Capture of Two Moth Species in Traps Placed at Different Heights in Sex Pheromone Treated Apple Orchards[1]

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J. Entomol. Sci. 46(3): 223-231 (July 2011)

Abstract Studies were conducted to compare the effect of trap placement above and below sex pheromone mating disruption (MD) dispensers on captures of codling moth, *Cydia pomonella* (L.), and oriental fruit moth, *Grapholita molesta* (Busck), in apple orchards. Traps were placed at a height of 1.8 m or 4.5 m in the tree canopy whereas MD dispensers were placed at 3.1 m within the tree canopy; an adjacent set of plots were treated similarly with only insecticides (nonMD). All trees were approximately 4.8 - 5.1 m in height. Capture of codling moth adults in traps was highest in traps placed at 4.5 m in both MD and nonMD plots and lowest in traps placed at 1.8 m in MD treated plots. Reduction in adult codling moth capture was low to moderate (< 64%) in traps placed above dispensers and higher (>70%) in traps placed below dispensers over both years. Oriental fruit moth adult capture in 2007 was lowest in traps placed at 1.8 m in plots treated with MD. In 2008, capture of oriental fruit moth was highest in traps placed at 4.5 m.

Key Words *Cydia pomonella*, codling moth, *Grapholita molesta*, oriental fruit moth, sex pheromone mating disruption

The codling moth, *Cydia pomonella* (L.), and the oriental fruit moth, *Grapholita molesta* (Busck), are major pests in apples in the eastern United States. A commonly used tactic to control these 2 pests is sex pheromone mating disruption (MD) (Calkins 1998, Stelinski et al. 2005). A key to maximizing the efficacy of MD and assessing the need to apply supplemental insecticides is effectively monitoring codling moth and oriental fruit moth populations using traps baited with sex pheromone (Vickers and Rothschild 1991, Rothschild and Vickers 1991).

Trap placement is of critical importance to effectively monitor codling moth in apple orchards (Knight et al. 1999). Codling moth adults are most active in the upper canopy of trees (Borden 1931, Weissling and Knight 1995, Stoeckli et al. 2008), and several studies found that when codling moth monitoring traps are placed high in the tree canopy more adults are captured than when the traps are placed low in the tree canopy in sex pheromone treated (Barrett 1995, Knight 1995) and nonpheromone treated orchards (McNally and Barnes 1981, Ahmad and Al-Gharbawi 1986, Barrett 1995, Knight 1995, Tasin et al. 2008). Thus, the standard recommendation for monitoring codling moth has been to place traps high in the tree canopy.

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Trap placement also can be an important factor when monitoring oriental fruit moth populations (De Lame and Gut 2006). Oriental fruit moth monitoring traps placed low in the tree canopy have been shown to capture adults as effectively as traps placed higher in the tree canopy in conventionally-managed orchards (i.e., insecticides only) (Rothschild and Minks 1977, De Lame and Gut 2006), but several other studies have reported that oriental fruit moth capture is greater in traps placed at 1 - 2 m above the ground versus traps placed higher in the canopy (Beroza et al. 1973, Gentry et al. 1974, Rothschild 1975). Thus, the recommendation for monitoring oriental fruit moth in apple orchards has been to place sex pheromone monitoring traps at ≈ 1.7 m in height in the tree canopy (De Lame and Gut 2006). However, Kovanci et al. (2006) reported higher capture of oriental fruit moth in traps placed in the upper canopy. Also, De Lame and Gut (2006) found oriental fruit moth capture was greater in traps placed above or below a dispenser than in a trap placed at the same level as the dispenser in sex pheromone treated apple orchards. Trap distance from a dispenser is also important as Knight et al. (1999) reported that the reduction of moth capture in traps is greater the closer a trap is placed to a dispenser. Thus, De Lame and Gut (2006) recommended that dispensers be placed as far from a dispenser as possible in the canopy to provide the most sensitive estimate of MD efficacy.

