Managing Codling Moth (Lepidoptera: Tortricidae) with an Internal Grid of Either Aerosol Puffers or Dispenser Clusters Plus Border Applications of Individual Dispensers

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ABSTRACT

Field trials run from 2001 to 2003 evaluated the effectiveness of a combination of hand-applied sex pheromone dispensers (Isomate-C) applied on the perimeter of apple orchards with an internal grid of either pressurized aerosol emitters (puffers) or clusters of dispensers for control of codling moth, *Cydia pomonella* (L.). Puffers were placed in a grid at 1 per ha, while the dispenser clusters were applied at 4 - 8 per ha. Puffers were programmed to release either 240 or 360 mg (*E*, *E*)-8-10-dodecadienol (codlemone) per day in 48 puffs (every 15 min from 1500 – 0300 h). Dispensers were grouped in clusters of 50 (Isomate-C TT) or 100 (Isomate-C PLUS) releasing 56 and 33 mg codlemone per d, respectively. No significant differences were found in levels of fruit injury in puffer-treated orchards paired with similar orchards treated with 500 Isomate-C PLUS individually applied dispensers per ha. Similarly no significant differences in fruit injury were found in orchards treated with individually applied dispensers versus orchards treated with Isomate-C PLUS dispensers (100 per cluster) placed in screened cages or Isomate-C TT dispensers (50 per cluster) hung from plastic disks. Levels of fruit injury, however, were significantly higher in orchards treated with Isomate-C PLUS dispensers (100 per cluster) hung from plastic disks versus in orchards treated with individually applied dispensers. This later poor performance of the Isomate-C PLUS clusters was associated with its more restricted spacing of dispensers within the cluster and a significant reduction in the weight loss of dispensers compared with dispensers applied individually. These studies suggest that the use of puffers can effectively lower the cost of codling moth management through reductions in sex pheromone puff volume and emitter density.

Key Words: mating disruption, sex pheremones, puffers, apple

INTRODUCTION

Since 1990, uniformly distributed hand-applied dispensers loaded with (*E*, *E*)-8-10-dodecadienol (codlemone) have been the most commonly used approach to disrupt mating of codling moth, *Cydia pomonella* (L.) in North American tree fruit and nut crops (Thomson *et al.* 2000). Major problems associated with the use of hand-applied dispensers have been maintaining the chemical stability of codlemone (Brown *et al.* 1992; Millar 1995), seasonal variability in emission rates primarily due to changes in temperature (Howell 1992; Knight 1995a), material cost (Alway 1997), and the labor cost of applying hundreds of dispensers per hectare (Knight 1995b; Williamson *et al.* 1996). High emission, timer-activated mechanical aerosol dispensers (puffers) have been suggested as an alternative that can solve some of these problems (Mafra-Neto and Baker 1996; Shorey *et al.* 1996; Isaacs *et al.* 1999). Puffers are used at a low density, can protect sex pheromones from UV degradation and oxidation, allow the application of a consistent pheromone release rate

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throughout the season, and allow users to adjust the cycle and periodicity of sex pheromone release (Shorey *et al.* 1996).

Shorey and coworkers postulated that effective mating disruption depended on the concentration of sex pheromone released per area and was not significantly affected by the spacing between individual point sources (Farkas *et al.* 1974; Shorey *et al.* 1996; Shorey and Gerber 1996a, b, c). They showed that the distance between pheromone sources could be quite large. For example, a perimeter application of emitters 100 m apart effectively disrupted *Platynota stultana* (Walsingham) and *Spodoptera exigua* (Hübner) mating (Shorey *et al.* 1996).

Puffers were initially evaluated for codling moth in walnuts where tree height and large canopy size had precluded the adoption of hand-applied dispensers (Shorey and Gerber 1996b). A single orchard was treated with 2.3 puffers per ha with units spaced 40 m apart along its perimeter. Puffers were programmed to release approximately 5.0 mg codlemone per puff every 30 min (254 mg/ha per d). Moth catches in traps baited with synthetic lures and virgin females were reduced 95 and 98% in this orchard versus in traps placed in an untreated orchard (Shorey and Gerber 1996b). The current standard protocol for codling moth control with puffers recommends the use of 2.5 – 5.0 puffers per ha arranged primarily around the perimeter of orchards. However, in large blocks (> 16 ha) a few puffers are placed along the upwind interior of the orchards (Elkins 2002).

