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ABSTRACT Field studies were conducted from 1992 to 1996 to select the most effective sex pheromone blend for mating disruption of the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), in tree fruit orchards in Washington. Dispensers loaded with a 2-component pheromone blend, (Z)-11-tetradecen-1-yl (Z11-14:OAc) and (*E*)-11-tetradecen-1-yl (E11-14:OAc), a 3-component blend that included the addition of (Z)-11-tetradecenal (Z11-14:Ald), and a 4-component blend also including (Z)-11-tetradecen-1-ol (Z11-14:OH) were compared within 0.1-ha orchard plots and 100-m^2 field cages. The addition of Z11-14:Ald to the 2 acetate components with or without Z11-14:OH did not improve mating or disruption of communication. No disruption occurred in field cages treated with E11-14:OAc alone or an 88:12 (%) E:Z 11-14:OAc blend. Management of *C. rosaceana* with mating disruption was evaluated for 2 yr in three 16-ha apple orchards by using a 94:6% Z:E11-14:OAc blend. Orchards were treated with 1,000 polyethylene tube dispensers per hectare emitting ≈0.9 mg of pheromone per day. Populations were also monitored in 3 similar 8-ha orchards treated only with insecticides. Catches of male moths in traps baited with synthetic lures and virgin females were significantly lower (92–99%) in pheromone-treated than in untreated orchards. Larval population densities and fruit injury did not differ between treatments. No significant differences were found in larval population densities, trap catch, or fruit injury between the 2-ha center and the outer 14-ha areas of the pheromone-treated orchards. Significant increases in catch by lure-baited traps and fruit injury occurred in the pheromone-treated orchards from the 1st to 2nd yr of the study. The pheromone treatment saved ≈$250/ha in insecticide costs over 2 yr.

KEY WORDS *Choristoneura rosaceana*, mating disruption, sex pheromone, apple

OBLIQUEBANDED LEAFROLLER, *Choristoneura rosaceana* (Harris), has been an important pest of apple orchards in the eastern United States since the 1970s (Reissig 1978), but has only recently become a problem in apple orchards in Washington (Beers et al. 1993), pear orchards in California (Barnett et al. 1991), and cherry orchards in Oregon (Long et al. 1997). New integrated management programs are needed to manage this pest in tree fruits. The use of *Bacillus thuringiensis* Berliner endotoxins for leafrollers has increased in Washington (Washington Department of Agriculture 1995). Mating disruption is another approach being developed to manage *C. rosaceana* in the western United States (Alway 1996).

Characterization of the sex pheromone of *C. rosaceana* has varied both temporally and spatially. The sex pheromone was first identified by Roelofs and Tette (1970) in New York as the single component (Z)-11-tetradecen-1-yl acetate (Z11-14OAc). Cardé et al. (1977) listed the sex pheromone as a 98:2 (%) blend of Z11-14:OAc and (*E*)-11-tetradecen-1-yl acetate (E11-14:OAc). Weatherston et al. (1976) found that the addition of (Z)-11-tetradecenal (Z11-14:Ald) to the acetate blend significantly increased moth catches in baited-traps in Ontario. Yet, Hill and Roelofs (1979) subsequently found no activity of Z11-14:Ald in a pheromone blend for populations in New York. Instead, they reported that the sex pheromone of *C. rosaceana* consisted of 3 components: Z11-14:OAc, E11-14:OAc, and (Z)-11-tetradecen-1-ol (Z11-14:OH). Vakenti et al. (1988) detected Z11-14:Ald in female tip extracts in a population of *C. rosaceana* from western Canada and showed its importance in enhancing the attractiveness of the 3-component blend. Thomson et al. (1991) found that inclusion of Z11-14:Ald in a 4-component blend enhanced moth catch compared with the 3-component blend for populations in British Columbia, but not for populations in Quebec. Several trapping studies with *C. rosaceana* in California, Oregon, and Washington have caught 5–10 times more moths with the pheromone blend of *Argyrotaenia citrana* Fernald that includes Z11-14:Ald (Hill et al. 1975) than with similar lures loaded with the eastern blend of *C. rosaceana* (A.L.K., unpublished data).

