Effect of mating disruption dispenser placement on trap performance for monitoring codling moth (Lepidoptera: Tortricidae)

A. L. KNIGHT, B. A. CROFT[1], and K. A. BLOEM[2]

YAKIMA AGRICULTURAL RESEARCH LABORATORY AGRICULTURAL RESEARCH SERVICE, USDA 5230 KONNOWAC PASS RD. WAPATO, WA 98951

ABSTRACT

Capture of codling moth, *Cydia pomonella* L., in lure-baited, wing-style traps placed at varying distances from polyethylene dispensers (Isomate-C+) in the canopy of an apple orchard was investigated during 1997. Replicated studies of trap - dispenser position were conducted with releases of sterile moths around each trap. In the first experiment, moth catch was unexpectedly higher in traps placed 1 m below the 1997 dispenser's height (3.38 m) compared with traps at the dispenser's height. No differences were found in moth catch for traps placed adjacent to or 1 and 2 m distant from dispensers at the dispenser height. Subsequent analysis of the Isomate-C+ dispensers left in the field from 1996 found that they continued to emit low levels of sex pheromone through July. In the second experiment, the 1996 dispensers were removed from the trees around each trap and moth catch was significantly lower in traps placed 1 m below the 1997 dispenser height and in traps adjacent to the dispenser compared with traps 1 and 2 m distant at the dispenser's height. In a third test, moth catches were significantly reduced when the trap - dispenser distance was ≤ 0.3 m for both 1996 and 1997 dispensers. Moth catch did not vary in traps placed 0.3 to 2.0 m from either dispenser type. A *post-hoc* evaluation of trap placements used in an areawide project situated near Oroville, Washington, in 1996 found that 9% of traps were placed within 0.3 m of dispensers. This percentage of traps increased to 30% in 1997 following recommendations that traps should be placed higher in the canopy.

Key words: codling moth, sex pheromone, mating disruption, apple, lures, traps

INTRODUCTION

Traps baited with codlemone, the main sex pheromone component of codling moth, *Cydia pomonella* L., (Roelofs *et al.* 1971) have been used for 25 years to monitor populations in tree-fruit orchards (Butt *et al.* 1974; Maitlen *et al.* 1976). Codling moth catch in codlemone-baited traps has been used to establish action thresholds (Madsen and Vakenti 1972; Riedl and Croft 1974; Madsen *et al.* 1974) and as an indicator of codling moth phenology (Riedl *et al.* 1976; Beers and Brunner 1992). Codling moth catch in traps is also used to evaluate the success of mating disruption in orchards treated with sex pheromone (Vickers and Rothschild 1991).

The efficacy of numerous trap and lure types has been evaluated for codling moth (earlier work summarized in Riedl *et al.* 1986; Knodel and Agnello 1990; Vincent *et al.* 1990; Kehat *et al.* 1994). A synthesis of this work led to a standardization in the use of traps and lures, including placement of the trap within the canopy (Riedl *et al.* 1986). Codling moth adults are active in the upper canopy of trees (Borden 1931; Weissling and Knight 1995) and traps placed high in the canopy catch more moths than traps placed low in the canopy (Riedl *et al.* 1979; Ahmad and Al-

[1] Current address: Department of Entomology, Oregon State University, Corvallis, OR 97331
[2] Current address: USDA, APHIS, PPQ, NBCI, Florida A&M University, Tallahassee, FL 32312

Gharbawi 1986; Barrett 1995; Knight 1995a) or outside the canopy (Howell *et al.* 1990; Mani *et al.* 1995). Consideration of trap placement can also include the trap's orientation with wind direction, tree quadrant, and position with relation to the canopy's perimeter (Riedl *et al.* 1979; McNally and Barnes 1981). The importance of trap position within an orchard, e.g. traps on the edge versus internal traps, has also been evaluated (Westigard and Graves 1976).

