AREA-WIDE APPROACH FOR IMPROVED CONTROL OF ORIENTAL FRUIT MOTH *GRAPHOLITA MOLESTA* (BUSCK) (LEPIDOPTERA: TORTRICIDAE) BY MATING DISRUPTION

A. L. Il'ichev[1], L. J. Gut[2], D. G. Williams[1], M. S. Hossain[1] and P. H. Jerie[1]

[1] Department of Natural Resources and Environment, Tatura VIC, Australia 3616
[2] Department of Entomology, Michigan State University, East Lansing, Michigan, USA 48824-1311
Email: Alex.Il'ichev@nre.vic.gov.au

Summary

An area-wide mating disruption approach was employed to improve the protection of pome and stone fruit orchards against migration, edge damage and outbreaks of oriental fruit moth. The experiment started in the 1997-98 season, with an area of over 800 hectares comprised of 18 orchards treated with mating disruption in northern Victoria, Australia. The treated area was expanded in the 1998-99 season to encompass an area of over 1,100 hectares comprised of 40 orchards. Mating disruption dispensers were applied to every fruit tree in the area including not only peach and nectarine orchards disrupted in previous years, but also pear, apple, apricot and plum orchards where growers had not previously used mating disruption. Detailed monitoring of oriental fruit moth population and shoot tip and fruit damage indicated that application of area-wide mating disruption during two consecutive seasons provided sufficient control of oriental fruit moth. The area-wide mating disruption program 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. Hot spots and edge infestations of oriental fruit moth were reduced or eliminated through use of the area-wide approach.

Keywords: area-wide mating disruption, oriental fruit moth, sex pheromone

INTRODUCTION

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

Identification of the OFM female sex pheromone structure (George 1965; 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, has been termed mating disruption (MD) (Rothschild 1975). Rothschild (1979) 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.

The first area-wide MD program for OFM control was initiated during 1991-92 in the Tulbagh Valley in South Africa (Barnes and Blomefield 1997). The South African MD experiment included five-row border treatments in orchards adjacent to or surrounding 1200 hectares (ha) of peaches and nectarines previously treated with MD. This project had an outstanding success for two seasons, but when MD applications were stopped prior to a third season, OFM population quickly increased and caused 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 growers reported that damage to shoot tips and fruit has occurred on the border of MD peach blocks adjacent to fruit blocks that continue to be managed with insecticides only (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; Il'ichev *et al*. 1999a) 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 aimed to demonstrate that OFM populations would be reduced with the use of MD on all orchard blocks in the designated area. The expectation was that this approach would be more reliable and cost effective than a combination of MD and insecticide treatments. The project if successful would also demonstrate the environmental benefits through significant reduction of insecticide use. Cost-effectiveness and environmental benefits are separate topics that may be addressed in future publications. This paper reports the reduction of OFM populations during an area-wide MD experiment in northern Victoria, Australia.

MATERIALS AND METHODS

Description of the study area

The fruit production area located south of Cobram, northern Victoria, was chosen to conduct the area-wide MD experiment because most of the growers were already using this technique in their stone fruit blocks. The most severe OFM damage in the Cobram area was typically found at the edge of peach blocks under MD, adjacent to pear blocks under insecticide treatments. This pattern of damage has been reported elsewhere as a problem in MD treated orchards (Gut and Brunner 1998) and is generally referred to as an ‘edge effect’. Damage can spread from the edge to the interior of MD treated stone fruit blocks that are adjacent to pome fruits treated with insecticides only. Such outbreaks of higher OFM population levels were recorded in the Cobram area and were commonly referred to as ‘hot spots’ (Il’ichev *et al*. 1998). The main objective of the 1996-99 experiments was to investigate whether applying MD to all orchards in an area-wide basis would improve the effectiveness of MD by reducing or preventing the occurrence of OFM hot spots and edge effects.

In the 1996-97 season before the start of area-wide MD experiment, approximately 550 ha of separated peach and nectarine blocks in the Cobram region were treated with MD. Isomate OFM Plus (Shin-Etsu Chemical Co. Ltd., Japan for Biocontrol Ltd., Australia) was applied high in the tree canopy at a rate of four dispensers per tree or 1000 dispensers per ha. Isomate OFM Plus is a controlled release formulation of polyethylene tubing dispenser with 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). Blocks of pears, apples, plums and apricots on the same orchards were under an insecticide control program with spray applications of parathion-methyl and/or azinphos-methyl. MD in stone fruits was usually applied before the end of September and insecticide treatments were applied between seven and 14 times during the season.