In Pennsylvania, many growers have adopted MD as part of their control programs for codling moth and oriental fruit moth (Hull et al. 2009). However, in several MD treated apple orchards, a number of monitoring traps for codling moth were found to be placed well above the MD dispenser in the tree canopy. Also, it was noted that as the growing season progresses, the general shape of the trees change due to various natural factors (i.e., fruit crop loads, tree growth), and traps may not maintain the same proximal relationship to MD dispensers they had early in the growing season. The goal of this research was to understand the effect of MD dispenser placement on codling moth and oriental fruit moth adult capture in traps placed above and below the MD dispenser. This information should help growers monitor codling moth and oriental fruit moth more precisely and assist in improving management decisions, especially in orchards where pests are managed using MD.

Materials and Methods

Orchard sites. A 10-ha block of commercial apples in Biglerville, PA (USA), was used in 2007 and 2008 to evaluate the interaction between the placement height of sex pheromone traps and mating disruption dispensers for codling moth and oriental fruit moth. The block was divided into 16 plots of 9 trees (3 rows X 3 trees; 0.04 ha) in 2007 and 24 plots of 9 trees in 2008. Row and tree spacing in the block was 8.3 m and 5.1 m, respectively (≈ 270 trees/ha). Each plot was buffered by 7 trees within each row and 4 adjacent rows that received only insecticides. The block consisted of 4 rows of 'Yorking' followed by 2 rows of 'Golden Delicious' cultivars in a repeating pattern. All trees were approx. 4.8 - 5.1 m in height. Insecticides were applied to the entire orchard during both years.

Mating disruption. All MD plots were treated with CheckMate Duel® MD dispensers (Suterra LLC, Bend, OR) in 2007 and 50% of the MD plots were treated with the same product in 2008. The CheckMate Duel product is a hand-applied reservoir dispenser for both codling moth and oriental fruit moth. The pheromone for codling moth was (*E,E*)-8,10 dodecadien-1-ol [17.54%] totaling 270 mg active ingredients per dispenser plus inert ingredients [82.46%]. The oriental fruit moth blend was

(*Z*)-8-dodecen-1-yl acetate [11.93%], (*E*)-8-dodecen-1-yl acetate [0.80%], (*Z*)-8-dodecen-1-ol [0.15%] and other ingredients [87.12%] totaling 250 mg active ingredient per dispenser (Suterra LLC 2007). All CheckMate Duel treated plots received a total of 12 dispensers per plot (equivalent to 375 dispensers/ha), and all dispensers were applied at a height of 3.1 m. Dispensers were applied to 8 plots on 6 June in 2007 and 25 April in 2008. All CheckMate dispensers remaining in the trees after the 2007 season were removed from the orchard before the 2008 season.

The second MD product - Isomate CM/OFM TT® (CBC America, Commack, NY) - was also a hand-applied reservoir dispenser for both codling moth and oriental fruit moth. The pheromone blend for codling moth was (*E,E*)-8,10 dodecadien-1-ol [58.40%], dodecanol [9.23%], tetradecanol [1.87%] totaling 318.81 mg active ingredient per dispenser, and the blend for oriental fruit moth was (*Z*)-8-dodecen-1-yl acetate [21.25%], (*E*)-8-dodecen-1-yl acetate [1.36%], (*Z*)-8-dodecen-1-ol [0.23%] totaling 104.77 mg active ingredient per dispenser plus other ingredients [7.66%] (Pacific Biocontrol 2009). All Isomate treated plots received a total of 15 dispensers per plot (equivalent to 500 dispensers/ha), and dispensers were applied at a height of 3.1 m. Dispensers were applied to 8 plots on 25 April 2008. During both years, there were 8 plots that did not receive MD treatment and were used as controls.

