Sprayable Microencapsulated Sex Pheromone Formulation for Mating Disruption of Oriental Fruit Moth (Lepidoptera: Tortricidae) in Australian Peach and Pear Orchards

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J. Econ. Entomol. 99(6): 2048–2054 (2006)

ABSTRACT Areawide mating disruption treatments have been effective in controlling infestation of oriental fruit moth, *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae), in Australian pome and stone fruit orchards. Although successful, the areawide mating disruption program has been an expensive approach by using hand-applied Isomate dispensers. Sprayable microencapsulated (MEC) pheromone formulations that can be applied with standard spray equipment could substantially reduce the cost of application. Field trials conducted during two consecutive seasons (2002–2004) demonstrated that monthly applications of MEC-OFM phase V (3M Canada, London, Ontario, Canada) at a rate of 125 ml/ha (37.1 g [AI]/ha) in replicated 2-ha blocks of both peaches and pears reduced oriental fruit moth shoot tip and fruit damage as effectively as a single application of Isomate OFM Rosso hand-applied dispensers (500 dispensers per ha) and as or more effectively than standard broad-spectrum insecticide sprays. Fruit protection was achieved despite high oriental fruit moth population densities in both crops as measured by moth catches in terpinyl acetate food and pheromone traps. Similar numbers of oriental fruit moths were captured among all treatments in food traps but captures of males in pheromone traps were disrupted (96–99%) in pheromone-treated blocks relative to controls. The results of this study suggest that microencapsulated formulations of pheromone could be effectively used in areawide mating disruption programs for oriental fruit moth in Australia as a cost-saving alternative to reservoir-style dispensers requiring labor-intensive hand application.

KEY WORDS mating disruption, sprayable microencapsulated pheromone, oriental fruit moth

Oriental fruit moth, *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae), is a major pest of commercial stone and pome fruit orchards worldwide. Originally from northwestern China, oriental fruit moth is now a widely distributed pest throughout the world among the major stone-fruit growing regions of Europe, Asia, America, Africa, Australia, and New Zealand (Chapman and Lienk 1971). In Australia, this insect is a key pest damaging commercial stone and pome fruit, including peaches, nectarines, apricots, plums, pears, and apples. Late-season varieties of peach and nectarine are considered the primary hosts (Rothschild and Vickers 1991); however, in the past 10 yr, it also has become a major problem in pome fruit, especially pears in Australia (Il'ichev et al. 2004) and apples in the United States (Kovanci et al. 2005, Myers et al. 2006).

Pheromone-mediated mating disruption is a major part of integrated pest management (IPM) programs in Australian fruit orchards (Williams and Il'ichev 2003). Mating disruption (MD) treatments have successfully controlled oriental fruit moth in Victorian stone fruit for >15 yr (Vickers 1990, Sexton and Il'ichev 2000). For example, areawide MD treatments that covered >1,100 ha of Victorian orchards during two consecutive seasons led to a significant reduction of oriental fruit moth populations and damage to stone fruit. These significant decreases in shoot and fruit damage demonstrated that this pest can be effectively controlled using reservoir-style pheromone dispensers deployed by hand on a contiguous large scale (Il'ichev et al. 2002, Il'ichev and Sexton 2002).

Although successful, the areawide MD program was an expensive approach for oriental fruit moth management requiring labor-intensive hand application of Isomate dispensers (500 dispensers per ha). Development of sprayable microencapsulated pheromone formulations for mating disruption that can be applied with standard spray equipment in orchards has aimed to reduce the cost of application. Field trials of sprayable microencapsulated pheromone formulations for mating disruption of orchard pests were pioneered more than two decades ago (Cardé et al. 1975, Taschenberg and Roelofs 1976) and still continue (Knight and Larsen 2004), mostly in North America. Sprayable

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microencapsulated pheromone formulations for disruption of oriental fruit moth mating became available for field trials in Australia only recently after field trials and successful registration in the United States and Canada (Waldstein and Gut 2003, Trimble et al. 2004).

The pheromone blends encapsulated in microscopic polymer capsules release active ingredient slowly over time after spray application. Unfortunately, sprayable pheromone formulations have a shorter life span (2–4 wk) than hand-applied reservoir dispensers (24–28 wk) and are affected by rainfall and sunlight (Knight et al. 2004, Waldstein and Gut 2004). Therefore, timing of application for sprayable microencapsulated pheromone formulations is critical because applications should be made immediately before initiation of moth flight for each generation. The advantages of sprayable microencapsulated formulations are that they can be applied with standard orchard spray equipment to tall canopies, and application rates and timing can be easily adjusted throughout the season. In addition, microcapsules can be tank mixed with most insecticides and fungicides commonly used in orchard IPM programs (Knight and Larsen 2004).