Four major problems have occurred with the use of puffers for management of codling moth. First, placement of puffers on the perimeter of orchards has not been effective in preventing injury along the upwind edges of the orchards (Shorey *et al.* 1998). Greater wind speed and turbulence plus higher moth population density along orchard borders are problematic with this approach (Milli *et al.* 1997). A second problem has been their high cost. The fixed cost of individual cabinets housing the electronics ($40 amortized over 5 y) plus the yearly cost of the disposable pheromone-loaded canisters ($80) often limits the number of units deployed. Hand-applied dispensers in Washington State are typically applied at rates of 500 per ha and cost $125 per ha (Alway 1997). To be cost competitive puffer density should be 1.5 – 2.0 units per ha. A third problem has been the loss of units during the season due to wind, vandalism, and a variety of mechanical malfunctions. The unreliable performance of puffers has required expensive maintenance and frequent monitoring of units (Knight 2002). A fourth problem has been the occurrence of severe marking of fruit and foliar phytotoxicity surrounding units due to incidental contact with the sex pheromone solution (Giroux and Miller 2001).

An alternative approach was developed that alleviates some of these constraints (Knight 2002). Orchards are treated with an internal grid of puffers spaced 50 m from the border and 100 m apart (one puffer per ha) in combination with a perimeter application of hand-applied dispensers (1,000 per ha). This design was tested in apple orchards for codling moth alone or codling moth and obliquebanded leafroller, *Choristoneura rosaceana* (Harris), using canisters loaded with the sex pheromone of both species (Knight 2002). This method provided good control of both pests at a lower cost per ha than the use of uniformly distributed hand applied dispensers. However, these studies were only conducted in large, regular-shaped orchards with flat terrain and have not sufficiently addressed the utility of this approach in smaller, irregular-shaped orchards with sloping topography (Knight 2002). The initial success of this approach also suggests that lower puffer volumes of sex pheromone should be evaluated. Unfortunately, problems with the reliability of the puffer units and phytotoxic effects persisted in this study and grower adoption has been slowed by these problems. An alternative design has been proposed that would replace the mechanical puffers with clusters of hand-applied dispensers to generate high emission point sources (Knight 2002).

Herein, I report results from field evaluations conducted in apple from 2001-03 using grids of both puffers and clusters of dispensers to manage codling moth. Studies were conducted with puffers emitting two rates of sex pheromone and with four types of clusters that varied in dispenser density, dispenser type, and dispenser spacing within the cluster. Results demonstrate that an internal grid of widely spaced emitters can be effectively used as part of an integrated management approach for codling moth and can further reduce the costs associated with using sex pheromones.

MATERIALS AND METHODS

Studies were conducted in 20 – 60 apple orchards of several cultivars (primarily 'Delicious', 'Fuji' and 'Granny Smith') near Brewster, WA each year from 2001-03. All orchards evaluated in 2001 were 16 ha with level terrain. Orchards in 2002-03 varied in size from 4.0 – 16.0 ha and very often were irregular in shape with a moderately sloping terrain (3.0 – 6.0^{o} slope).

Field trials were conducted to evaluate the effectiveness of a combination of hand-applied sex pheromone dispensers (Isomate-C PLUS, Pacific Biocontrol, Vancouver, WA) applied on the perimeter of apple orchards with an internal grid of either pressurized aerosol emitters (puffers) or clusters of hand-applied dispensers (Isomate C Plus and Isomate C TT, Pacific Biocontrol, Vancouver, WA). Puffer cabinets (Paramount Puffer®, Paramount Farming, Bakersville, CA) were spaced in an internal 100 x 100 m grid (1 per ha) beginning 50 m from the edges of the orchard. Orchards treated with clusters of dispensers received four clusters of dispensers per ha spaced in an internal 50 x 50 m grid, except for five orchards in 2003 that were treated with eight clusters of dispensers per ha spaced 35 x 35 m apart. Cluster grids were spaced beginning 25 m from the edge of the orchard. The perimeter of these orchards was also treated with a 10-20 m wide band of hand-applied Isomate-C PLUS dispensers at a rate of 1,000 dispensers per ha.

