Effect of Monitoring Trap and Mating Disruption Dispenser Application Heights on Captures of Male *Grapholita molesta* (Busck; Lepidoptera: Tortricidae) in Pheromone and Virgin Female-Baited Traps

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ABSTRACT Studies were conducted in 0.07- to 0.18-ha peach and apple plots to determine the effects of pheromone trap and hand-applied emulsified wax pheromone dispenser application heights on captures of *Grapholita molesta* in traps baited with pheromone lures or virgin females. Traps and pheromone dispensers were placed either low (1.2–1.8 m) or high (2.7–4 m) within tree canopies. In the majority of cases, equivalent numbers of male *G. molesta* were caught in traps placed at the low and high positions in both pheromone-treated and untreated plots. Furthermore, pheromone dispensers placed at the low and high positions equally disrupted orientation of male *G. molesta* to pheromone traps placed at either height and to virgin female traps placed at 1.2–1.8 m within canopies season-long at most sites. Our results indicate that for trees ≤3.5 m tall, dispensers with release rates ≥18 mg/ha/h placed at 1.5–2.0 m (heights easily reached from the ground) should effectively disrupt mating of *G. molesta* throughout tree canopies. In trees between 3.5 and 4.5 m tall, the dispensers should be moved to ≈1.5 m from the top of the canopy. For trees taller than 4.5 m, we recommend hanging dispensers both in the top and bottom thirds of tree canopies. Most commercial Michigan peach and apple trees are <3.5 m tall. Eliminating the need to apply dispensers high in the canopy in most orchards will enable growers to reduce application costs, thereby facilitating increased adoption of mating disruption for *G. molesta* control by growers.

KEY WORDS *Grapholita molesta*, mating disruption, pheromone dispenser height, trap height, emulsified wax dispenser

Understanding the biology and behavior of the target insect is essential to optimizing a mating disruption program (Suckling and Karg 2000). Studies of field crop (e.g., Sharma et al. 1971, Kaae and Shorey 1973), orchard (e.g., Suckling and Shaw 1992, Barrett 1995, Agnello et al. 1996), and forest (e.g., Sower and Daterman 1977) pests have identified the locations in crop canopies where mating of females or captures of males in pheromone traps are most likely to occur in the presence or absence of a pheromone treatment. Obtaining this type of information is an important step toward the development of effective pheromone-based monitoring and control programs.

Several studies have investigated the effect of pheromone trap height on captures of codling moths, *Cydia pomonella* L. (Riedl et al. 1979, McNally and Barnes 1981, Thwaite and Madsen 1983, Ahmad and Al-Gharbawi 1986, Howell et al. 1990). The highest captures of *C. pomonella* males have most often been in pheromone traps placed high in tree canopies, suggesting that males may be more numerous or active there. Based on this information, the recommended height for placement of pheromone dispensers for disrupting mating of *C. pomonella* is in the upper third of the tree canopy. Passive trapping and direct behavioral observations of male and female *C. pomonella* have more recently confirmed that activity is greatest in the upper canopy region of apple and pear orchards (Weissling and Knight 1995). More importantly, Weissling and Knight (1995) also showed that vertical positioning of pheromone dispensers influences the degree of *C. pomonella* mating disruption; percent mating of tethered virgin female *C. pomonella* increased with increasing heights in both untreated orchards and pheromone-treated orchards with pheromone dispensers placed at 2 m in ≈4-m-tall apple trees. This pattern was not apparent when dispensers were placed at the top of the canopy (4 m). Weissling and Knight (1995) concluded that dispensers should be positioned in the upper canopy for effective mating disruption of *C. pomonella.*

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Table 1. Orchard specifications

Orchard	Status	Plot size (ha)	Plot dimensions (trees)	Tree spacing (m)	Canopy ht (m)		Trap/dispenser position (m)	
					To base	To top	Low	High
2001 peach	Unmanaged	0.07	5 by 5	4.6 by 6.1	0.9	3.6	1.7	2.9
2002 peach	Commercial[a]	0.10	8 by 5	4.3 by 6.1	1.2	3.0	1.5	2.7
Wide apple	Unmanaged	0.18	7 by 7	5.5 by 6.7	0.9	5.5	1.8	4.0
Narrow apple	Unmanaged	0.14	12 by 7	3.0 by 5.5	0.6	4.9	1.2	3.6

[a] Insecticide treatments consisted of three permethrin sprays.

The oriental fruit moth, *Grapholita molesta* (Busck, Lepidoptera: Tortricidae), is a major economic pest of stone and pome fruits worldwide (Chapman and Lienk 1971, Rothschild and Vickers 1991). Studies to date (Beroza et al. 1973, Gentry et al. 1974, Rothschild and Minks 1974, 1977, Rothschild 1975, Atterholt 1996, Evenden and McLaughlin 2004) have yielded conflicting results as to whether captures of *G. molesta* are influenced by vertical positioning of pheromone traps or pheromone dispensers. Monitoring traps for *G. molesta* are typically placed at head height (≈1.7 m). However, the industry-recommended application height for hand-applied dispensers for control of *G. molesta* is in the upper third of tree canopies (e.g., Isomate-M 100; Shin-Etsu Chemical Co., Tokyo, Japan and CheckMate OFM; Suterra LLC, Bend, OR), which can increase the difficulty and cost of dispenser application. A basis for this recommendation is lacking. The increasing incidence of *G. molesta* in apples and accompanying interest in mating disruption for control of this pest in Michigan provided strong impetus for us to study the effects of vertical positioning of monitoring traps and pheromone dispensers within tree canopies on captures of *G. molesta* in pheromone lure and virgin female-baited traps.