Application of the area-wide MD treatment

The area-wide MD experiment was established in September-October, 1997, 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 the previous season. The balance of 250 ha under area-wide MD was comprised of 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 registered rate of four 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 hot spots associated with OFM migration would be greatly reduced.

Three properties where OFM was managed with insecticides rather than MD were established as controls in the 1997-98 season. Two were orchards of mixed stone and pome fruits, adjacent to the north and south borders of the area-wide MD experiment, and the other was a single block of pears adjacent to peaches under MD within the area-wide program.

The area-wide MD experiment was expanded in 1998 to include 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 registered rate of two dispensers per tree or 500 dispensers per ha. Isomate OFM Rosso is a controlled release formulation of polyethylene tubing dispenser with 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 dispenser was used rather than the standard Isomate OFM Plus dispenser because of the opportunity to apply a MD formulation at a lower application rate and increased field longevity (Sexton and Il’ichev 2001).

Five properties where OFM was managed with insecticides rather than MD were designated as controls in the 1998-99 season. All five included various pome and stone fruit blocks. Four orchards were adjacent to the north, west and south borders of the area-wide MD experiment, and the other was located on the western part of the experimental area, inside the expanded area-wide MD and surrounded by orchards under MD.

Monitoring with food traps

Food traps were used to monitor the population of both male and female of OFM in fruit blocks under MD and in control blocks. These food traps are not specific to OFM, but capable of indicating the level of OFM population. Each trap (Efecto-fly trap, Avond Pty.Ltd., Western Australia) was filled with 1 L of 100 g/L 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.

Food traps were placed in the MD treated stone fruit blocks in the 1996-1997 season. Moth captures were used to investigate the distribution of moth throughout the interface of a MD peach block adjacent to a pear block under three different OFM management programs. The programs were MD on the whole pear block (Pear MD), MD on a 10 pear tree barrier adjacent to the peach block (Pear MD barrier) and an insecticide chemical spray program (Pear Chem.). The monitoring data from 1996-97 was critical to subsequent experimental planning and design because it allowed us to identify initial levels of OFM in properties with edge effects and hot spots before the area-wide MD application.

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. More than 230 food traps were placed in the area for monitoring in 1997. The number of traps deployed was increased to 280 to accommodate the increase in size of the experimental area. Traps were in place prior to the start of OFM flights in the middle of August and weekly monitoring continued for at least two weeks after the last OFM moths were captured in April.

The identified hot spot in property 2 was monitored with 21 food traps distributed in three lines of seven traps through the interface of pears and peaches. The hot spot in property 1 was much bigger than in property 2 and had an additional set of 21 food traps to cover the whole area infested. There were five trees between traps.

Shoot tip and fruit damage assessments

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 burrow to the stone, filling the tunnel with brown particles of excreta.

Shoot tip damage assessments were carried out after the second OFM flight during three consecutive seasons. Assessments were conducted in the hot spot of 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 (25 at random on both the east and west sides of the canopy) were counted on each of the 21 peach trees in the six rows where food traps had been placed across the pear and peach interface.

Fruit damage assessments were carried out only within property 1, because property 2 had no visible tip damage and no damaged fruit after the first year of the area-wide MD experiment. The assessments were made prior to the first picking dates (24.02.97, 28.01.98 and 3.03.99) and the last picking dates (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. All damaged fruit were cut open for OFM larval identification during fruit damage assessments. Larvae found in pome fruit were saved and later examined under a microscope for species identification. OFM larvae were distinguished from codling moth (*Cydia pomonella* L.) by the presence of an anal comb.

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 six rows of peach trees in each experiment was analysed for the trends and autocorrelation using ASREML (NSW Agriculture) and GENSTAT 5. Release 4.2 (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 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 over the whole experimental area.

RESULTS

OFM capture in food traps

The average weekly catch per trap from the food traps in 1996-97 showed three distinct peaks of activity associated with the first, second and fourth generation of OFM flights but the third generation was low and spread out (Figure 1). The pattern was especially apparent in the pear blocks under insecticide treatments, with averages of greater than 20 moths per trap per week (moths/t/w) for the three flights. The first generation peaked at an average of 35 moths/t/w. The OFM numbers decreased after the first flight in all peach MD blocks. The population of OFM in the 'Pear MD barrier' remained low after the second flight whereas, in the rest of the pear block under insecticide treatments, the population showed distinct peaks at the second and fourth generations. The peak of the second generation flight was higher under insecticide treatment and reached an average of 50 moths/t/w. These results indicated that MD worked effectively in most peach blocks, decreasing the initial level of OFM population compared with pears under insecticide treatments (Pear Chem.) (Figure 1).