Puffers were evaluated in 2001 and 2002 in 22 orchards. The cabinet of puffers is constructed of high-density polyethylene plastic (32 x 15 x 12 cm) and powered by four 'AA' batteries. Puffer operation was controlled by a remote controller and puffers operated only at temperatures > 10 ^{o}C. Cabinets were mounted on wood blocks and attached with a metal clip to trees in the upper third of the canopy. Puffer canisters are pressurized metal cylinders loaded with either a 25.0% or a 16.7% solution of codlemone plus solvents and propellants. Canisters emit a 30 mg spray through a solenoid-metered valve every 15 min from 1500 – 0300 h. Studies were conducted in 2001 with puffers emitting either a 7.5 or 5.0 mg A.I. dose (codlemone). Studies in 2002 tested only the 5.0 mg dose.

The effectiveness of using clusters of Isomate-C dispensers was evaluated in 39 orchards from 2001-03. Two different polyethylene Isomate-C dispensers were used in clusters, Isomate-C PLUS and Isomate-C TT. Both dispensers are loaded with a 60:33:7 blend of (*E*, *E*)-8-10-dodecadien-1-ol, dodecanol, and tetradecanol. Isomate-C PLUS and Isomate-C TT dispensers were loaded with 182.3 and 382.4 mg active ingredients, respectively. Only Isomate-C PLUS dispensers were used in 2001 and they were clustered in square, screened boxes (19.0 x 19.0 x 21.0 cm). One hundred dispensers were placed vertically in the screened boxes in alternating cells and were spaced on average (SE) 2.4 (0.1) cm apart. The screened sides of the box had a 0.41 cm^2 mesh and the ends of the box were constructed with a 0.10 cm^2 screen to prevent dispensers from falling out. Plastic bucket lids (21.7 cm diameter) were used to hold clusters of dispensers during 2002-03. The plastic lids had either 100 slits (0.15 x 0.7 cm) or 50 0.48 cm-diameter holes cut in the lids for Isomate-C PLUS or Isomate-C TT dispensers, respectively. One end of each dispenser was inserted vertically into the plastic lid. The mean (SE) spacing of Isomate-C PLUS and Isomate-C TT dispensers hanging from the lid was 1.3 (0.2) cm and 3.0 (0.2) cm, respectively. Studies were conducted with Isomate-C PLUS in 13 orchards in 2002 and with Isomate-C TT in 11 and 10 orchards in 2002 and 2003, respectively. During 2003 five orchards each were treated with four or eight clusters per ha. The screened boxes and plastic lids were attached to poles with wire hangers. Clusters of dispensers were placed in the upper third of the canopy.

Comparison orchards (controls) were selected each year and paired with orchards treated with puffers or dispenser clusters. Orchard pairs were selected based on similarity in size, proximity, cultivar, ownership, spray practices and pest pressure (based on percent fruit injury the previous year). All comparison orchards were treated with Isomate-C PLUS dispensers applied at a rate of 500 dispensers per ha.

Pheromone lure-baited delta-shaped traps were deployed in all orchards at a density of 1 per 2 ha placed around the perimeter of each orchard 10 m from the edge. Orchards treated with dispenser clusters in 2001 and 2003 plus the associated comparison orchards were also monitored with two (2001) or three (2003) pear ester-baited traps placed 50 m from the edge of orchards and >100 m from the nearest trap. Pear ester lures were used in these two studies to provide a second measure of moth population density that would be more independent of the sex pheromone treatment. Trécé Inc. (Adair, OK) provided all monitoring traps and lures. Traps were placed in the upper third of the orchards' canopy using a permanent PVC pole. Sex pheromone-baited traps were checked weekly and pear ester-baited traps were checked every 4 wk. Lures were replaced after 8 wk and removable sticky trap liners were replaced as needed.

Pre-harvest fruit injury was assessed by sampling 30 fruit from 20 trees selected within each quadrant of each orchard (2,400 fruit sampled per orchard). An equal number of fruit were sampled from the interior and from the edge (< 30 m from the perimeter) of each quadrant. Spray records were obtained from the growers and field managers at the end of each season.

The weight loss of each dispenser type for dispensers applied individually or within a cluster was analyzed in 2002. Six new dispensers of each type were weighed on 29 April. Isomate-C Plus dispensers were then twisted on to a plastic clip and attached to branches in a pear orchard. Isomate-C TT dispensers were placed over branches in the same orchard. Five new dispensers were randomly selected from the outer rim and five from the center of four clusters and were weighed. Clusters were hung individually in pear trees spaced 10 m apart. All dispensers were reweighed on 25 September.

