Dose–Response of Codling Moth (Lepidoptera: Tortricidae) to Ethyl (*E*, *Z*)-2,4-Decadienoate in Apple Orchards Treated with Sex Pheromone Dispensers

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ABSTRACT Studies were conducted in apple, *Malus domestica* Borkhausen, orchards to evaluate the attractiveness of the kairomone, ethyl (*E*, *Z*)-2,4-decadienoate (pear ester), loaded at various rates into gray halobutyl septa, to adult codling moth, *Cydia pomonella* L. All studies were conducted in orchards treated with sex pheromone mating disruption. Lure loadings from 0.01 μg to 50.0 mg were evaluated in 12 orchard plots in 1999. Lures loaded with 1.0–50.0 and 0.1–50.0 mg caught significantly more male and female moths than the blank control, respectively. Field dose–response studies were repeated with five lure rates (0.1–40.0 mg) of pear ester during four periods during the 2000 season. Significant seasonal date and rate effects were found for the capture of males and female moths. The 0.1-mg lure caught significantly fewer males than the 1.0-, 3.0-, and 40.0-mg lures. The 40.0-mg lure caught significantly fewer female moths than the 1.0- and 3.0-mg lures. The 3.0-mg lure caught a higher proportion of virgin females than the 10.0- and 40.0-mg lures. The attractiveness of the 1.0 and 3.0 mg pear ester loadings were compared with a sex pheromone lure during a 10-wk trial in 2002. Both pear ester lures caught significantly fewer moths than the sex pheromone lure during the first 4 wk of the study and over the entire 10-wk period. However, no difference among lures occurred during week 5, and the 3.0-mg lure caught significantly more moths than the sex pheromone lure during week 6. The 3.0-mg lure caught a significantly higher proportion of female moths and a higher proportion of virgin female moths than the 1.0-mg lure. These studies suggest that the optimal loading of pear ester for capture of codling moth in mating disrupted apple orchards likely depends on the specific objectives of the monitoring program.

KEY WORDS *Cydia pomonella*, monitoring, sex pheromone, codlemone, kairomone

ETHYL (*E*, *Z*)-2,4-DECADIENOATE (pear ester), derived from ripe pear fruits, is a potent kairomone attractant for both sexes of codling moth, *Cydia pomonella* L., in apple, *Malus domestica* Borkhausen; pear, *Pyrus communis* L.; and walnut, *Juglans regia* L. (Light et al. 2001). Initial tests with the pear ester in walnut orchards established a response threshold of 10 μg when loaded into a gray halobutyl elastomer septum and a similar level of attractiveness as sex pheromone (codlemone) at rates from 0.1 to 20.0 mg (Light et al. 2001). The relative attractiveness of pear ester (1.0-mg lure) for codling moth was found to differ among host plants, with walnut > apple > pear. Seasonal differences were also observed with a decline in attractiveness relative to sex pheromone from the first to the second adult moth generation in apple (Light et al. 2001).

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Development of an optimized controlled-release formulation of pear ester to monitor codling moth has not been reported. Lure type, loading rate, and ambient temperature are three primary factors affecting the emission rate of lures (Daterman 1982). In addition, seasonal differences in host volatile profiles present in orchards may influence the attractiveness and drawing range of kairomone lures (Light et al. 2001). Pear ester has typically been loaded in gray septa to minimize problems associated with the chemical stability of some attractants, especially dienes (Brown and McDonough 1986). Unfortunately, lure loading has not been standardized across the published studies. The pear ester was evaluated with 3.0-mg loads across four pear cultivars in orchards treated with sex pheromone in California, Oregon, and Washington (Knight et al. 2005). These pear ester lures were more attractive than the sex pheromone lures in all pear cultivars under sex pheromone mating disruption (MD) except in 'Bartlett' orchards that had high moth population densities and fruit injury. Septa loaded with 40.0 mg of pear ester were more attractive than septa loaded with 1.0–10.0 mg in 'Bartlett' pear orchards and were more effective than lures loaded with 3.0 mg in detecting the start of first-generation moth emergence (Knight and Light 2004a). Lures loaded with 10.0 mg pear ester were shown not to be attractive to eight lepidopteran pests of nine horticultural crops in California and Washington (Knight and Light 2004b).