Trap placement and monitoring. Each treatment plot received a single, separate Pherocon® VI white large plastic delta trap (LPD) (Trece, Inc., Adair, OK) for each species. Traps were placed on the east side (codling moth) and west side (oriental fruit moth) of the center tree in each plot. In half of the plots for each treatment, traps were placed at a height of 4.5 m and in the other half, the traps were placed at a height of 1.8 m. Traps for both species were placed at the same height within each plot. Trap placement height was assigned using a completely randomized design.

Pherocon codling moth 1X Long-Life® grey rubber septa lures (Trece, Inc., Adair, OK) containing only codling moth pheromone (i.e., codlemone) were used from 6 June through 1 August in 2007, and 25 April through 1 July in 2008. Pherocon codling moth DA Combo® (DAC) (Trece, Inc., Adair, OK) grey rubber septa lures loaded with codlemone and kairomone - ethyl (*E,Z*)-2,4-decadienoate (pear ester) (Light et al. 2001) were used from 1 August until 11 September in 2007, and 1 July through 1 October in 2008. For monitoring oriental fruit moth, Pherocon oriental fruit moth 1X Long-Life® (Trece, Inc., Adair, OK) grey rubber septa lures containing oriental fruit moth pheromone were used. Oriental fruit moth lures were replaced once per season (i.e., ≈ early July) in 2007 and 2008. All traps were checked twice per week during both years. Codling moth males and females were differentiated by the presence of a black rectangle marking on the underside of the forewing (Fernandez et al. 2007).

Statistical analyses. All cumulative moth capture data for each monitoring lure type from 2007 and 2008 were transformed [log(x+1)] and subjected to a two-factor (pheromone treatment and trap height) analysis of variance (Minitab Inc. 2003). The separation of means was determined using Tukey's test (Minitab Inc. 2003). When the interaction between the two factors was significant, a two sample *t*-test was performed on the log-transformed moth captures for each factor separately (Minitab Inc. 2003). All tests were run at an $\alpha = 0.05$ significance level.

Results

Moth capture. In 2007, there was a significant interaction between trap placement height and pheromone treatment on moth capture ($F = 17.81$; $df = 1, 12$; $P = 0.001$) in

traps baited with codling moth 1X lures (Table 1). MD did not have an effect on moth capture in traps placed high in the tree canopy (t = -1.28; df = 6; P = 0.249), however, moth capture was 44% greater in traps placed above MD dispensers than in traps placed high in untreated plots. Also, codling moth capture in traps placed high in untreated plots was similar to moth captures in traps placed low in untreated plots (t = -1.28; df = 6; P = 0.249). Traps placed above MD dispensers captured more codling moth than traps placed below dispensers (t = 10.41; df = 6; P < 0.001), and traps placed low captured about 98% more codling moth in untreated plots than in MD treated plots (t = 4.29; df = 6; P = 0.005) (Table 1).

In 2008, fewer codling moth adults were captured in traps baited with codling moth 1X lures placed low versus traps placed high in the tree canopy across all treatments (F = 88.91; df = 1, 20; P < 0.001) (Table 1). Overall adult codling moth capture in codling moth 1X traps was also lower in MD treated plots than in untreated plots (F = 3.48; df = 2, 20; P = 0.05). Codling moth capture in low traps was reduced by about 64% in CheckMate Duel treated plots and 82% in Isomate treated plots. The capture of codling moth adults in traps placed high was reduced by less than 52% in MD treated plots compared with untreated plots at the same height.

Traps baited with DAC lures placed high in the tree canopy captured more codling moth adults than traps placed low in 2007 (F = 11.94; df = 1, 12; P = 0.005) (Table 2). MD treatment did not affect codling moth captures in 2007 (F = 1.31; df = 1, 12; P = 0.274). However, a 73% reduction in codling moth capture was recorded in traps placed below dispensers when compared with traps placed low in untreated plots, whereas codling moth capture was 25% greater in traps placed above dispensers when compared with traps placed high in untreated plots.

