ABSTRACT

KOVANCI, ORKUN BARIS. Mating disruption for control of the Oriental fruit moth, *Grapholita molesta* (Busck) (Lepidoptera:Tortricidae), in North Carolina apple orchards. (Under the direction of James F. Walgenbach and George G. Kennedy.)

Oriental fruit moth, *Grapholita molesta* (Busck), has been a primary pest of peaches for many years throughout the world, and recently it has also emerged as a key pest of apples in the eastern United States. The implementation of the Food Quality Protection Act has eliminated the use of many organophosphate insecticides and encouraged the search for alternatives to organophosphates for control of Oriental fruit moth. Large and small plot studies were conducted to evaluate mating disruption as an alternative control tactic against Oriental fruit moth in North Carolina apple orchards during 2000-2002. The efficacy of Isomate-M 100 pheromone dispensers and microencapsulated sprayable pheromone was compared to insecticide-treated and non-managed orchards. Pheromone trap catches were significantly reduced in mating disruption blocks compared with conventional and non-managed orchards. Pheromone traps placed in the upper canopy captured significantly more moths than traps placed in the lower canopy across all treatments. Male OFM responded optimally to traps baited with 100 µg lures compared with 30 and 300 µg lures regardless of treatment. The loss of OFM pheromone from red rubber septa over a four-wk period exhibited a first-order release rate for septa loaded with 100 and 300 µg pheromone, but a more constant release rate from septa loaded with 30 µg pheromone. Based on pheromone trap captures, there was little difference among rates of sprayable pheromone ranging from 12.4 to 49.1 g (ai)/ha, but efficacy declined at 2.4 g (ai)/ha applied at monthly intervals. The 6.2 g

(ai)/ha rate applied at 2-wk intervals was significantly less effective than monthly applications of 12.4 and 24.7 g (ai)/ha. Significantly fewer moths were caught in pheromone traps deployed in blocks treated in late May with Isomate-M 100, Isomate-M Rosso and Isomate-M 100 plus 3M sprayable pheromone compared with traps in conventional insecticide treatments, and Isomate-M 100 applied in late June. Overall, fruit damage by OFM larvae was quite low in mating disruption blocks.

MATING DISRUPTION FOR CONTROL OF THE ORIENTAL FRUIT MOTH,

Grapholita molesta (Busck) (LEPIDOPTERA:TORTRICIDAE),

IN NORTH CAROLINA APPLE ORCHARDS

By

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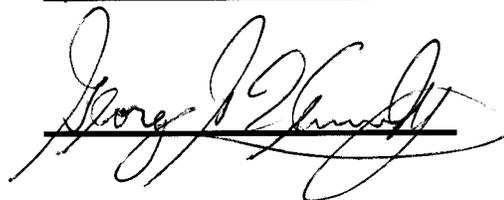
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DEDICATION

This work is dedicated first to my father, Dr. Bahattin Kovanci, who not only taught me the fundamentals of entomology and pest management, but also inspired me to pursue a career in insect science through his own overwhelming enthusiasm for the study of insects. Secondly, it is dedicated to my mother, who has encouraged me with her love and support throughout my graduate study.

Finally, I dedicate this work to Turkish farmers who are willing to adopt alternative pest management systems that utilize integrated and sustainable approaches while reducing the use of pesticides and maintaining environmental quality.

BIOGRAPHY

Orkun Baris Kovanci was born in Ankara, the capital of Turkey, on July 21, 1975, to Sevla and Bahattin Kovanci. He was raised in Bursa, which is nestled in the foothills of Mount Uludag in northwestern Turkey. There he attended public schools, graduating from Bursa boys high school in 1992. That same year he enrolled in the Faculty of Agriculture at Uludag University.

Influenced by his father's dedication to the study of insects, Orkun gravitated toward entomology as a career. In 1995, he was awarded with a German Academic Exchange Service (DAAD) internship in entomology at the University of Bonn, where he developed an interest in integrated pest management. He earned a Bachelor's of Science degree in Plant Protection in 1996. In the fall of 1996, he began his Master's study in the Department of Plant Protection at Uludag University. He received a scholarship from Israel's Center for International Cooperation (MASHAV) for a course on "Protected cultivation of high value crops" in 1998. In the same year, he earned a Master of Science degree. In 1999, he won a scholarship from Uludag University and Turkish Higher Education Council to pursue a doctoral degree in entomology in the United States of America.

TABLE OF CONTENTS

LIST OF TABLES

Chapter I

Chapter II

Chapter III

LIST OF FIGURES

Chapter I

Chapter II

Chapter III

Appendix

CHAPTER I

COMPARISON OF MATING DISRUPTION WITH CONVENTIONAL PEST MANAGEMENT FOR THE CONTROL OF ORIENTAL FRUIT MOTH, *Grapholita molesta* (BUSCK) (LEPIDOPTERA:TORTRICIDAE), IN NORTH CAROLINA APPLE ORCHARDS

ABSTRACT

The efficacy of mating disruption using Isomate-M 100 pheromone dispensers and two formulations of microencapsulated sprayable pheromone for management of Oriental fruit moth, *Grapholita molesta* (Busck), were compared to conventional insecticides in large plot studies in Henderson County, NC, in 2000 and 2001. In addition, small and large plot experiments were conducted to test the response of OFM males to different rates of sprayable pheromone applications. 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 OFM larvae was quite low (<1%) in mating disruption blocks, and was generally lower than in conventional and non-managed blocks. Based on male moth response to pheromone traps in small plot studies, there was little difference among rates 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 OFM population pressure in large plot studies. Mating disruption proved to be a viable alternative to organophosphate insecticides for managing OFM populations in North Carolina apple orchards.

INTRODUCTION

The Oriental fruit moth (OFM), *Grapholita molesta* (Busck), is a major pest of stone and pome fruits in North America (Allen and Plasket 1958). Although OFM has long been an important pest of peaches, only recently has it become a key tortricid pest of apples in the Mid-Atlantic region (Walgenbach et al. 1999, Hull et al. 2001, Usmani and Shearer 2001). In North Carolina (NC), OFM completes at least four generations per season, with adult flight lasting from late March through October, a minimum time period of 150 days (J. Walgenbach, unpublished data). OFM larvae feed in the apple, usually at the calyx end and often do not feed on seeds (Chapman and Lienk, 1971).

In NC, chemical control of OFM has relied on broad-spectrum organophosphate and carbamate insecticides, which are under review as a result of the Food Quality Protection Act (FQPA). Chemical control of late season OFM populations has been difficult for a number of reasons. The last insecticide application during a season is typically made between mid August and early September. Unfortunately, this timing does not protect apples during much of September and October (Walgenbach 2002). In addition, resistance to organophosphate and carbamate insecticides has been documented in OFM populations on peach in the Niagara Peninsula of Ontario and on apple in New Jersey (Pree et al. 1998, Kanga et al. 2001, Shearer and Usmani 2001). The increasing importance of late-season OFM damage on apple has increased interest in the use of alternative management tactics.

Mating disruption, the release of sufficient quantities of insect pheromone into the orchard environment to prevent or reduce sexual communication, has proven to be a viable alternative to conventional insecticide programs for the control of OFM 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 resistance, reduced residues on fruit and in the environment, and reduced costs associated with worker protection and labor management (Thomson et al. 2001).

Commercially acceptable levels of control, using hand-applied dispensers, have been demonstrated for OFM in peach orchards in California and Virginia (Weakley et al. 1987, Pfeiffer and Killian 1988). OFM has recently been the target of intensive mating disruption programs worldwide in peach in Australia, South Africa, South America and southern Europe (Rice and Kirsch 1990, Vickers 1990, Molinari and Cravedi, 1992, Barnes et al. 1997).

Over the years, a diversity of pheromone dispensing systems has been developed (Weatherston 1990), and more are currently being developed and field-tested. Hand applied polyethylene tubes hung within the tree canopy have been most commonly used and have produced economically acceptable control (Kirsch, 1988). Although they have a long field life, the relatively high cost and difficulties associated with application has encouraged the development of alternative dispensing technologies (Jenkins 2002). A new advancement includes microencapsulated formulations that can be applied using conventional sprayers (Casagrande and Jones, 1997). However, most of these materials are shorter-lived

4

compared to hand applied dispensers and rain wash-off is a concern (Jenkins, 2002). Although there are many products available for OFM mating disruption, little is known about the relative efficacy of different pheromone dispensing systems in NC apples.

OFM is typically monitored by pheromone trapping of male moths (Hughes and Dorn 2002). Trap catches have been one of the main criteria for assessing the efficacy of mating disruption (Rotschild 1981, Carde and Minks 1995), but little information is available on factors influencing the performance of pheromone traps in orchards treated with mating disruption. Thomson et al. (1999) reported that capture of codling moths in pheromone traps baited with 1 mg of codlemone was frequently an unreliable indicator of efficacy. Charmillot (1990) showed that trap catches could be significantly increased by using traps baited with 10 mg lure and locating them in the upper part of the canopy.

The overall objective of this work was to assess the efficacy of OFM mating disruption programs using Isomate M100 dispensers (Shin-Etsu Chemical, Tokyo, Japan) and microencapsulated sprayable pheromones (3M Canada, London, Ontario), and to determine the effect of trap height and pheromone load on the response of male moths to pheromone traps in mating disruption and non-pheromone treated orchards.

MATERIALS AND METHODS

General procedures. A number of different experiments were conducted to compare the efficacy of Isomate-M 100 dispensers and different rates and formulations of microencapsulated sprayable pheromones with conventionally managed insecticide-treated orchards in Henderson County, NC, in 2000 and 2001. In addition, OFM populations were also monitored in nearby abandoned orchards which served as non-managed controls for mating disruption and insecticide-treated orchards. All treatments, except abandoned orchards, were sprayed with carbaryl (Sevin 50WP, 80WPS and/or XLR, Aventis, Research Triangle Park, NC) at petal fall for thinning and for control of the first OFM generation. Mating disruption treatments were initiated just before emergence of second generation adults in late May. Although every effort was made to locate treatments within sites as close together as possible, in some instances the abandoned orchard treatments were located as far as 3 km apart.

Treatments. Treatment descriptions are as follows.

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-dodenenol (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 a rate of 250/ha at the end of May just before the beginning of second generation flight. Dispensers were designed to last 100 days. In Isomate-treated orchards, codling moth was managed with either Isomate C Plus pheromone dispensers (Shin-Etsu Chemical, Tokyo, Japan) applied at 990 per ha, or three

6

applications of tebufenozide – one application each in May, July and August. In all

mating disruption orchards, one tebufenozide application was made against each of

the two tufted apple bud moth generations in June and mid August. Tebufenozide

was used in mating disruption treatments because it has relatively low toxicity to

OFM (Borchert 2003).

OFM Sprayable Pheromone. Sprayable pheromone was a water-based

microencapsulated formulation containing 18.6% Z8-12:Ac, 1.2% E8-12:Ac, and Z8-

12:OH and 80% inert ingredients. Unless otherwise specified, sprayable pheromone

(Phase III) 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 1000-

1400 liters/ha of water; 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 non-pheromone treated conventional block was

included at each site, and sprayed with five to six applications of organophosphate

insecticides – azinphos-methyl (Guthion 50WP, Bayer Crop Science, Research

Triangle Park, NC) and/or phosmet (Imidan 70WP, Gowan, Yuma, AZ) for OFM and

codling moth control, and tebufenozide (Confirm 2F, Dow Agrosciences,

Indianapolis, IN), 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 to early September). One tebufenozide application

was made against each of the two tufted apple bud moth generations in June and mid August.

Abandoned (Non-managed). For each study site, OFM populations were also monitored in a nearby abandoned orchard that received no pheromone or insecticide.

Pheromone trapping. OFM 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 effect of pheromone lure rate in traps and trap height within the canopy was examined in each treatment. Traps were baited with rubber septa (Thomas scientific, Swedesboro, NJ) impregnated with either 100 or 300 μg OFM 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 hexane, followed by 50 μl of clean hexane. Pheromone lures were changed monthly.

Traps were placed in the lower and upper canopy of 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 surface blemishes caused by a complex of lepidopterous larvae, "entry" described

larval tunneling in the fruit, and "live worm" was 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 and by inspecting each fruit and then cutting damaged fruit to check for internal infestation. At harvest, a minimum of 100 fruit from each of the 10 trees per treatment was evaluated and all fruit were cut to check for the presence of internal lepidopterous damage. All larvae were collected and identified to species. In 2001, fruit were also examined for the presence of OFM eggs.

Mating Disruption Program Comparison. The objective of this study was to: 1) assess the efficacy of Isomate-M 100, sprayable pheromone, and conventional insecticide programs in managing oriental fruit moth; and 2) assess the effects of trap height and septum dosage on pheromone trap catches in mating disruption, conventional insecticide, and abandoned orchards. Each treatment was replicated at three different grower locations in 2000 (Barnwell, Henderson and Staton) and 2001 (Henderson, Staton, Coston). Below is a brief description of each study site.

Study sites. The Barnwell orchard, which consisted of an 8-ha mixed-variety block of 'Delicious', 'Golden Delicious' and 'Rome Beauty' apples, was divided into three treatments. Plots varied in size from 2.5 (Isomate and sprayable plot) to 3 ha (Conventional plot). Three rows of a non-pheromone buffer zone between Isomate and sprayable plots were sprayed with five applications of organophosphate insecticides. Tree height ranged from 3 to 6 m. Located approximately 2 km from these plots was an abandoned orchard (3 ha). The Staton orchard was a 9-ha block of 'Golden Delicious' apples that was used for both mating disruption treatments and

the conventional insecticide treatment, each approximately 3 ha in size. Tree height ranged from 2 to 5 m. The abandoned orchard was located approximately 3 km from the other treatments. A nearby abandoned orchard was used for the trial in 2001.

The Henderson orchard which consisted of a 6-ha block of 'Golden Delicious' and 'Rome Beauty' apples, was used for the two mating disruption treatments, and an adjacent 2.5 ha non-managed orchard was used as the abandoned site. The conventional treatment was located approximately 1 km from mating disruption blocks. Tree height ranged from 2 to 7 m. The abandoned treatment was separated from other treatments by woods. The Coston orchard was a 10.5-ha block of 'Golden Delicious' and 'Rome Beauty' apples, and was divided into 3 blocks receiving the conventional insecticide treatment (5 ha), the sprayable pheromone treatment (3 ha), and the Isomate-M 100 treatment (2.5 ha). Tree height ranged from 2 to 6 m. A 2.5 ha abandoned treatment was located <0.2 km from the other treatments.

Pheromone traps. At all locations in 2000, and at the Henderson site in 2001, a total of 16 traps was placed in each treatment; 8 each in the lower and upper portion of the canopy. Four traps in each of canopy portion were baited with lures containing 100 μg and four were baited with 300 μg OFM pheromone. At the Staton and Coston sites in 2001, a total of 12 traps per treatment were placed in the upper canopy; three traps each baited with lures containing 0, 30, 100, 300 µg OFM pheromone. The 0 µg lures were treated only with hexane. Trees of similar height were used for trapping.

Data analysis. The experiment was conducted in a split plot design with sub-plots arranged in a Latin square design. 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 using analysis of variance (ANOVA) (SAS 2001). ANOVA was performed on the pooled data from 2000. A separate ANOVA was conducted for the Henderson orchard in 2001. Since trap placement and pheromone loads were different in the Staton and Coston orchards in 2001, data were analyzed separately using a split-plot design. ANOVA was conducted on the mean of three replicates for the subplot factor (septum dosage).

If there were significant interaction effects, LSMEANS comparisons were used to identify these 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. Data were analyzed using Fisher's Protected LSD test.

Mean percentage fruit damage data were transformed using arcsine square root and subjected to an ANOVA. Fisher's Protected LSD test was used to compare treatment means (P = 0.05).

Small Plot Sprayable Pheromone Rate Study. This study was conducted to compare the efficacy of different rates of sprayable pheromone formulations, using pheromone trap catches as an assessment method.

Treatments. Trials were conducted in three different commercial apple orchards in Henderson County, NC, in 2000 and in 2001. At each site, plots were 0.4 ha in size and treatments consisted of sprayable pheromone application at rates of 0, 12.4, 30.9, and 49.4 g (ai)/ha in 2000, 0, 2.4, 12.4, and 37.1 g (ai)/ha in 2001.

11

Phase III and VI 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. Numbers of males caught in pheromone traps were used to evaluate treatment effects in test plots. A total of two traps were placed in the lower canopy in each treatment in 2000; one each baited with 100 and 300 μg OFM lures. In 2001, three traps were deployed in the upper canopy of each treatment, one each baited with lures impregnated with 0, 100 and 300 μg pheromone. The 0 μg treatment lure was treated only with 0.2 μl hexane.

Data analysis. The experimental design was a split plot design with three replications. Treatments were the main plots. The subplot was septum dosage. Based on inspection of plots of residuals, data were transformed using square root transformation before ANOVA, but data are presented as back transformations. Trap captures following the first and second applications were analyzed separately using repeated measures ANOVA. This analysis was conducted to help assess the residual activity of treatments. Trap counts were transformed using square root before repeated measures. Fisher's protected LSD test was used for mean separation (P = 0.05).

Large Plot Sprayable Pheromone Rate Study. The objective of this study was to compare two rates of sprayable pheromone with conventional insecticides in large plot studies. Trials were conducted in three different commercial apple

orchards (Barnwell Ranch, Dalton, and Apple Ole) in Henderson County, NC, 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.

Study sites. Barnwell Ranch was a 6-ha block of 'Delicious' apples that was divided into three adjacent plots. Dalton was a 10-ha block of 'Golden Delicious' apples that was divided into two adjacent treatment blocks and a nearby insecticide-treated control block. Apple Ole was a 10-ha block of 'Golden Delicious' and 'Delicious' apples that was divided into three adjacent plots of equal size.