The aim of this study was to evaluate the effectiveness of a new sprayable microencapsulated pheromone formulation (MEC-OFM phase V) in comparison with standard hand-applied reservoir dispensers (Isomate OFM Rosso) and conventional broad-spectrum insecticide sprays for oriental fruit moth control in peaches and pears. The sprayable microencapsulated formulation, MEC-OFM phase V, is not registered in Australia, and the work presented here are the results of the first Australian field trials.

Materials and Methods

Experimental Sites. Field trials were established in commercial fruit orchards in the Goulburn Valley of northern Victoria. The experiments were conducted in peaches and pears and set up as a randomized incomplete block design with treatments applied to 2-ha plots. There were four replicates of each treatment established in peaches and three replicates in pears during the 2002–2003 field season. During 2003–2004, there were three replicates in peaches and four replicates in pears. Blocks of peaches (varieties Golden Queen, Taylor Queen, and Tatura 204) and pears (varieties William Bon Chretien and Packham's Triumph) were established for experimental treatments at the end of August or beginning of September during each season. The first oriental fruit moth catch in pheromone traps indicated the time for treatment applications and deployment of food traps for monitoring.

Pheromone Treatments. The microencapsulated sprayable pheromone formulation MEC-OFM phase V (3M Canada, London, Ontario, Canada) was provided by Certis Australia Pty. Ltd. (Greenway, ACT, Australia). The formulation contains 18.6% (Z)-8-dodecenyl acetate, 1.2% (*E*)-8-dodecenyl acetate, 0.2% (Z)-8-dodecenol, and 80% inert ingredients and is known to release pheromone for ≈40 d (Krugly 2003). The application rate was 25 ml of experimental product per 100 liters of water applied at 500 liters per ha to deliver 125 ml of product per ha (37.1 g [AI]/ha). Sprayable pheromone was applied to randomly selected 2-ha blocks of fruit trees with the orchardists' normal airblast ground spray equipment typically used for application of pesticides; application pressures did not exceed 150 psi. The MEC-OFM was applied at least 6 h before anticipated rainfall, in calm wind conditions. In the 2002–2003 season, all peach and pear blocks were sprayed monthly with five or six applications per season. During the 2003–2004 season, pear blocks were sprayed monthly as before, but peach blocks were sprayed fortnightly with 10–12 applications per season.

The MEC-OFM formulation was compared against a standard application of Isomate OFM Rosso (Shin-Etsu Chemical Co. Ltd., Japan for Biocontrol Ltd., Australia) dispensers deployed at the registered rate of 500 per ha (two dispensers per tree). The Isomate OFM Rosso dispenser is a controlled release formulation made of polyethylene tubing that is 1.2 mm in diameter. It is filled with the following three-component blend of sex pheromone: (Z)-8-dodecenyl acetate (223 mg per dispenser), (*E*)-8-dodecenyl acetate (14.5 mg per dispenser), and (Z)-8-dodecenol (2.5 mg per dispenser). The average loading is above the nominal figure of 240 mg of active ingredient per dispenser. Isomate dispensers were applied to randomly selected blocks (2 ha) of fruit trees at the same time (usually at the beginning of September) as the first treatment of sprayable pheromone.

Randomly selected 2-ha blocks of fruit trees without an MD treatment, but under a conventional insecticide spray program for oriental fruit moth management, were used as a control. These commercial peach and pear blocks were treated with seven to 14 applications of methyl-parathion or azinphos-methyl according to standard oriental fruit moth management practices in Australia (Williams and Il'ichev 2003).

Monitoring of Adult Moths. Efecto-fly traps (Avond Pty. Ltd., Western Australia) were used as food traps for oriental fruit moth monitoring. Three food traps were deployed ≈36 m apart within a tree row near the middle of each replicate plot. Each trap was filled with 1 liter of 10% brown sugar solution and 12 drops of terpinyl acetate solution (48.5 ml of terpinyl acetate with 1.5 ml of nonionic wetting agent and 50 ml of warm water). Food traps were placed in the tree canopy at a height of 1.5–2.0 m and monitored weekly. Moths caught in traps were identified and counted in the field. Monitoring was commenced in late August or early September and was terminated in mid-April.