The experimental use of sex pheromones to disrupt *C. rosaceana* adult communication was first reported by Reissig et al. (1978) and more recently by Agnello et al. (1996) and Lawson et al. (1996) in New York.

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Table 1. Sex pheromone content and mean daily emission characteristics of dispensers used in small-plot, caged, and orchard trials from 1992–1996

Dispenser type	AI (SEM), mg	Sex pheromone blend, %	Mean emission rate (mg/d)
Membrane 1	88.3 (3.6)	96 Z11-14:OAc 4 E11-14:OAc	0.87[a]
Membrane 2	96.8 (2.1)	90 Z11-14:OAc 4 E11-14:OAc 6 Z11-14:Ald	0.97[a]
Membrane 3	101.4 (1.8)	94 Z11-14:OAc 4 E11-14:OAc 1 Z11-14:Ald 1 Z11-14:OH	1.10[a]
Membrane 4	84.5 (1.2)	100 E11-14:OAc	0.91[a]
Membrane 5	95.4 (2.6)	88 E11-14:OAc 12 Z11-14:OH	NA
Rope 1[b]	165.4 (2.1)	94 Z11-14:OAc 6 E11-14:OAc	0.87
Rope 2[b]	180.5 (2.2)	88 Z11-14:OAc 6 E11-14:OAc 6 Z11-14:Ald	1.01
Spiral 1[c]	180.0	94 Z11-14:OAc 6 E11-14:OAc	1.00
Spiral 2[c]	180.0	90 Z11-14:OAc 4 E11-14:OAc 6 Z11-14:Ald	1.00
Spiral 2b, 2c, 2d[d]	160.0	See footnote[d]	NA

[a] Dispensers were aged in an apple orchard from 18 August to 13 October 1994. Ten dispensers were analyzed on each date.

[b] Data from Knight (1996).

[c] Data from I. Weatherston, personal communication, and estimated from Fitzpatrick et al. (1995).

[d] Spirals 2b, 2c, and 2d were loaded with a 5:1, 2:1, and 1:1 ratio of Z11-14:OAc and Z11-14:Ald, respectively. The isomeric purity of Z11-14:OAc was ≈94%.

Deland et al. (1994) evaluated mating disruption of *C. rosaceana* in small apple blocks in British Columbia. Levels of disruption of *C. rosaceana* in these trials have been moderate, and the potential effectiveness of mating disruption for this pest species in western North America remains unclear for at least 3 reasons: (1) tests were conducted in either small plots (<0.2 ha) or small orchard blocks (2–4 ha); (2) tests all used either a 2-component pheromone blend (Z11-14:OAc: E11-14:OAc) or a 3-component blend (2 acetate components plus Z11-14:OH); and (3) no disruption trials in western North America have included Z11-14:Ald within the pheromone blend.

We report data from small-plot field trials to determine the most effective pheromone blend for mating disruption of *C. rosaceana* populations in Washington, and from a 2-yr large-scale evaluation of mating disruption in commercial apple orchards.

Materials and Methods

Small-plot Field Studies. Dispensers loaded with either 2 sex pheromone components (Z11-14:OAc and E11-14:OAc), 3-components (Z11-14:OAc, E11-14:OAc, and Z11-14:Ald), or 4 components (Z11-14:OAc, E11-14:OAc, Z11-14:Ald, and Z11-14:OH) were provided by 3 manufacturers. The average loading, pheromone blend, and emission rate of each dispenser are listed in Table 1. Rope dispensers (Pacific Biocontrol, Vancouver, WA) were 20-cm polyethylene-sealed tubes attached to an internal aluminum wire. Membrane dispensers (Consep, Bend, OR) consisted of a plastic barrier membrane (4 by 16 cm) with a 2.5-cm-diameter release area. Spiral dispensers (Ecogen, Billings, MT) were polyvinyl chloride tubes coiled into a 2-cm ring.

Residual pheromone content of new membrane dispensers and those aged in the field and collected every 14 d (n = 4) from 18 August to 13 October, 1994 were analyzed with gas chromatography. Dispensers were cut into 2-cm pieces and rinsed continuously with dichloromethane for 3 h. Samples were processed with a HP7673 automatic sampler and a Series II 5890 gas chromatograph by using a 60 m by 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/min, and a final temperature of 300°C for 10 min. Undecanol was used as the internal standard. Recovery rates for each pheromone component was >90%. Emission rates of the 2 rope dispensers were determined similarly and are reported in Knight (1996). The emission rates from spiral dispensers were not determined but were estimated to be ≈1.0 mg/d (Fitzpatrick et al. 1995).