Standardization of trap use in orchards using mating disruption is of critical importance in monitoring codling moth. The occurrence of 'false negatives' (absence of trapped moths despite the occurrence of fruit injury) has been particularly problematic in such orchards, especially in orchards monitored with lures loaded with 1 mg of codlemone (Knight 1995b; Gut and Brunner 1996). Higher moth catches have been generated by using lures with higher pheromone loads (Charmillot 1990; Knight 1995a; Gut and Brunner 1996; Judd *et al.* 1996) and by placing traps in the upper third of the canopy (Riedl *et al.* 1986; Barrett 1995; Knight 1995a; Gut and Brunner 1996). One factor that has not been considered in formulating recommendations for codling moth trap placement in orchards using mating disruption is the proximity of dispensers and traps. Herein, we report studies examining the effect of dispenser and trap placement and proximity on codling moth trap performance.

MATERIALS AND METHODS

Studies were conducted in a 20-ha apple orchard (mixed planting of 'Red Delicious' and 'Golden Delicious'), situated near Moxee, WA in 1997. Tree height (±SE) averaged 3.99 (0.06) m (n = 160). Isomate C+ dispensers (Pacific Biocontrol, Vancouver, WA) were attached to branches using plastic clips. Dispensers for 1996 and 1997 were attached with different colored clips: blue in 1996; red in 1997. Two dispensers were placed in the upper canopy of each tree at a rate of 1,000 dispensers per ha each year. Dispensers were applied on 21 April in 1996 and 23 April 1997. Dispenser application height (±SE) averaged 3.38 (0.05) m (n = 160) and was similar both years. In many instances, dispensers in 1997 were clipped adjacent to dispensers from 1996. Dispensers were loaded with 220 mg of a three-component sex pheromone blend (62:31:7%) of 8,10-dodecadien-1-ol (93% EE [codlemone], 3.8% EZ, 2.6% ZE, 0.6% ZZ), 1-dodecanol, and 1-tetradecanol; and 13% inert ingredients (UV inhibitors and antioxidants). The residual content of 1996 dispensers (n = 14) were analyzed by our laboratory on several dates in 1997 with gas chromatography. Dispensers were cut into 2 cm pieces and rinsed continuously with dichloromethane for 3 hours. Samples were processed with a HP7673 automatic sampler and a Series II 5890 gas chromatograph using a 60 m x 0.32 mm capillary column coated with dimethylpolysiloxane. Samples were injected in splitless mode with 40°C initial temperature for 6 min., a ramp rate of 25°C per min., and a final temperature of 300°C for 10 min. Undecanol was used as the internal standard. Recovery rates for each pheromone component were > 90%. Dispensers (n = 5) placed in the orchard in 1997 were analyzed biweekly by Scenturion Inc. (Clinton, WA). These data were provided by Pacific Biocontrol (Vancouver, WA).

Wing-style traps with IC sticky liners (Trece Inc., Salinas, CA) were placed every 50 m in the orchard and baited with a red septa loaded with 10 mg of codlemone (Trece Inc., Salinas, CA). In experiment 1, traps were placed at approximately the same height or 1.0 m lower than 1997 dispensers (red clip); and either adjacent, 1.0, or 2.0 m distant from dispensers; five positions replicated six times. Dispenser - trap distances were measured from the dispenser to the mid-point on the outside of the trap. Experiment 1 was run from 7 to 14 June, 1997. In experiment 2, traps were placed on 14 June on different trees but in the same relative positions as experiment 1; five positions replicated eight times. However, all the 1996 dispensers (blue clips) were removed from the test trees and the two adjoining trees within each row prior to the start of this experiment. In experiment 3, codlemone-baited traps were placed on new trees at 0.15, 0.30, 0.61, 1.0, and 2.0 m from either a 1996 or a 1997 dispenser; ten positions replicated nine times.

In addition, to demonstrate whether either dispenser was attractive to moths, similar traps were baited with either 1996 or 1997 dispensers. These traps were placed at 3.38 m height and all other dispensers within 3 m of each trap were removed. Five replicates of each treatment were run from 16 to 18 June, 1997, and four replicates were run from 19 to 24 June, 1997.