Moth catches in food traps revealed four properties with high OFM populations on the edges during the 1996-97 season. Also during this season, high catches indicated that there were hot spots in two properties within the experimental area. The average trap catch in the whole area was between 5-10 moths/t/w, but in hot spots it was much higher between 20-30 moths/t/w. During 1996-97 the MD was applied only on peach blocks in these hot spots.

Monitoring data for the first OFM flight in 1997-98 using food traps placed on 18 properties under area-wide MD confirmed one distinct hot spot in each of properties 1 and 2. In the hot spot on property 1, the initial population level on peaches was high, with a peak of the first generation flight of about 85 moths/t/w in 1996-97, when adjacent pears were treated with insecticides. In 1997-98, when adjacent pears were treated with MD, the peak of the first generation flight was about 45 moths/t/w (Figure 2). During 1997-98 under the area-wide MD treatment, the OFM numbers decreased in 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 moths/t/w.

In the hot spot at property 2, after the area-wide MD application, the OFM population was greatly reduced and it continued to be low until the end of the season. The initial level of the first OFM generation in property 2 was much lower (about 13 moths/t/w) (Figure 3) than in property 1 (about 85 moths/t/w) (Figure 2). In subsequent generations, the OFM number became insignificant in property 2 and there

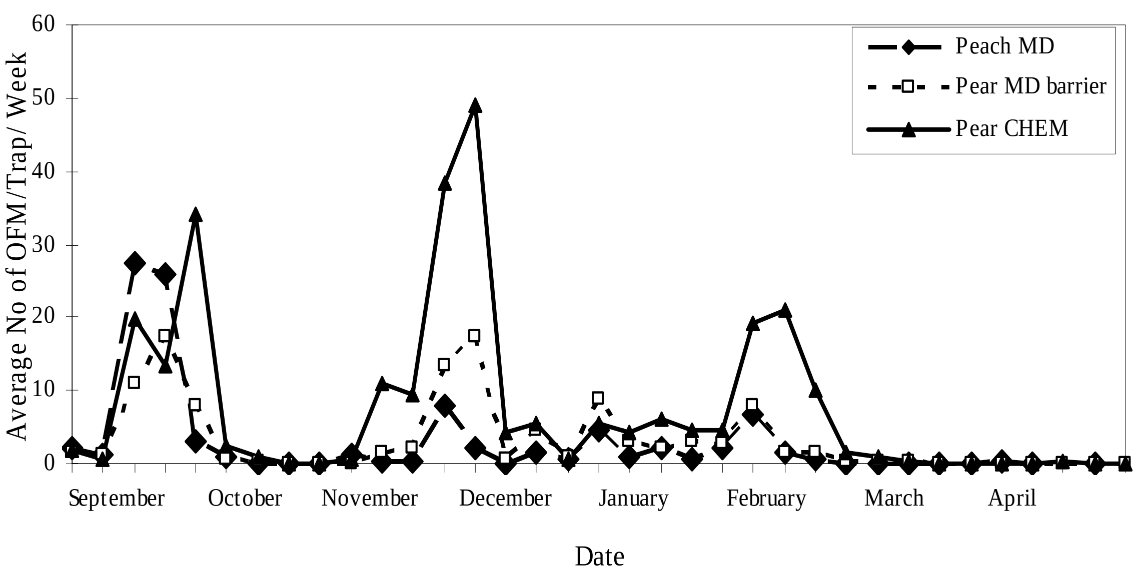

Figure 1. Average number of OFM in pear and peach blocks under different treatments.
Monitoring by food traps was conducted during the 1996-97 season in the hot spot area of property 1 in Cobram before application of area-wide MD.