Each replicate block also received one pheromone trap (Trécé Inc., Salinas, CA) baited with a red septum loaded with 0.1 mg of pheromone (Trécé Inc.). Male moths were counted and removed from traps weekly. Lures were replaced every 6–8 wk or once per moth flight.

Shoot Tip and Fruit Damage Assessments. Shoot tip damage assessments (only in peaches) were carried

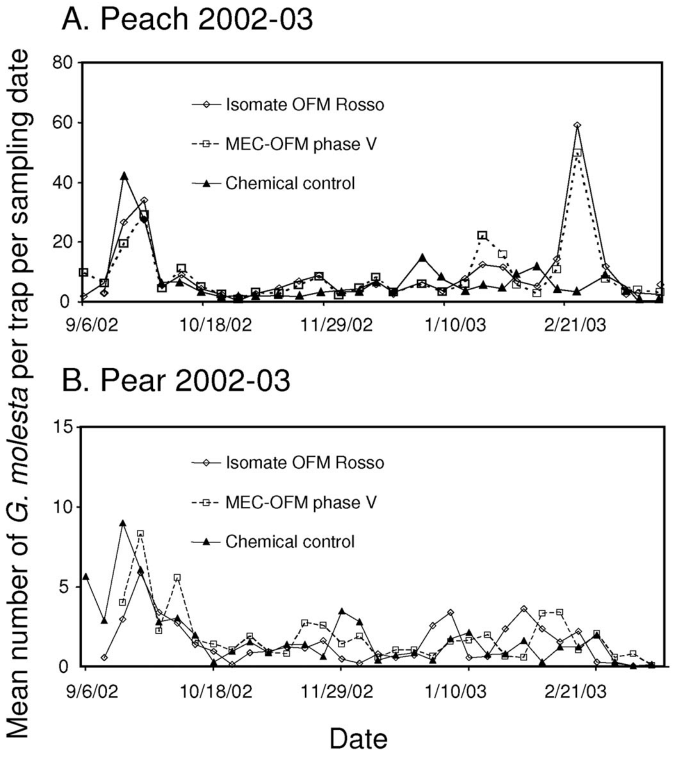

Fig. 1. Mean captures of oriental fruit moth per week in food traps throughout the 2002–2003 season in replicated 2-ha peach (A) and pear (B) blocks treated with MEC-OFM phase V, Isomate OFM Rosso, or organophosphate sprays (chemical control).

out after the second oriental fruit moth flight usually at the end of November or beginning of December. Fifty shoot tips (25 from both east and west sides of the tree canopy) were randomly selected for inspection on each of 10 peach trees in the row where food traps were deployed per replicate block.

Fruit damage assessments were carried out on peaches and pears ≈1 wk before the first harvest dates. Damage to peach and pear fruit was assessed with a random sample of 100 fruit collected from each of the trees where food traps were deployed. Another 100 fruit from each of three fruit bins per plot were sampled during harvest. All damaged peach and pear fruit were cut open for identification of oriental fruit moth larvae. Larvae found in pears were saved in alcohol and later more carefully examined under a microscope for oriental fruit moth identification by determining presence of the anal comb. The number of damaged fruit was recorded and used for analyses.

Statistical Analyses. Weekly moth catch in food and pheromone traps (except for weeks of nil catches) and shoot and fruit injury data were analyzed using GenStat 8, release 8.1. (Lawes Agricultural Trust, Rothamsted Experimental Station, Harpenden, Hertfordshire, England) (GenStat 2005). Treatment differences were determined using residual maximum likelihood and the Wald test. Pear or peach blocks and traps were included as random effects and treatment as a fixed effect. All count data were a $\log_e$ transformed before analysis to satisfy the assumptions underlying the statistical procedures. Shoot and fruit injury data were arcsine transformed before analysis. Untransformed means and standard errors are presented.

Results

2002–2003 Field Season Monitoring. Mean moth captures per week in food traps in peaches during the 2002–2003 season are shown in Fig. 1A and suggest high population densities in our experimental blocks at the onset of the experiment. Moth catches peaked during the first flight in September in plots treated with the standard chemical control. In the MEC-OFM- and Isomate-treated plots, catches peaked during the last flight in early March when moth catches in the chemical control plots were low (Fig. 1A). By the end of the season, oriental fruit moth captures decreased in the control plots, whereas catches in the MD-treated blocks slightly increased (Fig. 1A). Over the course of the season, significantly ($F = 17.4$; df = 2, 11; $P < 0.01$) fewer oriental fruit moths (mean ± SE) were captured in food traps in control plots (8.8 ± 35.4) than in plots treated with MEC-OFM (369.1 ± 36.2) or Isomate hand-applied dispensers (347.8 ± 36.2). However, there was no significant ($P > 0.05$) difference between the mean number of moths captured between the two pheromone treatments.