During 2008, adult codling moth capture in traps baited with DAC lures was lower (F = 4.17; df = 2, 20; P = 0.031) in MD treated plots than in plots that did not receive pheromone treatment (Table 2). In traps placed low in CheckMate Duel and Isomate treated plots codling moth capture was reduced by 88% and 76%, respectively. Whereas, capture in traps placed high was reduced by 64% and 61% in CheckMate Duel and Isomate treated plots when compared with traps at the same height in untreated plots.

Table 1. Cumulative codling moth adult capture in traps baited with codling moth 1X lures placed at 1.8 and 4.5 m in the tree canopy in sex pheromone treated (MD) and untreated orchards in 2007 and 2008.

2007*	1.8 m (± sem)	4.5 m (± sem)
CheckMate Duel	0.25 (0.25) b	21.5 (4.94) a
No MD	13.75 (7.55) a	14.25 (5.31) a
2008		
CheckMate Duel	2.00 (1.08) cd	47.50 (12.70) ab
Isomate CM/OFM TT	1.00 (1.00) d	41.00 (12.90) b
No MD	5.50 (1.19) c	84.25 (46.30) a

Means within each year followed by the same letter are not statistically significant.
*Interaction was significant

Table 2. Total cumulative codling moth adult capture in traps baited with codling moth DAC lures placed at 1.8 and 4.5 m in the tree canopy in sex pheromone treated (MD) and untreated orchards in 2007 and 2008.

2007	1.8 m (± sem)	4.5 m (± sem)
CheckMate Duel	4.00 (2.62) b	33.00 (2.82) a
No MD	15.00 (2.84) b	24.25 (6.90) a
2008		
CheckMate Duel	0.50 (0.29) d	25.00 (7.56) b
Isomate CM/OFM TT	1.00 (1.00) cd	27.00 (5.52) ab
No MD	4.25 (2.02) c	70.25 (29.90) a

Means within each year followed by the same letter are not statistically significant.

Codling moth capture was greater ($F = 91.21$; $df = 1, 20$; $P < 0.001$) in traps baited with DAC lures placed high in the canopy than in traps placed low in the canopy during 2008 (Table 2).

In 2007, there were no differences in adult female codling moth capture in traps baited with DAC lures placed at either height ($F = 1.79$; $df = 1, 12$; $P = 0.206$) or in MD treated versus untreated plots ($F = 0.02$; $df = 1, 12$; $P = 0.880$). There were also no differences in the capture of adult female codling moth at either height ($F = 3.43$; $df = 1, 18$; $P = 0.081$) or in the MD treated or untreated plots ($F = 0.64$; $df = 2, 18$; $P = 0.537$) in 2008. A mean of > 2 females were captured in each of the treatments during both years.

In 2007, there was a significant interaction between trap placement height and pheromone treatment on cumulative oriental fruit moth capture ($F = 6.65$; $df = 1, 12$; $P = 0.024$) (Table 3). Oriental fruit moth capture was similar in traps placed high in MD treated and nonMD plots ($t = -0.15$; $df = 6$; $P = 0.884$). In untreated plots, cumulative oriental fruit moth capture also was similar in traps placed low and high ($t = 0.43$; $df = 6$; $P = 0.681$). Traps placed low in the tree canopy captured more oriental fruit moth in untreated than in MD treated plots ($t = -2.97$; $df = 6$; $P = 0.025$). In MD treated plots, oriental fruit moth capture was higher in traps placed above dispensers than in traps placed below dispensers ($t = 5.07$; $df = 6$; $P = 0.002$) (Table 3). During 2008, more oriental fruit moth adults were captured over the season in traps placed high in the tree canopy than in traps placed low ($F = 48.30$; $df = 1, 18$; $P < 0.001$) (Table 3). MD did not have an effect on oriental fruit moth capture at either height ($F = 0.23$; $df = 2, 18$; $P = 0.800$).

