the data from the hot spot in the property 2 was not presented. This result indicates that one season of area-wide MD application was able to control the hot spot with a medium level of OFM population (10-15 OFM w/t). The area-wide MD experiment in the first year of application helped growers to reduce the number of insecticide sprays against OFM by half.

*1998 - 99 season.* This season the new dispensers of Isomate OFM Rosso for area-wide MD experiment were used. The new dispensers have longer lifetime and lower rate of application (500 dispensers per ha) compare to Isomate OFM Plus. This helps to make the area-wide MD approach more cost effective for growers because of the reduced labor cost.

The monitoring results of this season indicated that area-wide MD experiment during the second year successfully reduced the OFM in the hot spot in property 1.

The initial population level in this hot spot in the 1996-97 season was about 85 OFM w/t. After 2 consecutive seasons of area-wide MD application, the peak of the first generation in 1998-99 was about 20 OFM w/t and in second and following generations it was low (0-3 OFM w/t) (Figure 2). During the second year of area-wide MD experiment most of the growers did not spray insecticides against oriental fruit moth at all.

*Shoot tip and fruit damage assessments.* Figure 3 shows the percentage of shoot tip damage in peaches under MD in the hot spot at property 1. Shoot tip damage assessments were usually carried out after second OFM flight during 3 consecutive seasons. The graphic lines in Figure 3 demonstrated the distribution of the average percentage of shoot tip damage from 3 lines of 21 peach trees adjacent to the pear block in the hot spot at property 1. Statistical analysis of the results indicated that shoot tip damage was significantly higher in the first 4 rows of trees in the 1997-98 season. There was a decline in shoot tip damage from tree 1 to tree 4 ( $p < 0.01$ ), thereafter, there was no change in shoot tip damage down the rows ( $p = 0.86$ ). The correlation in shoot tip damage between neighboring trees from tree 5 to tree 21 down the rows was recorded ( $p < 0.01$ ).

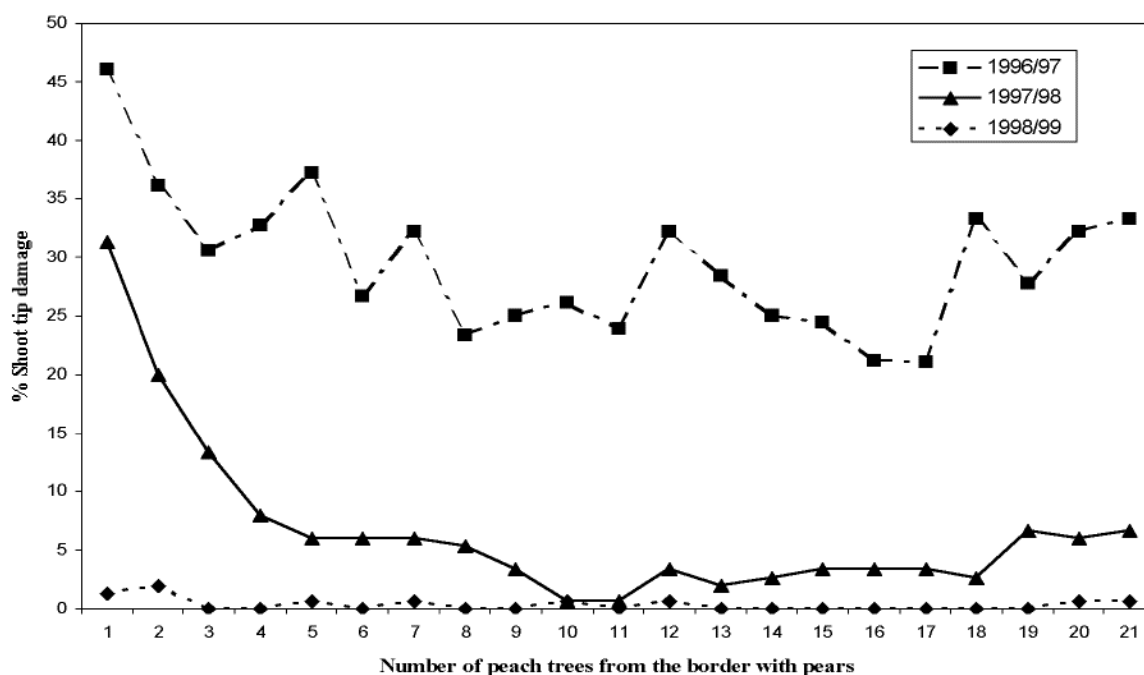
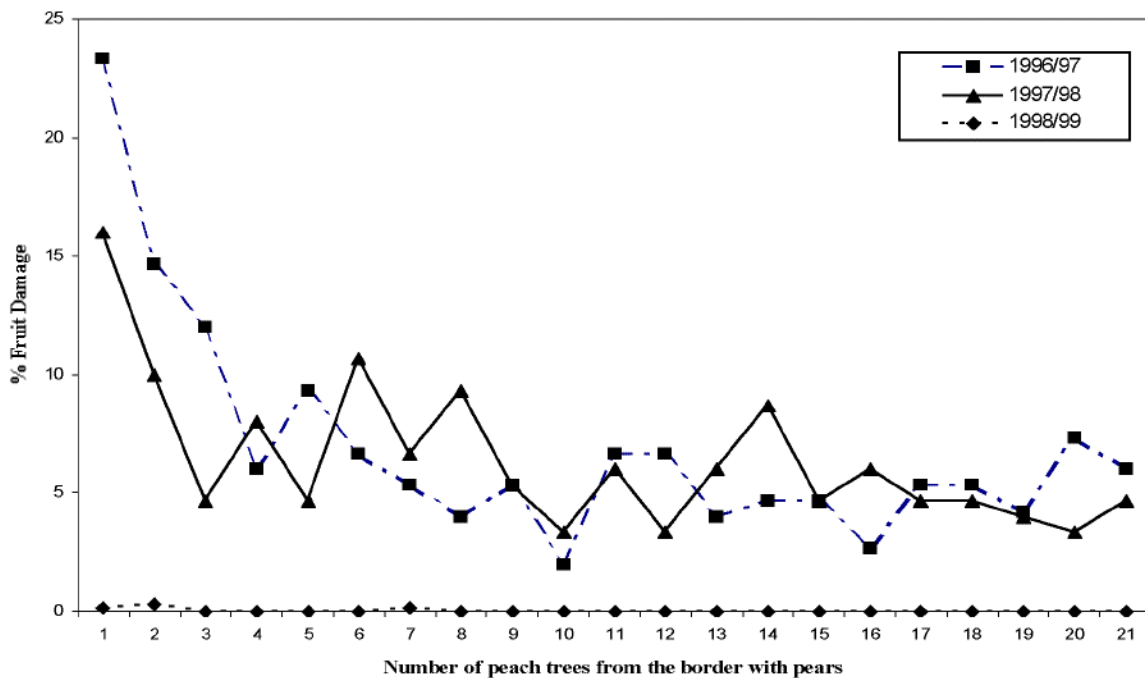


