Comparison of Mating Disruption with Pesticides for Management of Oriental Fruit Moth (Lepidoptera: Tortricidae) in North Carolina Apple Orchards

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ABSTRACT The efficacy of mating disruption by using Isomate-M 100 pheromone dispensers and two formulations of microencapsulated sprayable pheromone for management of oriental fruit moth, *Grapholita molesta* (Busck), was compared with conventional insecticides in large plot studies in Henderson County, North Carolina, in 2000 and 2001. In addition, experiments were conducted in small and large plots to test the response of oriental fruit moth males to different application rates of sprayable pheromone. Pheromone trap catches were significantly reduced in mating disruption blocks compared with conventional and abandoned orchards. Pheromone traps placed in the upper canopy captured significantly more moths than traps placed in the lower canopy across all treatments, and lures loaded with 100 μg of pheromone caught more moths than traps with 300 μg, but the difference between doses was statistically significant at only one location in 2001. Isomate-M 100 provided excellent trap shutdown and was significantly more effective than sprayable pheromone formulations. Fruit damage by oriental fruit moth larvae was very low ($\leq$1%) in mating disruption blocks and was generally lower than in conventional and nonmanaged blocks. Based on male moth response to pheromone traps in small plots, there was little difference among doses of sprayable pheromone, ranging from 12.4 to 49.1 g (AI)/ha, but efficacy declined at 2.4 g (AI)/ha. With the exception of one orchard, there was no significant difference between 12.4 and 37.1 g (AI)/ha under low and high oriental fruit moth population pressure in large plot studies. Mating disruption proved to be an alternative to organophosphate insecticides for managing oriental fruit moth populations in North Carolina apple orchards.

KEY WORDS mating disruption, pheromones, apple

ORIENTAL FRUIT MOTH, *Grapholita molesta* (Busck), is a major pest of stone and pome fruits in North America (Allen and Plasket 1958). Although oriental fruit moth has long been an important pest of peaches, only recently has it become a key pest of apples in the Mid-Atlantic region (Felland and Hull 1998, Bergh and Engelman 2001). In North Carolina, oriental fruit moth completes at least four generations per season, with adult flight lasting from late March through October (Borchert et al. 2004a).

In North Carolina, the internal feeding lepidopteran complex of oriental fruit moth and codling moth, *Cydia pomonella* (L.), has traditionally been managed with multiple applications of broad-spectrum organophosphate insecticides, which are under review as part of the Food Quality Protection Act of 1996. Chemical control of late season oriental fruit moth populations has been difficult for a number of reasons. The last insecticide application applied to apples in North Carolina is typically made between mid-August and early September. Unfortunately, this timing does not protect apples during the most intense oriental fruit moth egg-laying period in September (Borchert et al. 2004a). In addition, oriental fruit moth resistance to organophosphate and carbamate insecticides has been documented from populations in eastern North America (Pree et al. 1998, Kanga et al. 2001, Usmani and Shearer 2001) and has probably contributed to the problem in North Carolina (J.F.W., unpublished data). The increasing importance of late season oriental fruit moth damage on apples has increased interest in the use of alternative management tactics.

Mating disruption, the release of sufficient quantities of insect pheromone into the orchard to prevent or reduce sexual communication, has proven to be a viable alternative to conventional insecticide programs for the control of oriental fruit moth populations in peach orchards (Cardé and Minks 1995). It offers many advantages, including reduced insecticide use, and thus conservation of natural enemies, decreased potential for the development of insecticide

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resistance, reduced insecticide residues on fruit and in the environment, and reduced costs associated with worker protection and labor management (Thomson et al. 2001).

A diversity of pheromone dispensing systems have been developed and used for oriental fruit moth (Weatherston 1990). Hand-applied polyethylene tubes hung within the tree canopy have been most commonly used and have produced economically acceptable insect control (Kirsch 1988). Although they have a long field life, the relatively high cost and difficulties associated with application have encouraged the development of alternative dispensing technologies (Jenkins 2002). Recently, microencapsulated formulations that can be applied using conventional sprayers have shown promise in Canadian peaches as an alternative to hand-applied dispensers (Casagrande and Jones 1997). Sprayable formulations generally have shorter residual activity compared with hand-applied dispensers, and rain washoff is a potential concern (Jenkins 2002). Trimble et al. (2004) recently reported on the use of sprayable pheromones plus insecticides as an integrated approach to managing oriental fruit moth on peaches in Canada.

The disruption of male moth orientation to pheromone traps has been one of the main criteria in assessing the efficacy of mating disruption (Rothschild 1981, Cardé and Minks 1995), but little information is available on factors that influence the performance of oriental fruit moth pheromone traps in orchards treated with pheromones for mating disruption. Thomson et al. (1999) reported that capture of codling moths in pheromone traps baited with a 1 mg of codlemone was frequently an unreliable indicator of efficacy. Charmillot (1990) showed that using traps baited with a 10-mg lure and placing them in the upper canopy could significantly increase trap catches.

The overall objective of this work was to assess the efficacy of oriental fruit moth mating disruption programs by using hand-applied Isomate-M 100 (Shin-Etsu Chemical, Tokyo, Japan) dispensers and microencapsulated sprayable pheromones (3M Canada, London, Ontario, Canada) and to determine the effect of trap height and pheromone lure load on the response of male moths to pheromone traps in mating disruption and nonpheromone-treated orchards.

Materials and Methods

General Procedures

Several experiments were conducted to compare the efficacy of Isomate-M 100 pheromone dispensers and different rates and formulations of microencapsulated sprayable pheromones with conventionally managed insecticide-treated orchards in Henderson County, North Carolina, in 2000 and 2001. For one study, oriental fruit moth populations also were monitored in nearby abandoned orchards, which served as nonmanaged controls for mating disruption and insecticide-treated orchards. Unless otherwise described, treatments were applied to large plots (2–4-ha plots) consisting of the same varieties ('Delicious', 'Golden Delicious', or 'Rome Beauty') and tree size and were replicated on different farms in Henderson County. Trees ranging in age from 10 to 20 yr were used for all studies, and although tree size varied among farms, tree height rarely varied by >1 m on the same farms. The two mating disruption blocks and conventional insecticide-treated blocks at a specific site were separated by 20–50 m. Although effort was made to locate abandoned treatments as close as possible to the respective study sites, in some instances the abandoned blocks were located as far as 3 km from a study site.