Materials and Methods

Experimental Design

The experiment was repeated in four different orchards during two growing seasons. The sizes of the plots and tree canopies and the heights at which dispensers and traps were placed in each orchard are provided in Table 1. In 2001, the experiment was conducted in an unmanaged peach orchard in Douglas, MI. The 2002 experiments were conducted in a commercial peach orchard and two unmanaged apple orchards in Coloma, MI. The 2001 and 2002 peach orchards were planted similarly, but the trees in the 2002 orchard were shorter and had fuller canopies. Trees in the apple orchards were almost twice as tall as the peach trees and therefore provided a stronger test of the effects of vertical placement of pheromone traps and dispensers. The wide apple orchard (with wider tree spacing) contained the largest trees (>5 m tall) and these were planted at one half the density of the trees in the narrow apple orchard (having narrower tree spacing).

The experiments were set up as completely randomized designs and tested two factors: pheromone treatment and trap height. The three levels of the pheromone treatment were: untreated (no-pheromone), pheromone dispensers applied in the bottom third of the canopy (low-dispenser), and pheromone dispensers applied in the top third of the canopy (high-dispenser). The two levels of trap height were: traps placed in the bottom third of the canopy (low traps) and in the top third of the canopy (high traps). Each of the three treatments was applied to four replicate plots in the peach orchards and three in the apple orchards.

Trap data were gathered season long and analyzed separately for each *G. molesta* generation. Three *G. molesta* generations are the norm in Michigan. The first generation begins between late April and early May, the second between late June and early July, and the third in early August, ending in late September. A single delta-style pheromone trap (Scenturion, Clinton, WA) baited with a Scenturion rubber septum *G. molesta* lure (Suterra LLC, Bend, OR) was placed in each of two trees, located at least 11 m apart, in the center of each plot. One pheromone trap was placed in the top third of the canopy and the other in the bottom third of the canopy (Table 1). The traps were checked every 3–4 d, at which time the high trap was moved to the low position in the same tree and the low trap to the high position in the same tree. Pheromone lures were replaced once per *G. molesta* generation (≈6–8 wk).

In addition to monitoring moths with pheromone traps, in 2002, four to five traps baited with virgin female *G. molesta* were placed in all plots three to four times during the peak flight of each *G. molesta* generation. Each virgin female trap consisted of a delta trap (Scenturion, Clinton, WA) baited with one virgin female (≤3 d old) placed in a wire screen cage and provided with a 2-cm cotton wick soaked in 5% sucrose solution. These traps were hung at heights of 1.2–1.8 m and placed only on nonborder trees that were not adjacent to a tree containing a pheromone trap. The traps were left in the plots for 3 d and then checked and collected. Virgin females were obtained from a colony of *G. molesta* originally collected as larvae in an infested apple orchard in Fennville, MI, in July 2001. They were reared on a pinto bean-based diet (Shorey and Hale 1965) at 24°C and 16:8 L:D. Pupae were sexed (George 1965) and females were reared individually in 118-ml plastic cups, each containing a 2-cm cotton wick soaked in 5% sucrose solution. Cups were kept under natural light conditions. Voucher specimens of adults and larvae are deposited in the Albert J. Cook Arthropod Research Collection, Michigan State University Department of Entomology, East Lansing, MI. Data gathered from traps in which the female was absent or dead when the trap was checked were not used in our analyses. Data were analyzed from 10 to 14 traps per plot per generation in the 2002 peach orchard, 8–15 traps per plot per generation in the wide apple orchard, and 9–15 traps per plot per generation in the narrow apple orchard.

Pheromone Dispenser Formulation

All experiments were conducted using a commercial emulsified wax pheromone formulation, Confuse-OFM (Gowan Co., Yuma, AZ). Two applications of Confuse-OFM provide efficacy equivalent to that of one application of Isomate-M 100 (Shin-Etsu Chemical Co.), the commercial standard, in peach orchards (de Lame 2003). Confuse-OFM deposits were applied using a 1-liter plastic squirt bottle in 2001 and a forestry paint-marking gun (Idico Products Co., New York, NY) in 2002. One deposit consisted of ≈2.7 ml (2.6 g) Confuse-OFM in 2001 and ≈3 ml (2.8 g) Confuse-OFM in 2002. Applications were made once at the beginning of each *G. molesta* generation at a rate of 74 g active ingredient (AI)/ha or ≈580 deposits/ha per application in 2001 and 520 deposits/ha per application in 2002, evenly distributed throughout the plots. Three applications were made in the 2001 peach and 2002 apple orchards. Only two applications were made in the 2002 peach orchard because the plot was harvested and the experiment terminated when third-generation adults were just appearing in traps. Confuse-OFM is a monolithic dispenser (Fan and Singh 1989) with first-order release kinetics. Field release rates of these dispensers were not measured concurrent to these studies; however, based on previous research (de Lame 2003), we estimate the release rates of the dispensers ranged from 180 mg/ha/h initially to 5.2 mg/ha/h at 8 wk, with release rates during peak *G. molesta* flight (weeks 3–4 of each generation) of 43–18 mg/ha/h.

Shoot Growth Measurements

New growth on peach and apple shoots was measured on 7 and 14 September 2002. Samples were taken on transects from northeast to southwest through each of the 2002 orchards. Twenty randomly chosen shoots, evenly divided between the top and bottom halves of the canopy, were cut from 10 randomly chosen trees along the transect. Shoot growth was measured as the distance from the first growth scar for that year to the tip of the shoot. Current year's growth was discerned from previous years' growth by the appearance and texture of the woody tissue. New peach shoots were green in color, versus the red-brown-colored older tissues. Apple shoot growth from the current year was pubescent, whereas older apple shoots were smooth.