Discussion

Our findings suggest that if a trap for monitoring codling moth or oriental fruit moth adults is placed above a MD dispenser, the pheromone released by the MD dispenser will not consistently inhibit males from finding these monitoring traps. Whereas the high traps in plots treated with either Isomate CM/OFM TT or CheckMate Duel dispensers captured significantly fewer moths than high traps in the plots without MD in

Table 3. Cumulative oriental fruit moth adult capture in traps baited with oriental fruit moth lures placed at 1.8 and 4.5 m in the tree canopy in sex pheromone treated (MD) and untreated orchards in 2007 and 2008.

2007*	1.8 m (± sem)	4.5 m (± sem)
CheckMate Duel	1.00 (0.41) b	19.25 (5.92) a
No MD	20.50 (13.60) a	15.75 (3.01) a
2008		
CheckMate Duel	1.25 (0.63) b	39.00 (24.70) a
Isomate CM/OFM TT	1.00 (0.71) b	34.75 (7.23) a
No MD	3.00 (1.58) b	45.00 (22.40) a

Means within each year followed by the same letter are not statistically significant.
*Interaction was significant

2008, the reduction in codling moth capture was low (≈ 50%) in traps baited with codling moth 1X lures and moderate (≈ 60 - 65%) in traps baited with DAC lures. The 2008 results coupled with the 2007 data in which similar numbers of codling moth were captured in traps placed high in MD treated and untreated plots indicates that if the dispenser is not placed in the top of the tree canopy, the dispenser headspace (atmospheric area above the dispenser containing a pheromone concentration) may not cover the entire portion of the canopy above the dispenser. Several studies have shown pheromone concentrations to peak on the same plane as the dispensers, and decrease as distance above a dispenser increases in orchards and vineyards (Caro et al. 1980, Karg and Sauer 1995, Suckling et al. 1999, Koch and Witzgall 2001). Also, Karg et al. (1994) found that leaves below dispensers released higher amounts of pheromone than leaves located in other directions, indicating that pheromone easily moves downward and outward from a dispenser, but upward movement is more restricted. Our results, although conducted with different MD dispensers, support these previous findings as codling moth capture was generally similar in traps placed above dispensers to that observed in traps placed high in untreated plots. Caro et al. (1980) recommended placing MD dispensers in the area where the insect is most likely to mate. In the case of codling moth, the adults tend to be most active in the middle to upper part of the tree canopy (Borden 1931, Weissling and Knight 1995, Stoeckli et al. 2008). Even if the density of dispensers that are placed in an orchard is increased, it may not be enough to effectively disrupt the ability of codling moth to locate traps in the upper canopy if the dispensers are not placed high in the canopy. Therefore, the correct placement of dispensers high in the tree canopy is of paramount importance to successfully monitor and manage codling moth in a MD environment.

Our results also indicate that codling moth adults are more often captured in the upper canopy. This is consistent with the findings of McNally and Barnes (1981), Ahmad and Al-Gharbawi (1986), and Tasin et al. (2008) that codling moth capture is highest in the upper part of the tree canopy in nonMD orchards, and with Barrett (1995), and Knight (1995) who showed codling moth capture to be highest in the top of the tree canopy in MD treated orchards.

Female codling moth capture in DA Combo baited traps for both 2007 and 2008 was very low. These lures do not appear to be highly attractive to codling moth females although the pear ester can be attractive to codling moth females (Light et al. 2001).