Core Management Treatments. The different studies consisted of variations of one or more of the same core management treatments, i.e., hand-applied Isomate-M 100 dispensers, 3M sprayable pheromone, conventional insecticides, and an abandoned orchard. For all treatments except the abandoned orchard, an application of carbaryl (Sevin 50 WP, 80WPS and/or XLR, Aventis, Research Triangle Park, NC) was made at petal fall for fruit thinning and for control of the first oriental fruit moth generation. Mating disruption treatments were initiated in late May, just before emergence of second-generation adults (Borchert et al. 2004a). Below is a description of the core treatments.

Isomate-M 100. Each dispenser contained 243.8 mg of synthetic sex pheromone: 88.5% (Z)-8-dodecenyl acetate (Z8–12:Ac), 5.7% (*E*)-8-dodecenyl acetate (E8–12:Ac), and 1% (Z)-8-dodecen-1-ol (Z8–12:OH), and 4.8% inert ingredients. Dispensers were placed in the tree canopy at least 2 m above the ground. They were applied at 250 dispensers per hectare at the end of May, just before the beginning of second generation flight. In North Carolina, Isomate-M 100 dispensers emit >95% of pheromone content over ≈90 d (J.F.W., unpublished data). In Isomate-M 100-treated orchards, codling moth was managed with either Isomate-C Plus pheromone dispensers (Shin-Etsu Chemical, Tokyo, Japan) applied at 990 dispensers per hectare, or three applications of tebufenozide (Confirm 2 F, Dow Agrosciences, Indianapolis, IN), in May, July, and August. In all mating disruption orchards, an additional tebufenozide application was made in June for control of first generation tufted apple bud moth, *Platynota ididaeusalis* (Walker). Tebufenozide was used in mating disruption treatments because it has relatively low toxicity to oriental fruit moth (Borchert et al. 2004b).

Oriental Fruit Moth Sprayable Pheromone. Sprayable pheromone was a water-based microencapsulated formulation containing 18.6% Z8–12:Ac, 1.2% E8–12:Ac, and 0.2% Z8–12:OH and 80% inert ingredients. Although the release rate of phase III formulation is unknown, under laboratory conditions (23°C, 40% RH) phase V formulation releases pheromone for ≈40 d (Krugly 2003). Unless otherwise specified, sprayable pheromone (phase III or V) was applied at 37.1 g (AI)/ha the last week of May, mid-July, and mid-August. Sprayable pheromone was applied with an airblast sprayer delivering 1,000–1,400 liters of water per hectare; water volume varied among study sites. Codling moth and tufted apple bud moth control programs were as described above for the Isomate treatment.

Conventional Insecticide. A nonpheromone-treated conventional block was included at each site, and sprayed with five to six applications of organophosphate insecticides: azinphos-methyl (Guthion 50 WP, Bayer Crop Science, Research Triangle Park, NC) and/or phosmet (Imidan 70 WP, Gowan, Yuma, AZ) for oriental fruit moth and codling moth control, and the insect growth regulator tebufenozide for tufted apple bud moth control. Organophosphate insecticides were timed to coincide with egg-laying periods of each of the three generations of codling moth (two applications for the first generation in May and early June, one or two applications for the second generation in July, and one application against the third generation in late August). One tebufenozide application was made against each of the two tufted apple bud moth generations in June and mid-August.

Abandoned (Nonmanaged). For each study site, oriental fruit moth populations also were monitored in a nearby abandoned orchard that received no pheromone or insecticide.

Pheromone Monitoring. Oriental fruit moth male moth populations were monitored in each treatment with wing-style pheromone traps (Pherocon 1C Trap, Trécé, Salinas, CA) from late May to early October.

Pheromone traps were checked weekly, and trap bottoms were replaced when needed to maintain a clean surface. The effects of pheromone lure dosage in traps and trap height within the canopy were examined in all treatments. Traps were baited with hexane-extracted rubber septa (Thomas Scientific, Swedesboro, NJ) impregnated with different amounts of oriental fruit moth pheromone (Bedoukian Research Inc., Danbury, CT), which consisted of 90.4% Z8–12:Ac, 6.1% E8–12:Ac, 1.1% Z8–12:OH, and 2.4% inert materials. Each septum was loaded with pheromone in 25 μl of hexane, followed by 50 μl of clean hexane. Pheromone lures in traps were changed monthly. Traps were placed in the lower and upper tree canopy in each treatment. The low traps were placed on the periphery of trees at eye level ($\approx$1.6 m), whereas high traps were hung within 0.5 m of the top of the canopy, often near the trunk of a tree.

Damage Assessment. Fruit damage was assessed twice during the season: at the beginning of third generation flight in July and at harvest in late August to late September. Injury was placed into one of three categories, with "stings" representing only surface blemishes caused by oriental fruit moth and codling moth, "entry" describing larval tunneling into the fruit, and "live worm" used for fruit infested by a live larva. Within each treatment, fruit damage was evaluated by picking 100 fruit arbitrarily from each of 10–16 trees per treatment, inspecting, and then cutting each fruit to check for internal infestation. All larvae were collected and identified to species.

Mating Disruption Comparison Study

The objective of this study was to 1) assess the efficacy of Isomate-M 100, sprayable pheromone, and conventional insecticide programs for managing oriental fruit moth; and 2) assess the effects of trap height and dosage of pheromone in lures on pheromone trap catches in the three management treatments: mating disruption, conventional insecticide, and abandoned orchards. Each treatment was replicated at three grower locations in 2000 (Barnwell, Henderson, and Staton) and 2001 (Coston, Henderson, and Staton).