At the start of each experiment, 300 sterile, unsexed moths were released around each trap by tapping chilled moths out of petri plates onto both the tree and the ground. Sterile codling moths of both sexes were obtained from the codling moth mass-rearing SIR facility in Osoyoos, British Columbia. Moths were sterilized with gamma radiation (33 krad) from a $Cobalt^{60}$ source (dose rate of 1,150-1,320 rad/min) and held at 0 to 2°C before field release. All experiments used a randomized complete block design. Numbers of moths caught per trap were analyzed with analysis of variance (ANOVA) and means were separated with Fisher's LSD (Hintze 1987). The analyses were repeated on transformed data (log(x+1.)) with the same results; results based on untransformed data are presented. Moth catch in experiment 3 was analyzed as moths caught per trap per day. A two-way ANOVA was used to examine the effects of dispenser age and trap - dispenser distance. Due to a significant interaction between these factors ($P < 0.05$) separate ANOVA's were run for each year and between the two dispenser ages at each distance.

An evaluation of grower's placement of dispensers and traps to monitor codling moth in orchards using mating disruption was conducted within the U.S.D.A. areawide codling moth management program situated in the U. S. near Lake Osoyoos and adjacent with the Canadian border. Dispenser and trap height and the distance between traps and new dispensers were measured for all traps in this 150-ha site from 1995 to 1997. ANOVA's were run for each factor among the 3 years. Means were separated with Fisher's LSD.

RESULTS

Experiment 1. Significant differences were found in moth catch based on the relative trap and dispenser position in the canopy ($F = 3.2$; df = 4, 25; $P = 0.03$: Table 1). Moth catch was significantly higher in traps placed 1 m below the dispensers than in all traps placed 10 - 30 cm above the dispenser height. No difference in moth catch occurred in traps placed adjacent to the dispenser and traps placed 1 or 2 m away at the same height.

Table 1

Mean number of codling moths caught in 10 mg lure-baited traps placed at several positions in the canopy in relation to 1997 Isomate-C+ dispensers. Dispensers were applied on 23 April, 1997 and the test was conducted from 7 to 14 June, 1997.

	Trap position in relation to:		Mean no. of moths
Treatment	Position of dispenser[1]	Distance from dispenser[2]	caught per trap(±SE)
1	Same height	Adjacent	5.2 (1.7)bc
2	Same height	1 m	5.5 (2.3)bc
3	Same height	2 m	4.8 (1.1)c
4	1 m below	1 m	12.7 (2.6)a
5	1 m below	2 m	11.2 (2.3)a

Column means followed by a different letter are significantly different, $P < 0.05$, Fisher's LSD

[1] Trap heights (±SE) were on average 0.10 (0.02), 0.19 (0.03), and 0.26 (0.06) m above dispensers in treatments 1 - 3, respectively. Trap heights (±SE) were on average 1.03 (0.06) m and 1.07 (0.08) m below dispensers in treatments 4 and 5, respectively.

[2] Trap distance (±SE) from the nearest 1997 dispenser averaged 0.18 (0.03) in treatment 1; 1.07 (0.10) m and 1.24 (0.12) m in treatments 2 and 4, respectively; and 2.16 (0.08) m and 2.23 (0.18) m in treatments 3 and 5, respectively.

Analysis of dispensers. Dispensers placed in the field in April 1996 still contained and released codlemone through July, 1997 (Table 2). The mean daily loss of codlemone from the 1996 dispenser during June and July averaged 0.15 mg. The purity of the EE8,10-12:OH isomer in these samples ranged from 78 - 89%. In comparison dispensers applied in 1997 had much higher release rates (0.6 mg codlemone per d) and a higher purity, 91-93% (Table 2).

Table 2

Residual content (±SE), isomeric purity and mean daily loss of E8,E10-12:OH from Isomate-C+ dispensers applied on 21 April, 1996, and 23 April, 1997, and sampled from June to July, 1997.