A number of studies have presented conflicting data about oriental fruit moth capture within tree canopies. Several studies found that there was no difference in oriental fruit moth capture in traps placed high or low in the tree canopy without MD (Evenden and McLaughlin 2004, De Lame and Gut 2006), whereas Kovanci et al. (2006) found oriental fruit moth capture to be higher in the upper canopy in apple orchards. Atterholt (1996) also found that oriental fruit moth traps placed high in the tree canopy capture more oriental fruit moth in almond orchards whereas other several studies have shown oriental fruit moth capture to be greater in the lower part of the tree canopy than in the upper canopy (Beroza et al. 1973, Gentry et al. 1974, Rothschild 1975, Rothschild and Minks 1977). In our studies, oriental fruit moth capture in 2007 was similar in traps placed at 1.8 m and 4.5 m in plots without MD. The 2007 results are similar to those found by Evenden and McLaughlin (2004) and De Lame and Gut (2006) but different from the other studies. During the 2008 season, oriental fruit moth captures were higher in traps at 4.5 m than at 1.8 m in plots not treated with MD which is similar to the results found by Atterholt (1996). In both 2007 and 2008, oriental fruit moth capture was similar in traps placed at 4.5 m within MD treated and untreated plots suggesting that the dispensers did not fully inhibit the ability of male oriental fruit moth to locate monitoring traps placed above the dispenser. This finding is similar to our results for monitoring codling moth. In 2007, oriental fruit moth capture at 1.8 m in CheckMate Duel treated plots was lower than in untreated plots, thus indicating that MD can effectively inhibit the ability of oriental fruit moth males to locate a monitoring trap when the trap is placed below a dispenser.

Possible explanations for the differences in oriental fruit moth capture between our results and those previously cited might include the effect of tree height, range of heights monitored, and also possible effects of host plants as Rothschild and Minks (1977) conducted their study in peach orchards. It is possible that different crops with different canopy structures affect the height where oriental fruit moth adults are most active. Beroza et al. (1973) do not mention how tall the trees were in their study, and they only placed traps between 0 - 3 m from the ground. The findings of Atterholt (1996) can likely be explained by the size of almond trees which are usually much larger than apple trees. Also, trees in our study were tall (>5 m) and, therefore, the fruit were most likely located higher than in the study by Rothschild and Minks (1977) in peaches.

In conclusion, the placement of a monitoring trap in relation to the placement of a dispenser is important; the most effective position for monitoring the activity of codling moth and oriental fruit moth adults to make management decisions in a MD treated apple orchard is high in the tree canopy. The MD dispenser should be placed as high in the canopy as possible (upper 10 - 15% of tree canopy) to provide the most effective disruption of communication between males and females in the upper tree canopy. Because the amount of pheromone in the headspace above a dispenser decreases with distance from a dispenser (Suckling et al. 1999), this placement will ensure that dispensers placed above traps will release the amount of pheromone necessary to disrupt ability of moths to find traps. MD will not effectively disrupt the ability of male moths to find monitoring traps that are placed above the dispenser. Future efforts should address whether there is a difference in moth capture at different heights in relation to a dispenser in tall (i.e., ≈ 5 m) apple trees versus shorter (i.e., ≈ 2 - 3 m) trees. The canopy structure of a tree may affect the pheromone distribution differently,

both within the tree and the orchard, and in intensive orchard plantings where the tree canopies are more open than in taller trees with denser canopies in low density plantings. In addition, more research is needed on possible changes in the dispenser placement pattern such as, placing 50% of the MD dispensers in the lower 50% of the tree canopy and the other 50% in the top half of the canopy. Suckling et al. (1999) showed that peak pheromone concentration within the tree declines as dispenser placement height increases. If dispensers are placed at multiple heights within a tree, the pheromone released from the dispensers may possibly be more uniformly distributed throughout the entire canopy and, thus, be more likely to effectively reduce adult captures in monitoring traps placed at any height within the tree canopy.

Acknowledgments

The authors thank B. Rice and Westbrook Orchards for cooperating in these studies. We also thank Suterra LLC and CBC America for donating the pheromone dispensers used in this study and the Pennsylvania Department of Agriculture (ME No. 445577) and the State Horticultural Association of Pennsylvania for their financial support of this project. We acknowledge numerous summer interns for hanging the pheromone dispensers and monitoring traps throughout the season.

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