Statistical analysis. Mean moth catch per trap, number of insecticide sprays applied for codling moth, and percent fruit injury in orchards treated with uniformly distributed individual dispensers versus grids of puffers or dispenser clusters were analyzed with the Wilcoxon Rank Sum test (Analytical Software 2000). The mean daily weight loss for dispensers applied individually or placed in the middle or outer rim of clusters in 2002 was analyzed for each dispenser type with a Kruskal-Wallis test (Analytical Software 2000).

RESULTS

No significant differences were found for mean moth catch, number of insecticide sprays applied, and codling moth fruit injury between puffer-treated and individually applied dispenser-treated orchards at either puffer emission rate (Table 1). Ap-

Table 1.

Summary data for paired apple orchards treated with either an internal grid of one aerosol puffer per ha plus a perimeter treatment of Isomate-C PLUS dispensers or 500 Isomate-C PLUS dispensers per ha. Puffers released either 5.0 or 7.5 mg sex pheromone per puff. No significant differences were found in moth catch, number of insecticide sprays applied, and percent fruit injury between the paired puffer and Isomate-treated orchards, Wilcoxin Signed Rank tests, two-tailed *P*-value > 0.05.

Puff-size (mg)	Year (no. orchards)	Mean (SE) moth catch per trap		Mean (SE) no. sprays		Mean (SE) % fruit injury	
		Puffers	Dispensers	Puffers	Dispensers	Puffers	Dispensers
7.5	2001 (10)	1.5 (0.8)	2.5 (1.1)	0.8 (0.2)	0.9 (0.2)	0.22 (0.15)	0.20 (0.12)
5.0	2001 (5)	4.3 (1.8)	5.7 (2.1)	1.3 (0.4)	2.4 (0.6)	0.20 (0.13)	0.54 (0.20)
5.0	2002 (7)	6.9 (1.9)	7.8 (3.6)	1.5 (0.4)	1.4 (0.4)	0.12 (0.03)	0.08 (0.07)
5.0	All (12)	5.8 (1.5)	6.9 (3.0)	1.4 (0.2)	1.8 (0.3)	0.15 (0.06)	0.27 (0.11)

ple orchards had low codling moth population densities as evidenced by low cumulative moth catches in sex pheromone-baited traps (< 10 moths per season) (Table 1). Growers supplemented their use of puffers and dispensers with 1 – 3 insecticide sprays per season. Insecticides applied for codling moth included azinphosmethyl, phosmet, and methoxyfenozide. Nearly half of all sprays were applied only to the borders of orchards.

Orchards treated with clusters of dispensers had similar moth catches and supplemental insecticide sprays applied as orchards treated with individual dispensers during all three years (Table 2). Codling moth fruit injury in orchards treated with individually applied dispensers paired with orchards treated with either screened box clusters with Isomate-C Plus or plastic lid clusters of Isomate-C TT dispensers were not significantly different in any of the three years (Table 2). However, fruit injury was significantly higher during 2002 in orchards treated with plastic lid clusters of Isomate-C Plus dispensers than in the paired orchards treated with individually applied dispensers (Table 2). During 2003, orchards treated with 4.0 and 8.0 clusters per ha loaded with Isomate-C TT dispensers had similar levels of codling moth injury as orchards treated with 500 or 1,000 dispensers per ha, respectively (Table 2)

The mean weight loss of dispensers within plastic lid clusters versus those individually applied varied between dispenser type (Table 3). No difference was found in the mean weight loss of Isomate-C TT dispensers placed in clusters versus dispensers applied individually. The mean daily emission rate of codlemone from these clusters during the season averaged 55.6 mg. In comparison, Isomate-C Plus dispensers in both the center and edge of clusters loss significantly less weight during the season than dispensers applied individually (Table 3). The mean daily emission rate of codlemone from these clusters averaged only 32.7 mg during the season.

DISCUSSION

These studies show that treating orchards with a high-density application of dispensers on the perimeter and a widely spaced grid of high emission emitters internally can be substituted for the application of hundreds of individually applied dispensers to manage codling moth in apple. The use of either pressurized canisters releasing puffs of sex pheromone every 15 min or the continuous passive diffusion of

Table 2.
Summary data for paired apple orchards treated with either an internal grid of clusters of Isomate-C dispensers at 4.0 or 8.0 clusters per ha plus a perimeter treatment of Isomate-C PLUS dispensers or treated with 500 – 1,000 Isomate-C PLUS dispensers per ha. Clusters were baited with either 100 Isomate-C PLUS or 50 Isomate-C TT dispensers.[1]