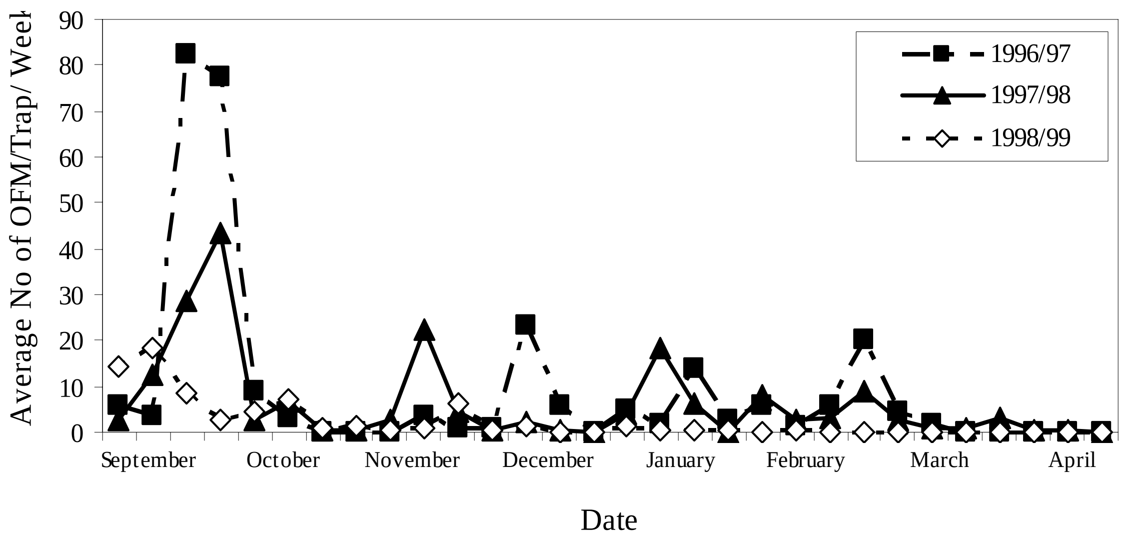

Figure 2. Average number of OFM in peach block under MD in the hot spot area of property 1. Monitoring by food traps was conducted during the 1996-97, 1997-98 and 1998-99 seasons.

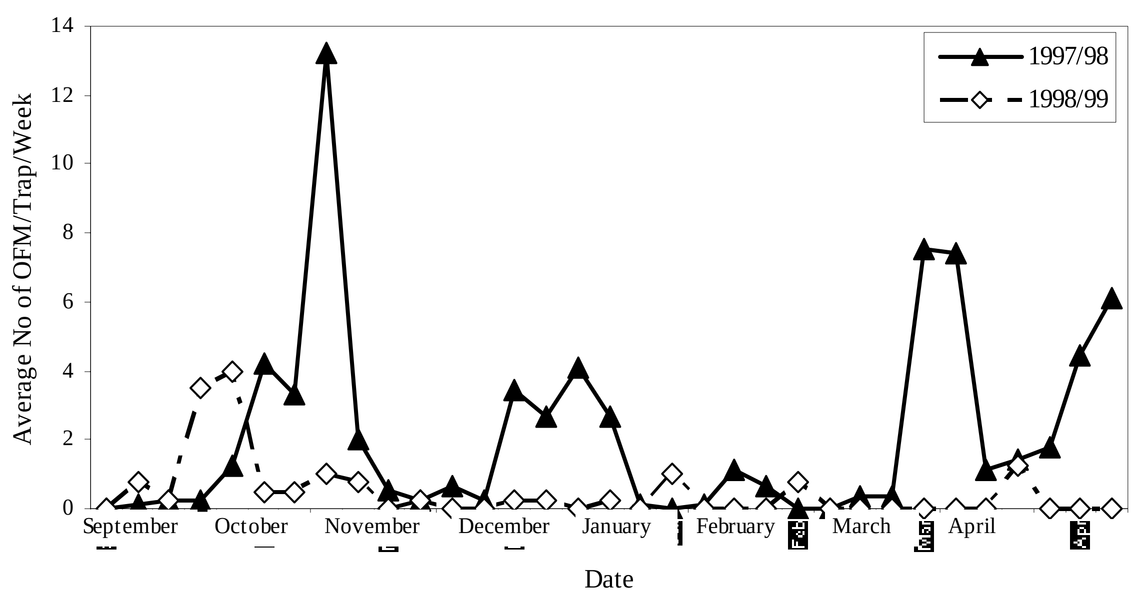

Figure 3. Average number of OFM in peach block under MD in the hot spot area of property 2. Monitoring by food traps was conducted during the 1997-98 and 1998-99 seasons.

was no visible shoot tip and fruit damage in this property (Figure 3). 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 moths/t/w). The area-wide MD experiment in the first year of application helped growers to halve the number of insecticide sprays against OFM.