Figure 3. Shoot tip damage assessments for the 1996 - 97, 1997 - 98 and 1998 - 99 seasons. The average percentage of shoot tip damage from 3 lines of peach trees adjacent to pear block in the hot spot at property 1.

The results of fruit damage assessments and the distribution of damage throughout the interface of peach MD block (Figure 4) statistically confirmed the higher level of

fruit damage in the border of peach MD blocks next to the pear blocks. The statistical analysis of the fruit damage distribution indicated that in the peach MD block there was a reduction in fruit damage to tree 4 ( $p < 0.04$ ), and a further reduction from tree 4 to tree 21 ( $p = 0.05$ ) in the 1996-97 season. There was no correlation in fruit damage between neighboring trees from tree 5 to tree 21 down the rows ( $p = 1$ ). Log damage was a reasonable negative linear fit to tree numbers (adjusted  $R^2 = 23\%$ ;  $p < 0.001$ ), thus indicating that decline in fruit damage was greatest nearer tree 1. During the next 1997-98 season the similar pattern in fruit damage distribution was recorded with significant reduction in fruit damage from tree 1 to tree 3 ( $p < 0.04$ ), but there was no further reduction from tree 4 to tree 21 ( $p > 0.05$ ). Log damage was a reasonable negative linear fit to tree numbers (adjusted  $R^2 = 25\%$ ;  $p < 0.001$ ), thus indicating that decline in fruit damage was greatest nearer tree 1 (Figure 4).



**Figure 4.** Fruit damage assessments for the 1996 - 97, 1997 - 98 and 1998 - 99 seasons. The average percentage of fruit damage from 3 lines of peach trees adjacent to pear block in the hot spot at property 1.

## Discussion

The concentration of the higher level of shoot tip and fruit damage near the border (edge effect) of the peach MD block with adjacent pear block without MD treatment may indicate that OFM population in pears contributed to the infestation of neighboring peach trees treated with MD. Our further observations indicated that higher damage at the edge of the peach blocks may be due to migration of mated OFM fe-

males from pear blocks under insecticide treatment to adjacent peach MD blocks (Il'ichev *et al.*, 1998).