Statistical Analyses

Pheromone trap data from the 2001 peach orchard and 2002 apple orchards were transformed [log(x + 1)] and subjected to a two-factor (pheromone treatment and trap height) analysis of variance (ANOVA; SAS Institute 1999). Means were separated using Tukey's test (SAS Institute 1999). When the interaction between the two factors was significant, comparisons were made of all cell means (LSMEANS, adjust = Tukey; SAS Institute 1999). The significance level for all tests was $\alpha = 0.05$.

Moth captures in pheromone traps in the 2002 peach orchard and in virgin female traps in all 2002 orchards could not be normalized and were analyzed using the Kruskal-Wallis test (SAS Institute 1999). If the Kruskal-Wallis test yielded significant differences between treatments and there were more than two different treatment rank sum values, these were separated using the Student-Newman-Keuls-type Nemenyi test (Zar 1999). The Nemenyi test was more conservative than the Kruskal-Wallis test. As a result, in some instances, although data were found to be significantly different by the Kruskal-Wallis test at $P < 0.05$, when rank sums were separated using the Nemenyi test at the same significance level, they were not found to be significantly different. In those instances, the P value for the Nemenyi test was raised to 0.1 to identify the differences in the rank sums detected by the Kruskal-Wallis test. To our knowledge, no mathematical method exists to test for the interaction of factors in non-normal data sets gathered in experiments using multiple-factor designs. Therefore, the pheromone trap data from the 2002 peach orchard was examined graphically for the presence of a significant interaction between trap height and pheromone treatment factors (Zar 1999; graph not shown).

Percent trap shutdown (100 − [no. moths captured in pheromone plot/no. moths captured in untreated plot × 100]) is a measure of the efficacy of a pheromone treatment (Rothschild 1975). Percent trap shutdown for each experiment was quantified by averaging the percent trap shutdown values calculated for each trap position-dispenser position combination in each generation for that experiment.

Shoot growth data were analyzed by ANOVA without transformation (SAS Institute 1999). Means were separated with Tukey's test at $\alpha = 0.05$ (SAS Institute 1999). The significance of differences between individual comparison pairs was determined by comparing all cell means (LSMEANS, adjust = Tukey; SAS Institute 1999).

Results

Peach Orchards

Pheromone Traps. In 2001 and 2002, significantly more moths were caught in pheromone traps placed

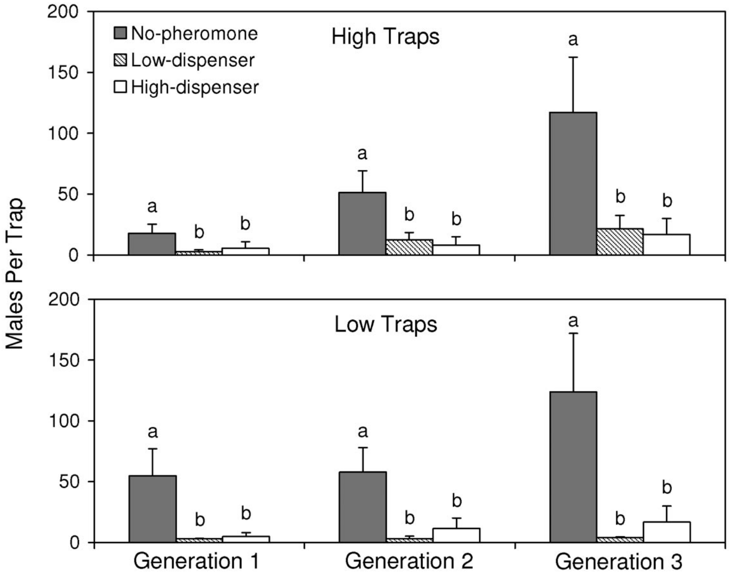

Fig. 1. 2001 peach orchard. Numbers of *G. molesta* male moths caught in pheromone traps placed in the top third of the canopy (high traps) and in the bottom third of the canopy (low traps) in untreated plots (no-pheromone), plots with pheromone dispensers in the bottom third of the canopy (low-dispenser), and plots with pheromone dispensers in the top third of the canopy (high-dispenser). Bars labeled with the same letter within a generation are not significantly different (Tukey, $P < 0.05$). Error bars are SEs.

in the untreated plots than those in the pheromone-treated plots (Figs. 1 and 2; Table 2). However, there were no significant differences in the numbers of moths caught in the low-dispenser and high-dispenser treatments. In both years, for all generations, there also were no significant differences in the numbers of moths caught in the high versus low traps (Figs. 1 and 2; Table 2). While the percent pheromone trap shutdown in the pheromone-treated plots in 2002 was high (98.6 ± 0.4% [mean ± SE]), the percent pheromone