Pheromone traps. Two pheromone traps per treatment, one each baited with 100 and 300 μg OFM lures and placed in the upper canopy, were used to monitor OFM populations. Traps baited with different lure rates were placed 40-60 m apart within each treatment. Treatment blocks were usually located about 100 m apart. The Dalton control block was an exception and located about 1 km apart from other treatment blocks.

Data analysis. Data were analyzed using split plot design with treatments as main plots and septum dosage as sub plots. Locations served as replicates. Pheromone trap data were transformed using log (x + 0.5) and damage data using arsine square root before ANOVA (SAS 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. OFM populations varied

considerably among test sites in 2000 (Fig. 1.1). ANOVA on the pooled data from

2000 revealed a significant difference among treatments. OFM trap catches were

significantly lower in mating disruption blocks compared with abandoned blocks.

However, catches in conventional insecticide-treated blocks did not differ

significantly from those in mating disruption and abandoned plots. This was probably

due to the large variation in moth captures among insecticide-treated blocks,

because population levels of OFM varied greatly from one area to another. In fact,

there was a significant interaction among locations and treatment. Pheromone traps

caught significantly fewer moths in mating disruption blocks at all locations

compared with conventional insecticide and abandoned blocks, except in the Staton

conventional block where OFM populations were relatively low (Table 1.1). A similar

trend was observed in the Henderson orchard in 2001 (Fig. 1.2). Trap captures were

significantly lower in mating disruption blocks compared with both conventional

insecticide and abandoned blocks.

Considerably fewer moths were caught in mating disruption blocks and

insecticide-treated blocks compared with abandoned blocks at Staton and Coston in

2001(Table 1.2). There was a significant difference among treatments at both

locations. Location effect was not statistically significant (F = 3.51; df = 1, 64; P =

0.16). However, the location by treatment interaction was significant. In Staton,

significantly fewer moths were caught in the Isomate compared with the sprayable

block. However, there were no significant differences between mating disruption treatments at Coston.

Several researchers have shown that OFM trap catches were significantly reduced in mating disruption blocks in peach orchards in Australia, Canada, France, South Africa and USA (Rothschild 1975, Audemard et al. 1989, Rice and Kirsch 1990, Pree et al. 1994, Barnes and Blomefield 1997, Atanassov et al. 2002). Consistent with these findings, our results suggest that mating disruption treatments were highly successful in disrupting male orientation to synthetic pheromone traps.

Isomate-M 100 provided excellent trap shutdown and was significantly more effective than both sprayable pheromone treatments at all locations except Coston in 2000 and 2001 (Table 1.1 and Table 1.2). This was particularly evident at the Barnwell orchard, where OFM populations were high (Fig. 1.1). At this site, Isomate-M 100 remained highly effective in suppressing pheromone trap catches through September, while catches in the sprayable block increased late in the season. In fact, a small number of OFM moths were caught in sprayable blocks at all sites in September in 2000. Since rain wash-off is a concern for sprayable pheromone formulations (Jenkins 2002), late season trap catches could be attributed to the continuous wet weather during the month of August in 2000. When data were pooled for 2000, trap catches in Isomate and sprayable blocks were not significantly different ($P = 0.29$), although Isomate-M 100 reduced trap catches to a greater extent than sprayable pheromone. Agnello et al. (2000) found that pheromone trap catches of OFM in Isomate and sprayable blocks were very low throughout the entire season, although a few moths were caught in an Isomate plot at one site in

15

New York. Robertson and Hull (2001) also showed that trap capture was almost completely suppressed in Isomate-M 100 blocks.

First captures of moths occurred 3-4 wk after the first sprayable pheromone application at all locations in 2000, suggesting that an application of sprayable pheromone lasted 3 to 4 wk. A similar trend was observed for the second pheromone applications, which suppressed trap captures of OFM males for 3-4 wk. However, there was a sudden increase in trap captures late in the season. In 2001, trap catches showed similar trends, but first catches were recorded 2 wk after the first application. Studies with a microencapsulated formulation of pheromone plus synergist resulted in suppression of trap captures of male OFM for 2 wk (Beroza et al. 1973, Gentry et al. 1974).

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

Trap height and septum dosage. Pheromone traps placed in the upper canopy caught considerably more moths than traps placed in the lower canopy across all treatments averaged over three locations in 2000 (Fig. 1.3A). The

difference between trap catches in high and low traps was statistically significant (F = 85.81; df = 1, 108; $P < 0.01$). However, there was a significant relationship between trap height and treatment in 2000. Trap catches 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 1.3). In 2001, OFM males were again captured in significantly higher numbers in traps placed in the upper compared with lower portion of the canopy (F = 14.97; df = 1, 48; P = 0.03). However, treatment x height interaction was not significant, and traps placed in the upper canopy had a higher trap capture in each treatment.

Apparently, OFM males prefer to fly higher in the canopy in mating disruption blocks. This suggests that the pheromone concentration in the air may have affected flight behavior. 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 non-pheromone 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 (Fig. 1.3B). Although the difference between doses was not significant in 2000 (F = 1.36; df = 1, 108; P = 0.26), it was different in 2001 (F = 18.72; df = 1, 48; P = 0.02). OFM males did not respond differently to traps baited with 100 and 300 μg lures among treatments

averaged over three locations in 2000, whereas 100 µg lures caught significantly more OFM males in the abandoned block in 2001(Table 1.4).

Mean cumulative OFM pheromone trap captures in non-baited traps and traps baited with 30, 100 and 300 µg lures averaged across four treatments at two locations are shown in Fig. 1.4A. ANOVA on the pooled data showed a significant difference among pheromone dosages per septum (F = 12.83; df = 3, 64; P < 0.01). Traps baited with 100 µg lures caught significantly fewer moths compared with 0 and 300 µg lures. However, the attractiveness of 100 µg lures did not significantly differ from 30 µg lures. A significant interaction was detected between pheromone dosage per septum and location (F = 3.07; df = 3, 64; P = 0.03). Trap capture at loadings of 30, 100 and 300 µg did not differ statistically at Coston (Fig 1.4B), whereas 100 µg lures were statistically different than 300 µg lures at Staton.

These results suggest that male OFM responded optimally to traps baited with 100 µg lures under orchard conditions regardless of treatment. Roelofs et al. (1973) reported that pheromone traps baited with 200 µg of OFM pheromone captured significantly more moths than traps with 1, 10 or 1000 µg pheromone, while Gentry et al. (1974) showed that dosages of 500 µg and 2000 µg were equally effective. Complete arrestment of male flight at loads of 1000 µg has also been reported (Baker et al. 1981, Sanders and Lucuik 1996). In contrast, several researchers have shown that optimum loadings of OFM pheromone containing about 6% of the E isomer to be between 3 and 30 µg/septum for upwind flight of male moths in wind tunnels (Baker et al. 1981, Linn et al. 1988, Baker and Haynes 1989). Loadings of 30 and 100 µg correspond to calculated release rates of 20 and

70 ng/septum/hr (Sanders and Lucuik 1996). The release rate from 100 µg lures is almost three times that of the highest release rate recorded from OFM females, which is 25.3 ng/h. (Lacey and Sanders, 1992). However, the release rate of pheromone from septum often decreases with time in the field (Miller et al. 1997). Also, pheromones are usually released at a faster rate with increasing temperatures. 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 per septum did not improve the sensitivity of pheromone trap catches in pheromone-treated, insecticide-treated or untreated blocks.

Egg searches. Egg counts were higher in abandoned blocks compared with mating disruption and conventional blocks at all sites in both July and September (Table 1.5). Only a few eggs were found in sprayable and conventional insecticide blocks. No eggs were detected in Isomate blocks. These findings suggest that mating disruption and insecticide treatment may have affected oviposition. However, further egg searches at frequent intervals will be necessary to confirm this interpretation.

Damage assessment. With the exception of abandoned blocks, there was no damage caused by internal lepidopterous larvae in July 2000 (Table 1.6). At harvest, mean percentage fruit with live worms was quite low (<0.5%) in mating disruption blocks, and damage in mating disruption blocks and conventional blocks did not differ. The sprayable pheromone block at Staton had 9 live worms, which was the largest number of live worms found in mating disruption blocks among all sites. Although the highest incidence of mean larval stings was found in the sprayable

block (1.5%) in 2000, there was no significant difference among treatments. Similar results were obtained for the number of entries averaged over locations. Since no damage was observed in mating disruption blocks in July, it can be concluded that the majority of fruit damage containing live worms, entries and stings occurred in August and September.

During the mid-July damage assessment in 2001, the mean percentage of fruit with live worms and entries in mating disruption blocks and conventional blocks was significantly lower than the abandoned blocks. However, mean number of stings was not significantly different among treatments. At harvest, no live worms were found in the Isomate and conventional blocks. The mean number of fruit containing live worms and entries were significantly higher in abandoned blocks compared to mating disruption and conventional blocks. The relatively high number of entries in the sprayable blocks was due solely to results at the Staton orchard. At this site, all larvae were identified as codling moth. Mean number of stings did not differ among treatments.

Small Plot Sprayable Pheromone Rate Study. Although all three sprayable pheromone rates (12.4, 30.9 and 49.4 g (ai)/ha) had fewer cumulative moth captures compared with the non-pheromone control in 2000, these differences were not significant (Fig. 1.5A) ($F = 3.77$; df = 3, 8; $P = 0.08$). The lack of significant differences among rates was likely due to a very low OFM population at one location (McCraw), which accounted for a significant location by treatment interaction. Significantly fewer moths were caught in pheromone treatments compared with the

control at the Barnwell and Henderson sites, and there were no differences among rates of pheromone at these locations (Table 1.7).

In 2001, all pheromone treatments again reduced cumulative trap capture below those in the control (Fig. 1.5B), and the difference was statistically significant ($F = 19.90$; df = 3, 16; $P < 0.01$). In contrast to 2000, there was no location by treatment interaction ($F = 0.99$; df = 6, 16; $P = 0.46$). Significantly fewer moths were captured in the 37.4 g rate compared with the 2.4 g rate.

Pheromone trap capture was extremely low in all of the sprayable pheromone treatments. Ten wk after application, a cumulative of almost 40 moths per trap was captured in the control, while ≤4 moths per trap were caught in any of the sprayable pheromone treatments (Fig. 1.6A). Repeated measures ANOVA showed that there were significant differences among treatments following the first application in 2000 ($F = 6.47$; df = 3, 8; $P = 0.03$). The significant treatment x time (week) interaction also indicates 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, but all pheromone treatments significantly reduced cumulative trap capture by 4 wk after application. There were no significant differences among pheromone treatments across time. Location effect and the location by treatment interaction was not significant (for location $F = 3.34$; df = 2, 8; $P = 0.09$; for location x treatment interaction $F = 1.67$; df = 6, 8; $P = 0.25$).

Results following the second application of treatments in July were very similar to the first application. Mean cumulative trap capture in the control 7 wk after application was 47.3 moths per trap, while cumulative capture did not exceed 10

moths per trap in any of the sprayable pheromone treatments (Fig. 1.6B). 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 x treatment interaction (F = 2.58; df = 18, 48; P < 0.01); no significant differences were detected among treatments until 3 wk after application. In all pheromone treatments, except 30.9 g/ha, traps caught significantly fewer moths compared with the control from wk 3 to 7, but there were no differences among the three rates of pheromone. The location x 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 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 following the first application in 2001. Additionally, the significant treatment x 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 wk 4 to 7 significantly fewer moths were caught by traps in the 2.4 g rate compared with those in the 37.1 g rate (Fig. 1.7A). Pheromone trap captures in the 12.4 g rate were intermediate between the 2.4 and 37.1 g rates, and did not differ from either rate between wk 4 to 7. Location (F = 0.64; df = 2, 16; P = 0.54) and the location x treatment interaction (F = 2.55; df = 6, 16; P = 0.06) were not significant.

Following the second application in July 2001, treatments were again significantly different (F = 22.17; df = 3, 16; P < 0.01), and treatment effects differed significantly over 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. 1.7B). Pheromone trap capture increased in all sprayable pheromone treatments between wk 4 to 9, but the rate of increase was higher in the 2.4 g rate compared with 12.4 or 37.1. Trap captures in the 2.4 g rate were significantly higher compared with 12.4 g in wk 5 and 7. Similar significant differences were detected between 2.4 g and 37.1 g rates in wk 7 and 8. Location (F = 2.64; df = 2, 16; P = 0.10) and the location x 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 rates ranging from 12.4 to 49.1 g (ai)/ha over time, but efficacy declined at the 2.4 g (ai)/ha 3 to 4 wk after application. The cost of mating disruption is often an impediment to adoption (Rice and Kirsch, 1990). 3M sprayable formulation for OFM is labeled at 24.7 to 37.1 g (ai)/ha. Since the 12.4 g (ai)/ha rate was equally effective as higher rates, the cost of a single application could potentially be decreased by 40% as a result of using the reduced dosage.

Rubber septa lures loaded with 100 µg of pheromone caught more moths compared with 300 µg across all treatments (Fig. 1.8A), although the difference between doses was not significant in 2000 (F = 0.79; df = 1, 8; P = 0.40). Trap capture was significantly higher in traps baited with 100 or 300 µg of OFM pheromone than control septa loaded only with hexane across all treatments in 2001

(Fig. 1.8B) (F = 27.26; df = 2, 16; P < 0.01). The response of OFM males to 100 and

300 µg lures did not differ significantly, although 100 µg lures caught more moths

compared with 300 µg across all treatments.

Rubber septa lures loaded with 300 µg of pheromone caught more moths

than those loaded with 100 µg across all treatments during first and second

application in 2000, although the difference between doses was not significant (F =

0.06; df = 1, 8; P = 0.81 for first application; F = 1.05; df = 1, 8; P = 0.34 for second

application). Septum dosage effects were consistent over time (F = 0.78; df = 9, 72;

P = 0.63 for first application; F = 1.80; df = 6,48; P = 0.12 for second application).

Significantly more moths were captured in traps baited with 100 or 300 µg of

OFM pheromone compared with control septa across all treatments after both the

first and second applications in 2001 (F = 11.15; df = 2, 16; P < 0.01 for first

application; F = 27.28; df = 2, 16; P < 0.01 for second application). The septum dose

by time interaction was significant during the first application (F = 3.44; df = 12, 96; P

< 0.01). There were no differences in trap captures between the 100 or 300 µg of

OFM pheromone except at wk 3. Captures in traps baited with 100 µg lures were

significantly higher compared with 300 µg lures in wk 3.

Large Plot Sprayable Pheromone Rate Study. Sprayable pheromone

treatments reduced trap captures below the control (Fig. 1.9), but differences among

treatments were not statistically significant. OFM populations varied considerably

among test sites (Table 1.8). Location effect (F = 11.33; df = 2, 6; P = 0.02) and the

treatment by location interaction 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, OFM populations were relatively high. 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. Unlike Barnwell Ranch, trap capture was significantly lower in blocks treated with 37.1 g than those with 12.4 g (ai)/ha or the insecticide-treated control at Dalton.

It appears that 12.4 and 37.1 g (ai)/ha were equally effective under low and high OFM population pressure at all locations except Dalton. One possible explanation for the results obtained at Dalton is that the sloped terrain resulted in relatively higher trap captures in blocks treated with 12.4 g (ai)/ha. 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 high ground. This phenomenon has been observed with several pests in different areas of the world, particularly for codling moth in apple orchards on hilly terrain in California (Rice 1993). In the Dalton orchard, this may have contributed to the higher trap captures in the higher (12.4 g treatment) compared with the lower areas (37.1 g treatment) of the orchard.

Clearly, the results of these studies demonstrate that OFM mating disruption with either Isomate M100 or sprayable pheromones was successful in managing this insect when combined with chemical control of the first generation. Mating disruption has been most successful in orchards with low initial populations (Pree et al. 1994, Trimble 2001, Atanassov 2002) and control failures due to high initial pest populations have been reported (Audemard 1988).

The use of mating disruption reduced the use of conventional insecticides considerably by eliminating the 4 - 5 organophosphate applications per season. Mating disruption treatments can be as effective as insecticides for controlling OFM (Rotschild 1975). Our results supported the conclusion that pheromone treatments can decrease OFM damage to levels obtained with conventional insecticide programs (Rice and Kirsch 1990). Mating disruption may be even more effective than conventional insecticide programs if applied using an area-wide approach (Vickers *et al* 1985). Il'ichev (2002) showed that area-wide mating disruption worked effectively and was able to control high levels of OFM successfully. This approach needs to be evaluated for mating disruption of OFM in NC apple orchards.

Monitoring is crucial to the successful use of mating disruption programs (Rotschild 1981). The relative efficiency of pheromone traps varies with respect to their placement (McNeil 1991). Based on our results, trap height appeared to be a critical factor affecting the performance of OFM pheromone trap capture. Thus, pheromone traps should be placed in the upper part of canopy for monitoring OFM.

Based on the results of these trials, mating disruption appears to be a feasible alternative to conventional insecticides for managing OFM populations in North Carolina apple orchards. It should be noted, however, that some factors could affect the success of an OFM mating disruption program. These factors include OFM population pressure, trap height, the amount of OFM pheromone per septum, the type of pheromone-dispensing system used, the application rate of sprayable pheromone, weather conditions, the topography of the orchard and the potential for migration of mated females from non-managed orchards.

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Table 1.1. Mean (±SEM) cumulative Oriental fruit moth pheromone trap captures in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards. Henderson County, NC.