		1996 Dispensers	
Date	Residual (mg) 8,10-12:OH	% EE8,10-12:OH	Mean loss (mg per d) EE8,10-12:OH
01 June	10.1 (2.2)	88.8	-
26 June	6.3 (1.3)	77.5	0.15
04 July	5.3 (1.8)	84.0	0.13
31 July	0.8 (0.3)	79.4	0.17
		1997 Dispensers	
Date	Residual (mg) 8,10-12:OH	% EE8,10-12:OH	Mean loss (mg per d) EE8,10-12:OH
5 June	103.0 (0.6)	93.0	-
19 June	95.9 (1.7)	92.1	0.53
17 July	75.4 (1.0)	91.3	0.70
31 July	65.5 (1.4)	92.8	0.57

Table 3

Mean number of codling moth caught in 10 mg lure-baited traps placed at several positions in relation to 1997 Isomate-C+ dispensers following the removal of 1996 dispensers on 14 June, 1997. Test was conducted from 14 to 21 June, 1997.

	Trap position in relation to:		
Treatment	Position of dispenser[1]	Distance from dispenser[2]	Mean no. of moths caught per trap(±SE)
1	Same height	Adjacent	7.1 (3.6)c
2	Same height	1 m	29.8 (3.9)ab
3	Same height	2 m	34.0 (5.9)a
4	1 m below	1 m	19.1 (4.6)bc
5	1 m below	2 m	18.8 (6.5)bc

Column means followed by a different letter are significantly different, $P < 0.05$, Fisher's LSD

[1] Trap height (±SE) were on average 0.08 (0.02), 0.14 (0.10), and 0.07 (0.06) m above dispensers in treatments 1 to 3, respectively. Trap heights (±SE) were on average 1.01 (0.06) and 0.98 (0.07) m below dispensers in treatments 4 and 5, respectively.

[2] Trap distance (±SE) from the nearest 1997 dispenser averaged 0.15 (0.03) in treatment 1; 1.18 (0.08) and 1.20 (0.13) m in treatments 2 and 4, respectively; and 2.04 (0.08) and 2.03 (0.15) m in treatments 3 and 5, respectively.

Experiment 2. Moth catch was significantly affected by the relative positions of the trap and dispensers following the removal of the 1996 dispensers from the test and adjoining trees (F = 4.4; df = 4, 35; $P < 0.01$: Table 3). Similar to experiment 1, trap height was a significant factor affecting moth catch (F = 5.8; df = 1, 28; P = 0.02), but in contrast to the earlier test (Table 1), moth catch was higher in traps positioned higher in the canopy (Table 3). Moth catch was significantly lower in traps 0.15 m from dispensers compared with traps at 1 and 2 m distant at the same height. No significant difference in moth catch was found across both trap heights for traps placed 1 or 2 m from dispensers ($F = 0.1$; df = 1, 28; $P = 0.71$).

Experiment 3. Significant differences in moth catch occurred as a function of trap distance to both 1996 and 1997 dispensers (1996: $F = 4.2$; df = 4, 40; $P < 0.01$; 1997: $F = 12.4$; df = 4, 40; $P < 0.001$) (Table 4). Moth catch was significantly lower when the trap was placed ≤ 0.3 m than at 1.0 to 2.0 m from a 1996 dispenser. The effect of the 1997 dispenser on trap catch was more pronounced than with the 1996 dispenser. Moth catch was significantly lower at 0.15 m than at all other distances (0.3 - 2.0 m); and moth catch was significantly lower at 0.3 m than from 0.6 to 2.0 m. The effect of dispenser age on moth catch across all dispenser - trap distances was only significantly different at 0.15 m ($F = 12.2$; df = 1, 16; $P < 0.01$).

Traps baited with either 1996 or 1997 dispensers caught moths, mean catch (±SE) per trap per day was 1.52 (0.47) and 0.72 (0.20), respectively. However, moth catch did not differ significantly between dispenser type ($F = 2.5$; df = 1, 16; $P = 0.13$).