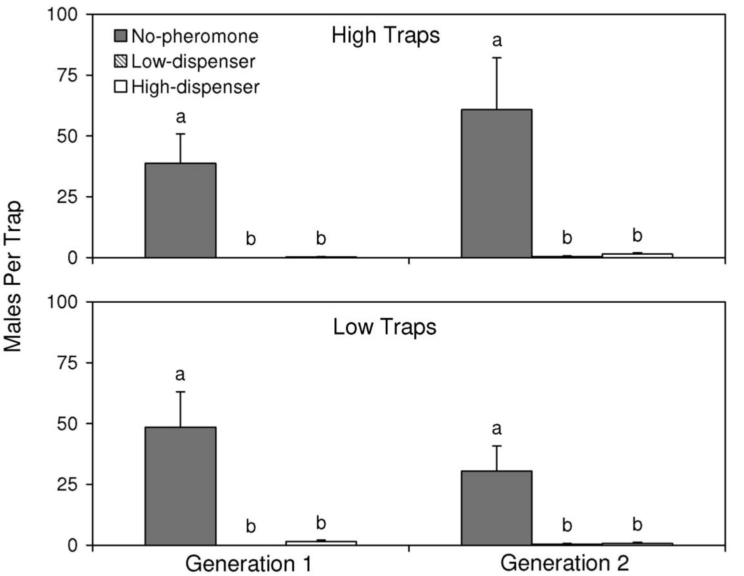

Fig. 2. 2002 peach orchard. Numbers of *G. molesta* male moths caught in pheromone traps placed in the top third of the canopy (high traps) and in the bottom third of the canopy (low traps) in untreated plots (no-pheromone), plots with pheromone dispensers in the bottom third of the canopy (low-dispenser), and plots with pheromone dispensers in the top third of the canopy (high-dispenser). Bars labeled with the same letter within a generation are not significantly different (Nemenyi, $P < 0.05$). Error bars are SEs.

Table 2. Results of statistical tests of data gathered from pheromone traps

Orchard	Generation	Factor[a,b]	*F or* χ^{2c}	df	*P*
2001 peach	1	Pheromone treatment	11.20	2	0.0007
		Trap ht	2.74	1	0.11
		Interaction	0.43	2	0.66
	2	Pheromone treatment	10.52	2	0.0009
		Trap ht	0.10	1	0.75
		Interaction	1.18	2	0.33
	3	Pheromone treatment	11.56	2	0.0006
		Trap ht	0.56	1	0.46
		Interaction	0.49	2	0.62
2002 peach	1	Pheromone treatment	19.01	2	<0.0001
		Trap ht	0.46	1	0.50
	2	Pheromone treatment	13.89	2	0.001
		Trap ht	0.95	1	0.33
Wide apple	1	Interaction	15.41	2	0.0005
	2	Pheromone treatment	8.39	2	0.005
		Trap ht	0.59	1	0.46
		Interaction	0.66	2	0.54
	3	Pheromone treatment	45.67	2	<0.0001
		Trap ht	1.70	1	0.22
		Interaction	1.62	2	0.24
Narrow apple	1	Interaction	4.02	2	0.05
	2	Pheromone treatment	59.50	2	<0.0001
		Trap ht	8.70	1	0.01
		Interaction	3.11	2	0.08
	3	Interaction	4.49	2	0.03

[a] If the interaction was significant, only test results for the interaction are given.
[b] A graphical test for a significant interaction was performed for the 2002 peach orchard data.
[c] χ^2 values are given for the 2002 peach orchard (Kruskal-Wallis test), *F* values are given for all other orchards (two-factor ANOVA).

trap shutdown in the pheromone-treated plots in 2001 was fairly low (85.4 ± 2.4%). The interaction between trap height and pheromone treatment was not significant in either 2001 or 2002 (Table 2).

Virgin Female Traps. The data gathered using virgin female traps in 2002 (Fig. 3) corroborated those obtained using pheromone traps (Fig. 2). Significantly more moths were caught in the untreated versus pheromone-treated plots (Fig. 3; Table 3). In both generations, the numbers of moths caught in the low-dispenser and high-dispenser treatments were not significantly different (generation 1: only two rank sum values, no Nemenyi test, generation 2: $P < 0.1$).

Apple Orchards

Wide Apple Orchard Pheromone Traps. During the second- and third-generation flights, significantly more moths were caught in the untreated than pheromone-treated plots (Fig. 4; Table 2). During those same generations, there were no significant differences in the numbers of moths trapped in the low- and high-dispenser treatments or in traps placed in the high and low positions (Fig. 4; Table 2). The interaction between trap height and treatment was not significant for those generations (Table 2).

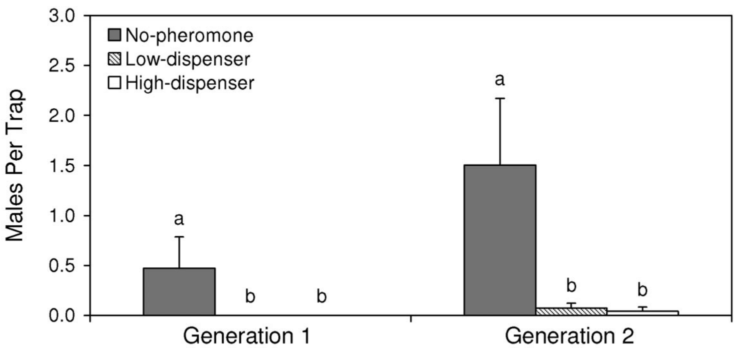

Fig. 3. 2002 peach orchard. Numbers of *G. molesta* male moths caught in virgin female traps placed at 1.2–1.8 m in tree canopies in untreated plots (no-pheromone), plots with pheromone dispensers in the bottom third of the canopy (low-dispenser), and plots with pheromone dispensers in the top third of the canopy (high-dispenser) for 3 d. Bars labeled with the same letter within a generation are not significantly different (generation 1: only two rank sum values, no Nemenyi test; generation 2: Nemenyi, $P < 0.1$). Error bars are SEs.