Year	Location	Treatment	n	Moths per trap[b]
2000	Barnwell	Sprayable pheromone$^{\alpha}$	16	8.8 (2.7)c
		Isomate-M 100 pheromone	16	0.6 (0.4)d
		Conventional	16	64.1 (10.8)a
		Abandoned	16	29.1 (5.9)b
	Henderson	Sprayable pheromone$^{\alpha}$	16	2.7 (1.5)c
		Isomate-M 100 pheromone	16	0.3 (0.2)d
		Conventional	16	6.8 (1.3)b
		Abandoned	16	28.9 (4.1)a
	Staton	Sprayable pheromone$^{\alpha}$	16	4.3 (1.6)b
		Isomate-M 100 pheromone	16	2.6 (2.2)c
		Conventional	16	0.9 (0.3)c
		Abandoned	16	97.8 (9.9)a
	Pooled data	Sprayable pheromone$^{\alpha}$	48	5.2 (1.2)b
		Isomate-M 100 pheromone	48	1.2 (0.8)b
		Conventional	48	23.9 (5.5)ab
		Abandoned	48	51.9 (6.2)a
2001	Henderson	Sprayable pheromone$^{\alpha}$	16	1.9 (0.8)b
		Isomate-M 100 pheromone	16	0.3 (0.1)c
		Conventional	16	22.2 (4.9)a
		Abandoned	16	29.3 (6.9)a

$^{\alpha}$In 2000 Phase III 3M Canada sprayable pheromone was used, and in 2001 Phase VI 3M Canada sprayable pheromone was used.

[b]Means with 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. ANOVA statistics for 2000 Pooled data are $F = 6.03$; df = 3, 108; $P = 0.03$; for 2001 Henderson $F = 142.17$; df =3, 48; $P < 0.01$. Treatment x Location interaction for 2000 Pooled data is $F = 39.14$; df = 6, 108; $P = 0.01$.

Table 1.2. Mean (±SEM) cumulative Oriental fruit moth pheromone trap captures in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards. Henderson County, NC. 2001

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

[α]Phase VI formulation of 3M Canada sprayable pheromone was used.

[b]Means with 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. ANOVA statistics for Pooled data is $F = 35.52$; df = 3, 64; $P < 0.01$. Treatment*Location interaction for Pooled data $F = 3.61$; df = 3, 64; $P = 0.02$.

Table 1.3.   Mean (±SEM) cumulative Oriental fruit moth pheromone trap captures in traps placed in the lower and upper canopy in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards. Henderson County, NC.

Year	Location	Treatment	n	Low Traps	High Traps	Low vs High[b]
						P values
2000	Pooled Data	Sprayable pheromone$^{\alpha}$	24	0.8 (0.3)c	9.7 (2.0)b	<0.01
		Isomate-M 100 pheromone	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$^{\alpha}$	8	0.6 (0.3)b	3.3 (1.5)b	<0.01
		Isomate-M 100 pheromone	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

$^{\alpha}$In 2000 Phase III 3M Canada sprayable pheromone was used, and in 2001 Phase VI 3M Canada sprayable pheromone was used.

[b]Means with 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. Treatment*trap height interaction for 2000 Pooled data are $F = 20.12$; df =3, 108; $P < 0.01$; for Henderson 2001 $F = 23.48$; df =3, 48; $P = 0.01$.

Table 1.4. Mean (±SEM) cumulative Oriental fruit moth pheromone trap captures in traps using lures baited with 100 and 300 μg pheromone in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards. Henderson County, NC.

Year	Location	Treatment	n	Low Dosage (100 μg)	High Dosage (300 μg)	Low vs High[b] P values
2000	Pooled Data	Sprayable pheromone[α]	24	6.5 (2.1)c	4.0 (1.0)c	0.92
		Isomate-M 100 pheromone	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[α]	8	2.3 (1.3)b	2.4 (1.1)b	0.15
		Isomate-M 100 pheromone	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

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

[b]Means with 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. Treatment*septum dosage interaction for 2000 Pooled data are $F = 0.43$; df =3, 108; $P = 0.73$; for Henderson 2001 $F = 26.53$; df =3, 48; $P = 0.01$.

Table 1.5. Number of OFM eggs on apples non-managed (abandoned), conventional insecticide treated, and mating disruption orchards in July and in September. Henderson County, NC. 2001

Location	Season	Treatment	n	Fresh Eggs	Hatched eggs
Henderson	July	Sprayable pheromone	500	0.0	1.0
		Isomate-M 100 pheromone	500	0.0	0.0
		Conventional	500	0.0	3.0
		Abandoned	500	0.0	4.0
Coston		Sprayable pheromone	500	0.0	0.0
		Isomate-M 100 pheromone	500	0.0	0.0
		Conventional	500	0.0	3.0
		Abandoned	500	0.0	31.0
Staton		Sprayable pheromone	500	0.0	0.0
		Isomate-M 100 pheromone	500	0.0	0.0
		Conventional	500	0.0	0.0
		Abandoned	500	8.0	19.0
Henderson	September	Sprayable pheromone	1000	0.0	1.0
		Isomate-M 100 pheromone	1000	0.0	0.0
		Conventional	1000	0.0	0.0
		Abandoned	1000	66.0	178.0
Coston		Sprayable pheromone	1000	0.0	0.0
		Isomate-M 100 pheromone	1000	0.0	0.0
		Conventional	1000	0.0	0.0
		Abandoned	1000	135.0	678.0
Staton		Sprayable pheromone	1000	0.0	1.0
		Isomate-M 100 pheromone	1000	0.0	0.0
		Conventional	1000	0.0	0.0
		Abandoned	1000	82.0	479.0

Table 1.6. Mean (±SEM) percentage fruit damage in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards averaged across three different locations. Henderson County, NC.

Year	Season	Treatment	n	Sting	Entry	Live worm
				Damage[b](%)		
2000	July	Sprayable pheromone[α]	3	0.0 (0.0)b	0.0 (0.0)b	0.0 (0.0)b
		Isomate-M 100 pheromone	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
	September	Sprayable pheromone[α]	3	1.5 (0.4)a	0.7 (0.4)a	0.3 (0.3)a
		Isomate-M 100 pheromone	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[α]	3	0.2 (0.1)a	0.4 (0.4)b	0.1 (0.1)b
		Isomate-M 100 pheromone	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
	September	Sprayable pheromone[α]	3	0.8 (0.3)a	3.4 (2.3)b	0.1 (0.1)b
		Isomate-M 100 pheromone	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

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

[b]Means with 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 arcsine square root, but data shown are back transformations. In 2000, data from Barnwell, Henderson, and Staton orchards are pooled. Data from Henderson, Staton and Coston orchards are pooled in 2001. ANOVA statistics for stings, entries and live worms 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 $F = 1.07$; 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 $F = 2.52$; df = 3,6; $P = 0.15$; $F = 38.86$; df = 3, 6; $P < 0.01$; $F = 63.24$; df = 3, 6; $P < 0.01$; for September 2001 $F = 2.23$; df = 3, 6; $P = 0.18$; $F = 46.73$; df =3, 6; $P < 0.01$; $F = 51.21$; df = 3, 6; $P < 0.01$.

Table 1.7. Mean (±SEM) cumulative seasonal Oriental fruit moth pheromone trap captures in small blocks treated with 12.4, 30.9 and 49.4 g (ai)/ha of sprayable pheromone compared with non-pheromone treated control. Henderson County, NC. 2000

Location	Pheromone rate (g [ai]/ha)	n	Moths per trap$^{\alpha}$
Barnwell	12.4	2	10.0 (2.0)b
	30.9	2	14.5 (3.5)b
	49.4	2	18.0 (13.0)b
	Control	2	202.5 (63.5)a
Henderson	12.4	2	1.0 (1.0)b
	30.9	2	0.5 (0.5)b
	49.4	2	0.5 (0.5)b
	Control	2	61.0 (29.0)a
McCraw	12.4	2	5.5 (0.5)a
	30.9	2	11.5 (0.5)a
	49.4	2	0.5 (0.5)a
	Control	2	8.0 (7.0)a
Pooled Data	12.4	6	5.5 (1.7)b
	30.9	6	8.8 (2.8)b
	49.4	6	6.3 (5.0)b
	Control	6	90.5 (40.9)a

$^{\alpha}$Means with 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 square root, but data shown are back transformations. Treatment*location interaction for Pooled data is $F = 4.22$; df = 6, 8; $P = 0.03$.

Table 1.8. Mean (±SEM) cumulative Oriental fruit moth pheromone trap catches in large blocks treated with 12.4,and 37.1 g (ai)/ha of sprayable pheromone compared with insecticide-treated control. Henderson County, NC. 2001

Location	Pheromone Rate (g[ai]/ha)	n	Moths per trap[α]
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

[α]Means with 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. ANOVA statistics for Pooled data are $F = 2.22$; df = 2, 6; $P = 0.22$. Treatment*location interaction for Pooled data is $F = 5.70$; df = 4, 6; $P = 0.03$.
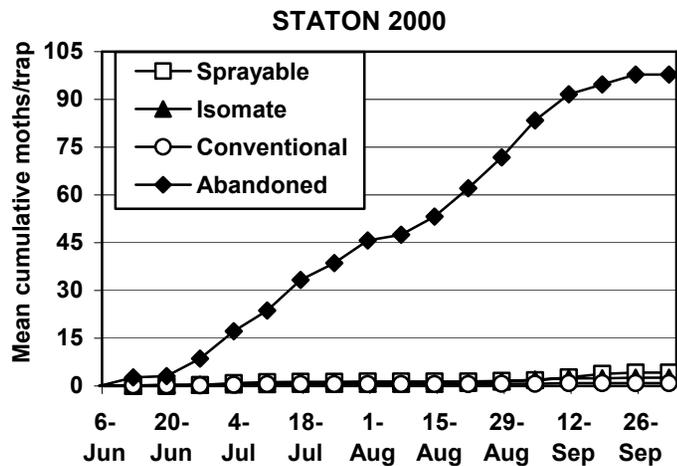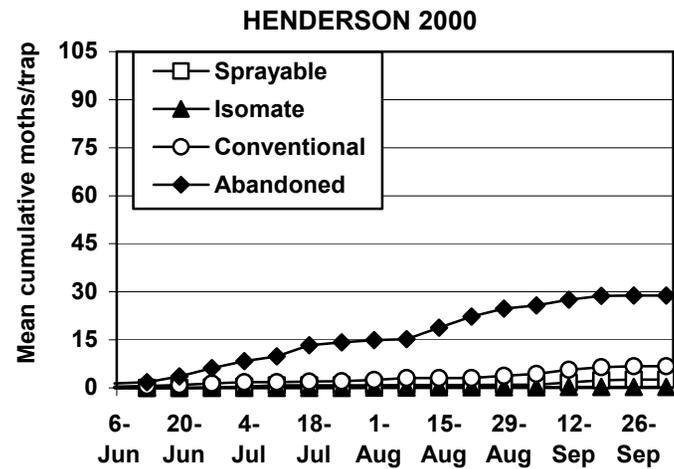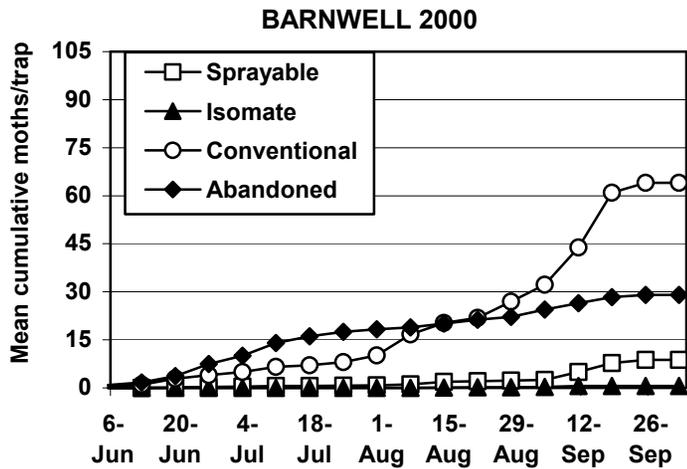
Fig. 1.1. Mean cumulative Oriental fruit moth pheromone trap captures in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards at Barnwell **(A)**, Henderson **(B)**, Staton **(C)**, and averaged across three orchards **(D)**. Henderson County, NC. 2000.
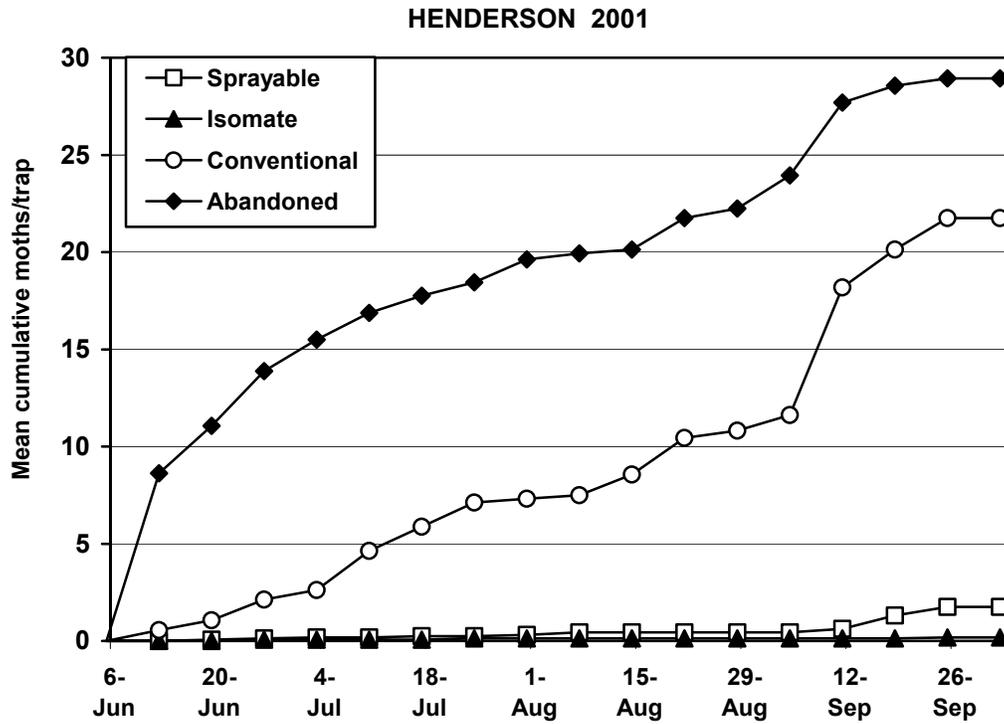
HENDERSON 2001