Pheromone Traps. At all locations in 2000, and at the Henderson site in 2001, a total of 16 traps was placed in each management treatment; eight each in the lower and upper portion of the canopy. Four traps in each canopy position were baited with lures containing 100 μg and four were baited with 300 μg of oriental fruit moth pheromone. Traps were dispersed among eight trees per treatment, with a trap placed in the upper and lower canopy of each tree. In addition, the 100- and 300-μg lures were randomly assigned to each tree such that the paired lower and upper canopy trap in each tree had the same lure load. At the Staton and Coston sites in 2001, a total of 12 traps per management treatment were placed in the upper canopy only, consisting of three traps each baited with lures containing 0, 30, 100, and 300 μg of oriental fruit moth pheromone. The 0-μg lures were treated only with hexane. Traps were uniformly distributed within blocks, with one-half of the traps on the periphery of the block (third row from the border) and one-half in the interior.

Data Analysis. Pheromone trap data were analyzed as a split-plot design with subplots. Main plots consisted of mating disruption, conventional insecticide, and abandoned treatments. Trap height and septum dosage were the subplots. Statistical analysis was carried out on the mean of four replicates for each subplot factor by using analysis of variance (ANOVA) (SAS Institute 2001). A separate ANOVA was conducted for the Henderson orchard in 2001. Because trap placement and pheromone lure loads were different in the Staton and Coston orchards in 2001 compared with the 2000 studies, data from each year were analyzed separately using a split-plot design. ANOVA was conducted on the mean of three replicates for each subplot factor (septum dosage). LSMEANS comparisons were used to identify any significant interaction effects. Data are presented as mean cumulative moth catches per trap, but based on inspection of plots of residuals, trap counts were transformed using log $(x + 0.5)$ before ANOVA. Means were separated using Fisher's protected least significant difference (LSD) test ($P = 0.05$). Mean percentage of fruit damage data were transformed using arcsine square-root and subjected to ANOVA. Fisher's protected LSD test was used to compare treatment means ($P = 0.05$).

Small Plot Sprayable Pheromone Study

This study was conducted to compare the efficacy of different rates of sprayable pheromone formulations in small plots, by using pheromone trap catches as an assessment method. Trials were conducted in three different commercial apple orchards in 2000 (Barnwell, Henderson-B, and McCraw) and in 2001 (Barnwell, Barnwell-B, and Henderson-B). At each site, nonreplicated plots were 0.4 ha, and treatments consisted of sprayable pheromone application at rates of 0, 12.4, 30.9, and 49.4 g (AI)/ha in 2000, and 0, 2.4, 12.4, and 37.1 g (AI)/ha in 2001. Phase III and V formulations of pheromone were used in 2000 and 2001, respectively. Two applications were made in both 2000 and 2001. In 2000, the first application was made on 31 May at all locations and the second on 9 August at site 1 and 12 August at sites 2 and 3. In 2001, the first application was made on 31 May and the second on 31 July at all locations.

Pheromone Traps. Number of male moths caught in pheromone traps was used to evaluate treatment effects in test plots. In total, two traps were placed in the lower canopy in each treatment in 2000; one each baited with 100 and 300 μg of oriental fruit moth lures. In 2001, three traps were deployed in the upper canopy of each treatment, one each baited with lures impregnated with 0, 100, or 300 μg of pheromone. Traps were placed in the center of plots, and traps within the same plot were spaced ≈8 m apart.

Data Analysis. Pheromone trap data were analyzed as a factorial design, with sprayable pheromone treatments and lure dose as factors. Based on inspection of plots of residuals, data were transformed using square-root before ANOVA, but data are presented as back transformations. Trap captures after the first and second applications were analyzed separately using repeated measures ANOVA (SAS Institute 2001). Fisher's protected LSD test was used for means separation ($P = 0.05$).

Large Plot Sprayable Pheromone Study

The objective of this study was to compare two rates of sprayable pheromone with conventional insecticides in large plots. Trials were conducted in three different commercial apple orchards (Barnwell Ranch, Dalton, and Apple Ole) in 2001. At each site, phase III sprayable pheromone was evaluated at 12.4 and 37.1 g (AI)/ha and compared with a conventional insecticide treatment. Three applications of sprayable pheromone were made at each location: the last week of May, and in mid-July and mid-August.

Pheromone Traps. Two pheromone traps per treatment, one each baited with 100 and 300 μg of oriental fruit moth lures and placed in the upper canopy, were used to monitor oriental fruit moth populations. Traps baited with different lure rates were placed 40–60 m apart within each treatment. Treatment blocks were separated by ≈20 m within locations, except for the conventional block at the Dalton site, which was located ≈1 km apart from other treatment blocks.

Data Analysis. Pheromone trap data were analyzed using a factorial design with core management treatments and lure dosage as factors. Locations served as replicates. Pheromone trap data were transformed using log (x + 0.5) before ANOVA (SAS Institute 2001). Fisher's protected LSD test was used to compare treatment means ($P = 0.05$). Data are presented as back transformations.

Results and Discussion

Mating Disruption Program Comparison. Oriental fruit moth populations varied considerably among study sites in both 2000 and 2001, with mean season total trap capture in the conventional treatments ranging from 0.9 (Staton) to 64.1 (Barnwell) in 2000 and from 3.5 (Staton) to 22.2 (Henderson) in 2001. In 2000, there was a significant interaction between location and treatment ($F = 39.14$; df = 6, 108; $P = 0.01$). Pheromone traps caught significantly fewer moths in mating disruption compared with conventional blocks at all locations except Staton, where oriental fruit moth populations were low. A similar trend was observed at the Henderson orchard in 2001, where trap captures were significantly lower in mating disruption compared with conventional and abandoned blocks ($F = 142.17$; df = 3, 48; $P = 0.01$).