A complete comparative study of lure loading on the attractiveness of the pear ester in apple has not been reported. Ioriatti et al. (2003) tested two loading rates (0.1 and 20.0 mg) of pear ester in apple orchards not treated with sex pheromone MD in Italy. They found that these two lures caught a similar number of moths and a similar proportion of female moths during both adult flights. Furthermore, traps baited with either the 0.1 or 20.0 mg pear ester lure were significantly less attractive than traps baited with a sex pheromone lure. Light et al. (2001) hypothesized that the pear ester (1.0 mg lure) was less effective later in the season in apple because of increased competition with apple host volatiles. However, whether the attractiveness of the pear ester could be improved by increasing the lure loading, as was done in pear (3.0-mg lure, Knight et al. 2005; 40.0-mg lure, Knight and Light 2004a), has not been tested in apple.

Here, we report the results from studies (1999–2002) conducted to evaluate the influence of lure loading (0.01 μg to 50.0 mg) on the attractiveness of the pear ester for codling moth in apple orchards treated with sex pheromone MD. These studies were conducted at different periods during the season. The influence of lure loading on the number of moths caught and the sex ratio and female mating status are presented.

Materials and Methods

Studies were conducted in apple orchard plots (mixed plantings of 'Delicious' and 'Golden Delicious') situated near Moxee, Wapato, and Zillah, WA, in 1999, 2000, and 2002. All orchards were treated with Isomate-C Plus dispensers (Pacific Biocontrol, Vancouver, WA) at rates from 600 to 1,000/ha. Dispensers were loaded with 182.3 mg of a 60:33:7 blend of (*E*,*E*)-8–10-dodecadien-1-ol, dodecanol, and tetradecanol. Gray halobutyl elastomer septa (No. 1888, size No. 1; West Co., Phoenixville, PA) were used as lure substrates in all studies. Diamond-shaped sticky traps (Pherocon IIB, Trécé, Adair, OK) were used in all tests. The mean heights of orchard canopies ranged from 3.2 to 4.2 m, and traps were placed on plastic poles $\approx$1.0 m from the top of the canopy. All captured moths were sexed and the mating status of dissected females (presence or absence of a spermatophore in the bursa copulatrix) was determined in 2000 and 2002. Supplemental insecticide sprays for codling moth were not applied to any of these orchards.

1999. The attractiveness of pear ester lures with loadings of 0.0, 0.01, 0.1, 1.0, and 10.0 μg and 0.1, 1.0, 10.0, and 50.0 mg was evaluated in 12 orchard plots from 12 to 23 August. Lure-baited traps were placed in each orchard in a randomized complete block design with orchard plots constituting replications. Traps were spaced 30 m apart and checked once at the end of the test. Decade serial dilutions of a stock material (93.7% A.I. purity; Aldrich Chemical, Minneapolis, MN) using methylene chloride were prepared by D.M.L. Septa were loaded by adding 100-μl aliquots of solution to the well of the septa, except for the 50.0-mg lures, which were prepared by adding five consecutive 100-μl aliquots of a 100 μg/μl solution with a 1-h reloading interval.

2000. A study comparing five lure loadings (0.1, 1.0, 3.0, 10, and 40.0 mg) of pear ester was conducted with a completely randomized design during four periods of the season: 12–17 May, 26 May to 7 June, 20 July to 3 August, and 11–24 August. Trécé provided the lures used in this study, and the 40.0-mg loading was selected as the highest rate because of concerns about the variability among lures treated with higher loadings. The 3.0-mg load was added to this study to more closely examine the optimal rate for capturing female codling moths. Ten trap replicates were placed in the same orchard on each date. Traps were spaced 25 m apart with one replicate of each lure per orchard row. Replicate rows were spaced 30 m apart. Traps were checked once at the end of each period. New lures and traps were used at the start of each period, and lure locations were rerandomized. Traps baited with solvent-loaded lures ($n = 5$) were placed in this orchard during each time period to assess the potential contamination of traps. Moth catch in these traps were trivial during the season and these data are not reported.