Table 4

Mean (±SE) daily moth capture in wing-style sticky traps baited with a red septa loaded with 10 mg codlemone placed in an apple orchard treated with Isomate-C+ dispensers (1,000 per ha) in both 1996 and 1997. The test was conducted from 21 to 23 June and 28 June to 4 July, 1997.

Avg. distance (m) between trap and dispensers	Moth capture per trap per day	
	1996 Dispensers	1997 Dispensers
0.15	5.34 (0.66)aA	2.30 (0.57)aB
0.30	5.89 (0.90)abA	6.11 (1.01)bA
0.60	6.37 (0.57)abA	8.68 (0.96)cA
1.0	7.82 (0.64)bcA	8.50 (0.73)cA
2.0	9.22 (1.01)cA	9.22 (0.73)cA

Column means followed by different lower case letters and row means followed by different upper case letters are significantly different, P < 0.05, Fisher's LSD.

Table 5

Summary of mean (±SE) tree, trap, and dispenser heights (m) and distance (m) between trap and dispensers, and percentages of traps at varying distances from dispensers for the Lake Osoyoos codling moth areawide project from 1995 to 1997.

	1995	1996	1997
No. of traps	114	167	152
Tree height (m)	3.31 (0.04)a	3.26 (0.05)a	3.25 (0.05)a
Dispenser height (m)	2.88 (0.07)a	2.94 (0.05)a	2.94 (0.05)a
Trap height (m)	2.68 (0.03)a	2.46 (0.04)b	2.89 (0.03)c
Trap - dispenser distance (m)	N.A.	1.72 (0.09)b	0.93 (0.08)a
% traps at each distance class (m) from dispensers			
≤ 0.15	-	2.4	10.5
>0.15 < 0.30	-	6.7	20.4
> 0.30 < 1.00	-	8.4	18.4
> 1.00 < 2.00	-	9.6	21.7
> 2.00	-	72.9	28.9

Means within rows followed by different letters are significantly different, $P < 0.05$, Fisher's LSD.

Lake Osoyoos Areawide Program. Dispenser height and the height of the tree where dispensers were hung did not vary during the 3 years of the Lake Osoyoos areawide project (dispenser height: $F = 0.47$; df = 2, 430; $P = 0.62$; tree height: $F = 0.421$; df = 2, 430; $P = 0.67$). On average, dispensers were placed 0.31 to 0.42 m below the tops of the tree canopy (Table 5). However, trap height varied significantly each year during the 3-year project ($F = 52.39$; df = 2, 430; $P < 0.0001$). Traps were placed on average the highest in 1997 (Table 5). The mean distance between traps and dispensers varied from 1996 to 1997 ($t = 5.92$, df = 317, $P < 0.01$). In association with the higher trap height in 1997 versus 1996, the mean distance between traps and dispensers decreased 0.8 m (Table 5). The percentage of traps placed ≤ 0.3 m from dispensers increased from 9.1 to 30.9% from 1996 to 1997.

DISCUSSION

A prerequisite in using codlemone-baited traps to establish action thresholds for codling moth is the standardization of all facets of trap use. Factors that have been well studied include trap and dispenser maintenance and trap placement in the canopy (Riedl *et al.* 1986). Our data show that the proximity of mating disruption dispensers and traps is another significant factor affecting moth catch. Our data demonstrate that placing monitoring traps too close to dispensers, even year-old dispensers, can reduce moth catches. This effect could reduce the effectiveness of traps in detecting populations and predicting crop damage at harvest. Our evaluation of trap and dispenser positioning in growers' orchards showed that the performance of a significant percentage of these traps was likely affected by this factor (Table 5).