The monitoring results of the 1998-99 season indicated that the area-wide MD experiment during the second year successfully reduced OFM in the hot spot in property 1. During the second full season of the area-wide MD application the population in the first flight in this hot spot in the 1998-99 season was about 20 moths/t/w. Then the OFM population declined to a very low level of 0-3 moths/t/w in the third flight and no moth catches were recorded after the third flight (Figure 2). As a result most of the growers did not spray insecticides against OFM during the second year of the area-wide MD experiment in the 1998-99 season.

Only one of the control blocks had sufficient moth number to be suitable for comparison of OFM population trends between seasons. The results (Figure 4) indicated that there was no general decline in OFM in control blocks managed without MD.

Shoot tip and fruit damage assessments

Figure 5 shows the percentage of shoot tip damage in peaches under MD in the hot spot at property 1. The data in Figure 5 demonstrated the distribution of the average percentage of shoot tip damage from three lines of 21 peach trees adjacent to the pear block in the hot spot at property 1. Before the area-wide MD was applied, shoot tip damage in the hot spot at property 1 in 1996-97 was about 30-35% and distributed throughout the peach block. Statistical analysis of the results collected after area-wide MD application indicated that shoot tip damage was significantly higher in the first four 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 ($p=0.86$). A significant correlation ($p<0.01$) in shoot tip damage between neighboring trees from tree 5 to tree 21 down the rows was recorded. After the second year of the area-wide MD application in 1998-99 less than 2% shoot tip damage was recorded in trees in the first two rows adjacent to pears.

The results of fruit damage assessments and the distribution of damage throughout the interface of peach MD block (Figure 6) statistically confirmed a higher level of fruit damage in the border of peach MD blocks next to the pear blocks.

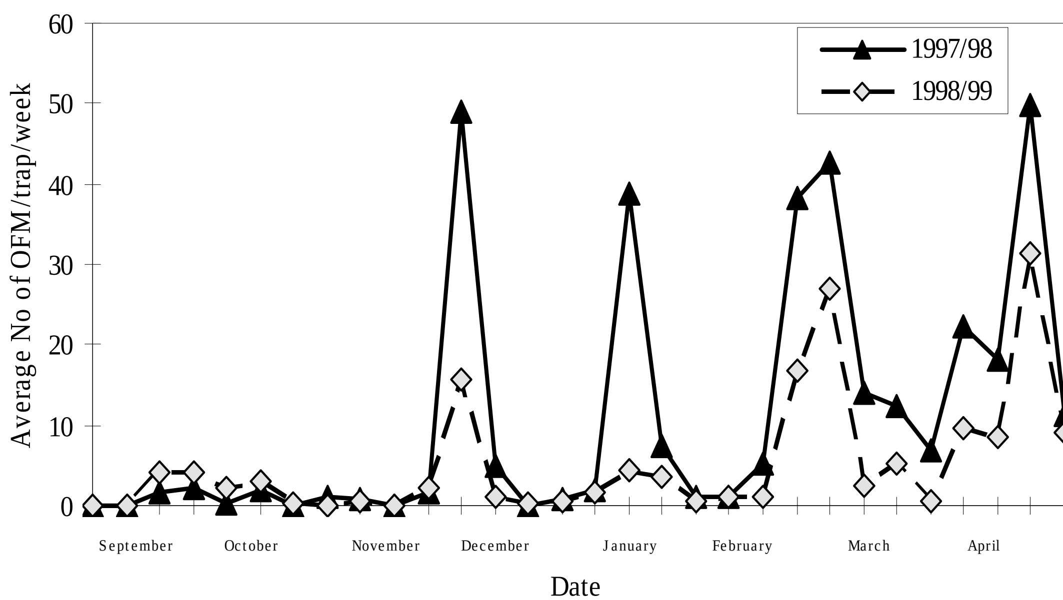

Figure 4. Average number of OFM in control peach block managed with insecticides without MD in the north border of the area-wide MD experiment. Monitoring by food traps was conducted during the 1997-98 and 1998-99 seasons.