2002. The attractiveness of 1.0 and 3.0 mg pear ester lures were compared with a sex pheromone lure prepared with a proprietary loading of codlemone (CM Megalure; Trécé) over a 10-wk period in eight apple orchards using a completely randomized design. Traps were placed in the field on 26 April, and the study was concluded on 8 July. Traps were spaced 50 m apart and checked and rerandomized in each orchard each week. Different technicians serviced traps baited with sex pheromone and pear ester lures independently on each date to minimize the risk of cross-contamination. Technicians wore latex gloves when handling all traps.

Data Analysis. The effects of lure loading on male, female, and total moth captures were tested with analysis of variance (ANOVA) (Analytical Software 2000). All count data were transformed with square root ($x + 0.01$) to correct for heterogeneity of variances before analysis. Proportional data (female catch and mating status) were subjected to an angular transformation before analysis. A two-way (loading by date) factorial ANOVA was used to compare the mean moth catch in traps baited with different lure loadings on four dates during the 2000 season. When the ANOVA was significant means were separated with Fisher least significant difference (LSD; $P < 0.05$) (Analytical Software 2000). Because of a significant interaction of lure loading and seasonal test period for the mean proportion of female moths caught in traps ($P < 0.05$) in 2002, separate ANOVAs were run for

Table 1. Catches of male and female codling moth in traps baited with lures with loads of pear ester from 0.01 μg to 50.0 mg, 12–23 Aug. 1999

Lure loading	Mean ± SEM catch per day		
	Males	Females	Total
0.01 μg	0.02 ± 0.01a	0.01 ± 0.01a	0.03 ± 0.01a
0.1 μg	0.09 ± 0.04ab	0.02 ± 0.01a	0.11 ± 0.05a
1.0 μg	0.09 ± 0.07ab	0.05 ± 0.03a	0.14 ± 0.11a
10 μg	0.03 ± 0.02a	0.09 ± 0.04a	0.12 ± 0.05a
0.1 mg	0.23 ± 0.08bc	0.23 ± 0.04b	0.47 ± 0.09b
1.0 mg	0.51 ± 0.28c	0.36 ± 0.10bc	0.87 ± 0.35bc
10.0 mg	0.57 ± 0.23c	0.65 ± 0.15d	1.21 ± 0.35c
50.0 mg	0.75 ± 0.37c	0.60 ± 0.15cd	1.35 ± 0.39c
Unbaited	0.07 ± 0.02ab	0.00 ± 0.00a	0.07 ± 0.02a

Means were transformed and subjected to ANOVA. Means in significant ANOVAs were separated with a LSD test ($P < 0.05$). Column means followed by a different letter are significantly different.

each test period. The proportion of virgin moths was analyzed only for the June and July samples in 2000 because of low female moth counts on the other dates. Paired *t*-tests were used to compare the proportion of female moths and virgin females caught in traps baited with either a 1.0 or a 3.0 mg pear ester lure in 2002.

Results

1999. The amount of pear ester loaded onto septa significantly affected mean moth catches of both sexes individually and for total numbers of moths: males ($F = 4.84$; df = 8,99; $P < 0.0001$), females ($F = 14.10$; df = 8,99; $P < 0.0001$), and total moths ($F = 9.82$; df = 8,99; $P < 0.0001$; Table 1). Traps baited with 1.0- to 50.0-mg lures caught significantly more males than the unbaited traps and traps baited with 0.01- to 10-μg lures. Traps baited with 0.1-, 1.0-, 10.0-, and 50.0-mg lures caught significantly more females than the unbaited traps and traps baited with 0.01- to 10.0-μg lures. Traps baited with 10.0- and 50.0-mg lures caught more females than traps baited with 0.1-mg lures; traps baited with 10.0-mg lures caught more females than traps baited with the 1.0-mg lure. Similarly, traps with 0.1- to 50.0-mg lures caught significantly more total moths than the unbaited traps and traps baited with 0.01- to 10.0-μg lures. The 10.0- and 50.0-mg lure-baited traps caught significantly more moths than traps baited with the 0.1-mg lure (Table 1).