Evaluation of pheromone blends were conducted in replicated (n = 5) plots (30 by 30 m) separated by 50 m within 2 apple orchards situated near Mattawa, WA. Trial 1 was conducted from 7 to 28 August 1992, and trial 2 from 8 June to 27 July 1993, and trial 3 was conducted in a cherry orchard situated near The Dalles, OR, from 26 May to 21 July 1993. In trials 1 and 2, both spiral and rope dispensers loaded with the 2- and 3-component blends were tested (Table 1). In trial 3, membrane dispensers loaded with the 2, 3, or 4 component blends were compared (Table 1). Untreated control plots were used in each trial. Apple orchard canopies averaged 2.5 m and dispensers were placed at 2 m. The cherry orchard canopy averaged 5.8 m and dispensers were placed at 4.0 m. All dispensers were tested at a rate of 1,000 dispensers per hectare. One wing style strap baited with a red septa (#3208-15870893, Trece, Salinas, CA), loaded with the 4-component western sex pheromone blend was placed in the center of each plot. Ten female-baited wing traps also were placed in each plot in the 1992 trials. Each female-baited trap was loaded with 2 virgin moths that had been collected <24 h old and stored at 5°C for 1–3 d from the laboratory colony. Moths were housed inside a screened PVC tube (5 cm o.d.) attached to the top inside of the trap. Moths were replaced weekly. Traps were evenly spaced within each plot and moths were placed >5 m from the edge. Mean weekly moth catch for each type of trap were transformed and subjected to analysis of variance (ANOVA). Separate analyses were conducted with each dispenser type in trials 1 and 2. Means were separated where significant differences occurred with the least significant difference (LSD) test (Hintze 1987).

Cage Experiments. Six cages (10 by 10 by 2.5 m) were used to measure the level of mating disruption with several pheromone treatments versus an untreated control. Cages were separated by at least 50 m of open ground. Each cage contained nine potted apple trees 2.5 m in height (a mix of 'Delicious' and 'Golden Delicious'). Trees were spaced 2.5 m apart in 3 rows. Nine dispensers (one on each tree at a height of 2.0 m) were placed in each cage in the pheromone treatments. Virgin female moths were tethered at a height of 1.5–2.0 m by tying a fine thread (25 cm) around 1 forewing and taping the end of the thread to a bamboo pole hung vertically from wires within each cage. Tethered females were situated within 0.5 m of foliage. Fifteen females were tethered per cage for each replicate. The same number of males (20–50) was added to each cage at the beginning of each test. Females were left in cages overnight and dissected the next day to determine their mating status. Approximately 15% of the females was either missing or partially eaten by spiders during these tests. Dispensers were removed from cages and treatments were rotated among cages after 48–72 h. Experiments with each of 3 types of dispensers loaded with 2–4-component blends and an untreated control were repeated 14 times between 14 July-23 September 1993. The 4th test compared membrane dispensers loaded either with E11-14:OAc or a 88:12 ratio of E:Z11-14:OAc versus an untreated control. The 5th test used spiral dispensers loaded with 160 mg of sex pheromone with 4 ratios of Z11-14:OAc and Z11-14:Ald: 15:1 (Spiral 2a), 5:1 (Spiral 2b), 2:1 (Spiral 2c), and 1:0 (Spiral 1). Moth catch data (sqrt [x + 0.05]) and the proportion of females mated (arcsin [sqrt(x)]) were transformed and subjected to ANOVA (Hintze 1987).