Peach shoot tips and fruit could attract mated females for oviposition from adjacent pear blocks, where they have developed a high population. The occurrence of shoot tip and fruit damage mostly on the borders of MD peach blocks may also indicate a behavioural avoidance of unmated females to MD. The females may have responded to a large amounts of synthetic sex pheromone by moving outside of the MD area to mate and then return for oviposition in response to the food attractant from shoot tip or ripening peach fruit (Il'ichev *et al.*, 1999b). Although there is no direct evidence that OFM females can detect their own sex pheromone, such a response has been reported in the females of some tortricid species (Den Otter *et al.*, 1996; Palaniswamy and Seabrook, 1978).

It is known that MD works most effectively in the presence of a low OFM population, and always required a sufficient amount of pheromone to be present in the atmosphere. Through the use of food traps it has been shown that mated females, albeit in small numbers, can be present even within large peach orchards where MD is applied. This situation indicates the possibility that mechanisms other than pheromone calling may lead to mating. In practice however, it is not possible to reliably estimate the population density of OFM, or to measure the amount of sex pheromone present in the air within the orchard (Cravedi, 1992). The use of portable electroantennogram recording equipment in the orchard allows measurement of the airborne pheromone concentrations (Rumbo *et al.*, 1995). Electroantennogram measurements demonstrated that concentration of pheromone for MD can fluctuate due to air movement and leaf absorption in an orchard (Suckling and Angerilli, 1996).

The South African experiment (Barnes and Blomefield, 1997) suggested that the success of area-wide MD depended on effective management of borders of orchards and blocks treated with MD. Two factors are relevant: the decrease in the concentration of pheromone from the MD dispensers at the edges of MD blocks due to wind (Suckling and Karg, 1997), and the migration of mated females of OFM from non mating disruption blocks into adjacent MD areas (Barnes and Blomefield, 1996).

The results reported in this paper also supported the view that the migration of mated OFM females from pears to peaches can lead to the breakdown of MD in the edge of peaches in this situation. The results of pear fruit damage assessment indicated higher level of OFM larva infestation and also suggested that OFM can concentrate in pear blocks under insecticide treatment and may provide a pest reservoir for further infestation of adjacent peaches under MD.

Comparison of the shoot tip damage level before area-wide MD experiment and two years later after area-wide MD treatment, demonstrated the significant reduction of damage in peach MD blocks. Figure 3 shows that the shoot tip damage was greatly reduced in the peach MD block within area-wide MD application in the 1997-98 compared to that of the 1996-97, and fell to almost zero during the 1998-99 season in the hot spot at the property 1. The hot spot with initially high number of

OFM such as in property 1 was eliminated by area-wide MD application in the second year (Figure 2). The hot spot with initially lower level of OFM in property 2 was controlled after 1 year of area-wide MD application.

Initial damage to peach fruits in the hot spot in property 1 (1996-97) was very high (about 25%) before the area-wide MD experiment. After the first year of area-wide MD application, the damage was reduced to 15% and after the second year of the experiment, damage was almost zero throughout whole peach block (Figure 4). Therefore, the OFM numbers (Figure 2), shoot tip (Figure 3) and fruit damage (Figure 4) were greatly reduced over 2 years of area-wide MD application. This indicates that the area-wide MD approach worked effectively.

Monitoring data from 4 places with edge damage effects (in 1996-97 during the first generation counts were about 4-8 OFM w/t) demonstrated a reduction in OFM population during the 1997-98 season (during second and following OFM generations were about 0-1 OFM w/t) after area-wide MD application. There was no detectable shoot tip and fruit damage found in these places at the end of the 1997-98 season. The situation was similar in all 4 locations. According to the OFM monitoring results and examinations of shoot tip and fruit damage all 4 places with edge damage effects were successfully controlled by the end of the 1997-98 season due to area-wide MD application in the whole territory.

The analysis of the monitoring data indicated that one season of area-wide MD application was able to control the hot spot with a medium level of OFM population (10-15 OFM w/t). Two consecutive seasons of area-wide MD application were able to control the higher level (up to 85 OFM w/t) of OFM hot spot.

The results of the OFM flight monitoring and assessment of damage distribution from shoot tip and fruit also supported that OFM can concentrate in pear blocks under insecticide treatments and may provide a pest reservoir for further infestation of adjacent peaches under MD. This also supports our view that the migration of mated females from pears to peaches can be one of the possible reasons leading to the breakdown of MD in the edge of peach blocks in this situation.

Our results indicated that the area-wide MD approach worked effectively and was able to control high level of OFM hot spots successfully. The area-wide MD experiment shows that the OFM population in the hot spots can be gradually reduced and that migration of mated females in the hot spots and any edge damage effects can be reduced. The area-wide MD application in the first year helped growers to reduce the number of insecticide sprays against OFM by half and in the second year, most of the growers did not spray against oriental fruit moth at all.

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