2000. Date of the test period was a significant factor affecting total moth catch ($F = 139.33$; df = 3,179; $P < 0.0001$), male moth catch ($F = 32.68$; df = 3,179; $P < 0.0001$), and female moth catch ($F = 63.19$; df = 3,179; $P < 0.0001$; Table 2). Loading rate of pear ester in lures was also a significant factor affecting total moth catch ($F = 4.26$; df = 4,179; $P < 0.01$), male moth catch ($F = 5.22$; df = 4,179; $P < 0.001$), and female moth catch ($F = 4.05$; df = 4,179; $P < 0.01$). The interaction of loading rate and test period was not significant in any of these three ANOVAs ($P > 0.05$). There was a significant interaction between rate and date of test period for the proportion of female moths caught in traps ($F = 2.44$; df = 12,153, $P < 0.01$). During the May trial, traps baited with the 40.0-mg lure had a significantly lower proportion of female moths ($F = 2.61$; df = 4,40; $P < 0.05$). Traps baited with a 0.1-mg lure in the June test had a significantly higher proportion of female moths than traps baited with 3.0- to 40.0-mg lures ($F = 3.76$; df = 4,45; $P < 0.05$).

Both the date of the test period ($F = 21.7$; df = 1,89; $P < 0.0001$) and lure loading ($F = 2.56$; df = 4,89; $P < 0.05$) significantly affected the proportion of trapped

Table 2. Seasonal comparison of the influence of pear ester lure loading in gray halobutyl septa on the capture of male, female, and the total no. codling moths in MD apple, 2000

Lure (mg)	Mean ± SE no. moths caught per trap per day				
	May	June	July	Aug.	Overall rate means
Males					
0.1	0.30 ± 0.04	0.13 ± 0.03	0.20 ± 0.06	0.03 ± 0.02	0.14 ± 0.02a
1.0	0.98 ± 0.20	0.36 ± 0.04	0.36 ± 0.10	0.11 ± 0.03	0.37 ± 0.06bc
3.0	0.64 ± 0.10	0.42 ± 0.05	0.29 ± 0.08	0.11 ± 0.04	0.30 ± 0.04bc
10.0	0.46 ± 0.10	0.38 ± 0.05	0.38 ± 0.08	0.04 ± 0.02	0.27 ± 0.04b
40.0	2.24 ± 0.88	0.51 ± 0.15	0.38 ± 0.07	0.01 ± 0.01	0.77 ± 0.30c
Overall date means	0.92 ± 0.21c	0.36 ± 0.04b	0.32 ± 0.03b	0.06 ± 0.01a	
Females					
0.1	0.12 ± 0.06	0.22 ± 0.04	0.21 ± 0.04	0.02 ± 0.01	0.12 ± 0.02a
1.0	0.13 ± 0.03	0.31 ± 0.04	0.45 ± 0.04	0.02 ± 0.02	0.19 ± 0.03b
3.0	0.08 ± 0.03	0.39 ± 0.08	0.30 ± 0.05	0.08 ± 0.02	0.17 ± 0.03b
10.0	0.14 ± 0.03	0.27 ± 0.04	0.28 ± 0.06	0.02 ± 0.01	0.15 ± 0.02ab
40.0	0.02 ± 0.02	0.23 ± 0.07	0.29 ± 0.07	0.02 ± 0.01	0.11 ± 0.03a
Overall date means	0.10 ± 0.02b	0.28 ± 0.03c	0.31 ± 0.03c	0.03 ± 0.01a	
Total moths					
0.1	0.42 ± 0.08	0.35 ± 0.05	0.41 ± 0.07	0.05 ± 0.03	0.26 ± 0.03a
1.0	1.11 ± 0.22	0.67 ± 0.05	0.81 ± 0.14	0.14 ± 0.04	0.56 ± 0.07b
3.0	0.72 ± 0.12	0.81 ± 0.13	0.59 ± 0.11	0.18 ± 0.04	0.47 ± 0.06b
10.0	0.60 ± 0.11	0.65 ± 0.08	0.65 ± 0.13	0.06 ± 0.02	0.42 ± 0.05ab
40.0	2.26 ± 0.88	0.74 ± 0.19	0.67 ± 0.13	0.02 ± 0.01	0.76 ± 0.21b
Overall date means	1.02 ± 0.20b	0.64 ± 0.05b	0.63 ± 0.05b	0.09 ± 0.02a	