Orchard Trials. All orchards monitored in this study were within a contiguous 486-ha block situated near Brewster, WA, that was treated with the sex pheromone dispenser ISOMATE-C+ (Pacific Biocontrol, Vancouver, WA) for codling moth. During 1995 and 1996 three 16-ha orchards of 'Granny Smith' were treated with 1,000 Hamaki-con (Shin-Etsu, Tokyo) rope dispensers (Rope1) per hectare in late May prior to moth flight. Dispensers (lot #s LR73014 and TT52003) were loaded with 165 mg of 11-14:OAc (94:6% of Z:E isomers). These dispensers emit ≈0.9 mg/d of pheromone during a typical growing season in Washington (Knight 1996). Pheromone-treated orchards were subdivided into a central 2 ha and the surrounding 14-ha subplots. The outside edge of the central subplot was 135 m from the outside edge of the entire orchard. Three 8-ha conventional orchards not treated with leafroller pheromone also were monitored during the 2-yr study. All six orchards were separated by at least 400 m.

All insecticide spray decisions were made by the grower and were based on sampling data and unpublished pest thresholds. The grower committed to not using any insecticides for leafrollers during the summer in the pheromone-treated orchards, unless his independent assessment of leafroller population densities increased well above his action threshold. Sprays applied per hectare for leafrollers during this study included the following: 2.3 liters of chlorpyrifos (Lorsban 4 E [emulsifiable], DowElanco, Indianapolis, IN) plus 37 liters of superior-type oil at delayed-dormant, 2.8 kg of azinphosmethyl (Guthion 50 WP [wettable powder], Bayer, Kansas City, MO), and 2.2 kg *of B. thuringiensis* (Dipel 2x, Abbott, Chicago, IL). Material costs used in our analysis were the prices quoted over the phone by a major chemical supply firm in Yakima, WA, in 1996.

Leafroller populations in each orchard and subplot were monitored using several methods during the season. Timed visual searches of trees were conducted for larvae in the spring (3.5, 5.0, and 2.0 h from 12 April to 15 June 1995; 12 April to 25 May 1996, and 25 April to 4 June 1997, respectively). Lure-baited traps were used to monitor adult male flight from 2 June to 28 September 1995, and from 8 June to 26 August 1996. One trap was placed in the center subplot and 8 traps were monitored in the outer subplot of each pheromone-treated orchard. Traps were placed at 2.8–3.2 m in the canopy. Traps were baited with red septa loaded with the 4 component blend. Lures were replaced every 4 wk. Trap sticky bottoms were replaced every other week or weekly if needed. Five similar traps were evenly distributed in each untreated control plot. Seven female-baited traps were placed in both the inside and outside pheromone-treated subplots and in the untreated control plots. Females were replaced each week from 9 June to 29 September 1995, and from 28 June to 16 August 1996. Female moths were tethered and placed in orchards overnight during the 4 wk of peak flight (from 6 July to 10 August 1995 and from 12 July to 1 August 1996). The total number of moths tethered in each plot was 60 and 120 in 1995 and 1996, respectively. Larval populations were sampled during the summer by inspecting 10 shoots from 100 trees over a 4-wk period (from 18 July to 17 August 1995, and from 30 July to 28 August 1996. Fruit injury from leafrollers was sampled by inspecting 10 fruits high and low in the canopy from 100 trees from 21 August to 12 September 1995, and from 27 August to 18 September 1996. All moth, larvae, and fruit counts were transformed and subjected to ANOVA by using year as a repeated measure (Hintze 1987). Analyses compared the pheromone-treated and untreated blocks and the inside and outside pheromone-treated orchard subplots. If the year by treatment interaction proved to be significant, a 1-way ANOVA was used to compare treatments on each date. The Fisher LSD was used to separate significant treatment means.

Results

Small-Plot Field Studies. Mean emission rates from membrane dispensers aged 56 d in the field were from 0.87 to 1.10 mg/d (Table 1). These values were similar to those previously reported for both the rope and spiral dispensers used in our tests (Knight 1996, Fitzpatrick et al. 1995).

Trap performance was significantly affected by treatments in all field trials conducted in 1992–93 (Table 2). In the August 1992 tests, both lure and female-

Table 2. Replicated small plot (0.1-ha) field trials evaluating the effectiveness of various sex pheromone blends released from rope, spiral, and membrane dispensers for disruption of *C. rosaceana* in apple and cherry