Fig. 1.2. Mean cumulative Oriental fruit moth pheromone trap captures in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards at Henderson. Henderson County, NC. 2001.
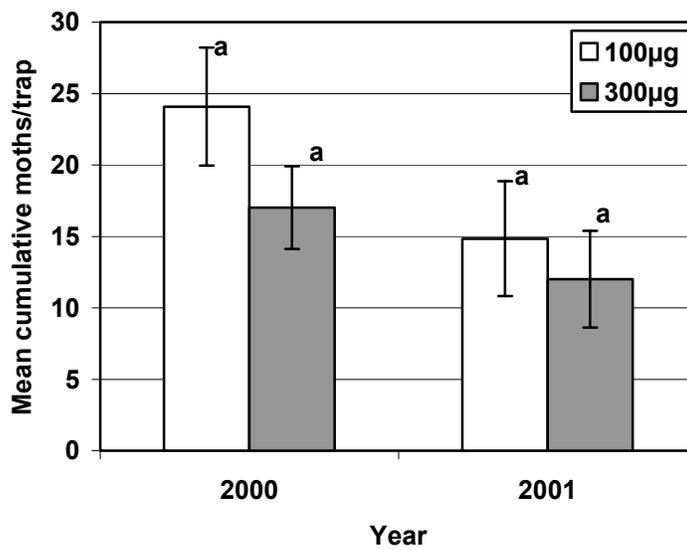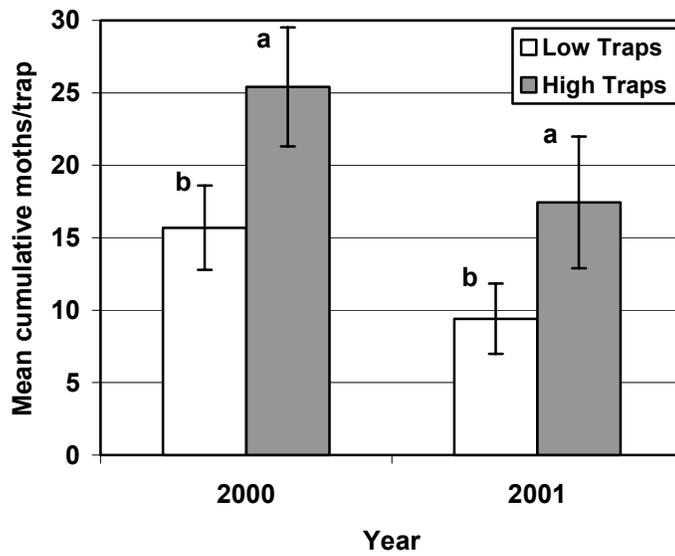
Fig. 1.3. Mean (±SEM) cumulative Oriental fruit moth catches in **A)** pheromone traps placed in the lower and upper canopy **B)** pheromone traps baited with 100 and 300 µg septa lures averaged over three locations in 2000 and in Henderson orchard in 2001.
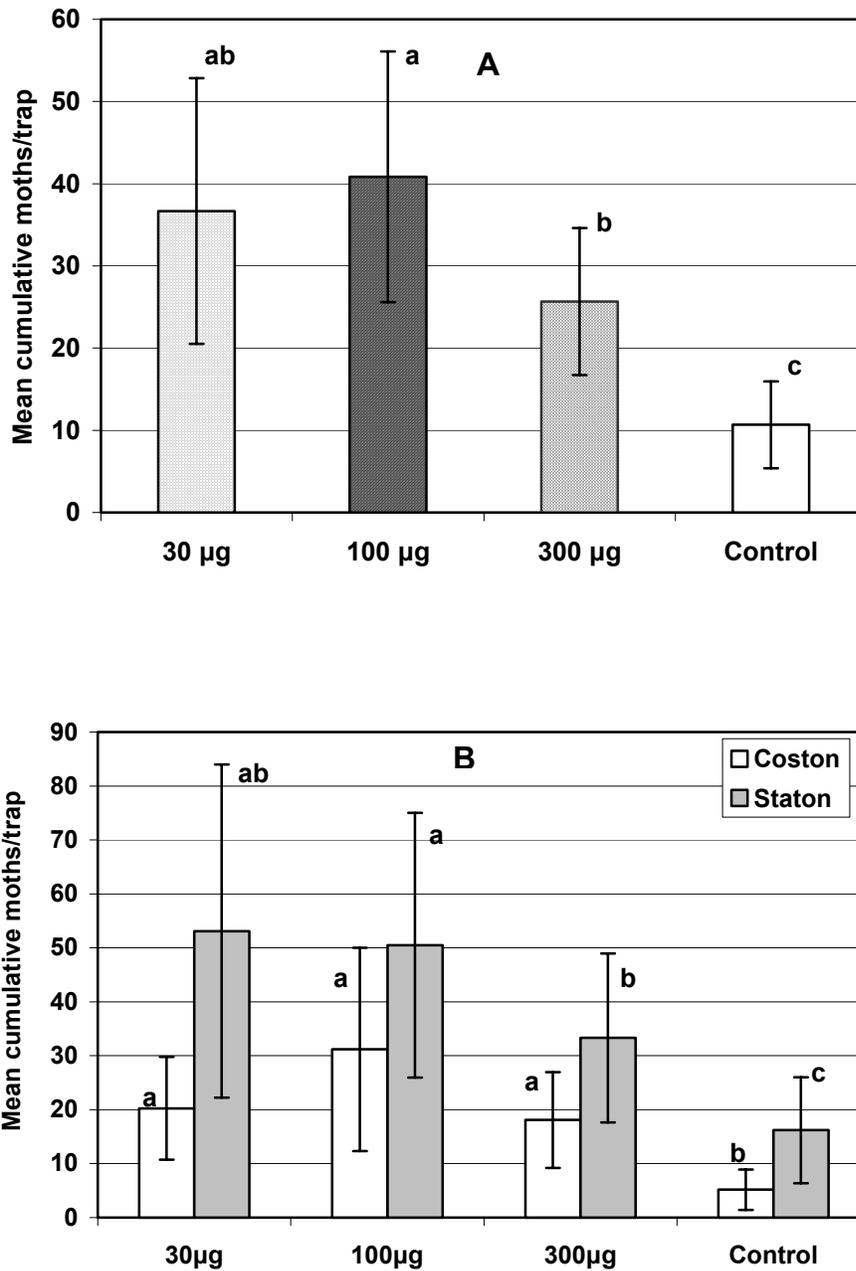
Fig. 1.4. Mean (±SEM) cumulative Oriental fruit moth pheromone trap captures in traps baited with 0 (Control), 30, 100 and 300 µg lures in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards **A)** averaged across two locations **B)** at Coston and Staton orchards. Henderson County, NC. 2001.
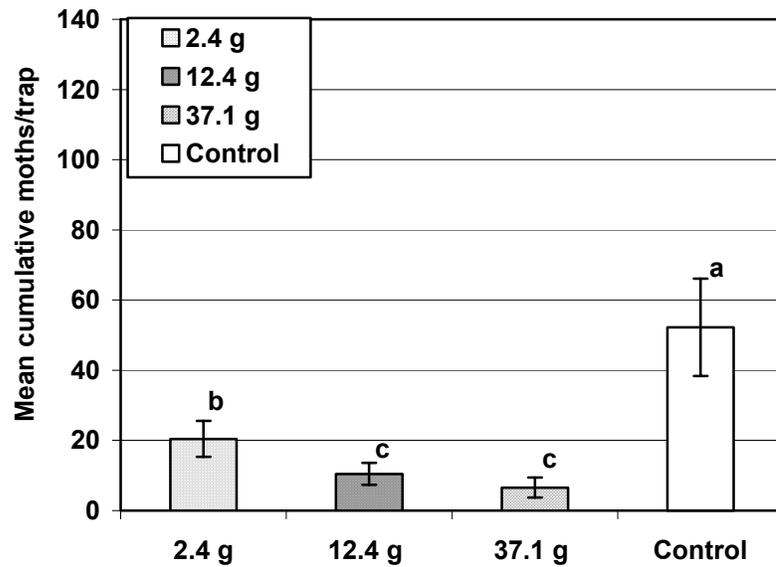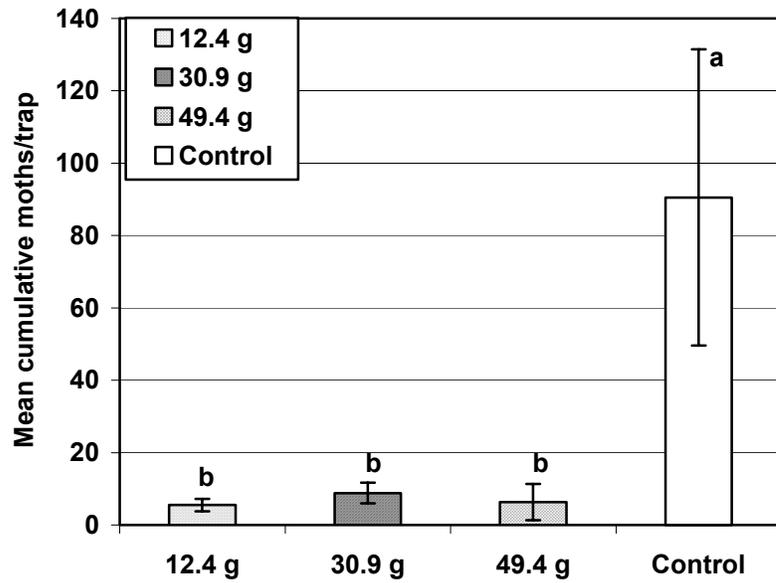
Fig. 1.5. Mean (±SEM) cumulative seasonal Oriental fruit moth pheromone trap captures **A)** in small blocks treated with 12.4, 30.9 and 49.4 g (ai)/ha of sprayable pheromone and non-pheromone treated control, and **B)** in blocks treated with 2.4, 12.4 and 37.1 g (ai)/ha of sprayable pheromone and non-pheromone treated control averaged across three locations. Henderson County, NC. 2001.
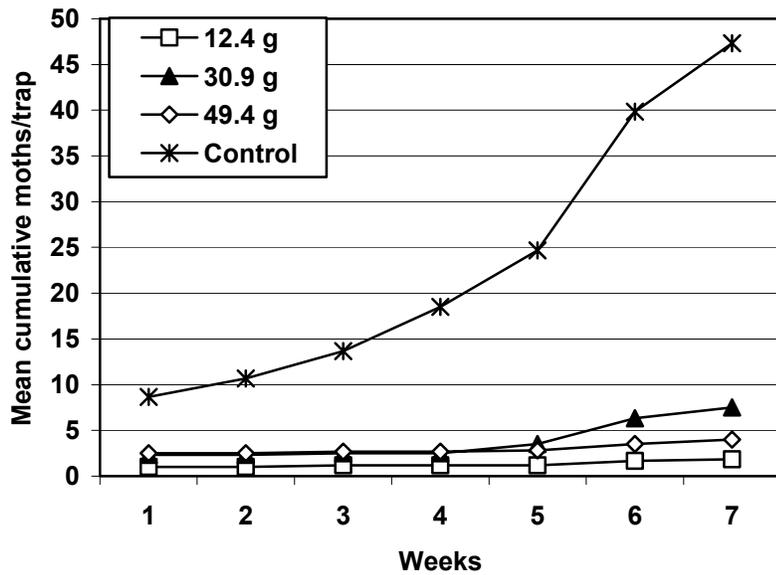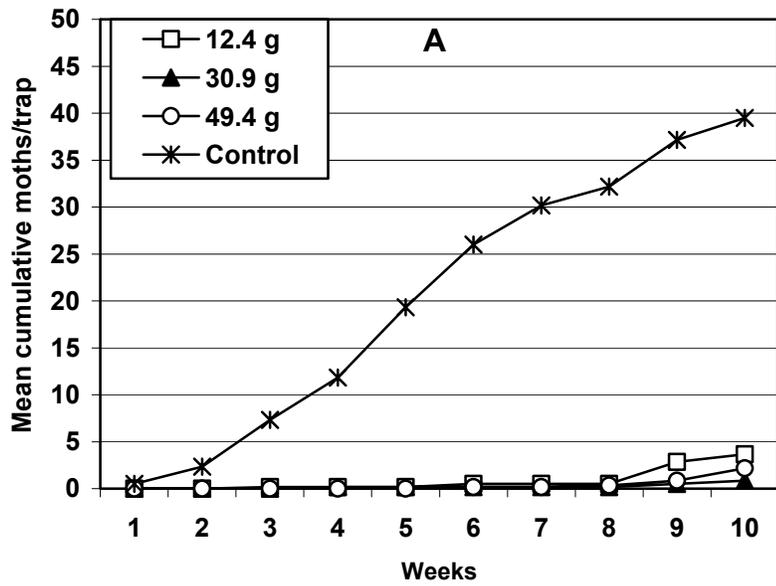
Fig. 1.6. Mean cumulative Oriental fruit moth pheromone trap captures in small blocks treated with 12.4, 30.9 and 49.4 g (ai)/ha of sprayable pheromone and non-pheromone treated control averaged across three locations in Henderson County, NC, during first (**A**) and second application (**B**) in 2000.

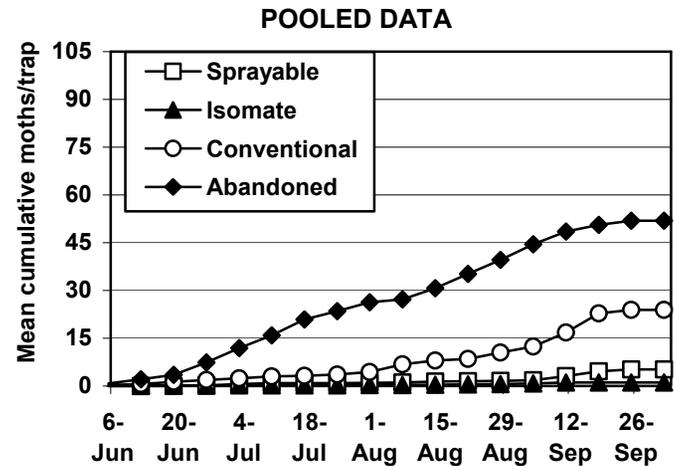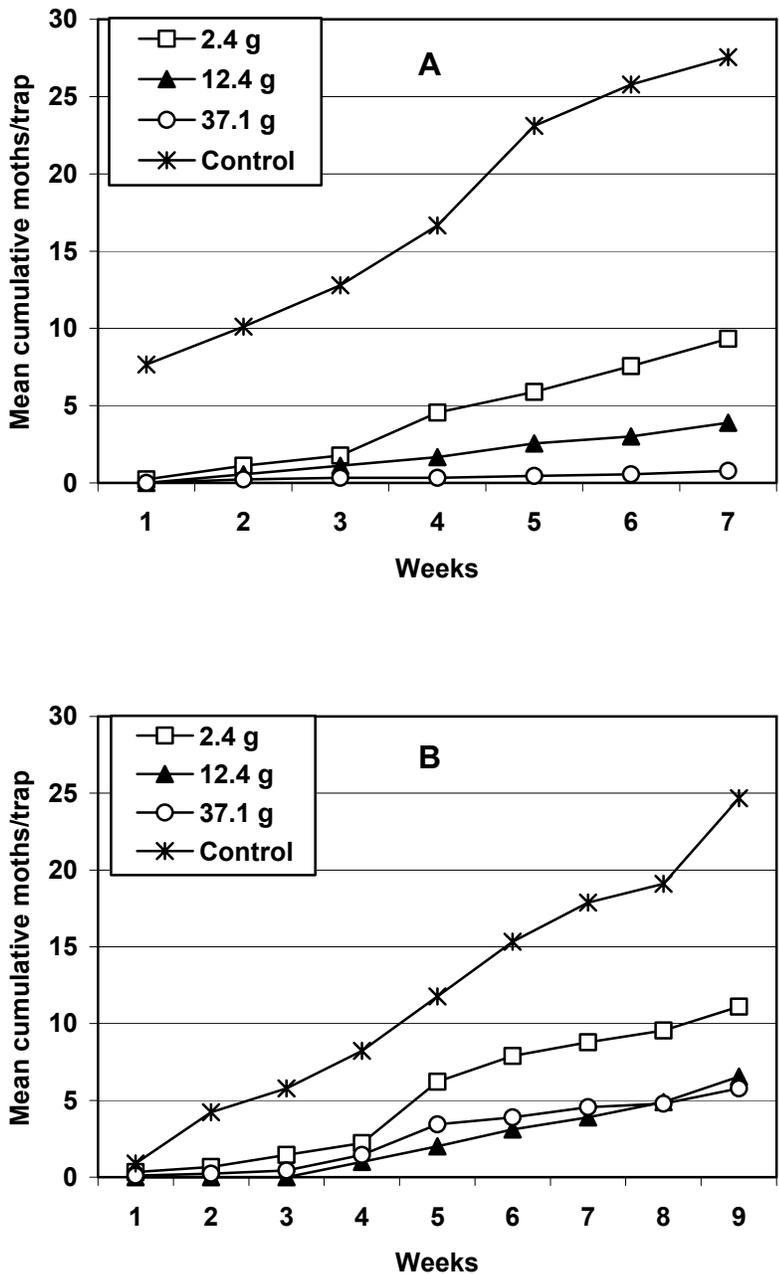**Fig. 1.7.** Mean cumulative Oriental fruit moth pheromone trap captures in small blocks treated with 12.4, 30.9 and 49.4 g (ai)/ha of sprayable pheromone and non-pheromone treated control averaged across three locations in Henderson County, NC, during first (**A**) and second application (**B**) in 2001.
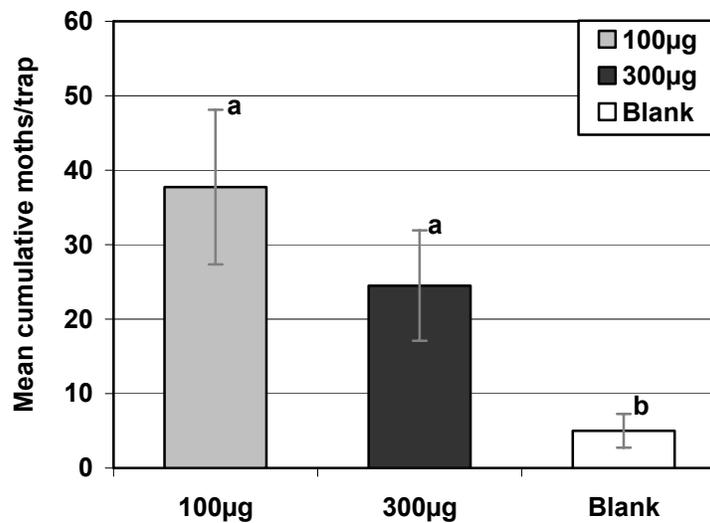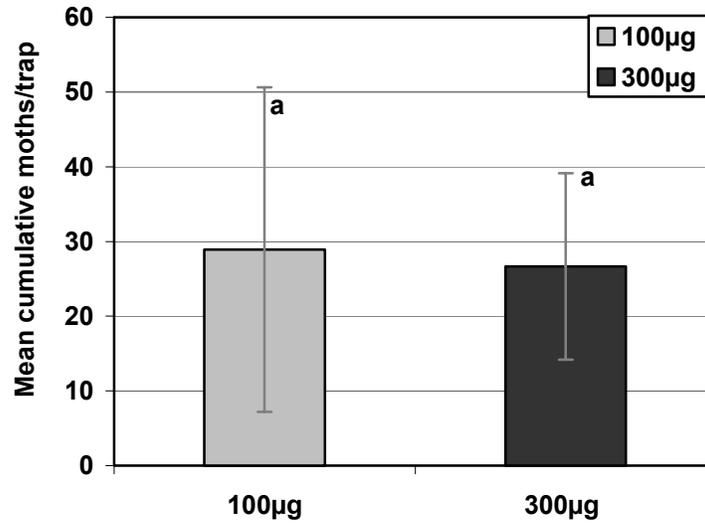
Fig. 1.8. Mean (±SEM) cumulative Oriental fruit moth pheromone trap captures **A)** in pheromone traps baited with 100 and 300 µg septa lures averaged over four different treatments (12.4, 30.9 and 49.4 g (ai)/ha of sprayable pheromone and non-pheromone treated control) in three locations in 2000 **B)** in pheromone traps non-baited and baited with 100 and 300 µg septa lures averaged over four different treatments (2.4, 12.4 and 37.1 g (ai)/ha of sprayable pheromone and non-pheromone treated control) in three locations in 2001.
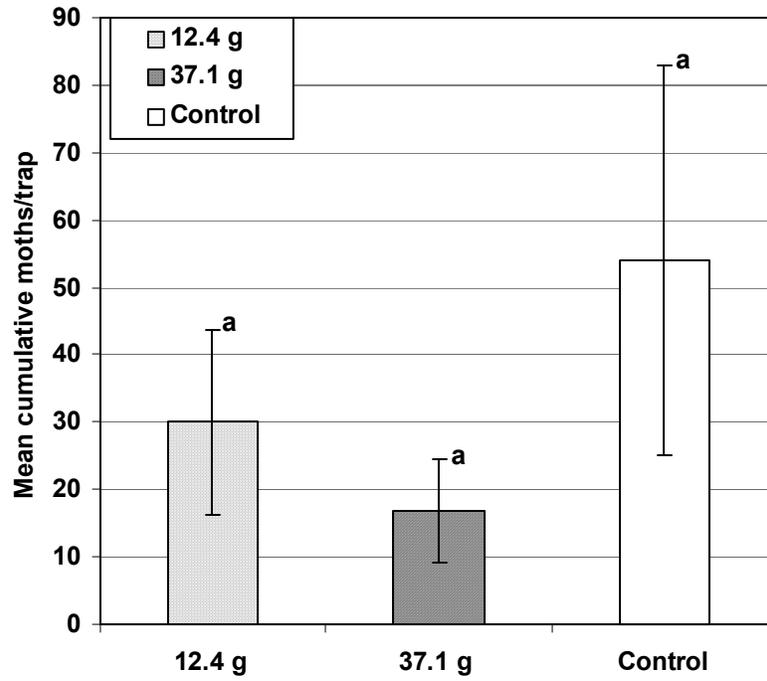
Fig. 1.9. Mean (±SEM) cumulative Oriental fruit moth pheromone trap catches in large blocks treated with 12.4,and 37.1 g (ai)/ha of sprayable pheromone compared with insecticide-treated control averaged across three locations. Henderson County, NC. 2001.