Table 3. Results of Kruskal-Wallis tests of data gathered from virgin female traps

Orchard	Generation	χ^2	df	*P*
2002 peach	1	7.16	2	0.03
	2	5.82	2	0.05
Wide apple	1	6.00	2	0.05
	2	6.76	2	0.03
	3	6.72	2	0.03
Narrow apple	1	6.00	2	0.05
	2	6.82	2	0.03
	3	7.62	2	0.02

The interaction between trap height and pheromone treatment was significant for generation 1 (Fig. 4; Table 2). Multiple comparisons of all cell means revealed no significant effect of trap or dispenser height, but a significant effect of pheromone treatment, except for the following comparisons. Significantly more moths were caught in the high traps in the low-dispenser treatment than in the high traps in the high-dispenser treatment ($P = 0.004$). In addition, significantly more moths were caught in the high traps than the low traps placed in the low-dispenser treatment ($P = 0.04$). Also, significantly more moths were caught in the low traps placed in the high-dispenser treatment compared with the high traps placed in this treatment ($P = 0.01$). The percent pheromone trap shutdown for the wide apple orchard pheromone-treated plots was 96.8 ± 0.9%.

Narrow Apple Orchard Pheromone Traps. In generation 2, significantly more moths were caught in the untreated than the pheromone-treated plots (Fig. 5; Table 2). However, there were no significant differences in the numbers of moths trapped when dispensers were placed high or low. Furthermore, significantly more moths were caught in high traps than in low traps (Fig. 5; Table 2). The interaction between trap height and pheromone treatment for generation two was not significant (Table 2).

The interaction between trap height and pheromone treatment was significant for generations 1 and 3 (Fig. 5; Table 2). There was no significant effect of trap height or dispenser height, but a significant effect of the pheromone treatment, except that significantly more moths were caught in the high versus low traps placed in the low-dispenser treatment in both generations (generation 1: $P = 0.005$; generation 3: $P = 0.004$). Percent trap shutdown for the narrow apple orchard pheromone-treated plots was 97.0 ± 0.8%.

Virgin Female Traps. The patterns of moth captures in virgin female traps (Fig. 6) corroborated those from the pheromone traps (Figs. 4 and 5). In both orchards, during all generations, significantly more moths were caught in the untreated plots than pheromone-treated plots (Table 3), and there were no significant differences in the numbers of moths caught in virgin female traps placed in the low- versus high-dispenser plots (wide: generations 1 and 3: Nemenyi, $P < 0.1$; generation 2: Nemenyi, $P < 0.05$; narrow: generation 1: Nemenyi, $P < 0.1$; generation 2: Nemenyi, $P < 0.05$; generation 3: only two rank sum values, no Nemenyi test).

Shoot growth in the 2002 peach and apple orchards. The period of shoot growth was shortest in the wide apple orchard, followed by the narrow apple orchard. By contrast, shoot growth in the 2002 peach orchard,

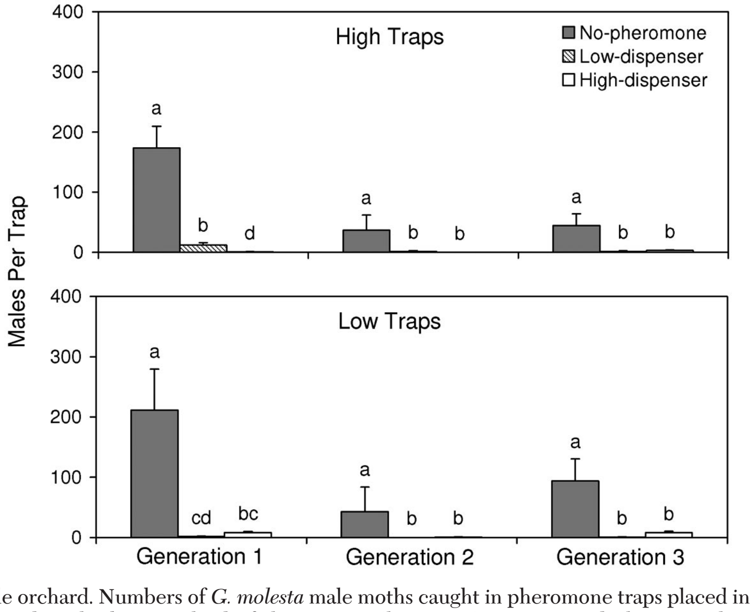

Fig. 4. Wide apple orchard. Numbers of *G. molesta* male moths caught in pheromone traps placed in the top third of the canopy (high traps) and in the bottom third of the canopy (low traps) in untreated plots (no-pheromone), plots with pheromone dispensers in the bottom third of the canopy (low-dispenser), and plots with pheromone dispensers in the top third of the canopy (high-dispenser). Bars labeled with the same letter within a generation are not significantly different (Tukey, $P < 0.05$). Error bars are SEs.