Treatment per ha[2] (# paired orchards)	Mean (SE) moth catch per trap		Mean (SE) no. cover sprays	Mean (SE) % fruit injury
	Sex pheromone	Kairomone		
2001				
4 C-Plus box clusters (5)	2.6 (0.9)	3.0 (1.0)	0.8 (0.2)	0.00 (0.00)
500 C-Plus dispensers	2.8 (0.8)	3.4 (0.7)	1.0 (0.0)	0.12 (0.06)
2002				
4 C-TT lid clusters (11)	8.4 (2.7)	-	1.5 (0.5)	0.15 (0.08)
500 C-Plus dispensers	10.1 (3.6)	-	2.0 (0.5)	0.14 (0.06)
4 C-Plus lid clusters (13)	10.7 (2.9)	-	1.6 (0.4)	0.14 (0.06)**
500 C-Plus dispensers	6.5 (2.1)	-	1.8 (0.4)	0.05 (0.03)**
2003				
8 C-TT lid clusters (5)	2.4 (1.5)	8.8 (6.1)	1.8 (0.4)	0.20 (0.20)
1,000 C-Plus dispensers	1.2 (0.6)	2.2 (0.6)	1.8 (0.4)	0.00 (0.00)
4 C-TT lid clusters (5)	2.6 (1.6)	4.8 (1.9)	1.4 (0.6)	0.13 (0.10)
500 C-Plus dispensers	7.4 (5.9)	3.8 (2.6)	1.8 (0.4)	0.00 (0.00)

[1] '**' *P*-value < 0.01, two-tailed Wilcoxin Signed Rank test. All other statistical comparisons were not significant, $P > 0.05$.
[2] One hundred Isomate C-PLUS dispensers were placed in screened boxes in 2001 and attached to plastic lids in 2002. Fifty Isomate C-TT dispensers were attached to plastic lids in 2002-03.

Table 3.
Mean (SE) weight loss (mg per d) of dispensers aged in the field, 29 April - 25 September 2002[1]

Dispenser	Individual dispenser	Dispenser in the center of cluster	Dispenser on the outer rim of cluster	*P*-value
Isomate-C TT	1.74 (0.11)	1.84 (0.04)	1.87 (0.05)	*0.52*
Isomate-C PLUS	0.71 (0.08)a	0.56 (0.02)b	0.53 (0.02)b	*< 0.01*

[1] Row means followed by a different letter were significantly different, $P < 0.05$, Kruskal-Wallis one-way nonparametric analysis of variance using a chi-squared approximation.

sex pheromone from clusters of dispensers were both effective. Charmillot *et al.* (1995) used a perimeter-only application of sex pheromone dispensers to reduce injury from *Lobesia botrana* Denis & Schiffinmüller in vineyards, and they were the first to suggest a grid design. A similar approach for codling moth where dispensers are applied only to the perimeter of orchards has not been tested.

Most of the orchards treated with sex pheromones in these studies were also sprayed with insecticides for control of codling moth. Thus it is not possible to assess the effectiveness of the sex pheromone treatments alone. In general, sex pheromone is considered to be an important part of an integrated management program for codling moth, and can rarely be used as a single control tactic (Brunner *et al.* 2002). The latest survey of insecticide usage in Washington State reported that on average three to four sprays are applied for codling moth (National Agricultural Statistical Service 2002). Many orchards in the Brewster area have been treated with three to six insecticide applications in the past few years due to increased pest populations (A.L.K., unpublished data). Based on these data the use of sex pheromone in our study reduced insecticide use 40-60% compared with conventionally treated orchards.

Nearly half of all insecticides were applied only to the borders of orchards in our study. Codling moth injury most commonly occurs on the borders of orchards regardless of whether orchards are treated with hand-applied dispensers (Pfeiffer *et al.* 1993), treated with puffers placed on the perimeter (Elkins 2002), or treated only with insecticides (Madsen *et al.* 1975). Effective disruption of codling moth along border areas will remain problematic due to this area's reduced canopy structure and greater wind speed and turbulence that can reduce the sex pheromone concentration (Milli *et al.* 1997). Trimble and Vickers (2000) found that codling moth could be effectively managed over a three-year period in Ontario apple orchards with only border insecticide applications. The integration of border sprays with an internal grid of puffers/clusters may be an effective management alternative that has not yet been evaluated.