CHAPTER II

EVALUATION OF EXTENDED-SEASON ORIENTAL FRUIT MOTH
MATING DISRUPTION IN APPLES

ABSTRACT

During the 2000 and 2001 growing seasons, Oriental fruit moth, *Grapholita molesta* (Busck), mating disruption was successfully implemented in North Carolina apple orchards. However, low levels of late-season fruit damage occurred in some orchards treated in late May with Isomate-M 100 pheromone dispensers due to inadequate dispenser longevity. Similarly, increased late-season pheromone trap captures have also been observed in mating disruption blocks. To investigate alternative pheromone application schedules for Isomate-M 100 dispensers, the following treatments were compared in three different locations in Henderson County, NC, during 2002: Isomate-M 100 dispensers applied in late May; Isomate-M 100 dispensers applied in late June; Isomate-M 100 applied in late May plus a late August application of 3M sprayable pheromone; Isomate-M Rosso dispensers applied in late May; and conventional insecticides as a control. For sprayable pheromone applications, the efficacy of 3M sprayable pheromone applied at 6.2 g (ai)/ha at 2 wk intervals was compared with 12.4 and 24.7 g (ai)/ha applied at monthly intervals. Significantly fewer moths were caught in traps deployed in the treatments which included late May application of Isomate-M 100, Isomate-M Rosso and Isomate-M 100 plus 3M sprayable pheromone treatments compared with traps in conventional insecticide treatments, and Isomate-M 100 applied in late June. Large plot studies to determine the effects of different rates and application intervals of 3M sprayable pheromone revealed that the 6.2 g (ai)/ha was significantly less effective than the 12.4 and 24.7 g (ai)/ha, but there was no significant difference between 12.4 and 24.7 g (ai)/ha.

INTRODUCTION

Oriental fruit moth (OFM), *Grapholita molesta* (Busck), has been a primary

pest of peaches for many years, and recently it has also emerged as a key pest of

apples in the eastern United States (Hull et al. 2001). In North Carolina (NC), OFM

emerged as a serious pest of apples in 1998 (Walgenbach et al. 1999), when a

number of fruit loads were rejected at processing plants for the presence of OFM

larvae in the fruit. OFM completes four generations per year in NC, and because of

overlapping of generations late in the season, continuous egg laying can occur from

mid-July through October, which makes chemical control of the insect difficult

(Walgenbach et al. 2000).

In recent years, implementation of the Food Quality Protection Act (FQPA)

has eliminated or restricted the use of many organophosphate insecticides

commonly used for control of OFM. The occurrence of organophosphate resistant

OFM populations has also been documented (Pree 1997, Pree et al. 1998). These

factors have encouraged the use of alternative management strategies, one of the

most promising being pheromone-mediated mating disruption.

The use of sex pheromones for mating disruption of lepidopteran pests of

agriculture has, over the last decade, become an important component of integrated

pest management programs in a number of crops (Casagrande and Jones, 1997).

Mating disruption involves the prolonged release of large quantities of pheromone to

disrupt communication between male and female insects, which results in delayed

mating, fewer fertile eggs, and less damage (Kirsch 1988, Rice and Kirsch 1990,

Carde and Minks 1995, Knight 1996, Sexton and Il'ichev 2000). This technology has

been demonstrated to be effective for control of OFM (Rotschild 1975, Vickers et al. 1985, Weakley et al. 1987, Kirsch 1988, Audemard et al. 1989, Rice and Kirsch 1990, Pree et al. 1994, Cardé and Minks 1995, Barnes et al.1997).

Recently, OFM mating disruption has been successfully implemented in NC apple pest management programs. Several types of pheromone-dispensing systems are available, including hand-applied dispensers and microencapsulated sprayable pheromone formulations (Walgenbach et al. 2000). Isomate-M 100 (Shin-Etsu Chemical, Tokyo, Japan), a hand-applied dispenser, is the most commonly used pheromone-dispensing system in the US and has produced economically acceptable control (Cardé and Minks 1995). In NC, these dispensers have been applied in late May just before the emergence of second generation OFM; chemical control of the first generation is achieved by insecticides applied for control of other pests and for fruit thinning. Although Rice (1993) reported that mating disruption of several generations is necessary to achieve season-long control of OFM in California, this has not been found to be the case in North Carolina. Populations of second generation OFM adults and resultant eggs are typically very low in NC apple orchards, and it is not until the third or fourth generation that populations build to damaging levels (Borchert 2003). When Isomate-M 100 dispensers are applied in late May in NC, they remain active for about 70 d (J. Walgenbach, unpublished data). Consequently, one application may not provide season-long mating disruption for those cultivars harvested after August. In fact, low levels of late-season fruit damage have been observed in some orchards due to inadequate dispenser longevity. Unfortunately, there is little information on alternative or supplementary

approaches to obtain season-long mating disruption while avoiding multiple applications of Isomate-M 100 dispensers.

One alternative or supplementary approach is the use of sprayable pheromones. Sprayable pheromones are generally less persistent compared with pheromones in hand-applied dispensers, but they can be easily applied to large areas by conventional sprayers with minimal labor input (Gillespie et al. 1995). Sprayable pheromones could be readily incorporated into current mating disruption programs as needed (Epstein et al. 2003).

The purpose of this study was i) to investigate alternative pheromone application schedules of Isomate-M 100 dispensers, with and without supplementary sprayable pheromone applications; and ii) to compare the efficacy of sprayable pheromones applied at different rates and application intervals.

MATERIALS AND METHODS

Large Plot Isomate Trials. Large plot trials were conducted in two commercial apple orchards (Henderson and Staton) in Henderson County, NC, in 2002. All plots were treated with carbaryl (Sevin, Bayer Crop Science, Research Triangle Park, NC) at petal fall for thinning and for control of the first OFM generation. To investigate alternative pheromone application schedules, the following pheromone treatments were compared with conventional insecticides as specified below:

Treatments. 1) Late May application of Isomate-M 100. Isomate-M 100 dispensers were applied at the end of May just before the beginning of the second generation flight. 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 (E8-12Ac), and 1% (Z)-8-dodenenol (Z8-12:OH) and 4.8% inert ingredients]. Dispensers were deployed in the upper canopy of trees at least 2 m above the ground. They were applied at a rate of 250 dispensers/ha.

2) Late June application of Isomate-M 100. The application of Isomate-M 100 dispensers was delayed until late June, just before emergence of third generation moths. They were applied at a rate of 250 dispensers/ha. The use of a delayed application was intended to extend the release of pheromone into September and avoid a second application of dispensers.

3) Late May application of Isomate-M 100 supplemented with sprayable pheromone. Isomate-M 100 dispensers were applied at the end of May just before the beginning of the second generation flight. They were applied at a rate of 250

dispensers/ha. This treatment was supplemented with an application of sprayable pheromone (Phase V; 3M Canada Company, London, Ontario) at a rate of 24.7g (ai)/ha in late August. Sprayable pheromone was a water-based microencapsulated (MEC) formulation containing 18.6% Z8-12:Ac, E8-12:Ac, and Z8-12:OH and 80% inert ingredients.

4) Late May application of Isomate-M Rosso. Isomate-M Rosso (Shin-Etsu Chemical, Tokyo, Japan) was designed to extend the release of pheromone from dispensers to >150 d. Sexton and Il'ichev (2001) reported that Isomate-M Rosso released active ingredient above the threshold required for mating disruption in excess of 200 days in Australia. When applied in May in NC, dispenser longevity is approximately 140 d (J. Walgenbach, unpublished data). Dispensers were constructed of a brown-red colored polymer and consisted of two parallel tubes; one tube contained a piece of wire to provide stiffness and the other was filled with pheromone and sealed at the ends (Sexton, 2000). Each dispenser contained 250.2 mg active ingredients of OFM pheromone including 88.5% Z8-12:Ac , 5.7% E8-12:Ac, and 1% Z8-12:OH and 4.8% inert ingredients. Hand-applied dispensers were tied tightly to lateral branches in the upper third of the tree canopy in late May. They were applied at a rate of 400 dispensers/ha. No supplementary sprayable pheromone application was made.

All mating disruption treatments received two organophosphate insecticide applications for control of apple maggot; one in late June and one in early July. Two applications of methoxyfenozide (Intrepid 2F, Dow Agrosciences, Indianapolis,

IN) were applied for tufted apple bud moth, the first in late May and the second in mid August.

5) Conventional insecticide treatment. A non-pheromone treated conventional block was included at each site and sprayed with five to six applications of the organophosphate insecticides, azinphos-methyl (Guthion 50WP, Bayer Crop Science, Research Triangle Park, NC) and/or phosmet (Imidan 70WP, Gowan, Yuma, AZ) for OFM, codling moth and apple maggot control, and two applications of methoxyfenozide for control of the first (late May) and second (mid August) generation of tufted apple bud moth.

Study sites. Each treatment was replicated in two commercial apple orchards in Henderson County, NC. The Henderson orchard was a 10-ha block of 'Golden Delicious' and 'Rome Beauty' apples. Each treatment block was approximately 2 ha in size. Tree height ranged from 2 to 7 m. The Staton orchard was a 13-ha block of 'Golden Delicious' and 'Rome Beauty' apples that consisted of four 2 ha treatment blocks, and a 5 ha Isomate-M 100 block. Tree height ranged from 2 to 5 m.

Assessment of treatment efficacy. The efficacy of treatments was evaluated by comparing captures of adult male OFM in pheromone-baited traps and by inspection of fruit for OFM larval feeding injury at harvest during mid-September.

Wing-style pheromone traps (Pherocon 1C Trap, Trécé, Salinas, CA) were used to monitor OFM populations in each treatment. For each treatment, traps were hung at a density of one trap per 0.4 ha, and each trap was placed in the upper third of the canopy. Rubber septa (Thomas scientific, Swedesboro, NJ) were loaded with 100 μg of OFM pheromone (Bedoukian Research Inc., Danbury, CT) containing 93%

Z8-12:Ac , 6% E8-12:Ac, and 1% Z8-12:OH. Pheromone lures were changed every 4 wk. Traps were checked weekly from late May to early October. Trap bottoms were replaced as needed to maintain a clean surface.

Damage assessment. Fruit damage was assessed at harvest in mid-September. OFM injury was placed into one of three categories: "stings" represented surface blemishes caused by a complex of lepidopterous larvae, "entry" represented larval tunneling into the fruit flesh, and "live worm" was used for fruit infested with a live larva. Within each treatment, fruit damage was evaluated by picking 100 fruit arbitrarily from each of 10 trees per treatment. The insecticide treatment at Henderson was harvested before damage assessment was conducted, and a total of only 100 fruit were examined at this site. All fruit were cut to check for the presence of internal lepidopterous damage. Worms were collected and identified to species.

Data analysis. The study was conducted using a randomized complete block design and pooled data were subjected to analysis of variance (ANOVA) (SAS 2001). Data are presented as mean cumulative moth catches per trap, but counts were transformed to log (x+0.5) before analysis of variance (ANOVA). Fisher's protected LSD test was used for mean separation (P =0.05). Mean percentage fruit damage was transformed using arcsine square root and were subjected to ANOVA. Fisher's protected LSD test was used to compare treatment means (P = 0.05).

Large Plot Sprayable Pheromone Trials. Trials were carried out in three commercial apple orchards (Coston, Dalton and Marlowe) in Henderson County, NC in 2002. The efficacy of sprayable pheromone applied at 6.2 g (ai)/ha at 2 wk

intervals was compared to those applied at rates of 12.4 and 24.7 g (ai)/ha at monthly intervals. For each pheromone treatment, the initial application of Phase V formulation of sprayable pheromone was applied in late May. Additionally, a non-pheromone treated conventional insecticide block was included at each site, and these were sprayed with five to seven applications of the organophosphate insecticides azinphosmethyl and/or phosmet for OFM, codling moth and apple maggot control. All plots were treated with carbaryl at petal fall for thinning and for control of the first OFM generation. All sprayable pheromone treatments received two organophosphate (phosmet) applications, one in late June and one in early July for apple maggot control, and two methoxyfenozide applications for control of the first and second tufted apple bud moth generations. Pheromone trap monitoring, damage assessment and data analysis were carried out as described for Isomate-M 100 trials. The conventional insecticide treatment at the Coston site was harvested before the damage assessment in the insecticide-treated block, and a total of only 100 fruits that remained on trees were examined in this orchard.

Study sites. The Coston orchard was a 10.5-ha block of 'Golden Delicious' and 'Rome Beauty' apples, and was divided into a 4 ha conventional insecticide block, and three sprayable pheromone blocks each approximately 2-2.5 ha in size. The Dalton orchard was a 10-ha block of 'Golden Delicious' apples that consisted of three adjacent blocks and a nearby control block. Each treatment block was approximately 2.5 ha in size. Marlowe was a 10-ha block of 'Rome Beauty' apples, and was divided into four plots ranging in size from 2 to 3.2 ha. One treatment (12.4 g rate) was separated from other treatments by a shrubbery area.

RESULTS AND DISCUSSION

Large Plot Isomate Trials. Mean seasonal cumulative pheromone trap capture of OFM males ranged from 34 to 47 moths/trap in insecticide-treated blocks, indicating that OFM population pressure was moderate in both the Staton and Henderson orchards (Fig. 2.1). Season total OFM trap captures were significantly lower in all mating disruption blocks compared with insecticide-treated blocks (Table 2.1). Likewise, traps in blocks treated only with Isomate-M 100 blocks in late May, Isomate-M Rosso in late May, and Isomate-M 100 in late may plus sprayable pheromone in August caught significantly fewer moths compared with the delayed June application of Isomate-M 100. Treatment effects were consistent over locations.

Among pheromone treatments, the highest trap captures were in the delayed Isomate-M 100 treatment at each site. This was mainly due to early season catches before application of dispensers. Following application, there were no moth captures in this treatment (Fig. 2.1). Several moths were captured in September in the Isomate-M 100 treatment applied in late May, whereas there was no late season trap capture in the Isomate-M 100 treatment supplemented with sprayable pheromone in late August. Early season application of Isomate-M 100 dispensers supplemented with a single sprayable pheromone application in the latter part of the season was therefore successful in disrupting the ability of males to locate females in the orchard. This integrated approach not only achieved season-long mating disruption, but also demonstrated ease with which sprayable pheromone technology can be used in mating disruption programs. These findings suggest that sprayable

pheromones can be used as a supplementary tool to prevent short-term problems occurring before harvest. Similarly, Epstein *et al*. (2003) proposed that sprayable pheromones could be readily incorporated into current mating disruption programs as needed.

Isomate-M Rosso was highly effective for season-long suppression of trap capture. In Isomate-M Rosso blocks, OFM trap catches were impressively low throughout the season, remaining at zero in Staton and near zero in Henderson. This can be attributed to the longer residual emission of pheromone from Isomate-M Rosso dispensers (Sexton and Il'ichev, 2001). Additionally, the polyethylene used in Isomate-M Rosso may also have played an important role for higher release rates in late season, because it was constructed of a red colored pigment that protected the active ingredient from degradation in sunlight (Sexton, 2000).

Damage assessment. Damage in all categories was low in all treatments, except for the number of entries in the conventional insecticide blocks (Table 2.2). No live worms were found in mating disruption blocks. A single OFM larva was recovered from a damaged fruit in the conventional insecticide block at Staton. However, there was no significant difference among treatments averaged over locations. The highest incidence of entries was found in the conventional block (1.6%), although treatments did not differ from each other. There were no entries found in the Isomate-M Rosso or Isomate-M 100 plus 3M sprayable pheromone treatments. No significant difference was observed for the number of stings averaged over locations.

Low trap captures are not necessarily an indication of the efficacy of mating disruption (Charmillot 1990). But trap captures appeared to be related to low damage levels obtained in this trial. It should be noted, however, that all mating disruption blocks received two organophosphate applications in late June and early July for apple maggot control. These applications probably had an impact on second generation OFM activity in mating disruption blocks.