Column and row overall means for males, females, and total moths followed by a different letter were significantly different, two-way factorial ANOVA ($P < 0.05$, LSD).

Studies were conducted from 12 to 17 May, 26 May to 7 June, 20 July to 3 Aug., and 11 to 24 Aug. 2000.

Table 3. Comparison of codling moth catches in traps baited with 1.0 and 3.0 mg pear ester or a sex pheromone lure during a 10-wk field study in eight apple orchards treated with sex pheromone MD dispensers, 26 April to 8 July 2002

Field-aged lures (wks)	Mean ± SE moth catch per trap			Mean ± SE proportion female moths	
	Pear ester 1 mg	Pear ester 3 mg	Sex pheromone	Pear ester 1 mg	Pear ester 3 mg
1	1.0 ± 0.3a	0.8 ± 0.4a	13.8 ± 2.8b	0.00 ± 0.00a	0.50 ± 0.13b
2	0.3 ± 0.2a	0.3 ± 0.2a	0.5 ± 0.2a	0.00 ± 0.00	0.00 ± 0.00
3	4.5 ± 0.4a	4.3 ± 0.7a	22.3 ± 2.8b	0.15 ± 0.04a	0.34 ± 0.01b
4	2.5 ± 0.6a	1.5 ± 0.4a	14.0 ± 2.2b	0.73 ± 0.10a	0.72 ± 0.09a
5	14.8 ± 1.5a	17.0 ± 1.6a	18.5 ± 3.1a	0.46 ± 0.06a	0.67 ± 0.02b
6	9.5 ± 1.8a	16.8 ± 0.8b	8.2 ± 1.8a	0.48 ± 0.01a	0.56 ± 0.01b
7	2.6 ± 0.9a	3.3 ± 0.4a	7.4 ± 1.8b	0.73 ± 0.13a	0.79 ± 0.07a
8	1.0 ± 0.4a	3.4 ± 0.5b	3.5 ± 1.0b	0.00 ± 0.00a	0.47 ± 0.09b
9	0.4 ± 0.2a	0.5 ± 0.3a	5.0 ± 2.8a	0.67 ± 0.33	0.67 ± 0.33
10	0.5 ± 0.3a	0.5 ± 0.3a	0.8 ± 0.5a	0.75 ± 0.17	0.25 ± 0.25
Grand total	37.1 ± 3.0a	48.6 ± 3.7a	94.3 ± 8.6b	0.31 ± 0.06a	0.60 ± 0.04b

Mean moth catches for each week followed by a different letter were significantly different, one-way ANOVA (LSD test, $P < 0.05$). Mean proportion of female moths for each week followed by a different letter were significantly different (paired *t*-test, $P < 0.05$). Statistical tests were not conducted for the proportion of female moths during wks 2, 9, and 10 because of insufficient data.

females that were virgin, but there was no interaction between date of test period and lure loading (P = 0.97). The mean proportion of virgin females was 0.30 ± 0.05 (SE) in June and 0.06 ± 0.02 in July. A significantly higher mean proportion of virgin females was caught with the 3.0-mg lure (0.24 ± 0.06) than with the 10.0- (0.12 ± 0.06) or 40.0-mg lure (0.09 ± 0.05). The 0.1- (0.25 ± 0.08) and 1.0-mg lures (0.20 ± 0.05) were not different from the 3.0-mg lure, but the proportion of virgin females trapped was significantly higher with the 0.1- than with the 40.0-mg lure. The 1.0- and 10.0-mg lures were not different from the 40.0-mg lure.