The internal grid design has several operational advantages over the standard hand application of hundreds of dispensers per hectare including cost savings and ease of use. Grouping the same number of dispensers into clusters reduced application costs up to 35% among growers that I surveyed. Yet, this savings for growers was minimal because application costs for hand-applied dispensers are low, $15 for 500 dispensers per ha (Knight 1995b). The application and servicing of puffers was not measured in this study but was reported earlier to be only $3 per puffer (Elkins 2002). The material cost of the puffer grid design was slightly less expensive than the use of reduced rates of hand-applied dispensers ($111 versus $125 per ha), except for the high fixed cost of the remote control ($350).

Further reductions in the cost of an effective management program using clusters of dispensers are unlikely. Clusters loaded with 100 Isomate-C Plus dispensers did not perform as well as the standard program and were estimated to release 30 mg codlemone per d. Clusters with 50 Isomate-C TT dispensers released 40% more codlemone per d than clusters of 100 Isomate-C PLUS and provided effective control. Further evaluation of clusters loaded with 30 – 50 Isomate-C TT dispensers might establish a minimum threshold needed with this design. However, the complex interplay of factors impacting the population dynamics of codling moth in commercial pheromone-treated orchards would likely obscure any marginal improvement in performance. Instead, additional cost savings can more likely be achieved by reducing the amount of sex pheromone loaded in puffers.

The amount of sex pheromone loaded in Paramount Puffers® used in Washington State orchards could be reduced 50% by lowering the pheromone puff from 7.5 to 5.0 mg and the longevity of the pheromone loading in the canister from 200 to 150 d. Unlike in California, the flight period of codling moth lasts approximately 150 d from late April to mid September in Washington State. Further refinements in the arrangement of puffers especially when supplemented with insecticides could further reduce the cost. Studies have shown that individual puffers can disrupt male codling moth orientation to traps placed 200 – 450 m downwind (Shorey and Gerber 1996b, Cave *et al.* 2001), and suggest that their density could be reduced to one per several hectares. Puffer densities could likely be reduced in large, contiguous plantings. For example, the density of puffers declined from 4.0 to 2.8 per ha as the size of an area wide pear project in Lake County, California increased from 100 to 531 ha over a five-year period (Elkins 2002).

Puffers have been demonstrated to be an effective tool to manage codling moth under a variety of deployments (Elkins 2002, Knight 2002). The use of dispenser clusters was developed as an alternative due to the unreliability of puffers (Knight 2002). Yet, the characteristics of dispensers currently limit the maximum emission rate of codlemone from clusters. Thus, increasing the emission rates from clusters or the density of clusters will also increase the cost of this approach. Puffers allow greater flexibility in adjusting the emission rate and timing of release. Improvements in the operation and reliability of puffers will enhance their adoption. The use of an internal grid design may allow the development of a lower cost, effective management program for codling moth to be developed.

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REFERENCES

Alway, T. 1997. Mating disruption use in Washington State: grower survey report. Areawide IPM Update 2: 1-3.

Analytical Software. 2000. Statistix 7. Tallahassee, FL.

Brown, D.E., A.L. Knight, J.F. Howell, C.R. Sell, J.L. Krysan, and M. Weiss. 1992. Emission characteristics of a polyethylene pheromone dispenser for mating disruption of codling moth (Lepidoptera: Tortricidae). Journal of Economic Entomology 85: 910-917.

Brunner, J., S. Welter, C. Calkins, R. Hilton, E. Beers, J. Dunley, T. Unruh, A. Knight, R. VanSteenwyk, and P. Van Buskirk. 2002. Mating disruption of codling moth: a perspective from the western United States. International Organization of Biological Control West Palaeartic Regional Section Bulletin 29: 11-21.

Cave, F., M. Singleton, and S. Welter. 2001. Area of influence of aerosol emitters: immediate and residual effects, pp. 145-146. *In* Proceedings, 75th Western Orchard Pest & Disease Management Conference, 10-12 January 2001, Portland, OR. Oregon State University, Corvallis, OR.

Charmillot, P.J., D. Pasquier, N.J. Alipaz, and U. Neumann. 1995. Effet d'une ceinture de diffuseurs à attractif sexuel sur la distribution des captures de mâles, des accouplements de femelles attachées et de l'attaque de *Lobesia botrana* Den. & Schiff. en Vignoble. Journal of Applied Entomology 119: 201-206.