One drawback of OFM mating disruption is the perceived high cost (Kirsch 1988, Rice and Kirsch 1990). Proper timing of dispenser applications could reduce costs while achieving good control. Isomate-M 100 costs approximately $100/ha, and an additional $15/ha for application. Isomate-M Rosso dispensers cost twice as much as Isomate-M 100 dispensers. Also, they are applied at 1.6 times the number per ha of Isomate-M 100 dispensers. A single supplementary sprayable pheromone application at a rate of 24.7g/ha cost approximately $35/ha. Isomate-M 100 dispensers applied in late May provided acceptable control, although slightly more entries and stings were found in these blocks compared with other pheromone treatments. When Isomate-M 100 dispensers were applied alone in either late May or late June, the cost of mating disruption appeared to be minimal. Isomate-M Rosso was more expensive than the other pheromone treatments, but they were effective throughout the season.

Large Plot Sprayable Pheromone Trials. Based on pooled data from the three locations where studies were conducted, season total pheromone trap captures varied significantly with the rate of pheromone applied. For all rates of sprayable pheromone, significantly fewer moths were captured compared with the

conventional treatment, and significantly fewer moths were caught in the 12.4 and

24.7 g rates compared with the 6.2 g rate (Table 2.3). Trap captures varied

considerably among the three sites (Fig. 2.2), and there was a significant treatment x

location interaction. At Coston, where OFM populations were very low, there were

no differences among pheromone treatments. At the Marlowe and Dalton sites,

where OFM populations were relatively high, trap captures did differ significantly

among pheromone treatments. At both locations, late season trap captures

increased to significantly higher numbers in the 6.2 compared with 12.4 and 24.7 g

rates. It appears that the 6.2 g rate was effective in suppressing catches under low

OFM pressure at Coston, but efficacy declined with increasing population densities

encountered at the Dalton and Marlowe sites.

Although damage in the pheromone treatments was lower compared with the

conventional treatment, these differences were not significant (Table. 2.4). No larval

entry damage or live worms were detected in the 24.7 g rate of sprayable

pheromone, while the conventional treatment averaged 3.0 and 0.6% larval entries

and fruit with live worms, respectively. Among the pheromone treatments, fruit

damage was generally higher in the 6.2 g rate compared with high pheromone rates.

A total of four live OFM larvae were detected in the 6.2 g rate of sprayable

pheromone, all from the Marlowe site where late season pheromone trap captures

were relatively high in this treatment.

Despite relatively high OFM populations at the Dalton site, the 6.2 g rate of

sprayable pheromone appeared to perform better compared with the Marlowe site.

Environmental variables such as precipitation, temperature and wind velocity can all

affect pheromone release rates and aerial concentrations (Ogawa 1997), and differences in these variations among study sites may account for these differences. In addition, temperature (Brown et al. 1992), rainfall and sunlight can impact the adherence of microencapsulated pheromone to trees (Waldstein and Gut 2003). The late season increase in trap captures observed in the sprayable pheromone treatments may also be related to the differential adherence microcapsules to leaves of different ages. Waldstein and Gut (2003) showed that there was a greater propensity of microcapsules to adhere to branches and immature foliage compared with mature foliage.

Grower adoption of mating disruption as a management strategy can be adversely affected by fluctuations in the price of apples, the relatively high cost of mating disruption, and a perception of higher risk of crop loss compared with conventional insecticide management (Brunner et al. 2002). 3M sprayable pheromone for OFM is currently labeled at 24.7 to 37.1 g (ai)/ha, which costs approximately $35/ha and $52/ha per application, respectively. Our results suggest that a reduced dosage rate of 12.4 g (ai)/ha was as effective as 24.7 g (ai)/ha. This could result in significant cost savings for mating disruption programs while providing acceptable control. The cost of mating disruption can also be influenced by pest pressure. For example, the 6.2 g (ai)/ha treatment at 2-wk intervals was effective in managing low populations of OFM. But the risk of infestation appeared to increase with increasing population pressure.

Our results also suggest that Phase V formulation of 3M sprayable pheromone remained effective for 3 to 4 wk. Phase V is a modification of Phase I

formulation to reduce the initial burst of pheromone after application and to extend

residual activity. Efforts to increase the longevity of sprayable pheromones have also

included the addition of various adjuvants (Ellis and Hull, 2001). Epstein et al. (2003)

reported that the sticker Nu-Film 17 enhanced the performance of phase V

formulation of 3M sprayable pheromone during the second and third generation

OFM flights in Michigan, but performance was not increased during the first

generation flight. Sprayable pheromones offer growers considerable flexibility in the

rate and timing of application when tailoring mating disruption programs.

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Table 2.1. Mean cumulative (±SEM) Oriental fruit moth pheromone trap captures in blocks of apples treated with Isomate-M 100 dispensers applied in late May, Isomate-M 100 applied in late June, Isomate-M 100 applied in late May and treated with 3M sprayable pheromone in late August, Isomate Rosso applied in late May, and conventional organophosphate insecticides. Henderson County, NC. 2002

Location	Treatment	n	Moths per trap
Henderson	Isomate-M 100	5	1.4 (0.6)bc
	Isomate-M 100 + sprayable	5	0.0 (0.0)c
	Delayed Isomate-M 100	5	3.2 (1.7)b
	Isomate Rosso	5	0.2 (0.2)c
	Control	5	46.6 (4.7)a
Staton	Isomate-M 100	12	0.6 (0.3)c
	Isomate-M 100 + sprayable	5	0.2 (0.2)c
	Delayed Isomate-M 100	5	2.8 (1.4)b
	Isomate Rosso	5	0.0 (0.0)c
	Control	5	34.0 (10.4)a
Pooled	Isomate-M 100	17	0.8 (0.3)c
	Isomate-M 100 + sprayable	10	0.1 (0.1)c
	Delayed Isomate-M 100	10	3.0 (1.0)b
	Isomate Rosso	10	0.1 (0.1)c
	Control	10	40.3 (5.8)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. ANOVA statistics for pooled data are $F = 157.39$; df = 4, 20; $P <0.01$, Location effect $F = 4.02$; df = 1, 20; $P = 0.06$, and treatment x location interaction $F = 0.54$; df = 4, 20, $P = 0.71$.

Table 2.2.   Mean percentage (±SEM) fruit damage averaged across two different locations treated with Isomate-M 100 dispensers applied in late May, Isomate-M 100 applied in late June, Isomate-M 100 applied in late May plus 3M sprayable pheromone applied in late August, application at late season, Isomate Rosso applied in late May, and conventional organophosphate insecticides. Henderson County, NC. 2002

Treatment	n	Sting	Entry	Live worm
Isomate-M 100	2	0.5 (0.3)a	0.2 (0.1)a	0.0 (0.0)a
Isomate-M 100+sprayable	2	0.4 (0.1)a	0.0 (0.0)a	0.0 (0.0)a
Delayed Isomate-M 100	2	0.4 (0.0)a	0.1 (0.1)a	0.0 (0.0)a
Isomate Rosso	2	0.2 (0.0)a	0.0 (0.0)a	0.0 (0.0)a
Control	2	1.0 (1.0)a	1.6 (1.5)a	0.1 (0.1)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 arcsine square root, but data shown are back transformations. ANOVA statistics for stings, entries and live worms are $F = 0.10$, df = 4, 4, $P = 0.98$; $F = 1.34$, df = 4, 4, $P = 0.39$; $F = 1.00$, df = 4, 4, $P = 0.50$, respectively.

Table 2.3.   Mean cumulative (±SEM) seasonal total Oriental fruit moth pheromone trap captures in blocks of apples treated with 6.2, 12.4 and 24.7 g (ai)/ha of 3M sprayable pheromone, and conventional organophosphate insecticides. Henderson County, NC. 2002

Location	Pheromone rate (g [ai]/ha)	n	Moths per trap
Coston	6.2	4	2.0 (0.4)b
	12.4	4	4.3 (1.9)b
	24.7	4	1.3 (0.3)b
	Control	4	15.3 (0.8)a
Dalton	6.2	4	7.8 (2.6)b
	12.4	4	3.5 (1.4)c
	24.7	4	0.8 (0.5)c
	Control	4	61.0 (10.5)a
Marlowe	6.2	8	27.4 (7.1)a
	12.4	4	1.3 (0.8)b
	24.7	4	1.3 (0.8)b
	Control	4	12.8 (1.9)a
Pooled	6.2	16	16.1 (4.5)b
	12.4	12	3.0 (0.9)c
	24.7	12	1.1 (0.3)c
	Control	12	29.7 (7.4)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. ANOVA statistics for Pooled data are $F = 8.35$; df = 3, 24; $P = 0.02$, Location effect $F = 1.03$; df = 2, 24; $P = 0.37$, and treatment x location interaction $F = 4.14$; df = 6, 24, $P < 0.01$.

Table 2.4. Mean percentage (±SEM) fruit damage averaged across three different locations treated with 6.2, 12.4 and 24.7 g (ai)/ha of 3M sprayable pheromone and a conventional organophosphate insecticides. Henderson County, NC. 2002

Pheromone rate (g [ai]/ha)	n	Sting	Entry	Live worm
6.2	3	0.6 (0.3)a	0.6 (0.3)a	0.1 (0.1)a
12.4	3	0.2 (0.1)a	0.1 (0.0)a	0.0 (0.0)a
24.7	3	0.1 (0.1)a	0.0 (0.0)a	0.0 (0.0)a
Control	3	0.8 (0.3)a	3.0 (1.7)a	0.6 (0.4)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 arcsine square root, but data shown are back transformations. ANOVA statistics for stings, entries and live worms are $F = 2.06$, df = 3, 6, $P = 0.21$; $F = 2.97$, df = 3, 6, $P = 0.12$; $F = 1.92$, df = 3, 6, $P = 0.23$, respectively.

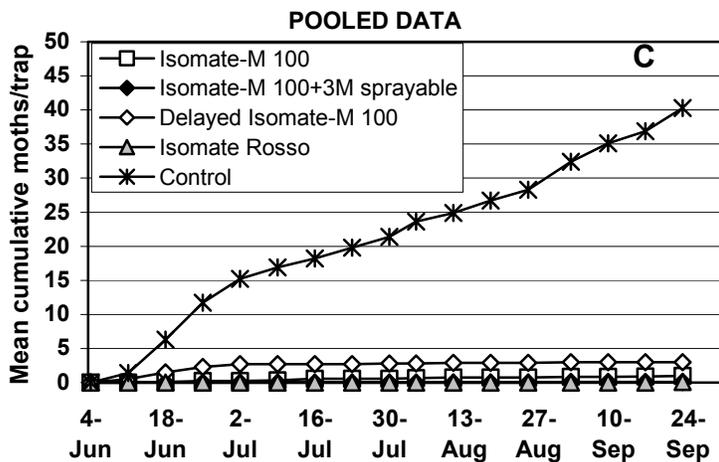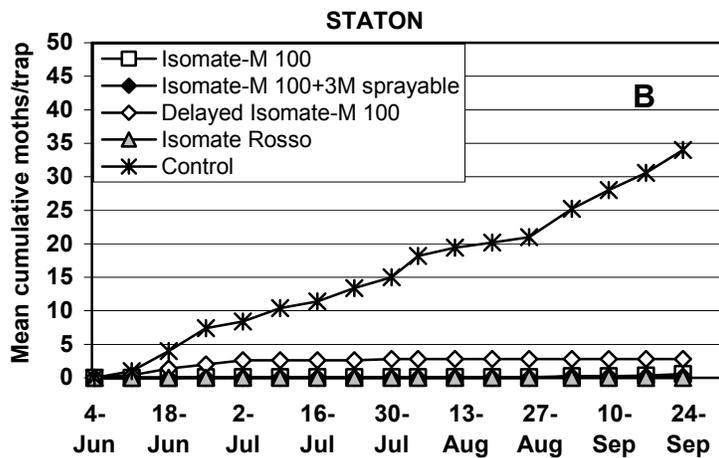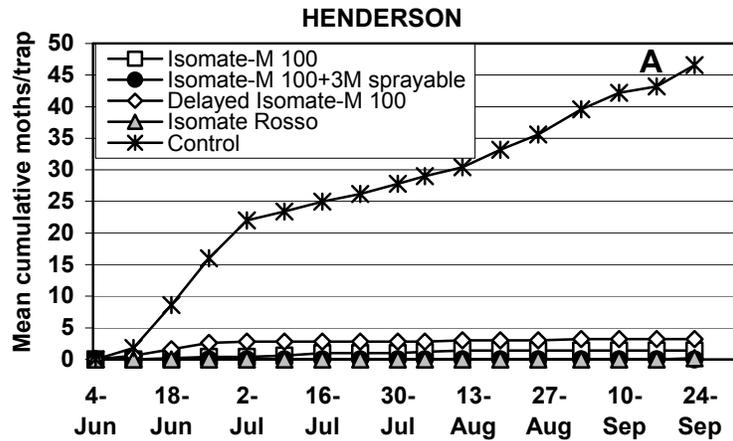**Fig 2.1.**   Mean cumulative Oriental fruit moth pheromone trap captures in blocks treated with Isomate-M 100 dispensers applied in May, Isomate-M 100 applied in late June, Isomate-M 100 applied in late May plus 3M sprayable pheromone in late August, Isomate Rosso applied in late May, and conventional organophosphate insecticides in Henderson (A) and Staton (B) orchards, and averaged across both orchards (C). Henderson County, NC. 2002
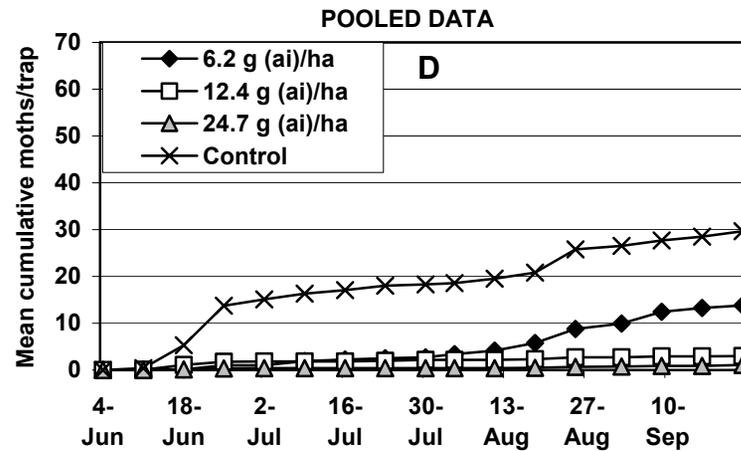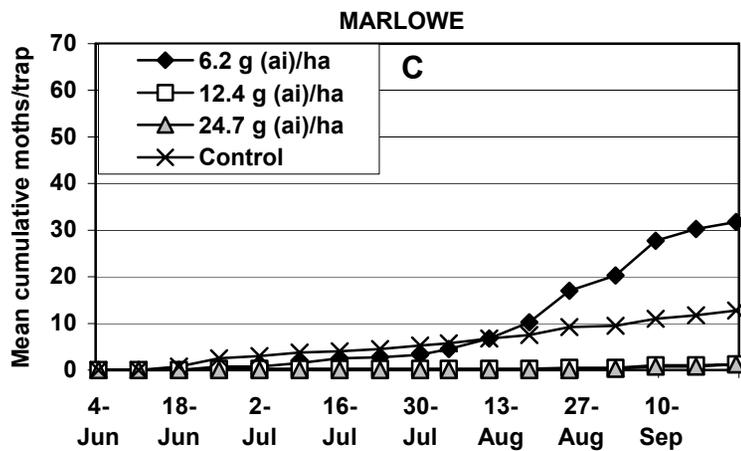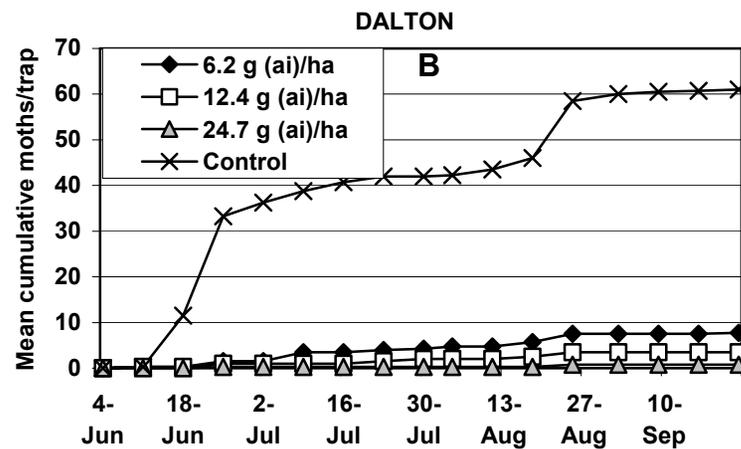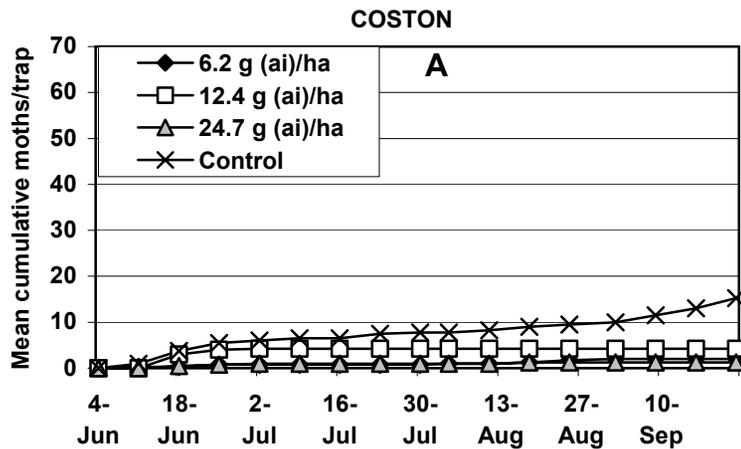
Fig 2.2. Mean cumulative Oriental fruit moth pheromone trap captures in blocks treated with 6.2, 12.4 and 24.7 g (ai)/ha of 3M sprayable pheromone and with conventional organophosphate insecticides in Coston (A), Dalton (B) and Marlowe (C) orchards, and averaged across all three locations (D). Henderson County, NC. 2002

CHAPTER III

**COMPARISON OF SEX PHEROMONE LOADING AND DISPENSER AGE
FOR MONITORING ORIENTAL FRUIT MOTH IN
NORTH CAROLINA APPLE ORCHARDS**

ABSTRACT

The effects of pheromone loading (30, 100 and 300 µg) and aging of red rubber septa in the field for 1-28 d on release of (Z)-8-dodecenyl acetate (Z8-12:Ac), the major sex pheromone component for the Oriental fruit moth (OFM), *Grapholita molesta (*Busck), were evaluated in Henderson County, NC, in 2002. Separate field tests evaluated the effects of trap height and pheromone loading of rubber septa for monitoring OFM in an abandoned orchard. The loss of OFM pheromone from red rubber septa over a 4-wk period exhibited a first-order release rate for septa loaded with 100 and 300 µg pheromone, but a more constant release rate from septa loaded with 30 µg pheromone. The highest release rate of pheromone from septa loaded with 100 and 300 µg pheromone occurred during the first 2 wk after placement in the field, and declined thereafter. Septa loaded with 300 µg lures released a lower percentage (38.1%) of pheromone over 28 d compared with 30 and 100 µg lures (47.9 and 48.1%, respectively) but the dose effect was not significant. In a trapping study in an abandoned orchard, significantly more moths were captured in pheromone traps placed in the upper compared with the lower canopy. Pheromone traps baited with 100 µg on rubber septa caught more moths compared with 300 µg. There was no apparent relationship between pheromone trap catch and septa age, with trap capture appearing to be a primary function of OFM population density.