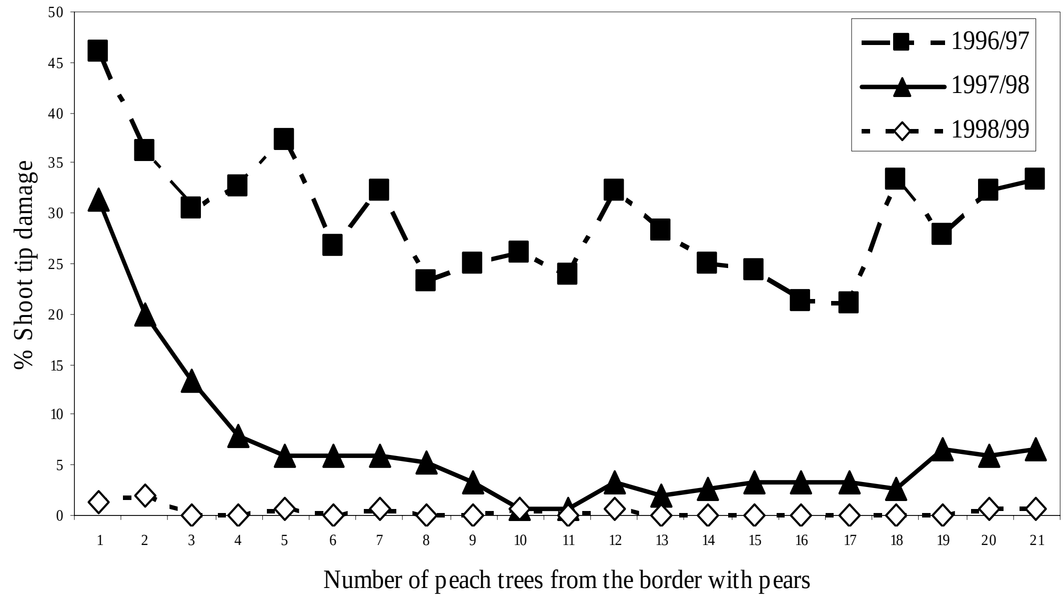

Figure 5. Shoot tip damage assessments for the 1996-97, 1997-98 and 1998-99 seasons. The average percentage of shoot tip damage from three lines of peach trees adjacent to pear block in the hot spot at property 1.

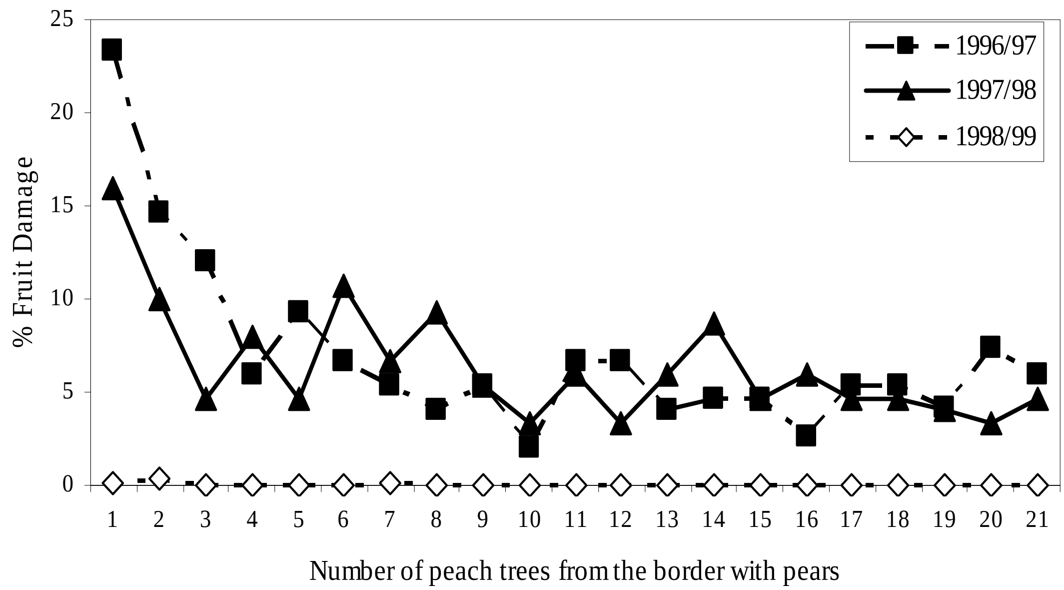

Figure 6. Fruit damage assessments for the 1996-97, 1997-98 and 1998-99 seasons. The average percentage of fruit damage from three lines of peach trees adjacent to pear block in the hot spot at property 1.