In 2001, considerably fewer moths were again caught in mating disruption and conventional blocks compared with abandoned blocks at Coston and Staton (Table 2). Pooled data from these two sites indicated a significant difference among treatments in cumulative trap capture ($F = 35.52$; df = 3, 64; $P < 0.01$). Location effect was not significant ($F = 3.51$; df = 1, 64; $P = 0.16$), but the location × treatment interaction was significant ($F = 4.26$; df = 3, 64; $P =$

Table 1. Mean (±SEM) cumulative oriental fruit moth pheromone trap captures in nonmanaged (abandoned), conventional insecticide-treated, and mating disruption orchards in Henderson County, NC

Yr	Location	Treatment[a]	n	Moths/trap
2000	Barnwell	Sprayable pheromone	16	8.8 (2.7)c
		Isomate-M 100	16	0.6 (0.4)d
		Conventional	16	64.1 (10.8)a
		Abandoned	16	29.1 (5.9)b
	Henderson	Sprayable pheromone	16	2.7 (1.5)c
		Isomate-M 100	16	0.3 (0.2)d
		Conventional	16	6.8 (1.3)b
		Abandoned	16	28.9 (4.1)a
	Staton	Sprayable pheromone	16	4.3 (1.6)b
		Isomate-M 100	16	2.6 (2.2)c
		Conventional	16	0.9 (0.3)c
		Abandoned	16	97.8 (9.9)a
2001	Henderson	Sprayable pheromone	16	1.9 (0.8)b
		Isomate-M 100	16	0.3 (0.1)c
		Conventional	16	22.2 (4.9)a
		Abandoned	16	29.3 (6.9)a

Means within the same location followed by the same letter are not significantly different by Fisher's protected LSD test ($P < 0.05$). Data were analyzed using log (x + 0.5), but data shown are back transformations.

[a] In 2000, phase III 3M Canada sprayable pheromone was used, and in 2001 phase V 3M Canada sprayable pheromone was used.

Table 2. Mean (±SEM) cumulative oriental fruit moth pheromone trap captures in nonmanaged (abandoned), conventional insecticide-treated, and mating disruption orchards in Henderson County, NC, 2001

Location	Treatment[a]	n	Moths/trap
Coston	Sprayable pheromone	12	0.8 (0.3)c
	Isomate-M 100	12	1.3 (0.9)c
	Conventional	12	3.7 (1.0)b
	Abandoned	12	68.8 (16.2)a
Staton	Sprayable pheromone	12	5.8. (1.3)b
	Isomate-M 100	12	2.3 (1.6)c
	Conventional	12	3.5 (0.9)c
	Abandoned	12	141.5 (26.0)a
Pooled data	Sprayable pheromone	24	3.3 (0.8)b
	Isomate-M 100	24	1.8 (0.9)b
	Conventional	24	3.6 (0.7)b
	Abandoned	24	105.2 (16.8)a

Means within the same column and location followed by the same letter are not significantly different by Fisher's protected LSD test ($P < 0.05$). Data were analyzed using log (x + 0.5), but data shown are back transformations.

[a] Phase V formulation of 3M Canada sprayable pheromone was used.

0.02). At the Staton site, significantly fewer moths were captured in the Isomate compared with the sprayable pheromone block, but there were no differences between these treatments at Coston.

Isomate-M 100 provided excellent suppression of pheromone trap capture and was significantly more effective than the sprayable pheromone treatment in five of the six cases (Tables 1 and 2) particularly evident at the Barnwell orchard in 2000, where oriental fruit moth populations were relatively high. At this site, Isomate-M 100 remained highly effective in suppressing pheromone trap catches through September, whereas catches in the sprayable pheromone block increased during the last 3 wk of September, or ≈4–8 wk after the last application in mid-August. Trimble et al. (2004) also reported that 3M OFM sprayable pheromone was less effective than Isomate-M 100 in suppressing trap capture in peaches.

One striking observation in the Isomate block at Staton in 2000 was that one of the edge traps adjacent to a wooded area, placed in the upper tree canopy, and baited with a 100-μg lure, captured a total of 36 moths out of a seasonal cumulative total of 41 moths caught in all 16 traps. It is thought that males can more easily locate traps at the edge of mating disruption blocks, because pheromone concentrations are considerably lower along borders than within the orchard because of wind effects (Milli et al. 1997). For this reason, Il'ichev et al. (1999) proposed the implementation of areawide mating disruption programs to minimize edge effects and migration of mated oriental fruit moth females.

Trap Height and Septum Dosage Comparison. There was a significant interaction between trap height and treatment in 2000 ($F = 20.12$; df = 3, 108; $P < 0.01$). Trap captures in high and low traps deployed in abandoned blocks did not differ statistically, whereas high traps caught significantly more moths in pheromone-treated and insecticide-treated blocks (Table 3). At the Henderson orchard in 2001, the treatment × height interaction was not significant ($F = 0.53$, df = 4, 48; $P = 0.55$), and traps placed in the upper canopy had a higher trap capture in each treatment, including the abandoned orchard.

Apparently, oriental fruit moth males preferred to fly higher in the canopy. Several researchers have shown that codling moth pheromone traps were more sensitive when they were placed in the upper part of the canopy in both pheromone-treated and nonpheromone-treated orchards (Charmillot 1990, Knight 1995). The assessment of the efficacy of mating disruption based solely on pheromone traps placed in the lower canopy may provide misleading information for predicting population densities (Thomson et al. 1999, Borchert and Walgenbach 2000).

Traps baited with rubber septa lures loaded with 100 μg of pheromone caught more moths than traps with 300 μg across all treatments in 2000 (24.1 ± 4.1 versus 17.0 ± 2.9 cumulative moths per trap), although this difference was not significant ($F = 1.36$; df = 1, 108; $P = 0.26$). In 200, 100-μg traps caught more moths than 300-μg traps ($F = 18.72$; df = 1, 48; $P = 0.02$), and this was because of a significant treatment × dosage interaction ($F = 26.53$; df = 3, 48; $P = 0.01$); significantly more moths were captured in 100- versus 300-μg lures only in the abandoned treatment (Table 4).

Table 3. Mean (±SEM) cumulative oriental fruit moth pheromone trap captures in traps placed in the lower and upper canopy in nonmanaged (abandoned), conventional insecticide-treated, and mating disruption orchards in Henderson County, NC

Yr	Location	Treatment[a]	n	Trap ht		Low vs upper
				Lower	Upper	P
2000	Pooled data	Sprayable pheromone	24	0.8 (0.3)c	9.7 (2.0)b	<0.01
		Isomate-M 100	24	0.1 (0.1)c	2.2 (1.5)c	<0.01
		Conventional	24	15.4 (5.9)b	32.4 (9.0)b	0.02
		Abandoned	24	46.5 (6.7)a	57.4 (10.4)a	0.50
2001	Henderson	Sprayable pheromone	8	0.6 (0.3)b	3.3 (1.5)b	<0.01
		Isomate-M 100	8	0.1 (0.1)b	0.4 (0.2)c	0.02
		Conventional	8	18.4 (5.4)a	26.0 (8.5)a	<0.01
		Abandoned	8	18.5 (5.4)a	40.0 (11.8)a	<0.01

Means within the same column and location followed by the same letter are not significantly different by Fisher's protected LSD test ($P <$ 0.05). Data were analyzed using log (x + 0.5), but data shown are back transformations.