INTRODUCTION

The Oriental fruit moth (OFM), *Grapholita molesta* (Busck), is a key pest of stone fruit throughout the world and of apples in eastern North America (Rotschild and Vickers 1991, Hull et al. 2001, Usmani and Shearer 2001). The identification of a four-component OFM sex pheromone, consisting of (Z)-8-dodecenyl acetate (Z8-12:Ac), (E)-8-dodecenyl acetate (E8-12:Ac), (Z)-8-dodecen-1-ol (Z8-12:OH), and dodecanol (12:0H) (Cardé et al. 1979), has led to the widespread use of pheromone traps to monitor OFM populations (Kirsch 1988). Trap catches have been used for detecting OFM adult emergence, timing insecticide applications, and assessing the efficacy of mating disruption (Rotschild 1981, Rice et al. 1982, Rice and Kirsch 1990).

Pheromone lures used in monitoring traps ideally should release the effective dose of pheromone at a constant rate throughout the trapping period (Vrkoč et al. 1988, Wall 1989). Controlled-release pheromone lures have included cotton dental wicks, rubber septa, polyethylene vials, laminates, hollow fibers, membranes, and polymeric systems (Jones et al. 1998). Rubber septa have been the most common substrates for the controlled release of many insect sex pheromones (Butler and McDonough 1981, Weatherston 1989). For example, Flint et al. (1978) showed that rubber septa were an excellent substrate for the controlled-release of gossyplure for pink bollworm. Rubber septa baited with codlemone have been the most widely used substrate for the codling moth (Riedl et al. 1986).

The selection of an appropriate dose of pheromone in lures is also critical for successful monitoring. Roelofs et al. (1973) reported that pheromone traps using

rubber septa baited with 200 μg of OFM pheromone caught significantly more males than traps baited with 1, 10, or 1000 μg. Unlike many moth species, OFM is not attracted to high concentrations of pheromone (Cardé and Minks 1995). Complete arrestment of male flight at loads of 1000 μg has been observed (Baker et al. 1981, Sanders and Lucuik 1996). Therefore, overloading OFM lures to extend longevity is not an option.

The longevity of field-aged red rubber septa depends on the release rate and the initial loading rate of pheromone (Maitlen et al. 1976, Daterman 1982). Maitlen et al. (1976) showed that codlemone exhibited a first order release rate from rubber septa, where initially a high amount of codlemone was released followed by a gradual decline in the rate over time. They reported that a 1 mg lure provides a optimal attraction for codling moth up to 4 wk, whereas a 5 mg lure remains effective for >4 months. However, Kehat et al. (1994a) found that both the release rate and the attractiveness of 1 mg lures decreased rapidly after 2 wk in the field. This apparent inconsistency was attributed to the effects of high summer temperatures.

For reliable OFM monitoring, pheromone lures should be replaced regularly, usually every 4 wk (Sziraki 1979, Vickers and Rotschild 1985, Pree et al. 1994, Robertson and Hull 2001). However, little information is available on factors influencing the longevity of field-aged rubber septa. Using pheromone lures without a full understanding of how pheromone load and dispenser age influence the attractiveness of lures could lead to unreliable trap catches (Thomson 1999, Knight 2002).

The objective of this study was to determine the effects of field aging and initial loading on the release rate and longevity of OFM pheromone from red rubber septa. In addition, field tests were conducted to determine the attractiveness of male OFM moths over time to traps baited with different amounts of OFM pheromone impregnated into red rubber septa.

MATERIALS AND METHODS

Preparation of lures. Red rubber septa (no. 1780J07, Thomas scientific, Swedesboro, NJ) were used in all experiments. Septa were first sonicated for 6 h in hexane, and then extracted three times with hexane for 24 h, and air-dried in a fume hood for 48 h before loading. Septa were impregnated with 30, 100 and 300 µg of OFM pheromone (Bedoukian Research Inc., Danbury, CT), which consisted of 90.4% (Z)-8-dodecenyl acetate, 6.1% (E)-8-dodecenyl acetate, 1.1% (Z)-8-dodecenol, and 2.4% inert materials, in 25 µl hexane. Hexane (50 µl) was added to aid in the penetration of pheromone into the rubber. Septa were stored at -20 ºC until used in experiments.

Evaluation of field-aged septa. To determine the release rate of pheromone from rubber septa aged in the field, lures loaded with different amounts of pheromone were placed in the field. Pre-extracted pheromone-loaded septa were pinned with brass safety pins (size 00), which were then attached to wire hangers. Septa were placed 1 cm apart on hangers. Hangers were deployed at 1.7 m height in an apple orchard at the Mountain Horticultural Crops Research Station (Fletcher, NC) on 11 June 2002 for an early season trial, and on 23 August for a late-season trial. In the early season trial, 42 septa were placed in the orchard, and seven septa of each dose (30, 100 and 300 µg) were removed 0, 1, 7, 14, 21 and 28 d after placement in the orchard. For the late-season trial, six septa of each dose were removed 0, 1, 7, 14, 21 and 28 d after placement in the orchard. After removal from the field, septa were stored at -20 °C until pheromone was extracted.

To extract pheromone from septa, each septum was separately extracted with intermittent vortexing for 90 min in a glass vial containing 3 ml of hexane and 30 μg of hexadecyl acetate (16:Acet) as an internal standard. The septum was extracted again with 3 ml hexane with shaken for 90 min. Both extracts were combined, capped with a Teflon-lined cap, and stored at -20 ºC. For chemical analyses, the volume of each sample was reduced to ~1 or 2 ml and ~1 μl was injected into a gas chromatograph (GC). Analyses were conducted on a HP5890 GC Series II (Agilent, Palo Alto, CA) equipped with a splitless injector (250 ºC) and a flame-ionization detector (250 ºC) and interfaced with a ChemStation. The column (HP-5, 30 m X 0.32 mm X 0.25 μm) was operated at 50 °C for 2 min, and then increased 20 ºC per min to 245 ºC and held for 5 min. Helium was used as the carrier at a flow rate of 30 cm sec^{-1}.

Field trapping study. To determine the response of OFM male moths to rubber septa loaded with 100 and 300 μg of pheromone, a trapping study was conducted in a 2-ha abandoned orchard in Henderson County, NC, in 2002. Scentry wing traps (Scentry Biologicals, Billings, MT) were used for the study. A total of 16 traps were placed in the orchard in a randomized complete block design with four replications: eight traps each were placed in the lower and upper third of the canopy, and four traps each at the different heights were baited with septa loaded with either 100 or 300 μg pheromone. Traps were monitored weekly from 11 June to 7 July in the early season trial, and from 16 August to 13 September in the late-season trial. Traps were rotated among trees each week so that each trap appeared at each tree for a 1 wk period.

Data analysis. Pheromone extraction data were analyzed using a 2 (season) x 3 (dose) x 6 (field age) factorial experiment. The effects of pheromone dose and field age during the two trial periods were tested with analysis of variance (ANOVA). Fisher's protected LSD test was used for mean separation ($P = 0.05$). If there were significant interaction effects, LSMEANS comparisons (SAS 2001) were used to identify these effects. Exponential and linear regression analyses were used to fit the release of pheromone from septa over time (SAS 2001). The average daily release rate of lures during each time interval was estimated by calculating the difference in mean sex pheromone content at the beginning and end of successive sample periods, and dividing by the number of days between sample periods.

Trap captures in pheromone traps over the 4 wk trapping period for the early and late-season trial were analyzed by ANOVA. Based on inspection of plots of residuals, data were transformed using log (x + 0.5) before ANOVA, but data are presented as back transformations. Fisher's Protected LSD test was used to compare treatment means ($P = 0.05$).

RESULTS AND DISCUSSION

Pheromone release from septa. The release of pheromone from septa loaded with 100 and 300 µg of pheromone was best described by exponential equations, while that from 30 µg lures was described by linear equations (Fig. 3.1). This trend was consistent in both the early and late-season trials, and the equations were very similar between the two trials. These data indicate a first order release rate from 100 and 300 µg lures, while release from the 30 µg lures was relatively constant. This difference between the release characteristics was probably due to the small amount of pheromone released from 30 µg lures compared with 100 and 300 µg lures.

The average daily pheromone release rates from septa loaded with different amounts of pheromone are shown in Table 3.1. The release rates from the 30, 100 and 300 µg lures did not differ significantly between seasons (F = 0.11; df = 1, 110; P = 0.74). In contrast, Kehat et al. (1994a) reported that the release rates from rubber septa loaded with 100 or 1000 µg of codlemone was higher during the summer than in spring. This was presumed to be due to the rapid drop in the emission rate of high-load lures under high summer temperatures. However, Knight (2002) proposed that the decline in attractiveness of septa was not caused by the reduction in the release rate, but by degradation of codlemone.

The highest rate of pheromone release generally occurred during the first 2 wk, which was the period when differences among septa loaded with different amounts of pheromone were greatest. For example, between days 1-7, the average release rates from 30, 100 and 300 µg lures (averaged across trial dates) were 1.0,

4.1 and 9.3 μg /d, respectively. However, there was less difference in the release

rate among lures aged in the field between 21-28 days; average release rates for 30,

100 and 300 μg lures were 0.2, 0.9 and 0.8 μg /d. The initial burst of pheromone

from high load lures was probably due to decreased penetration of pheromone into

rubber septa. Kehat et al. (1994a) and Gut and Brunner (1995) also showed a rapid

decline in the release rates of standard and high load lures for codling moth after 2

wk. This rapid decline was attributed to the chemical instability of codlemone, a

conjugated diene alcohol (Brown and McDonough 1986). Conversely, the release of

the honeydew moth pheromone ((Z)-11-hexadecenal) from rubber septa loaded with

0.2-20 mg was initially constant for 18 d, and then gradually declined (Anshelevich

et al. 1993).

Averaged across doses, septa aged in the field during the late season

(August and September) released a higher percentage of pheromone compared with

the early season (June and July); 43.8 and 45.7% of pheromone was released

during the early and late-season trials, respectively. However, these seasonal

differences were not significant (F = 0.92; df = 1, 132; P = 0.34). Temperatures were

similar during the two study periods (Fig. 3.2), with average daily temperatures of

21.2 and 20.3 ºC during the early and late-season trials, respectively. While

pheromone release from lures is generally considered to be greater with increasing

temperature (Quisumbing and Kydonieus 1989), temperature difference between

these trials did not appear to differentially affect OFM pheromone release from our

septa. Septa loaded with 300 μg lures released a lower percentage (38.1%) of

pheromone over 28 d compared with 30 and 100 μg lures (47.9 and 48.1%,

respectively) (Fig 3.3), but the dose effect was not significant (F = 0.92; df = 1, 132; P = 0.34). However, the dose x season effect was significant (F = 5.52; df = 2, 132; P < 0.01); septa loaded with 100 µg of pheromone released a significantly higher percentage of pheromone compared with 30 and 300 µg septa in the early season, but not in the late season.

Field trapping study. Trap height (F = 14.35; df = 1, 97; P < 0.01) and pheromone load in septa (F = 4.73; df = 1, 97; P = 0.03) were both significant factors affecting moth catch in pheromone traps (Table 3.2). The effect of field aging (1-4 wk) was not significant averaged over seasons (F = 2.25; df = 1, 97; P = 0.09). However, there was a significant interaction between season and field aging (F = 5.36; df = 3, 97; P < 0.01). A significant decline in moth capture with lure age was detected with 100 µg lures averaged over two trap heights early in the season. A similar, but not significant decline in moth capture with lure age was detected with 300 µg lures in the early season. During the early season trial, the highest moth counts averaged over the two trap heights for each pheromone load were found in traps baited with 2-wk-old lures, a period of time when pheromone release from lures was highest based on laboratory extractions. Whether this response was due to septa performance or declining OFM populations is unknown. Several researchers have shown that codling moth capture with lures loaded with 1 mg and 10 mg of codlemone was significantly higher compared with older lures (Kehat et al. 1994a, Gut and Brunner 1995, Knight et al. 2002). Similar results were obtained with 1-wk-old septa loaded with 1 mg of European vine moth pheromone (Anshelevich et al. 1994).

Results of the late-season trial, when total OFM captures were significantly higher compared with the early season trial ($F = 61.30$; df = 1, 97; $P < 0.01$), suggest that moth response did not decline in response to aging lures. During the late-season trial there was a trend of increased moth capture with lure age (Table 3.2). In fact, the highest moth captures were recorded in traps baited with 4-wk-old lures for each pheromone load. This was likely due to increasing OFM populations later in the season rather than a positive response of moths to aging lures, although these effects could not be separated in this study. Based on pheromone extraction studies, septa were releasing ~1 µg /d during this time. This amount is close to that of the highest release rate recorded from OFM females, which is 25.3 ng/h (~1.2 µg /d) (Lacey and Sanders 1992). These results are similar to those obtained with the peach twig borer, where there was no difference in moth capture in traps baited with one- versus four-wk-old septa (Kehat et al. 1994b).

Total moth capture was significantly higher in pheromone traps placed in the upper versus the lower canopy averaged across seasons (Fig 3.4A). Height effect was consistent over seasons ($F = 0.43$; df = 1, 97; $P = 0.51$). Similar observations have been made with the codling moth in both pheromone-treated and non-treated orchards (Charmillot 1990, Knight 1995).

Pheromone traps baited with 100 µg septa lures caught more total moths compared with 300 µg lures across seasons (Fig. 3.4B); this difference between doses was significant ($F = 14.26$; df = 1, 97; $P < 0.01$). The septa dose x season interaction was not significant ($F = 0.04$; df = 1, 97; $P = 0.85$). These results are consistent with those of Baker et al. (1981), who reported that significantly more

males were captured in traps baited with lures containing 100 versus 300 µg of 5.9 % of E8-12:Ac.

Our results showed that the mean percentages of pheromone released from all lures ranged from 34.4 % to 50.4 % after 0-28 d, and their release rates were $\leq$1.2 µg/d between days 21-28. Based on these results, red rubber septa loaded with 100 and 300 µg OFM pheromone effectively monitored Oriental fruit moth over a 4-wk period.