Elkins, R. 2002. Areawide implementation of mating disruption in pears using puffers. Pest Management Grant Final Report No. 00-0198S. California Department of Pesticide Regulation, Sacramento, CA.

Farkas, S.R., H.H. Shorey, and L.G. Gaston. 1974. Sex pheromones of Lepidoptera. The use of widely separated evaporators of Looplure for the disruption of pheromone communication in *Trichoplusia ni*. Environmental Entomology 3; 876-877.

Giroux, P.Y. and J.R. Miller. 2001. Phytotoxicity of pheromonal chemicals to fruit tree foliage: chemical and physiological characterization. Journal of Economic Entomology 94: 1170-1176.

Howell, J.F. 1992. Two years of commercial use of Isomate-C to disrupt mating for codling moth, pp. 176-181. *In* Proceedings 88th Washington State Horticultural Association, 7-9 December, 1992, Yakima, WA. Washington State Horticultural Association, Wenatchee, WA.

Isaacs, R., M. Ulczynski, B. Wright, L.J. Gut, and J.R. Miller. 1999. Performance of the microsprayer with application for pheromone-mediated control of insect pests. Journal of Economic Entomology 92: 1157-1164.

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

Knight, A.L. 2002. Development of aerosol devices for management of codling moth and leafrollers. International Organization of Biological Control West Palaeartic Regional Section Bulletin 25: 111-120.

Madsen, H.F., F.E. Peters, and J.M. Vakenti. 1975. Pest management: experience in six British Columbia apple orchards. The Canadian Entomologist 107: 873-877.

Mafra-Neto, A. and T.C. Baker. 1996. Timed, metered sprays of pheromone disrupt mating of *Cadra cautella* (Lepidoptera: Pyralidae). Journal of Agricultural Entomology 13: 149-168.

Millar, J.G. 1995. Degradation and stabilization of E8,E10-dodecadienol, the major component of the sex pheromone of the codling moth (Lepidoptera: Tortricidae). Journal of Economic Entomology 88: 1425-1432.

Milli, R., U.T. Koch, and J.J. de Kramer. 1997. EAG measurement of pheromone distribution in apple orchards treated for mating disruption of *Cydia pomonella*. Entomologia Experimentalis et Applicata 82: 289-297.

National Agricultural Statistical Service. 2002. Apple Chemical Use, Agricultural Chemical Use Survey, Washington State. http:www.nass.usda.gov/wa/chemuse/appchem.pdf.

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.

.H.Shorey, H.H. and R.G. Gerber. 1996a. Use of puffers for disruption of sex pheromone communication among navel orangeworm moths (Lepidoptera: Pyralidae) in almonds, pistachios, and walnuts. Environmental Entomology 25: 1154-1157.

Shorey, H.H. and R.G. Gerber. 1996b. Use of puffers for disruption of sex pheromone communication of codling moths (Lepidoptera: Tortricidae) in walnut orchards. Environmental Entomology 25: 1398-1400.

Shorey, H.H. and R.G. Gerber. 1996c. Disruption of pheromone communication through the use of puffers for control of beet armyworm (Lepidoptera: Noctuidae) in tomatoes. Environmental Entomology 25: 1401-1405.

Shorey, H.H., C.B. Sisk, and R.G. Gerber. 1996. Widely separated pheromone release sites for disruption of sex pheromone communication in two species of Lepidoptera. Environmental Entomology 25: 446-451.

Shorey, H., R. Gerber, and R. Elkins. 1998. Disruption of pheromone communication for control of codling moth in pears, pp. 23-36. *In* 1998 California Pear Research Reports. California Pear Advisory Board, Sacramento, CA.

Thomson, D., J. Brunner, L. Gut, G. Judd, and A. Knight. 2000. Ten years implementing codling moth mating disruption in the orchards of Washington and British Columbia. Starting right and managing for success. International Organization of Biological Control West Palaeartic Regional Section Bulletin 24 (2): 23-30.

Trimble, R.M. and P.M. Vickers. 2000. Evaluation of border sprays for managing the codling moth (Tortricidae: Lepidoptera) and the apple maggot (Tephritidae: Diptera) in Ontario apple orchards. Journal of Economic Entomology 93: 777-787.

Williamson, E.R., R.J. Folwell, A. Knight, and J.F. Howell. 1996. Economics of employing pheromones for mating disruption of the codling moth, *Carpocapsa pomonella*. Crop Protection 15: 473-477.