[a] In 2000, phase III 3M Canada sprayable pheromone was used, and in 2001 phase VI 3M Canada sprayable pheromone was used.

Table 4. Mean (±SEM) cumulative oriental fruit moth pheromone trap captures in traps by using lures baited with 100 and 300 μg of pheromone in nonmanaged (abandoned), conventional insecticide-treated, and mating disruption orchards in Henderson County, NC

Yr	Location	Treatment[a]	n	Septum dose (μg)		100 vs. 300 μg
				100	300	P
2000	Pooled data	Sprayable pheromone	24	6.5 (2.1)c	4.0 (1.0)c	0.92
		Isomate-M 100	24	2.0 (1.5)d	0.3 (0.1)d	0.30
		Conventional	24	28.3 (8.9)b	19.5 (6.4)b	0.95
		Abandoned	24	59.6 (10.3)a	44.2 (6.7)a	0.25
2001	Henderson	Sprayable pheromone	8	2.3 (1.3)b	2.4 (1.1)b	0.15
		Isomate-M 100	8	0.5 (0.4)b	0.8 (0.4)b	1.00
		Conventional	8	21.1 (5.7)a	23.9 (8.5)a	0.46
		Abandoned	8	36.9 (11.4)a	22.6 (7.8)a	0.02

Means within the same column and location followed by the same letter are not significantly different by Fisher's protected LSD test ($P < 0.05$). Data were analyzed using log (x + 0.5), but data shown are back transformations.

[a] In 2000, phase III 3M Canada sprayable pheromone was used, and in 2001 phase VI 3M Canada sprayable pheromone was used.

There was not a significant treatment × lure dosage effect in the Coston and Station orchards in 2001 ($F = 1.13$; df = 9, 48; $P = 0.43$), but there was a significant lure dosage effect when data were pooled among treatments ($F = 12.83$; df = 3, 48; $P = 0.01$). Traps baited with 100-μg lures caught significantly more moths than did 0- and 300-μg lures, but the attractiveness of 100-μg lures did not significantly differ from 30-μg lures (Fig. 1A). A significant interaction was detected between lure dosage and location ($F = 3.62$; df = 3, 48; $P = 0.03$). Trap capture at loadings of 30, 100, and 300 μg did not differ statistically at Coston, whereas 100-μg lures were statistically more attractive than 300-μg lures at Staton where moth populations were higher (Fig. 1B).

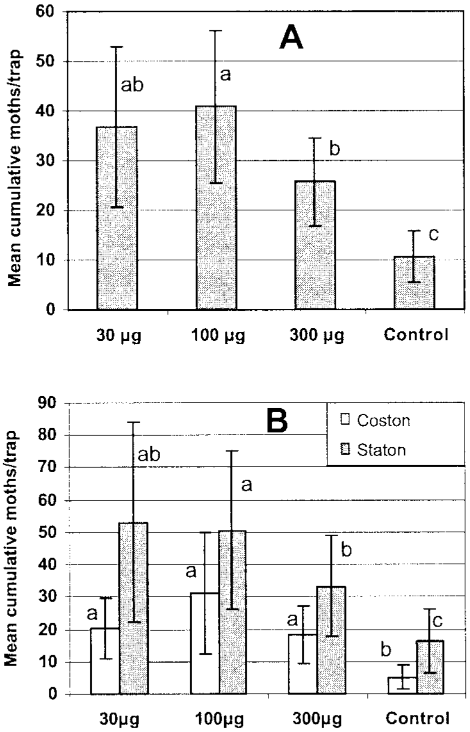

Fig. 1. Mean (±SEM) cumulative oriental fruit moth pheromone trap captures, averaged across treatments and locations, in traps baited with 0- (control), 30-, 100-, and 300-μg pheromone lures (A) and at the Coston and Staton orchards (B). Henderson County, North Carolina, 2001. Bars (within orchard in B) followed by the same letter are not significantly different by Fisher's protected LSD test ($P < 0.05$).

These results suggest that male oriental fruit moth responded optimally to traps baited with 100-μg lures under orchard conditions regardless of management treatment. Roelofs et al. (1973) reported that pheromone traps baited with 200 μg of oriental fruit moth pheromone captured significantly more moths than traps with 1, 10, or 1000 μg of pheromone, whereas Gentry et al. (1974) showed that dosages of 500 and 2000 μg were equally effective. Loadings of 30 and 100 μg correspond to calculated release rates of 20 and 70 ng per septum per hour (Sanders and Lucuik 1996). The release rate from 100-μg lures is almost 3 times that of the highest release rate recorded from oriental fruit moth females, which is 25.3 ng/h (Lacey and Sanders 1992). However, the release rate of pheromone from a septum often decreases with time in the field (Millar et al. 1997). Also, pheromones are usually released at a faster rate with increasing temperature. Kehat et al. (1994) showed that codling moth catches were negatively correlated with aging of septa. In summary, it can be concluded that an increase in the amount of pheromone beyond 100 μg per septum did not improve the sensitivity of pheromone trap catches in pheromone-treated, insecticide-treated or untreated blocks.