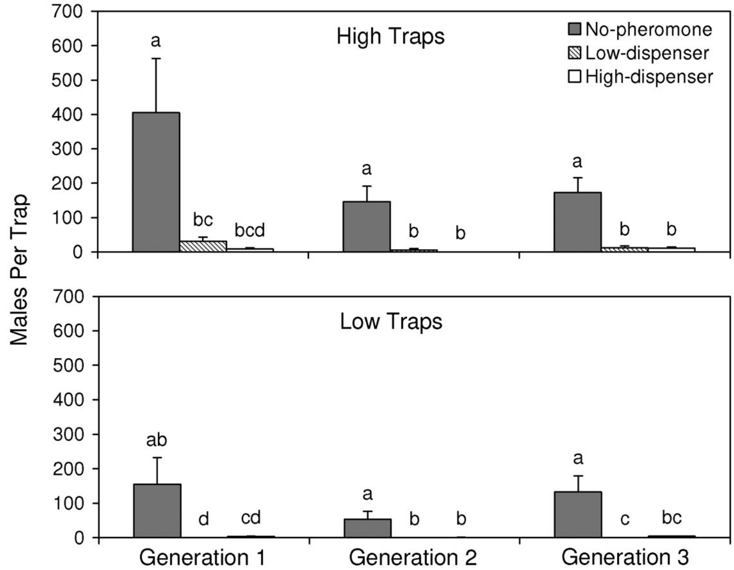

Fig. 5. Narrow apple orchard. Numbers of *G. molesta* male moths caught in pheromone traps placed in the top third of the canopy (high traps) and in the bottom third of the canopy (low traps) in untreated plots (no-pheromone), plots with pheromone dispensers in the bottom third of the canopy (low-dispenser), and plots with pheromone dispensers in the top third of the canopy (high-dispenser). Bars labeled with the same letter within a generation are not significantly different (Tukey, $P < 0.05$). Error bars are SEs. In generation 2, significantly more moths were caught in the high traps versus the low traps.

which was periodically irrigated, continued well into the season (unpublished data). Shoot growth in the three orchards was significantly different (Fig. 7; $F = 286.73$, df = 2, $P < 0.0001$); greatest in the 2002 peach orchard, followed by the narrow apple orchard, then the wide apple orchard. Overall shoot growth was significantly greater in the top half than the bottom half of the canopy ($F = 22.78$, df = 1, $P < 0.0001$). This difference was significant for the narrow apple ($P = 0.004$), but not for the wide apple ($P = 0.13$) or 2002 peach ($P = 0.44$) orchards. The interaction between orchard and shoot growth was not significant ($F = 1.07$, df = 2, $P = 0.35$).

Discussion

Vertical Placement of Pheromone Traps

In all but one case, there were no differences in the numbers of male *G. molesta* caught in pheromone traps placed in the top or bottom third of the tree canopies in plots not treated with pheromone (Figs. 1, 2, 4, and 5). The exception occurred during the second-generation flight in the narrow apple orchard. This lack of an effect of trap height on moth captures is in agreement with the results of Evenden and McLaughlin (2004), but is incongruent with the results of earlier studies (Beroza et al. 1973, Gentry et al. 1974, Rothschild and Minks 1974, 1977, Atterholt 1996). Evenden and McLaughlin (2004) found that captures of males in virgin female traps placed at head-height or in the top third of the canopies of 4-m tall apple trees in untreated plots were equivalent. Beroza et al. (1973) placed traps on poles at heights of 0, 0.9, 1.8, and 2.7 m between peach trees and checked these three times per week for 3 wk. They caught significantly more moths at 0.9 and 1.8 m than at the other heights. Gentry et al. (1974) repeated the study, but placed traps at 0.4, 0.9, 1.4, 1.8, and 2.2 m and conducted the study for 4 mo. They caught more moths at 0.9 m than at the other heights. Rothschild and Minks (1974, 1977) recorded male *G. molesta* approaching virgin female traps or pheromone traps hung on poles placed at the outer edge of the canopy of 2- to 4-m-tall peach trees for three successive nights. In both studies, they reported more moths approaching pheromone sources placed at 2 m than at 1 or 4 m, regardless of tree height, but differences weren't always significant. Atterholt (1996) placed traps at 1.8, 3.7, and 5.5 m, together on single poles, in the canopies of 7.6-m-tall almond trees and caught equivalent numbers of moths in traps placed at 3.7 and 5.5 m, but very few moths at 1.8 m.

Differences in experimental design may be responsible for the discrepancies between our results and some earlier findings. Unfortunately, with the exception of Atterholt (1996), prior studies did not report designs in enough detail to determine the reasons for differences in the outcomes of our experiments. The placement of traps within, rather than outside the canopy, can have a substantial influence on the numbers of moths captured. Riedl et al. (1979) and Howell et al. (1990) found that significantly fewer *C. pomonella* males were captured when traps were placed between, above, or below tree canopies, rather