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Table 3.1. Mean (±SEM) Oriental fruit moth pheromone release rate (µg/d) from red rubber septa aged in the field for different time periods

Pheromone load rate (µg/septa)	Aged in field (days)	µg/d	
		Jun – Jul trial	Aug – Sept trial
30	0-1	-[a]	2.3 (1.4)
	1-7	1.2 (0.2)	0.7 (0.2)
	7-14	0.6 (0.2)	1.0 (0.2)
	14-21	1.0 (0.1)	0.2 (0.1)
	21-28	-[a]	0.5 (0.2)
100	0-1	2.5 (3.3)	-[a]
	1-7	4.2 (0.4)	4.0 (0.6)
	7-14	1.8 (0.2)	2.6 (0.4)
	14-21	2.6 (0.6)	0.8 (0.5)
	21-28	0.7 (0.4)	1.1 (0.8)
300	0-1	-[a]	4.0 (12.7)
	1-7	8.4 (1.1)	10.2 (1.4)
	7-14	7.2 (2.8)	4.0 (1.7)
	14-21	0.6 (1.7)	4.8 (0.9)
	21-28	1.1 (2.0)	0.5 (1.9)

[a]Release rates could not be calculated, because mean pheromone content per septa did not change from the previous date

Table 3.2. Mean (±SEM) Oriental fruit moth capture in pheromone traps baited with 100 vs 300 µg pheromone, and traps placed in the upper and lower canopy. Henderson County, NC. 2002

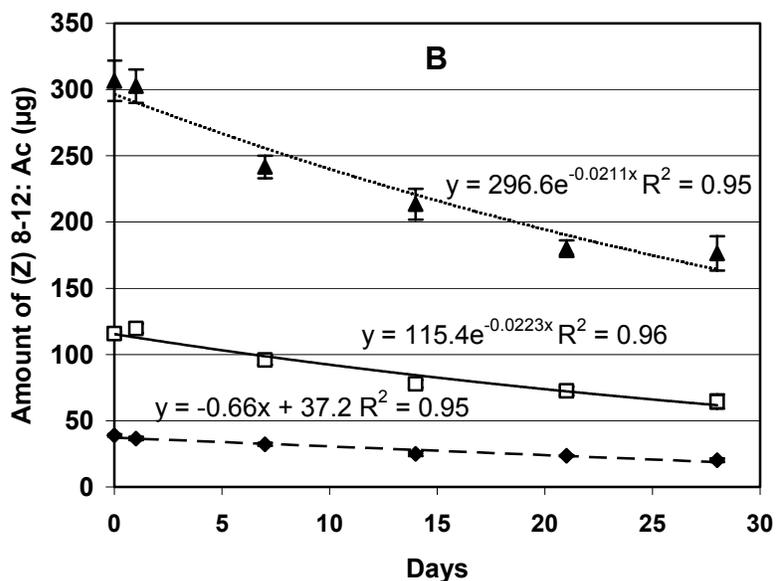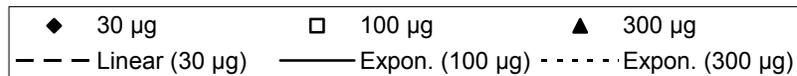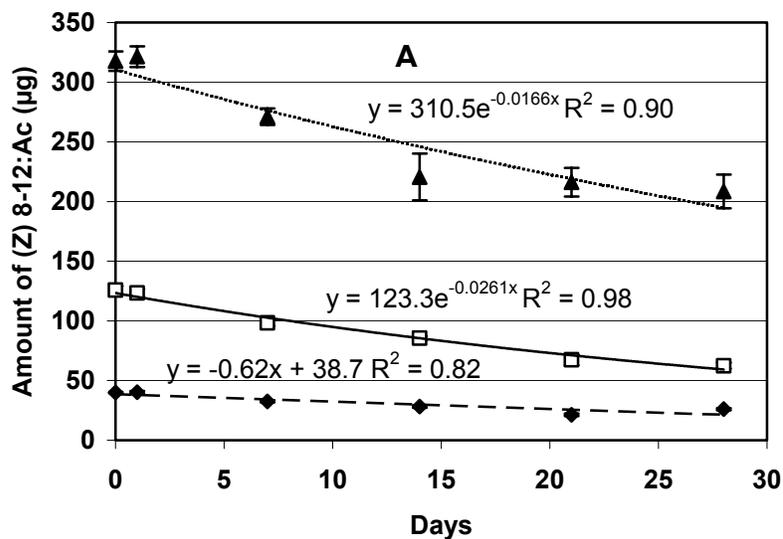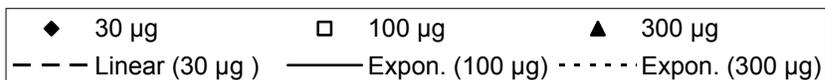| Trial	Septa load	Trap height	Moths/trap				
			Wk 1	Wk 2	Wk 3	Wk 4	Cumulative
Early season	100 µg	Low	0.8 (0.3)	2.3 (0.6)	1.0 (0.4)	0.3 (0.3)	4.4 (0.9)
		High	3.0 (0.9)	2.8 (1.3)	1.5 (0.9)	1.5 (1.0)	8.8 (1.1)
	300 µg	Low	1.5 (0.5)	1.0 (0.4)	0.0 (0.0)	1.0 (0.6)	3.5 (0.6)
		High	0.8 (0.3)	1.5 (0.6)	2.0 (0.4)	0.8 (0.5)	5.1 (0.8)
Late season	100 µg	Low	2.3 (0.5)	4.0 (0.8)	2.5 (1.3)	4.3 (2.0)	13.1 (1.9)
		High	3.5 (1.2)	7.0 (0.9)	4.3 (1.6)	9.3 (3.1)	24.1 (4.8)
	300 µg	Low	1.3 (0.3)	2.5 (0.5)	2.0 (1.4)	5.3 (2.4)	11.1 (4.1)
		High	2.5 (0.6)	2.8 (0.8)	3.3 (0.5)	7.3 (2.1)	15.9 (1.8)

Fig. 3.1. Release rate from field-aged red rubber septa loaded with 30, 100 and 300 μg OFM pheromone **A)** in the early season **B)** in the late-season. Henderson County, NC 2002.
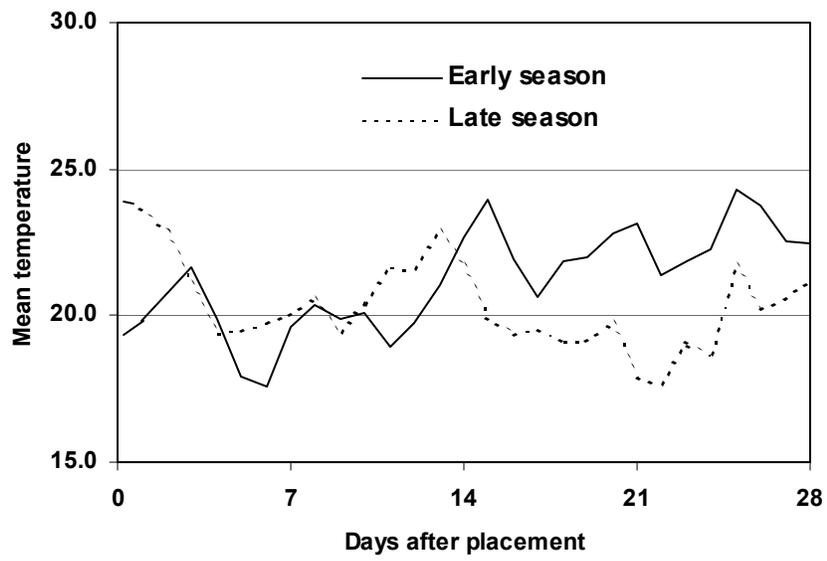
Fig. 3.2. Average air temperature during the early season (11 June - 8 July) and late-season (23 August -19 September) septa release trial. Henderson County, NC. 2002
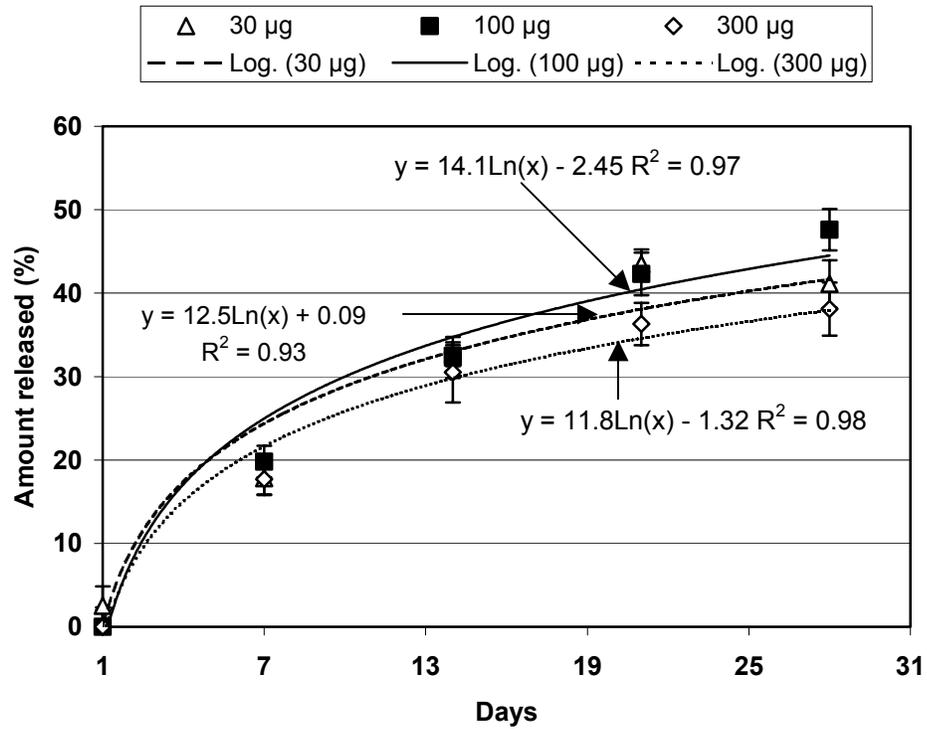
Fig. 3.3. Cumulative percentage of (Z) 8-12:Ac released from field-aged red rubber septa loaded with 30**,** 100 and 300 µg OFM pheromone averaged over seasons. Henderson County, NC 2002.
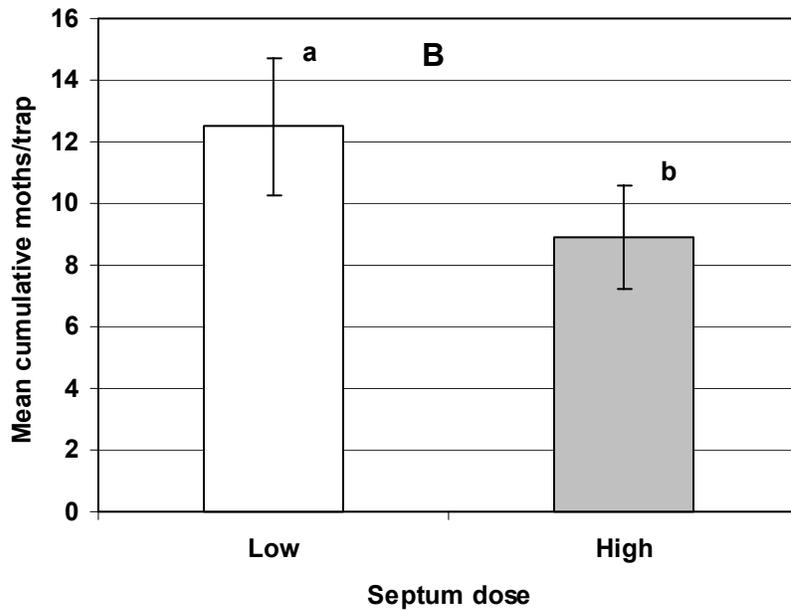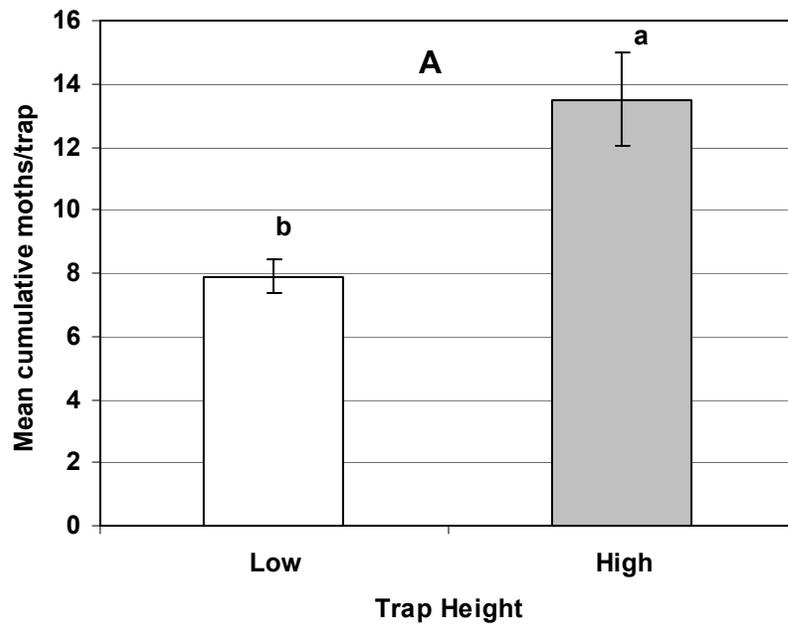
Fig. 3.4. Mean (±SEM) cumulative Oriental fruit moth catches in **A)** pheromone traps placed in the lower and upper canopy **B)** pheromone traps baited with 100 and 300 µg septa lures in Henderson abandoned orchard in 2002.

APPENDIX I

Preliminary studies with bait traps

INTRODUCTION

OFM is typically monitored by pheromone trapping of male moths (Hughes and Dorn 2002). Trap catches have been one of the main criteria for assessing the efficacy of mating disruption (Rotschild 1981). However, trap catches do not always correlate well with fruit damage (Rice and Kirsch 1990). Terpinyl acetate bait traps can attract both males and females. They are not specific to OFM, but they reflect the actual OFM abundance in the orchard (Il'ichev 2002). Preliminary studies were conducted to determine the effectiveness of bait traps as an alternative monitoring tool in mating disruption blocks.

MATERIAL AND METHODS

Pheromone and bait trapping. A total of 16 pheromone traps, 8 each in the lower and upper portion of the canopy, were placed in an abandoned orchard at Staton in 2000. Four traps each at the different heights were baited with 100 μg and 300 μg OFM pheromone. In addition to pheromone traps, two white colored Advantage bait traps (J. Oakes, Yazoo city, MS) were used to monitor both males and females. Bait traps were deployed at eye level. Baits were prepared from a mixture of terpinyl acetate (10 ml), emulsifier (Tween 20) (1 ml), brown sugar (1.8 kg), and water (18.9 liter). Each trap was filled with 500 ml of bait solution. The bait traps were monitored weekly by collecting moths and changing the terpinyl acetate. In 2001, bait traps were used to monitor the last generation of OFM in non-managed (abandoned), conventional insecticide treated, and mating disruption orchards at

97

Henderson, Coston and Staton. Only one terpinyl acetate bait trap per treatment was placed in orchards on 14 August and monitored until 18 September in 2001. Moths were collected in petri dishes and petri dishes were kept in the freezer. Females were dissected under a stereoscope to determine if they contained spermatophores in their spermatheca (Dustan 1964). Microdissection scissors (Bioquip pro., Rancho Dominguez, CA) were used for dissection.

Data analysis. The experimental deisgn was a randomized complete block design and bait trap captures were subjected to an ANOVA (SAS 2001). Counts were transformed using log (x+0.5) before analysis of variance (ANOVA). Fisher's protected LSD test was used for mean separation (P = 0.05).

RESULTS AND DISCUSSION

Mean number (±SEM) of captured moths was 9.9±6.3 adults in two bait traps, while pheromone traps caught a mean of 6.1±1.5 males averaged over 16 pheromone traps. Bait traps showed three distinct flight peaks, occurring 17 July, 7 August and 28 August (Fig. A1.1). Dustan (1964) observed that lure pails baited with brown sugar/terpinyl acetate trapped both sexes, but relatively few unmated females,and are thus of little value in assessing mating status of the females in the population. On the other hand, general population trends in bait trap catches can be related to levels of fruit infestation, while pheromone trap catches can not (Phillips 1973). Thus, it appears that bait traps can be used as an additional monitoring tool to evaluate the efficacy of mating disruption.

In 2001, last generation OFM males were also monitored using terpinyl acetate bait traps. Bait traps captured both males and females. Mean number

(±SEM) of captured moths was 1.3±1.1 females and 0.5±0.4 males averaged across

four treatments at two locations during the late season. Total moth captures in the

pheromone and insecticide-treated blocks were significantly lower than in

abandoned blocks (F = 29.68; df = 3, 3; P < 0.01). These results are in agreement

with those of Rice and Kirsch (1990) and Atanassov (2002), who reported similar

reductions in bait trap catches in pheromone-treated blocks. No moths were caught

in sprayable pheromone treated blocks. A total of only 5 moths were captured in

Isomate blocks at Staton. Of the four females captured, three had mated. These

females may have been immigrant moths, because they all were caught in the edge

trap facing a pack house. One mated female was also caught in the insecticide-

treated block in Coston. In abandoned blocks, OFM adults were covered with sticky

and dirty solution caused by debris from other moth species and wild wasps. No

attempt was made to dissect moths trapped in abandoned blocks. Although bait

traps were useful in monitoring female populations, especially mated females, they

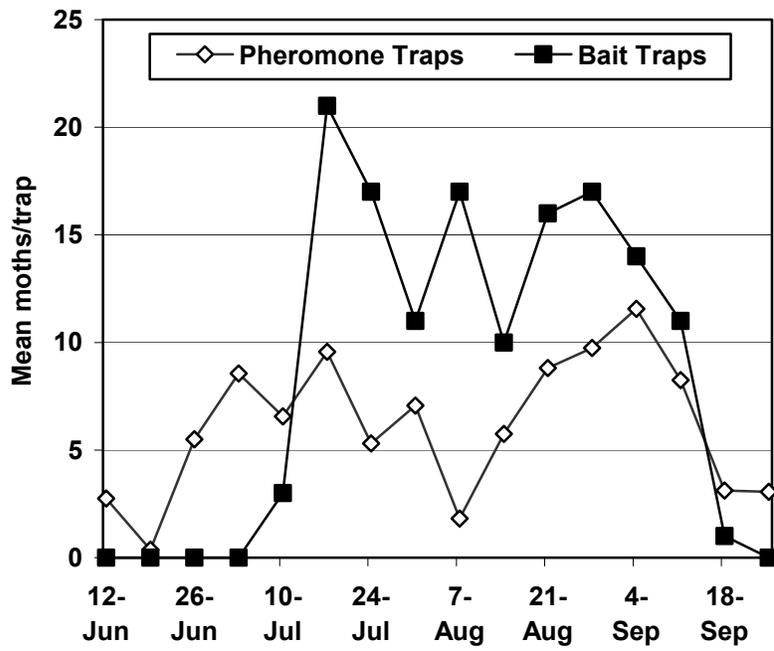were impractical due to moth identification and spillage problems.

Fig. A 1.1. Mean number of moths in pheromone traps and terpinyl acetate bait traps in a non-managed (abandoned) block (Staton) in 2000.