Damage Assessment. With the exception of abandoned blocks, there was no damage caused by internal-feeding lepidopteran larvae in July 2000 (Table 5). At harvest in September, mean percentage of fruit with live larvae was very low in all treatments (≤1.0%), and although the percentage of entries and live larvae occurring in the conventional treatment were higher than either mating disruption treatment, these differences were not significant. Larval stings on the exterior of fruit were slightly higher in the mating disruption compared with the conventional treatment, but again these differences were not significant. Because no damage was observed in mating disruption

Table 5. Mean (±SEM) percentage of fruit damage in nonmanaged (abandoned), conventional insecticide-treated, and mating disruption orchards averaged across three different locations in Henderson County, NC

Yr	Month	Treatment[a]	n	% damage		
				Sting	Entry	Live larvae
2000	July	Sprayable pheromone	3	0.0 (0.0)b	0.0 (0.0)b	0.0 (0.0)b
		Isomate-M 100	3	0.0 (0.0)b	0.0 (0.0)b	0.0 (0.0)b
		Conventional	3	0.0 (0.0)b	0.0 (0.0)b	0.0 (0.0)b
		Abandoned	3	0.7 (0.2)a	6.1 (1.3)a	1.5 (0.5)a
	Sept.	Sprayable pheromone	3	1.5 (0.4)a	0.7 (0.4)a	0.3 (0.3)a
		Isomate-M 100	3	1.2 (0.8)a	0.5 (0.1)a	0.2 (0.1)a
		Conventional	3	0.7 (0.3)a	1.7 (1.6)a	0.6 (0.5)a
2001	July	Sprayable pheromone	3	0.2 (0.1)a	0.4 (0.4)b	0.1 (0.1)b
		Isomate-M 100	3	0.5 (0.4)a	0.0 (0.0)b	0.0 (0.0)b
		Conventional	3	0.0 (0.0)a	0.3 (0.2)b	0.0 (0.0)b
		Abandoned	3	0.0 (0.0)a	8.7 (0.8)a	2.1 (0.2)a
	Sept.	Sprayable pheromone	3	0.8 (0.3)a	3.4 (2.3)b	0.1 (0.1)b
		Isomate-M 100	3	0.3 (0.2)a	0.8 (0.4)b	0.0 (0.0)b
		Conventional	3	0.2 (0.1)a	0.1 (0.1)b	0.0 (0.0)b
		Abandoned	3	1.3 (0.5)a	35.9 (4.9)a	4.2 (0.7)a

Means within the same column, year and month followed by the same letter are not significantly different by Fisher's protected LSD test ($P < 0.05$). Data were analyzed using arcsine square root, but data shown are back transformations. ANOVA statistics for stings, entries, and live larvae for July 2000 are $F = 36.24$; df = 3, 6; $P < 0.01$; $F = 68.28$; df = 3, 6; $P < 0.01$; $F = 37.54$; df = 3, 6; $P < 0.01$, respectively; for September 2000 are $F = 1.07$; df = 2, 4; $P = 0.42$; $F = 0.04$; df = 2, 4; $P = 0.96$; $F = 0.04$; df = 2, 4; $P = 0.96$; for July 2001 are $F = 2.52$; df = 3,6; $P = 0.15$; $F = 38.86$; df = 3, 6; $P < 0.01$; $F = 63.24$; df = 3, 6; $P < 0.01$; and for September 2001 are $F = 2.23$; df = 3, 6; $P = 0.18$; $F = 46.73$; df = 3, 6; $P < 0.01$; $F = 51.21$; df = 3, 6; $P < 0.01$.

[a] In 2000, phase III 3M Canada sprayable pheromone was used, and in 2001 phase V 3M Canada sprayable pheromone was used.

blocks in July, it can be concluded that the majority of fruit damage occurred in August and September.

During the mid-July damage assessment in 2001, the mean percentage of fruit with live larvae and entries in mating disruption and conventional blocks was significantly lower than in the abandoned blocks. Although there were no significant differences in damage among the mating disruption and conventional treatments at harvest in September, the sprayable pheromone treatment did have a numerically higher number of entries (3.4%) compared with the Isomate or conventional treatments. No live larvae were found in the Isomate (0.8% entries) and conventional (0.1% entries) blocks. The relatively high number of entries in the sprayable treatment was because of one location—Staton orchard. At this site, all larvae were identified as codling moth.

Fruit damage assessments suggest that mating disruption with both the Isomate-M 100 and 3M sprayable pheromone was equally effective as the four to five organophosphate insecticide applications in the conventional plots. It should be noted that two to three tebufenozide applications were made in mating disruption treatments for codling moth control and probably aided in suppressing oriental fruit moth populations. However, tebufenozide is a relatively weak insecticide against this pest (Borchert et al. 2004b), and the last applications were made 4–6 wk before harvest, so these effects were probably minimal. The fact that similar levels of fruit injury occurred in the Isomate and sprayable pheromone treatments despite slightly higher pheromone trap captures in the sprayable treatment, suggests that pheromone trap capture may not provide an accurate assessment of efficacy. Pheromone trap data may provide a more sensitive indicator of behavior than of potential fruit damage.

Small Plot Sprayable Pheromone Rate Study. Pheromone trap capture was extremely low in treatments of all three rates of phase III sprayable pheromone evaluated in 2000. Ten weeks after the first application on 31 May, a total of almost 40 moths per trap were captured in the control, whereas four or fewer moths per trap were caught in any of the sprayable pheromone treatments (Fig. 2A). Repeated measures ANOVA showed that there were significant differences among treatments after the first application in 2000 ($F = 6.47$; df = 3, 8; $P = 0.03$). The significant treatment × time (week) interaction also indicated that relative effects of treatments were not consistent over time ($F = 6.48$; df = 27, 72; $P < 0.01$). Treatments did not differ significantly during the first 3 wk, probably because of low overall moth populations, but all pheromone treatments significantly reduced cumulative trap capture over the control by 4 wk after application. There were no significant differences among pheromone treatments over time. Location effect ($F = 3.34$; df = 2, 8; $P = 0.09$) and the location × treatment interaction ($F = 1.67$; df = 6, 8; $P = 0.25$) were not significant.