Guidelines for placement of traps and dispensers for codling moth in sex pheromone-treated orchards has evolved over the past 25 years. Early studies in Europe and Australia placed both dispensers and traps at a mid-canopy height (Charmillot 1990; Vickers and Rothschild 1991). Weissling and Knight (1995) showed that mating disruption of tethered codling moths was improved when Isomate-C dispensers were placed < 1.0 m from the top of the canopy instead of in mid-canopy. Since 1991, most researchers in the United States testing mating disruption products for codling moth have placed dispensers in the upper third of the canopy while traps were placed at mid-canopy (1.5 - 2.0 m height) (Barnes *et al.* 1992; Pfeiffer *et al.* 1993; Knight 1995b; Trimble 1995; Judd *et al.* 1997). Recent guidelines, however, have recommended that traps be placed, similarly to dispensers, in the upper portion of the canopy to better track codling moth's phenology and to improve detection of local infestations (Barrett 1995; Gut and Brunner 1996). This evolution in the placement of traps and dispensers was reflected in the Lake Osoyoos areawide program from 1995 to 1997 (Table 5). Clearly, placing traps and dispensers at a similar height in the canopy minimizes their separation and increases the likelihood for interference. In addition, the number of sites available in the canopy decreases with increased placement height in pyramidal-shaped canopies.

It is remarkable that the mean distance between traps and dispensers was < 1.0 m in the Lake Osoyoos project in 1997 considering that the recommended rate for Isomate C+ dispensers is only 500 - 1,000 per ha or 1 - 2 dispensers per tree in a typical orchard. The architecture of the pruned apple tree may create only a small number of points in the canopy suitable for hanging traps and dispensers. Traps and dispensers are commonly fastened to plastic clips and are attached to unobscured branches in the canopy with a 1.0 to 2.0 cm diameter branch radiating out from the main trunk at 45 - 135°. The number of these available sites in the canopy has not been measured, however, it is not uncommon to observe dispensers applied over a 2 - 5 year time period to be clipped to the same branch in the canopy (unpubl. data). However, because the competitive interaction between traps and dispensers occurs only within a short distance (≤ 0.3 m), adequate space exists in the canopy of apple orchards, including young or dwarf, high density plantings, to avoid competition between traps and dispensers.

Improvements in the stability and longevity of the newer Isomate-C+ dispenser (Table 2) compared with the original Isomate-C dispenser (McDonough *et al.* 1992) makes the problem of trap - dispenser competition more acute. For example, the effect on trap performance of leaving the year-old 1996 dispensers in the canopy during experiment 1 appeared to counteract the importance of trap height (Table 1). While, year-old dispensers contained a lower percentage of the EE8,10-12:OH isomer and had only 20-25% of the emission rate of the 1997 dispensers (Table 2), yet remained attractive and competed with traps when they were placed $\leq$ 0.15 m apart (Table 4). The influence of these year-old dispensers on mating disruption of codling moth is unclear. Yet, these findings suggest that growers using the Isomate-C+ dispenser for at least two consecutive years have double the number of active dispensers per area releasing pheromone during the first codling moth flight and probably an elevated concentration of codlemone in the orchard environment. We would expect these factors (increase in point source density and atmospheric concentration) to result in higher levels of mating disruption of codling moth in these orchards than in orchards treated for only one year with Isomate-C+ dispensers.

However, the amount of sex pheromone remaining in Isomate-C+ dispensers and the additional level of mating disruption achieved in the following year after their application depends on the accumulation of heat units accumulated during the growing season and the subsequent fall and winter months. For example, daily temperatures in eastern Washington in 1998 were much warmer than in either 1996 or 1997 and Isomate-C+ dispensers in October contained < 10 mg of residual pheromone compared with 30 - 40 mg of pheromone in the two previous years (G. Thayer, personal communication). Therefore, it is likely that the 1998 dispensers provided only a minor contribution to mating disruption in the 1999 season. Nevertheless, the development of recommendations for dispenser density and emission rates for the Isomate-C+ dispenser needs to consider the residual contribution of year-old dispensers.