Trial no.	Date	Dispenser type	Pheromone blend[a]	Mean catch per trap: Lure-baited	% reduction	Female-baited	% reduction	Proportion of female-baited traps catching >1 moth	% reduction
	Aug. 1992	—	Untreated control	36.0 (15.9)a	—	6.9 (4.6)a	—	0.74 (0.12)a	—
1a		Rope 1	Acetate	2.2 (0.2)b	94	0.1 (0.03)b	99	0.08 (0.02)b	89
		Rope 2	Acetate, aldehyde	1.4 (1.2)b	96	0.3 (0.2)b	96	0.16 (0.09)b	78
1b		Spiral 1	Acetate	2.0 (0.9)b	94	0.6 (0.2)b	92	0.34 (0.07)b	54
		Spiral 2	Acetate, aldehyde	2.8 (2.1)b	92	0.1 (0.1)b	99	0.06 (0.04)c	92
	June–July 1993	—	Untreated control	16.6 (2.5)a	—				
2a		Rope 1	Acetate	1.0 (0.4)b	94				
		Rope 2	Acetate, aldehyde	0.4 (0.2)b	98				
2b		Spiral 1	Acetate	1.0 (0.5)b	94				
		Spiral 2	Acetate, aldehyde	0.8 (0.4)b	92				
3	May–July 1993	—	Untreated control	15.8 (5.8)a	—				
		Membrane 1	Acetate	0.4 (0.2)b	97				
		Membrane 2	Acetate, aldehyde	0.6 (0.2)b	96				
		Membrane 3	Acetate, aldehyde, alcohol	0.4 (0.4)b	97				

Moth catches in lure and female-baited traps within each trial followed by a different letter are significantly different, ANOVA, Fisher LSD, $P < 0.05$.

[a] See Table 1 for dispenser's pheromone loading and blend constituents.

baited traps caught significantly fewer moths in the pheromone-treated than the untreated control plots with rope dispensers in trial 1a ($F = 11.8$; df = 2, 12; $P = 0.001$ and $F = 5.9$; df = 2, 12; $P = 0.02$, respectively) and with spiral dispensers in trial 1b ($F = 9.7$; df = 2, 12; $P = 0.003$ and $F = 5.5$; df = 2, 12; $P = 0.02$, respectively). However, no differences were found in the mean catch in either trap type between pheromone blends released from either dispenser (Table 2). The percentage of female-baited traps catching males was also significantly different between the untreated and pheromone-treated blocks for both the rope and spiral dispensers ($F = 17.2$; df = 2, 12; $P < 0.001$ and $F = 16.9$; df = 2, 12; $P < 0.001$, respectively) (Table 2). However, the proportion of traps catching males was significantly lower in trial 1b with the Spiral 2 dispenser releasing an aldehyde–acetate blend than the Spiral 1 dispenser releasing only the acetate (Table 2). No difference between similar pheromone blends emitted from the rope dispenser was found in trial 1a (Table 2).

During 1993 significant reductions of moth catch by lure-baited traps occurred in pheromone-treated versus the untreated control in trials conducted with 3 types of dispensers in both apple and cherry orchards: apple with rope dispensers ($F = 54.6$; df = 2, 12; $P = 0.001$), apple with spiral dispensers ($F = 44.7$; df = 2, 12; $P = 0.001$), and cherry with membrane dispensers ($F = 16.1$; df = 3, 16; $P < 0.001$). No differences were found among pheromone blends in these 3 tests (Table 2).

Cage Experiments. Significant reductions in mating occurred among treatments by using 2- to 4-sex-pheromone component blends versus an untreated control in tests with the 3 dispenser types: rope dispensers, $F = 40.9$; df = 2, 39; $P < 0.001$; membrane dispensers, $F = 15.6$; df = 3, 52; $P < 0.001$; spiral dispensers, $F = 17.5$; df = 2, 12; $P < 0.001$ (Table 3). However, no differences were found among pheromone treatments in each test. The 4th test comparing membrane dispensers releasing E11-14:OAc or a 88:12 blend of E:Z11-14:OAc versus an untreated control revealed no significant differences in the proportion of mated females among treatments ($F = 2.8$; df = 2, 15; $P = 0.09$). Spiral dispensers loaded either with Z11-14:OAc or with varying ratios of Z11-14:OAc and Z11-14:Ald significantly reduced mating ($F = 2.9$; df = 4, 20; $P = 0.05$) compared with the untreated control, but no differences among pheromone treatments were detected (Table 3).