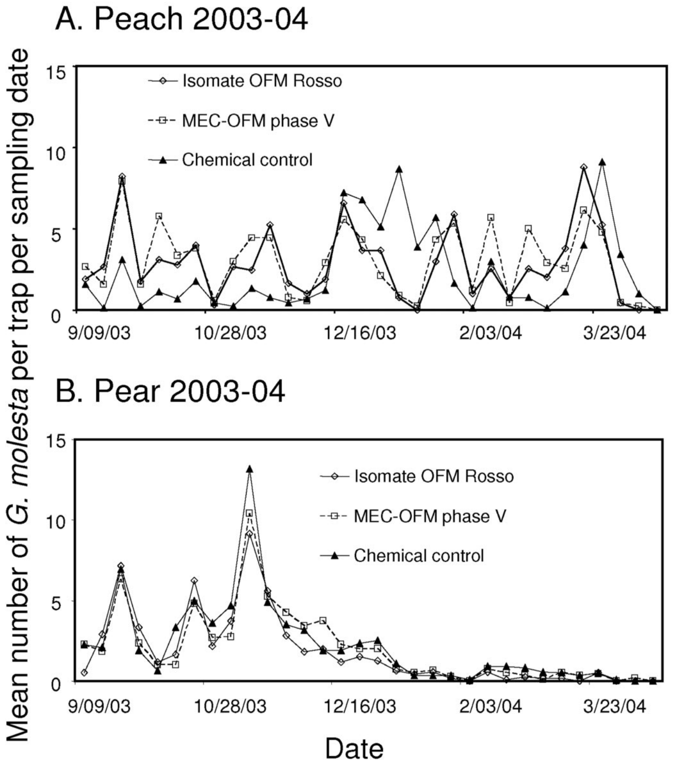

Fig. 2. Mean captures of oriental fruit moth per week in food traps throughout the 2003–2004 season in replicated 2-ha peach (A) and pear (B) blocks treated with MEC-OFM phase V, Isomate OFM Rosso, or organophosphate sprays (chemical control).

Mean captures per week in food traps in pears during the same season are given in Fig. 1B. Initial oriental fruit moth catches recorded in all experimental pear plots during the first flight in September 2002 were similar among treatments and substantially lower than the levels found in peaches. After the first flight, moth catches in food traps were low in all treatments, not exceeding four moths per trap per week. Mean ± SE captures in control plots (60.1 ± 6.7) were not significantly ($F = 0.7$; df = 1, 8; $P = 0.51$) different from those in plots treated with MEC-OFM (65.9 ± 6.7) or hand-applied Isomate dispensers (54.6 ± 6.7).

In peach blocks, significantly ($F = 9.6$; df = 5, 11; $P = 0.01$) more male moths were captured in pheromone traps in control blocks (512.8 ± 157.6) without MD than in plots treated with Isomate dispensers (8.8 ± 5.1) and MEC-OFM (22.8 ± 10.7). In pear blocks, significantly ($F = 8.5$; df = 5, 11; $P = 0.01$) more male moths were captured in control plots (99.8 ± 17.8) than in plots treated with Isomate dispensers (4.8 ± 2.3). However, the mean number of male moths captured in pheromone traps in pear plots treated with MEC-OFM (47.3 ± 25.0) was not significantly different ($P > 0.05$) from the other two treatments. Pheromone traps in Isomate-treated blocks captured male moths only during the 2 wk before and the first week after deployment of Isomate dispensers and did not catch males subsequently until nearly the end of the season. Alternatively, male catches in pheromone traps in MEC-OFM-treated plots increased slightly every 3–4 wk after each monthly application, suggesting limited (≈1-mo) longevity of effectiveness.

2002–2003 Field Season Shoot and Fruit Injury. Mean ± SE percentages of shoot tip damage in peaches, under MEC-OFM (2.4 ± 1.9) and Isomate (1.9 ± 1.5) treatments were significantly ($F = 134.1$; df = 4, 8; $P < 0.01$) lower than in control plots (12.0 ± 2.3). Mean percentage of peach fruit damage under chemical control (1.2 ± 0.3) was significantly ($F = 9.5$; df = 4, 8; $P = 0.02$) higher than that found in Isomate-treated plots (0.07 ± 0.03); no fruit damage was found in MEC-OFM-treated plots.