ACKNOWLEDGEMENTS

We would like to thank John Turner and Kathi Johnson (U.S.D.A., Wapato, WA) for their help in setting up the field studies and Cheryl Beck (U.S.D.A., Wapato, WA) for the analysis of the 1996 dispensers. We also acknowledge the helpful comments of Holly Ferguson (U.S.D.A., Wapato, WA), Bruce Barrett (Univ. Missouri, Columbia, MO), Larry Gut (Michigan State Univ., E. Lansing, MI), and Steve Welter (Univ. California, Berkeley, CA) on an earlier draft. The cooperation of Pedro Garza (Manzana Orchards, Moxee, WA) is greatly appreciated. This project was partially funded by the Washington Tree Fruit Research Commission.

REFERENCES

Ahmad, T. R. and Z. A. Al-Gharbawi. 1986. Effects of pheromone trap design and placement on catches of codling moth males. Journal of Applied Entomology 102: 52-57.

Barnes, M. M., J. G. Millar, P. A. Kirsch, and D. C. Hawks. 1992. Codling moth (Lepidoptera: Tortricidae) control by dissemination of synthetic female sex pheromone. Journal of Economic Entomology 85: 1274-1277.

Barrett, B. A. 1995. Effect of synthetic pheromone permeation on captures of male codling moth: (Lepidoptera: Tortricidae) in pheromone and virgin female moth-baited traps at different tree heights in small orchard blocks. Environmental Entomology 24: 1201-1206.

Beers, E. H. and J. F. Brunner. 1992. Implementation of the codling moth phenology model on apples in Washington State, USA. Acta Phytopathologica et Entomologica Hungarica 27: 97-102.

Borden, A. D. 1931. Some field observations on codling moth behavior. Journal of Economic Entomology 24: 1137-1145.

Butt, B. A., T. P. McGovern, M. Beroza, and D. O. Hathaway. 1974. Codling moth: cage and field evaluations of traps baited with a synthetic sex attractant. Journal of Applied Entomology 67: 37-40.

Charmillot, P. J. 1990. Mating disruption technique to control codling moth in western Switzerland. pp. 165-182. In: R. L. Ridgway, R. M. Silverstein, and M. N. Inscoe (Eds.), Behavior-modifying chemicals for insect management. Marcel Dekker, New York.

Gut, L. J., and J. F. Brunner. 1996. Implementing codling moth mating disruption in Washington pome fruit orchards. Washington State University - Tree Fruit Research Extension Center Information Series, No. 1, Wenatchee.

Hintze, J. L. 1987. Number cruncher statistical system. V. 5.01. Kaysville, UT. 286 pp.

Howell, J. F., R. S. Schmidt, D. R. Horton, S. U. K. Khattak, and L. D. White. 1990. Codling moth: Male moth activity in response to pheromone lures and pheromone-baited traps at different elevations within and between trees. Environmental Entomology 19: 573-577.

Judd, G. J. R., M. G. T. Gardiner, and D. Thomson. 1996. Commercial trials of pheromone-mediated mating disruption with Isomate-C to control codling moth in British Columbia apple and pear orchards. Journal of the Entomological Society of British Columbia 93: 23-34.

Judd, G. J. R., M. G. T. Gardiner, and D. R. Thomson., 1997. Control of codling moth in organically-managed apple orchards by combining pheromone-mediated mating disruption, post-harvest fruit removal and tree banding. Entomologia Experimentalis et Applicata 83: 137-146.

Kehat, M., L. Anshelevich, E. Dunkelblum, P. Fraishtat, and S. Greenberg 1994. Sex pheromone traps for monitoring the codling moth: effect of dispenser type, field aging of dispenser, pheromone dose and type of trap on male captures. Entomologia Experimentalis et Applicata 70: 55-62.

Knight, A. L. 1995a. Evaluating pheromone emission rate and blend in disrupting sexual communication of codling moth (Lepidoptera: Tortricidae). Environmental Entomology 24: 1396-1403.