The statistical analysis of the fruit damage distribution indicated that, in the peach MD block, there was a reduction in fruit damage from trees 1 to 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 neighbouring 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 a 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 the rate of decline in fruit damage was greatest nearer tree 1 (Figure 6). After the second year of the area-wide MD application in 1998-99 less than 0.3% fruit damage was recorded in the first two rows of peach trees adjacent to pears.

DISCUSSION

Our results indicated that the area-wide MD approach worked effectively and was able to control high levels of OFM in hot spots. The area-wide MD experiment shows that the OFM populations 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 halve the number of insecticide sprays against OFM and in the second year, most of the growers did not spray against oriental fruit moth at all.

The control blocks were expected to indicate if there had been a general decline in OFM in the district during the experimental period. The area-wide MD approach was so popular that we had difficulty obtaining suitable control blocks without MD. Only one of the control blocks had sufficiently high infestation level to be useful as a control. This block was managed with insecticides rather than MD and the OFM population did not decline over the life of the experiment (Figure 4). This suggests that the reduction in OFM in the hot spots was due to the effect of MD rather than seasonal variations in pest pressure.

Comparison of the shoot tip and fruit damage levels in MD peach blocks prior to treating all orchards with pheromone and two years after implementing the area-wide MD program demonstrated a significant reduction of damage in peach blocks after deploying the area-wide approach. The hot spot with an initially lower level of OFM in property 2 was controlled after one year of the area-wide MD application. Shoot tip damage was greatly reduced in the hot spot on property 1 in the first year of the experiment, and fell to almost zero in the second year of the area-wide MD program. 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 the 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. This indicates that the area-wide MD approach worked effectively.

The analysis of the trapping data also supports the conclusion that one or two seasons of the area-wide MD application are needed to control OFM depending on population density. One season was sufficient at property 2 with the medium population of OFM (10-15 moths/t/w), while two consecutive seasons of the area-wide MD application were required to control the higher level (up to 85 moths/t/w) of OFM in the hot spot at property 1.

Monitoring data from four sites with edge damage infestations further demonstrated a reduction in OFM population following implementation of the area-wide MD approach. According to moth captures in food traps and examination of shoot tip and fruit damage, all four locations with edge damage effects detected in the 1996-1997 season were successfully controlled by the end of the first season of area-wide MD (1997-1998).

Previous area-wide experiments (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 may be 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 can lead to the breakdown of MD in the absence of area-wide treatments. The concentration of shoot tip and fruit damage near the border (edge effect) of the peach MD block adjacent to the pear block not treated with MD suggests that the OFM population in pears contributed to the infestation of neighbouring peach trees treated with MD. Il'ichev *et al*. (1999b) observed that higher damage at the edge of the peach blocks occurred as a possible result of migration by mated OFM females from pear blocks under insecticide treatment to adjacent peach MD blocks.

Detailed studies are needed to understand why OFM damage in stone fruit blocks treated with MD most often occurs along the edge of the block adjacent to pome fruit blocks. Peach shoot tip and fruit could attract mated OFM 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 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).

ACKNOWLEDGEMENTS

This project was funded by the Department of Natural Resources and Environment (DNRE) and Horticultural Research and Development Corporation (HRDC) with the support of Canned Fruit Industry Council of Australia, Biocontrol Ltd., I.K.Caldwell Pty.Ltd., GV Crop Protection, Wayne Skinner Rural Supplies Pty.Ltd. and the Cobram fruit growers involved in the area-wide mating disruption project. We thank Mr. Stephen Sexton (Biocontrol Ltd. Australia) for experimental design discussions, Dr. Leigh Callinan (DNRE Bendigo) for statistical analysis, Mr. Avtar Saini (DNRE Tatura) for monitoring, Dr. Peter Witzgall from SLU, Alnarp, Sweden and Dr. Malcolm Campbell from DNRE, Tatura for valuable comments on the text.

REFERENCES

Barnes, B.N. and Blomefield, T.L. (1996). Mating disruption manual for codling moth and oriental fruit moth. Stellenbosch Institute for Fruit Technology: Infruitec, South Africa, 38 pp.

Barnes, B.N. and Blomefield, T.L. (1997). Goading growers towards mating disruption: the South African experience with *Grapholita molesta* and *Cydia pomonella* (Lepidoptera, Tortricidae). *Bulletin of the International Organisation for Biological Control, West Palaearctic Regional Section* **20**: 45-56.