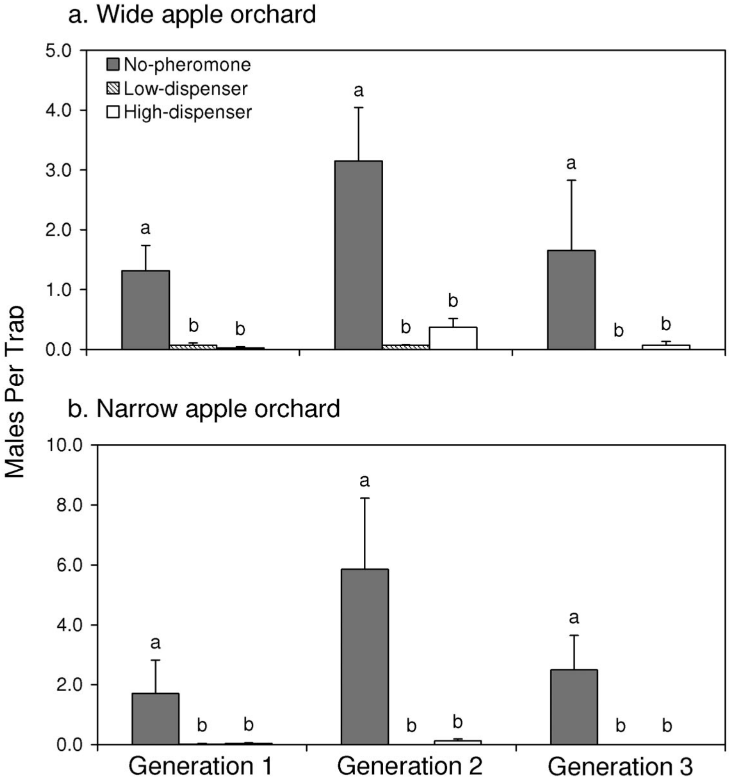

Fig. 6. Numbers of *G. molesta* male moths caught in virgin female traps placed at 1.2–1.8 m in tree canopies in the (a) wide and (b) narrow apple orchards in untreated plots (no-pheromone), plots with pheromone dispensers in the bottom third of the canopy (low-dispenser), and plots with pheromone dispensers in the top third of the canopy (high-dispenser) for 3 d. Bars labeled with the same letter within a generation are not significantly different (wide: generations 1 and 3: Nemenyi, $P < 0.1$; generation 2: Nemenyi, $P < 0.05$; narrow: generation 1: Nemenyi, $P < 0.1$; generation 2: Nemenyi, $P < 0.05$; generation 3: only two rank sum values, no Nemenyi test). Error bars are SEs.

than within them. Although canopy effects on moth captures have not been reported for *G. molesta,* traps in this study were consistently placed within the outer third of the canopy. While Atterholt (1996, personal communication) placed her traps within tree canopies, it is unclear whether Gentry et al. (1974) or Rothschild and Minks (1974, 1977) placed all of their traps within tree canopies, and it is evident that Beroza et al. (1973) did not.

Traps placed at different heights in one tree may compete with one another and capture different relative numbers of moths than if placed in separate trees. Thwaite and Madsen (1983) noted such an interaction for *C. pomonella* traps. Atterholt (1996) placed her

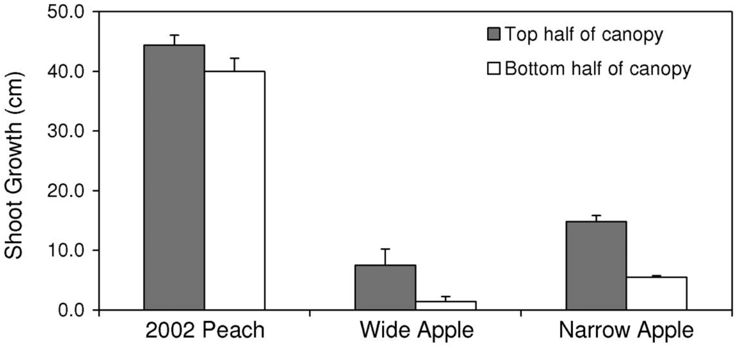

Fig. 7. Seasonal shoot growth measured in the top and bottom halves of the canopies of trees in the 2002 peach, wide apple, and narrow apple orchards. Shoot growth in the three orchards was significantly different and was significantly greater in the top half of the canopy (Tukey, $P < 0.05$). Error bars are SEs.

traps at several elevations on single poles, so competition between traps could have influenced her results. The other researchers (Beroza et al. 1973, Gentry et al. 1974, Rothschild and Minks 1974, 1977, Evenden and McLaughlin 2004) did not specify whether they placed traps at different elevations in the same tree or in separate trees. In addition, Atterholt (1996) may also have trapped fewer moths at the low height due to the sparseness of the canopy at 1.8 m. Almond tree canopies are not as full as apple or peach tree canopies. Although most previous studies suggest that trap height within the canopy in orchards not treated with pheromone may influence *G. molesta* moth catches under some orchard conditions, they generally do not provide clear evidence in favor of this hypothesis. The current study, conducted season-long and replicated under various orchard conditions, provides strong evidence to the contrary and supports Evenden and McLaughlin's (2004) findings.

There was an effect of trap placement on moth captures during generation two in the narrow apple orchard (Fig. 5). Reduced shoot growth in the bottom half of the canopy (Fig. 7) is one possible explanation for the lower number of male moths caught in pheromone traps placed low versus high in tree canopies in this case. Males are likely to be drawn to areas of tree canopies where greater numbers of females are present; females may spend more time in areas with more ovipositional sites. In this orchard, in which almost no trees bore fruit during the year this study was conducted, young shoots were the best ovipositional sites available to *G. molesta.* Differences in the numbers of moths caught in the traps placed low and high in the canopies in the narrow apple orchard first became apparent halfway through the first generation, then disappeared before the third generation (data not shown). This period of increased captures high in the canopy coincided with the period of greatest shoot growth in this orchard. Shoot growth accelerated when the weather warmed up, in early June. By early August, following increasingly hot and dry weather, shoot growth terminated (unpublished data).

In conclusion, under most conditions, vertical placement of pheromone traps in orchards not treated with pheromone does not significantly influence *G. molesta* captures. Thus, pheromone traps placed at any height, within tree canopies, should be equally effective for monitoring *G. molesta* in orchards not treated with pheromone. This has also been observed for tethered female *Epiphyas postvittana* (another tortricid moth), where mating was equivalent at 1.5 m and 3 m in an untreated orchard (Suckling and Shaw 1992; these authors did not report the trap locations in reference to the tree canopies, nor the tree heights).

Additional care may be necessary when monitoring *G. molesta* in pheromone-treated plots. During some sampling periods in the pheromone-treated apple plots, monitoring traps placed farthest away from dispensers, within tree canopies, caught more moths than those nearest to dispensers (Fig. 4: Generation 1 and Fig. 5: Generations 1 and 3). From a practical standpoint, placing a trap further away from a dispenser should provide a more sensitive estimate of the effectiveness of the pheromone treatment throughout the canopy (Knight et al. 1999). To more readily detect control failures, growers should be encouraged to place monitoring traps within tree canopies, as far away as conveniently possible from pheromone dispensers in orchards treated with pheromones.