There were no damaged pear fruit found in MEC-OFM- and Isomate-treated plots; but, in the control plots without MD, fruit damage averaged at 0.2 ± 0.03%. In addition, there was 0.1–0.2% oriental fruit moth damage found in bins harvested from chemical control plots of pears without MD treatment, but there were no damaged pear fruit found in bins harvested from pheromone treatments.

2003–2004 Field Season Monitoring. Fig. 2A presents weekly moth catches in food traps during the 2003–2004 field season. Catches recorded during the first flight in September 2003 were much lower than those observed during the first flight in September 2002. The lowest early-season catches were recorded in control plots, peaking at only about three moths per trap per week. During this season, mean catches did not exceed about nine moths per trap per week in any of the treatments. In the beginning of the season, oriental fruit moth catches were greatest in MEC-OFM- and Isomate-treated plots in September 2003 (Fig. 2A). Near the end of the season in March 2004, catches were highest in control and Isomate-treated plots (Fig. 2A). Throughout the season, there were no significant differences ($F = 0.04$; df = 2, 11; $P = 0.86$) between mean ± SE captures of oriental fruit moth in food traps in control plots (76.1 ± 335.8), plots treated with MEC-OFM (82.0 ± 19.9), or those treated with Isomate hand-applied dispensers (77.0 ± 23.4).

Mean oriental fruit moth captures per week in food traps in pears during the same season are given in Fig. 2B. Captures recorded in all treatment plots during the first flight in September 2003 were similar with a peak of about seven moths per trap per week. After the first flight, catches under all three treatments increased and peaked in November 2003. Mean ± SE captures in control plots (81.7 ± 5.7) were not significantly ($F = 1.3$; df = 2, 11; $P = 0.33$) different from those in plots treated with MEC-OFM (74.7 ± 5.7) or hand-applied Isomate dispensers (68.9 ± 5.7).

As in the previous season, mean ± SE male captures in pheromone traps in peach control plots (379.7 ± 23.3) were significantly ($F = 72.4$; df = 4, 8; $P = 0.01$) greater than in plots treated with MEC-OFM (5.7 ± 3.0) or Isomate hand-applied dispensers (2.0 ± 1.5). However, there were no significant ($P > 0.05$) differences in mean catches of male moths between MEC-OFM and Isomate treatments. In pear blocks, there were no significant ($F = 2.5$; df = 5, 11; $P = 0.15$) differences in male captures in pheromone traps between the MEC-OFM (38.0 ± 19.6), Isomate (1.3 ± 0.6), and control (11.3 ± 3.7) treatments.

2003–2004 Field Season Shoot and Fruit Injury. Mean percentage ± SE of shoot injury in MEC-OFM (1.2 ± 0.5) and Isomate treatments (0.7 ± 0.2) was not significantly ($F = 1.5$; df = 4, 8; $P = 0.4$) different from that recorded in chemical control plots (2.8 ± 2.1). There was no significant difference ($F = 0.3$; df = 4, 8; $P = 0.9$) in fruit damage between the three treatments, which averaged 0.33% for each treatment.

There were no damaged pear fruit found in MEC-OFM and Isomate-treated plots; but, in the control plots, fruit damage averaged 0.2%. Oriental fruit moth damage recorded in bins harvested from chemical control plots of pears without MD treatment also averaged 0.2%, but there was no damage recorded from plots treated with either of the two MD treatments.

Discussion

During two consecutive seasons, monthly applications (125 ml of product per ha; 37.1 g [AI]/ha) of MEC-OFM phase V were as effective as a single application of Isomate OFM Rosso dispensers (500 dispensers per ha) and more effective than organophosphate insecticide sprays in reducing oriental fruit moth damage in replicated 2-ha blocks of pear in Australia. Furthermore, this MEC-OFM treatment was also as effective as the Isomate treatment and equally or more effective than the chemical standard in reducing shoot and fruit injury in 2-ha peach blocks, when applied monthly or fortnightly. Our results are similar to those reported by Kovanci et al. (2005), where monthly applications of MEC-OFM phase V were equally effective to Isomate-M 100 (Shin-Etsu Chemical, Tokyo, Japan) dispensers applied at 250 dispensers per ha and equally or more effective than organophosphate sprays in reducing oriental fruit moth fruit damage in North Carolina apple orchard plots. In their study, efficacy of the MEC-OFM pheromone treatment did not differ over a range of application rates (12.4–37.1 g [AI]/ha). Similarly, Trimble et al. (2004) reported fruit damage below 1% with an integrated program using MEC-OFM phase V (and earlier MEC formulations by 3M Canada), which was comparable to integrated programs that incorporated Isomate OFM Rosso (Shin Etsu Chemical) and Rak 5 (BASF Aktiengesellschaft, Ludwigshafen, Germany) hand-applied dispensers. Collectively, these results support the use of sprayable pheromone formulations similar to the MEC-OFM phase V, formerly manufactured by 3M Canada, for effective control of oriental fruit moth.