Carde, A.M., Baker, T.C. and Carde, R.T. (1979). Identification of a four-component sex pheromone of the female oriental fruit moth, *Grapholitha molesta* Busck. (Lepidoptera: Tortricidae). *Journal of Chemical Ecology* **5**: 423-427.

Den Otter, C.J., De Cristofaro, A., Voskamp, K.E. and Rotundo, G. (1996). Electrophysiological and behavioural responses of chestnut moths *Cydia fagiglandana* and *C. splendana* (Lep., Tortricidae) to sex attractants and odours of host plants. *Journal of Applied Entomology* **120:** 413-421.

GenStat (2000). GenStat 5 for Windows. Release 4.2. Fifth Edition. VSN International Ltd., Oxford

George, J.A., (1965). Sex pheromone of the oriental fruit moth *Grapholitha molesta* Busck (Lepidoptera: Tortricidae). *Canadian Entomologist* **97**: 1002-1007.

Gut, L.J. and Brunner, J.F. (1998). Pheromone-based management of codling moth (Lepidoptera: Tortricidae) in Washington apple orchards. *Journal of Agricultural Entomology* **15**: 387-406.

Il'ichev, A.L., Jerie, P.H. and Hossain, M.S. (1998). Wide area mating disruption of oriental fruit moth *Grapholita molesta* Busck (Lepidoptera: Tortricidae) in Victoria. In: M.P., Zalucki, R.A.I., Drew and G.G. White (eds.) *Pest Management – Future Challenges. Proceedings of the Sixth Australasian Applied Entomological Research Conference, Brisbane, Australia*. Volume 1: 348-355.

Il'ichev, A.L., Hossain, M.S. and Jerie, P.H. (1999a). Migration of Oriental Fruit Moth *Grapholita molesta* Busck. (Lepidoptera: Tortricidae) under wide area mating disruption in Victoria, Australia. *Bulletin of the International Organisation for Biological Control, West Palaearctic Regional Section* **22**: 53-62.

Il'ichev, A.L., Hossain, M.S. and Jerie, P.H. (1999b). Application of wide area mating disruption for control of oriental fruit moth *Grapholita molesta* Busck (Lepidoptera; Tortricidae) migration in Victoria, Australia. *Bulletin of the International Organisation for Biological Control, West Palaearctic Regional Section* **22**: 95-103.

Palanaswamy, P. and Seabrook, W.D. (1978). Behavioural responses of the female eastern spruce budworm *Choristoneura fumiferana* (Lepidoptera, Tortricidae) to the sex pheromone of her own species. *Journal of Chemical Ecology* **4**: 649-655.

Rothschild, G.H.L. (1975). Control of oriental fruit moth (*Cydia molesta* (Busck) (Lepidoptera, Tortricidae) with synthetic female pheromone. *Bulletin of Entomological Research* **65**: 473-490.

Rothschild, G.H.L. (1979). A comparison of methods of dispensing synthetic sex pheromone for the control of oriental fruit moth, *Cydia molesta* (Busck) (Lepidoptera: Tortricidae), in Australia. *Bulletin of Entomological Research* **69**: 115-127.

Rothschild, G.H.L. and Vickers, R.A. (1991). Biology, Ecology and Control of the Oriental Fruit Moth. In: L.P.S. van der Geest, H.H. Evenhuis (Eds.), *World Crop Pests, Vol. 5, Tortricid pests: their biology, natural enemies and control*. Elsevier, Amsterdam. pp. 389-412.

Sexton, S.B. and Il'ichev, A.L. (2000). Pheromone mating disruption with reference to oriental fruit moth *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae). *General and Applied Entomology* **29**: 63-68.

Sexton, S.B. and Il'ichev, A.L. (2001). Release rate characteristics of two pheromone formulations for control of oriental fruit moth *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae) by mating disruption. *General and Applied Entomology* **30**: 31-34.

Suckling, D.M. and Karg, G. (1997). The role of foliage in mating disruption in apple orchards. *Bulletin of the International Organisation for Biological Control, West Palaearctic Regional Section* **20**: 169-173.

Vickers, R.A., Rothschild, G.H.L. and Jones, E.L. (1985). Control of the oriental fruit moth, *Cydia molesta* (Busck) (Lepidoptera: Tortricidae), at a district level by mating disruption with synthetic female pheromone. *Bulletin of Entomological Research* **75**: 625-634.

This page left blank intentionally