Similar results were obtained after the second application in mid-August 2000. Mean cumulative trap capture in the control 7 wk after application was 47.3 moths per trap, whereas cumulative capture did not exceed 10 moths per trap in any of the sprayable pheromone treatments (Fig. 2B). Variation among locations was high, indicated by a significant location effect ($F = 13.66$; df = 2, 8; $P < 0.01$), and this contributed to the lack of an overall significant treatment effect ($F = 2.86$; df = 3, 8; $P = 0.13$). However, there was a significant week × treatment interaction ($F = 2.58$; df = 18, 48; $P < 0.01$); no significant differences were detected among treatments until 3 wk after ap-

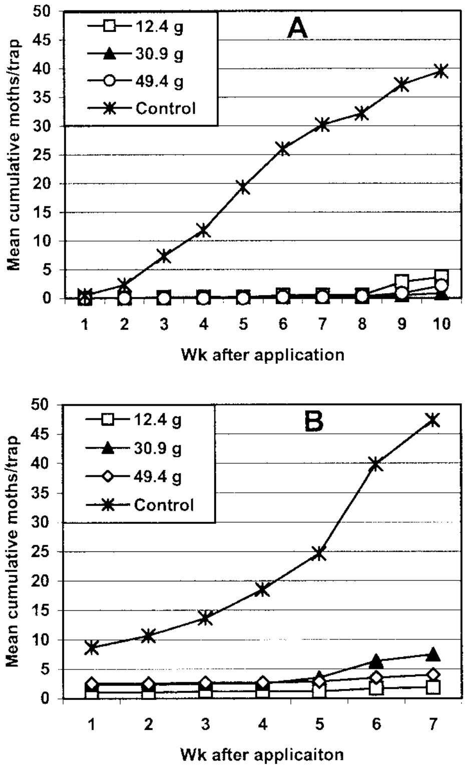

Fig. 2. Mean cumulative oriental fruit moth pheromone trap captures in small blocks treated with 0, 12.4, 30.9 and 49.4 g (AI)/ha of phase III sprayable pheromone after the first (A) and second application (B). Henderson County, North Carolina, 2000.

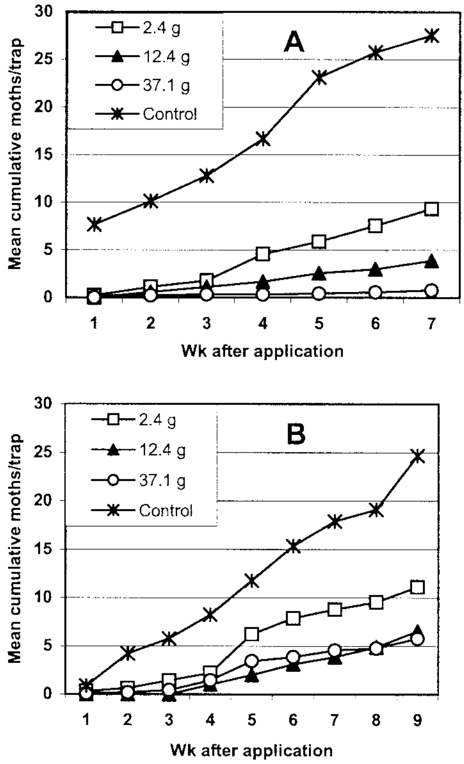

Fig. 3. Mean cumulative oriental fruit moth pheromone trap captures in small blocks treated with 0, 12.4, 30.9, and 49.4 g (AI)/ha of phase V sprayable pheromone after the first (A) and second application (B). Henderson County, North Carolina, 2001.

plication. In all pheromone treatments, except 30.9 g/ha, traps caught significantly fewer moths compared with the control from weeks 3 to 7, but there were no differences among the three rates of pheromone. The location × treatment interaction effect was not significant ($F = 2.86$; df = 6, 8; $P = 0.09$).

The lack of differences among sprayable pheromone rates ranging from 12.4 to 49.4 g/ha in 2000 led us to evaluate lower rates (2.4 and 12.4 g/ha) in 2001. There was a significant treatment effect ($F = 9.50$; df = 3, 16; $P = 0.01$) for cumulative pheromone trap captures for the 7-wk period after the first application on 31 May in 2001. Additionally, the significant treatment × week interaction ($F = 9.62$; df = 18, 96; $P < 0.01$) indicated that treatment effects varied over time. There was no difference in the efficacy of the different sprayable pheromone rates for the first 3 wk after application, but from week 4 to 7 significantly fewer moths were captured in the 37.1 compared with 2.4-g rate (Fig. 3A). Pheromone trap capture in the 12.4-g rate was intermediate between the 2.4- and 37.1-g rates, and did not differ from either rate between weeks 4 and 7. Location ($F = 0.64$; df = 2, 16; $P = 0.54$) and the location × treatment interaction ($F = 2.55$; df = 6, 16; $P = 0.06$) were not significant.

After the second application on 31 July 2001, treatments were again significantly different ($F = 22.17$; df = 3, 16; $P < 0.01$), and relative treatment effects differed significantly over time (treatment × time: $F = 2.42$; df = 24, 128; $P < 0.01$). There were no differences in trap captures among the three rates of sprayable pheromone for 4 wk after application (Fig. 3B). Pheromone trap capture increased in all sprayable pheromone treatments between weeks 4 and 9, but the rate of increase was higher in the 2.4 compared with 12.4- or 37.1-g treatment. Trap captures in the 2.4-g treatment were significantly higher than the 12.4-g in weeks 5 and 7. Similar significant differences were detected between 2.4 g and 37.1 g rates in week 7 and 8. Location ($F = 2.64$; df = 2, 16; $P = 0.10$) and the location × treatment interaction ($F = 0.59$; df = 6, 16; $P = 0.73$) effects were not significant.

Together, these results suggest that here was little difference among application rates of sprayable pheromone ranging from 12.4 to 49.1 g (AI)/ha over time, but efficacy declined at the 2.4 g (AI)/ha rate 3 to 4 wk after application. The cost of mating disruption is often an impediment to adoption (Rice and Kirsch 1990). The label rate of 3M Canada OFM sprayable formulation ranges from 24.7 to 37.1 g (AI)/ha. We have recently used oriental fruit moth sprayable