Knight, A. 1995b. The impact of codling moth (Lepidoptera: Tortricidae) mating disruption on apple pest management in Yakima Valley, Washington. Journal of the Entomological Society of British Columbia 92: 29-38.

Knodel, J. J. and A. M. Agnello. 1990. Field comparison of nonsticky and sticky pheromone traps for monitoring fruit pests in western New York. Journal of Economic Entomology 83: 197-204.

Madsen, H. S., A. C. Myburgh, D. J. Rust, and I. P. Bosman 1974. Codling Moth (Lepidoptera: Olethreutidae): Correlation of male sex attractant trap captures and injured fruit in South African apple and pear orchards. Phytophylactica 6: 185-88.

Madsen, H. F. and J. M. Vakenti 1972. Codling moths: Female-baited and synthetic pheromone traps as population indicators. Environmental Entomology 1: 554-557.

Maitlen, J. C., L. M. McDonough, H. R. Moffitt, and D. A. George 1976. Codling moth sex pheromone: Baits for mass trapping and population survey. Environmental Entomology 5: 199-202

Mani, E., T. Wildbolz, and W. Riggenbach. 1995. Effect of pheromone trap position in large and small tree and in the open field on the catch of codling moth, *Cydia pomonella,* males. Bulletin de la Société Entomologique Suisse. 68: 69-78.

McDonough, L. M., W. C. Aller, and A. L. Knight. 1992. Performance characteristics of a commercial controlled-release dispenser of sex pheromone for control of codling moth (*Cydia pomonella*) by mating disruption. Journal of Chemical Ecology 18: 2177-2189.

McNally, P. S. and M. M. Barnes. 1981. Effects of codling moth pheromone trap placement, orientation, and density on trap catches. Environmental Entomology 10: 22-26.

Pfeiffer, D. G., W. Kaakeh, J. C. Killian, M. W. Lachance, and P. Kirsch. 1993. Mating disruption for control of damage by codling moth in Virginia apple orchards. Entomologia Experimentalis et Applicata 67: 57-64.

Riedl, H. And B. A. Croft. 1974. A study of pheromone trap catches in relation to codling moth damage. The Canadian Entomologist 106: 525-537.

Riedl, H., B. A. Croft, and A. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological time models. The Canadian Entomologist 108: 449-460.

Riedl, H., S. A. Hoying, W. W. Barnett, and J. E. DeTar. 1979. Relationship of within-tree placement of the pheromone trap to codling moth catches. Environmental Entomology 8: 765-769.

Riedl, H., J. F. Howell, P. S. McNally, and P. H. Westigard. 1986. Codling moth management: use and standardization of pheromone trapping systems. University of California Division of Agricultural and Natural Resources. Bulletin 1918, Oakland.

Roelofs, W., A. Comeau, A. Hill, and G. Milicevic. 1971. Sex attractant of the codling moth: characterization with electroantennogram technique. Science 174: 297-299.

Trimble, R. M. 1995. Mating disruption for controlling the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), in organic apple production in southwestern Ontario. The Canadian Entomologist 127: 493-505.

Vickers, R.A. and G. H. L. Rothschild. 1991. Use of sex pheromone for control of codling moth pp. 339-354. In: L. P. S. Van der Geest and H. H. Evenhuis (Eds.), Tortricid pests. Elsevier, Amsterdam.

Vincent, C., M. Mailloux, E. A. C. Hagley, W. H. Reissig, W. M. Coli, and T. A. Hosmer 1990. Monitoring the codling moth (Lepidoptera: Olethreutidae) and the obliquebanded leafroller (Lepidoptera: Tortricidae) with sticky and nonsticky traps. Journal of Economic Entomology 83: 434-440.

Weissling, T. J. and A. L. Knight. 1995. Vertical distribution of codling moth adults in pheromone-treated and untreated plots. Entomologia Experimentalis et Applicata 77: 271-275.

Westigard, P . H. and K. L. Graves 1976. Evaluation of pheromone baited traps in a pest management program on pears for codling moth control. The Canadian Entomologist 108: 379-382.