2002. Traps baited with the sex pheromone lure caught significantly more moths than either of the pear ester lure-baited traps in week 1 (F = 21.3; df = 2,21; $P < 0.0001$), week 3 (F = 36.3; df = 2,21; $P <$ 0.0001), and week 4 (F = 27.8; df = 2,21; $P < 0.0001$). Moth catches were high during week 5 but were not significantly different among lures (P = 0.49). During week 6, the 3.0 mg pear ester lure-baited traps caught significantly more moths than traps baited with either the sex pheromone or the lower pear ester loading (F = 9.01; df = 2,21; $P < 0.01$). The 1.0 mg pear ester and sex pheromone lure did not differ in capture rate during this time interval. The following interval, week 7, the sex pheromone lure baited traps again caught significantly more moths than traps with either pear ester lure (F = 4.68; df = 2,21; $P < 0.05$). During week 8, both the sex pheromone lure and the 3.0-mg lure caught significantly more moths than the 1.0-mg lure and did not differ from each other (F = 4.28; df = 2,21; $P < 0.05$). Moth catches declined during weeks 9 and 10, and no significant differences occurred among lures (Table 3). The 3.0 mg pear ester lure caught a significantly higher proportion of female moths than the 1.0-mg lure during five individual time periods ($t >$ 3.06, df = 3–7, $P < 0.05$) and across the entire season (t = 4.00, df = 7, $P < 0.01$). The mean proportion of trapped females that were virgin was not significantly different between pear ester lures loaded with 1.0 (0.06 ± 0.06) and 3.0 mg (0.34 ± 0.12) over the entire season (t = 2.06, df = 7, P = 0.08).

Peak moth catch with the pear ester lure occurred during weeks 5 and 6, ≈2–3 wk later than with the sex pheromone lure, and coincided with a nearly equal sex ratio (Table 3). Pear ester lures caught moths over the entire 10-wk study. Moth catches, however, declined relative to the sex pheromone lure after 8 wk.

Discussion

Varying the loading of pear ester–baited gray elastomer septa had significant and consistent effects on the capture of total numbers of codling moth in apple orchards treated with sex pheromone MD during the season. Lures loaded with ≥1.0 mg pear ester were equally effective in catching codling moths late in the season (August 1999) and, in general, 40–60% of the moths caught were females. A similar pattern for total moth catches was observed when lures were tested across four distinct time periods (May through August) in 2000. These data suggest that a 1.0-mg loading of pear ester in a gray halobutyl elastomer septum is a minimum effective dose for monitoring codling moth in sex pheromone–treated orchards.

The results are more complicated when examining the effect of lure loading for each sex over the course of the season. For example, the 40.0-mg lure caught more than twice the number of moths as any other loading in a May trial in 2000, but <1.0% of these moths were females. In contrast, the 1.0- and 3.0-mg lures caught the greatest numbers of female moths over the 2000 season. The 3.0-mg lure caught a higher proportion of females than the 1.0-mg lure during 2002. Furthermore, the 3.0-mg lure caught a higher proportion of virgin females than the 10.0- and 40.0-mg lures in 2000.

Pear ester lures did not perform as well as a sex pheromone lures during the first moth flight across eight sex pheromone–treated orchards. This difference was caused by the poor relative performance of the pear ester lure–baited traps during the first 4 wk of the study. Previously, a 1.0 mg pear ester lure performed as well as a sex pheromone lure in six sex pheromone–treated apple orchards (Light et al. 2001).

However, these two studies used different sex pheromone lures. The 2000 study compared the pear ester against the CM-L2 (Trécé) gray septum that is recommended for orchards not treated with sex pheromones. The CM-Megalure used in our study was developed to monitor codling moth in sex pheromone–treated orchards and has a 10-fold higher loading of codlemone and can catch 50–100% more moths than the CM-L2 in treated orchards (Knight 2002a).