Fortnightly applications of MEC-OFM phase V in peaches during the 2003–2004 field season were only slightly more effective than monthly applications in 2002–2003. Percentage of orientational disruption of males to pheromone traps calculated as 1 − (mean moth catch per trap in the pheromone-treated block/mean moth catch per trap in the control block) × 100 in plots treated with MEC-OFM phase V by using monthly and fortnightly applications was 96 and 99%, respectively. However, protection of shoot and fruit injury was not improved by the more frequent applications in the second year of this study. Recent U.S. trials have suggested that more frequent applications of lower rates of MEC-OFM might improve efficacy over that achieved with fewer applications at higher rates (Hull et al. 2004; L.J.G. et al., unpublished data). This may be especially important in fruit-growing regions that receive large amounts of rain that dislodges microcapsules from tree foliage (Waldstein and Gut 2004). Frequency of application for effective management of oriental fruit moth in Australia is likely dependent on a number of biotic and abiotic factors such as pest density and variable environmental conditions and will require further research.

The MEC-OFM formulation tested here proved equally or more effective than a conventional program for managing oriental fruit moth in Australia based on broad-spectrum organophosphate insecticides. This level of fruit protection was achieved by a pheromone treatment alone, despite high moth population densities present in all treatment blocks as evidenced by substantial catches in food traps (Figs. 1 and 2). It is particularly notable that during the first season of this study, reduction of peach shoot and fruit damage was better in the pheromone treatments than in the chemical control, despite higher captures of moths in food traps in the pheromone-treated blocks than in the insecticide-treated blocks. These data suggest that male oriental fruit moths may have been attracted into pheromone-treated orchards. Witzgall et al. (1999) noted that male codling moth, *Cydia pomonella* (L.), were attracted into orchards treated with its main pheromone component, (*E,E*)-8,10-dodecadien-1-ol, yet disruption of mating was successfully achieved at low moth densities.

Although mating disruption using Isomate hand-applied dispensers for oriental fruit moth control has been particularly effective on an areawide scale in Australia (Il'ichev et al. 2002), this is the first report to suggest that a sprayable microencapsulated formulation could be an effective alternative for management of this pest by pheromones in Australia. The lower application cost of these formulations could increase adoption of mating disruption for oriental fruit moth in Australia (Gut et al. 2004). Although sprayable microencapsulated formulations of pheromone have not always proven highly effective for controlling certain tortricid species such as codling moth (Epstein et al. 2003, Knight and Larsen 2004, Knight et al. 2004), results from the current study and those discussed herein have consistently shown that such formulations effectively disrupt oriental fruit moth and reduce fruit injury below economically acceptable levels. The sprayable formulation evaluated in the current study is no longer manufactured or distributed by 3M Canada. However, commercial microencapsulated formulations of pheromone for disruption of oriental fruit moth are currently under development by other companies among the U.S. pest management industry. Although these new replacement formulations will require further field testing before they can be registered and adopted in Australia, the results of the current study strongly suggest that further development of MEC formulations for oriental fruit moth management in Australia is warranted.

Acknowledgments

We thank the following people from Department of Primary Industries (DPI), Tatura: Chris Sheehan, Elizabeth Alsop, and Neil Penfold for monitoring and assistance with data preparation for analysis; and Alvin Milner and Sorn Norng for experimental design discussions and for statistical analysis. Also we thank Stephen Sexton (Biocontrol Ltd. Qld., Australia) for supply of mating disruption dispensers. This research was conducted under the research project FR-01008, "Area-wide mating disruption for oriental fruit moth and codling moth control in fruit" funded by DPI, Victoria and Horticulture Australia Ltd.

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Received 30 May 2006; accepted 31 July 2006.