Success of *G. molesta* Mating Disruption

Some *G. molesta* males were captured in pheromone traps in most of the pheromone-treated plots (Figs. 1, 2, 4, and 5). However, with the exception of the 2001 peach orchard, pheromone trap shutdown in the pheromone-treated plots in all of the orchards used to conduct this study was nearly 100%. The moth population in the 2002 peach orchard was higher than those typically encountered in commercial peach orchards in Michigan (Fig. 2). Moth populations in the narrow and wide apple orchards were even greater (Figs. 4 and 5). Surprisingly, although the moth population in the 2001 peach orchard was no greater than the moth populations in the others, only 85% pheromone trap shutdown was achieved in that orchard. At this level of inhibition of moth captures, this pheromone treatment would not protect a fruit crop from *G. molesta* injury. The low level of trap shutdown may have resulted from reduced foliage in the 2001 peach orchard. This orchard had not been cultivated for several years. The trees were suffering from drought and pathogen infections, so tree canopies were sparse. Foliage can serve an important function in mating disruption by absorbing pheromone from the air and then releasing it, thus enhancing mating disruption by maintaining pheromone in the crop (Sauer and Karg 1998).

Vertical Placement of Pheromone Dispensers

In the 2001 peach, 2002 peach, and wide apple orchards, orientation disruption, as measured by male *G. molesta* captures in pheromone traps placed in the top or bottom third of tree canopies and virgin female traps placed at 1.2–1.8 m, was equivalent irrespective of dispenser height. The only exception was in the wide apple orchard during the first generation, when more moths were caught in the high traps placed in the low-dispenser treatment and in the low traps placed in the high-dispenser treatment. A slow release rate of pheromone from the dispensers during the low springtime temperatures (Fan and Singh 1989, Atterholt 1996) may have decreased the active space of the dispensers at this time, so that pheromone traps placed relatively far away from the dispensers may have been more easily detected by male *G. molesta.*

Our results are consistent with those reported for other types of formulations. Rothschild (1975) attached 1-ml closed polyethylene tubes, each containing 50 mg of pheromone, either at tree crowns or in the centers of the canopies of 3.4-m tall peach trees, and captured equivalent numbers of moths in both treatments. Evenden and McLaughlin (2004) tested the effect of placing LastCall OFM (IPM Tech Inc., Portland, OR) attracticide droplets at head-height or in the top third of the canopy, on male captures in virgin female traps placed at these heights in apple plots. The experiment ran for 20 d. Equivalent numbers of moths were caught in the virgin female traps regardless of trap or attracticide height.

In the narrow apple orchard, in all generations, equivalent numbers of moths were caught in the virgin female traps placed in both pheromone treatments. However, while statistically equivalent numbers of moths were caught in low and high pheromone traps placed in the high-dispenser treatment, more moths were caught in the high traps than low traps placed in the low-dispenser treatment in generations one and three. The large separation between the low and high positions of the traps and dispensers may have accounted for the increased captures in the high traps. The 2.4-m separation between the high and low canopy positions was greater than in any other orchard (Table 1). Atterholt (1996) placed dispensers at 1.8 m and monitored moths with pheromone traps placed at 1.8 m, 3.7 m, and 5.5 m in the canopy of the same almond tree. Traps at 1.8 m and 3.7 m (1.9 m above the dispensers) caught equivalent, low numbers of moths. However, traps placed at 5.5 m (3.7 m higher than the pheromone dispensers), caught significantly more moths. These results resemble those obtained in the narrow apple orchard in this study.

Interestingly, when the dispensers were placed in the top third of canopies in the narrow apple orchard, numbers of moths caught in the low and high pheromone traps were equivalent. Karg et al. (1994), quantifying EAG responses to apple leaves collected from positions up to 50 cm in the x, y, and z axes from two centrally-placed Shin-Etsu dispensers (Shin-Etsu Chemical Co., Ltd., Tokyo, Japan) releasing the pheromone of *Epiphyas postvittana* (a mixture of unsaturated 14-carbon acetates) found that the concentration of pheromone was greatest below the dispensers. They attributed the higher concentration of pheromone on leaves located below the dispensers to downdrafts through the canopy. The data gathered from the narrow apple orchard also suggest the existence of a larger active space below, rather than above the pheromone dispensers.

Based on our results, we conservatively estimate that in trees up to 3.5-m tall (which includes most commercial peach and apple trees in Michigan) dispensers with release rates equivalent to or greater than the minimum release rate of Confuse-OFM at peak flight ($\approx$18 mg/ha/h) will disrupt orientation of *G. molesta* throughout the tree canopy when placed at 1.5–2.0 m. In trees from 3.5- to 4.5-m tall, the dispensers should be moved to $\approx$1.5 m from the top of the tree canopy. In trees taller than 4.5 m, dispensers should be placed at two heights, in the top and bottom thirds of the canopies, for adequate mating disruption of *G. molesta.* Dispensers can easily be placed at 1.5–2.0 m without special equipment, thus reducing application costs for *G. molesta* dispensers in many commercial situations. Optimizing application height may also decrease the amount of pheromone carried out of the orchards by winds, increase the peak concentration of pheromone in the canopy (Suckling et al. 1999), and perhaps increase the longevity of the dispensers in the orchard, thereby further reducing the cost of mating disruption control for this pest.

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