Currently, sex pheromone–baited traps are used to monitor codling moth in apple orchards (Riedl et al. 1986). Delimiting the start of a sustained moth catch with these traps is used to initiate phenology models useful in predicting the timing of the start of egg hatch (Riedl et al. 1976). Moth catches have also been used to establish action thresholds and high catches can trigger the application of insecticide sprays (Madsen and Vakenti 1972). The 40.0 mg pear ester lure was found to be as effective in detecting the start of male emergence as a sex pheromone lure in 'Bartlett' pear (Knight and Light 2004a). Similarly, our data from apple suggest that this high load lure is most effective early in the season and catches mostly males. Further studies should investigate the use of this high-load lure in tandem with the codling moth phenology model (Beers and Brunner 1992).

The ability to capture female codling moths in traps with the pear ester lure offers several advantages not associated with the use of sex pheromone lures. Passive interception traps coated with oil were proposed as an effective tool to detect the emergence of female moths and the presence of mated females and to better predict the beginning of egg hatch (Knight 2000). These traps were effective but were rather cumbersome and reliable only in orchards with high population densities of codling moth. A pear ester–baited sticky trap is a much simpler approach to monitor female emergence; however, determining the start of sustained female emergence with any trapping system is problematic in orchards with low pest pressure. Establishing action thresholds for orchards based on the density of female moths is conceptually an improvement over the use of male moth counts, especially in sex pheromone–treated orchards (Knight 2002b). The sex pheromone MD treatment can have a significant impact on the capture of male moths, either by shutting down traps because of disruption of behavior (Knight 1995) or by creating false-positive catches of males immigrating into sex pheromone–treated orchards (Witzgall et al. 1999). A third beneficial factor of kairomone-based monitoring is the ability to assess the mating status of female moths in sex pheromone MD orchards. Previous studies have captured a high proportion of mated females within sex pheromone–treated orchards using light traps (Howell and Britt 1994) and interception traps (Knight 2000). The mean proportion of mated females in these previous studies has been between 50 and 60%, which is similar to the data collected with the 3.0-mg lure in the 2002 studies here.

Overall, our studies suggest that 3.0 mg would be a suitable loading of pear ester in gray halobutyl septa because of its effective monitoring of both sexes of codling moth over an extended time period. However, using both the 3.0- and the 40.0-mg lures in tandem early in the season might be a useful approach to assess the start of male (40.0-mg lure) and female emergence (3.0-mg lure) and the population density of each sex. The orchard could then be monitored with 3.0-mg lures during the remainder of the season. The 3.0 mg pear ester lure may also be an effective component of future lure and kill techniques for female codling moth, and the removal of a higher proportion of virgin versus mated females with this lure loading would be more effective in achieving population reduction (Knight et al. 2002).

The use and validity of using the pear ester to monitor codling should be conducted in a variety of important cultivars. The attractiveness of the pear ester lure relative to a sex pheromone lure was found to vary among pear cultivars (Knight et al. 2005). Seasonal and cultivar-related differences in the odor profile of apple orchards (Kakiuchi et al. 1986, Yahia et al. 1990, Bengtsson et al. 2001) could also have a significant impact on the effectiveness of pear ester kairomone lures. Apple studies reported from North America with the pear ester have all been conducted in mixed plantings of the midseason cultivars, 'Delicious' and 'Golden Delicious' (Light et al. 2001). Recent studies with the pear ester in Italy have been more disappointing and were conducted in the early-season cultivar, 'Gala' and solid blocks of 'Golden Delicious' (Ioriatti et al. 2003). In comparison, the pear ester–baited trap (3.0 mg) caught nearly four times more moths than traps baited with the Megalure during a full-season trial in 'Granny Smith' (late-season cultivar) in Australia (Thwaite et al. 2004). In addition, the potential for additive or synergistic adult responses to pear ester in combination with codlemone (Light et al. 1993, Yang et al. 2004) or other host plant volatiles (Coracini et al. 2004) should be addressed among different host cultivars.

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