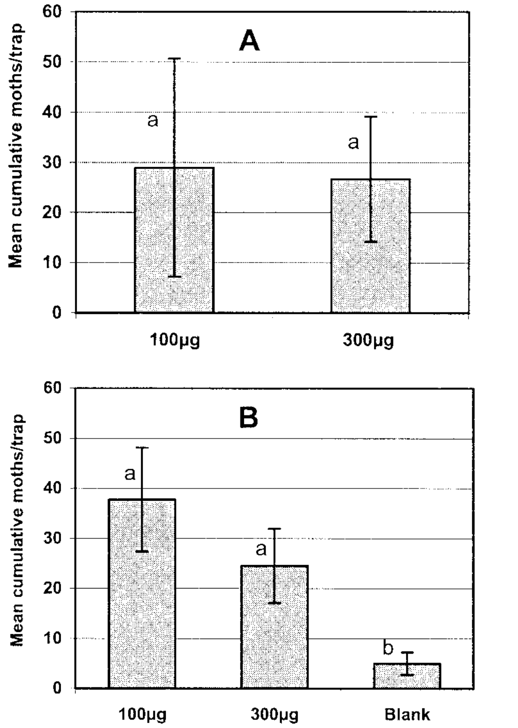

Fig. 4. Mean (±SEM) cumulative oriental fruit moth pheromone trap captures, averaged across sprayable pheromone treatments, baited with lures impregnated with 100 and 300μg of pheromone in 2000 (A) and 0, 100 and 300 μg of pheromone in 2001 (B). Henderson County, North Carolina.

pheromones at rates <12.4 g (AI)/ha with no increase in fruit damage compared with organophosphate-treated blocks (J.F.W., unpublished data), and this reduced rate potentially represents a 40% savings in cost.

The response of moths to traps baited with rubber septum lures loaded with 100 or 300 μg of pheromone in these small plot rate studies was similar to that observed in the large plot studies. Traps baited with 100-μg lures caught more moths than 300-μg lures across all treatments (Fig. 4A), but these differences were not significant (in 2000: $F = 0.79$; df = 1, 8; $P = 0.40$). In 2001 when control septa (no pheromone) were included, traps baited with 100 or 300 μg of oriental fruit moth pheromone caught significantly more moths than the control septa (Fig. 4B) ($F = 27.26$; df = 2, 16; $P < 0.01$). Although 100-μg lures caught more moths than 300-μg lures, these differences were not significant.

Large Plot Sprayable Pheromone Rate Study. Although sprayable pheromone treatments reduced pheromone trap (100-μg lures) captures below the insecticide-treated conventional treatment (Table 6) these differences among treatments were not statistically significant when data were pooled across sites ($F = 2.22$; df = 2, 6; $P = 0.22$), which was probably because of high variability among test sites. Location effect ($F = 11.33$; df = 2, 6; $P = 0.02$) and the treatment × location interaction ($F = 5.70$; df = 4, 6; $P = 0.03$) were significant. Although there was no significant difference at Apple Ole, there was a significant difference among treatments at the Barnwell Ranch and Dalton orchards. At Barnwell Ranch, oriental fruit moth populations were relatively high, and traps in the pheromone treatments caught significantly fewer moths than in the insecticide-treated control, but the difference between 12.4 and 37.1 g (AI)/ha was not statistically significant. In contrast, at the Dalton orchard, trap capture was significantly lower in blocks treated with 37.1 g (AI)/ha compared with the 12.4 g (AI)/ha or the insecticide-treated control.

Table 6. Mean (±SEM) cumulative oriental fruit moth pheromone trap catches in large blocks treated with 12.4 or 37.1 g (AI)/ha of sprayable pheromone compared with insecticide-treated control in Henderson County, NC, 2001

Location	Pheromone rate (g[AI]/ha)	*n*	Moths/trap
Barnwell Ranch	12.4	2	68.5 (24.5)b
	37.1	2	39.5 (4.5)b
	Control	2	144.5 (9.5)a
Apple Ole	12.4	2	9.5 (0.5)a
	37.1	2	10.5 (5.5)a
	Control	2	11.0 (4.0)a
Dalton	12.4	2	12.0 (3.0)a
	37.1	2	0.5 (0.5)b
	Control	2	6.5 (0.5)a
Pooled data	12.4	6	30.0 (13.8)a
	37.1	6	16.8 (7.6)a
	Control	6	54.0 (28.8)a

Means within location followed by the same letter are not significantly different by Fisher's protected LSD test ($P < 0.05$). Data were analyzed using log (x + 0.5), but data shown are back transformations.

It seems that the 12.4 and 37.1 g (AI)/ha rates were equally effective under low and high oriental fruit moth population pressure at all locations except Dalton. One possible explanation for the results at Dalton is the terrain in the 12.4-g treatment plot, which was on a steep slope, in contrast to that of the 37.1-g treatment. The steep terrain may have resulted in the sinking and drifting of pheromone out of the tree canopy down to the orchard floor, ultimately draining away from the plot's high ground. This phenomenon has been observed with several pests in different areas of the world, particularly codling moth in apple orchards on hilly terrain in California (Rice 1993). In the Dalton orchard, this may have contributed to higher trap captures in the higher (12.4-g treatment) than the lower areas (37.1-g treatment) of the orchard.

The results of these studies demonstrate that oriental fruit moth mating disruption with either Isomate-M 100 or sprayable pheromone was successful in managing this insect when combined with chemical control of the first generation. The use of mating disruption reduced the use of conventional insecticides considerably by eliminating the four or five organophosphate applications per season. Mating disruption may be even more effective than conventional insecticide programs if applied using an areawide approach (Vickers et al. 1985). Il'ichev (2002) showed that areawide mating disruption worked effectively and was able to successfully control high populations of oriental fruit moth.

Pheromone trapping is a useful tool for monitoring the efficacy of mating disruption (Rothschild 1981). The relative efficiency of pheromone traps varies with respect to their placement (McNeil 1991). Based on our results, trap height seemed to be a critical factor affecting oriental fruit moth trap capture, which was consistently higher in the upper canopy. In addition, pheromone lures loaded with the standard 100-μg dose were generally more effective than 30 or 300 μg.

Based on the results of these trials, mating disruption seems to be a feasible alternative to conventional insecticides for managing oriental fruit moth populations in North Carolina apple orchards. The success of sprayable oriental fruit moth pheromone is encouraging because it offers growers an alternative to hand-applied dispensers. The expense and limited availability of labor required for applying dispensers has been an obstacle to more widespread adoption of mating disruption in North Carolina, and sprayable pheromones provide flexibility in terms of timing of applications and rates applied.

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