Orchard Trials. The mean densities of overwintering larvae increased numerically across all orchards from 1995 to 1996 and again slightly from 1996 to 1997,

Table 3. Small cage (10 by 10 m) trials of sex pheromone dispensers for mating disruption of *C. rosaceana*

Test no.	Dispenser type	Pheromone blend[a]	Proportion of mated females
1	—	Untreated control	0.61 (0.05)a
	Rope 1	Acetate	0.09 (0.02)b
	Rope 2	Acetate, aldehyde	0.11 (0.02)b
2	—	Untreated control	0.66 (0.07)a
	Membrane 1	Acetate	0.20 (0.06)b
	Membrane 2	Acetate, aldehyde	0.22 (0.05)b
	Membrane 3	Acetate, aldehyde, alcohol	0.24 (0.04)b
3	—	Untreated control	0.42 (0.07)a
	Spiral 1	Acetate	0.06 (0.03)b
	Spiral 2a	Acetate, aldehyde	0.08 (0.05)b
4	—	Untreated control	0.75 (0.04)a
	Membrane 4	100% E11-14OAc	0.54 (0.07)a
	Membrane 5	88:12% E:Z11-14OAc	0.59 (0.08)a
5	—	Untreated control	0.42 (0.07)a
	Spiral 1	Acetate	0.18 (0.05)b
	Spiral 2a	Acetate, aldehyde (15:1)	0.18 (0.05)b
	Spiral 2b	Acetate, aldehyde (5:1)	0.18 (0.07)b
	Spiral 2c	Acetate, aldehyde (2:1)	0.12 (0.04)b

Within each test the mean proportion of females mating followed by different letters were significantly different, $P < 0.05$, LSD.

[a] See Table 1 for dispenser's pheromone loading and blend constituents.

Table 4. Larval densities for the overwintering and summer generations and fruit injury at harvest for *C. rosaceana* in untreated control orchards (C) and orchards treated with 1,000 Hamaki-con dispensers per hectare (P) during 1995–1996

Orchards	No. overwintering larvae sampled per h			No. of summer larvae sampled per 1,000 shoots		Fruit injury per 2,000 fruits, %	
	1995	1996	1997	1995	1996	1995	1996
C1	2.0	4.6	1.0	60	17	2.3	1.4
C2	0.3	3.4	2.0	5	11	0.8	0.7
C3	2.3	9.6	18.0	17	40	0.6	2.9
Mean (SEM)[a]	1.5 (2.0)	5.9 (2.0)	7.0 (2.0)	27.3 (13.0)	22.7 (13.0)	1.2 (0.5)	1.6 (0.5)
P1	0.3	0.2	0.7	4	14	0.1	1.0
P2	0.6	1.4	6.0	8	12	0.5	2.3
P3	2.0	7.0	6.5	58	16	1.2	1.5
Mean (SEM)[a]	1.0 (2.0)	2.9 (2.0)	4.4 (2.0)	23.3 (13.0)	14.0 (13.0)	0.6 (0.5)	1.6 (0.5)
% reduction P/C	33.4	50.8	37.1	14.7	38.3	50.0	—
ANOVA *P* values[b]							
Treatment		0.52		0.64		0.47	
Year		0.14		0.62		0.25	
Treatment × year		0.81		0.87		0.62	

[a] Means are least squares means from repeated measures ANOVA.
[b] Degrees of freedom in repeated measure ANOVAs were 1, 4 for summer larvae and fruit injury and 2, 8 for overwintering larvae.

but did not vary significantly between treatments or years (Table 4). Although the year-effect was marginally significant ($P = 0.14$), the use of different scouts each year probably increased variance among years and thus no contrast analysis was conducted. Summer larval population densities and fruit injury levels also did not vary between treatments or years (Table 4).

The sex pheromone treatment had significant effects on the performance of lure-baited and female-baited traps and tethered virgin females versus the untreated control (Table 5). Catches of males in lure-baited traps were significantly lower and reduced by >92% in the pheromone-treated versus the untreated control plots in both years. The proportion of female-baited traps catching at least 1 moth was significantly lower and reduced by >96% in the pheromone-treated versus the untreated control in both years. Mating of tethered females was significantly lower in the pheromone-treated versus the untreated control orchards in both years (Table 5).

No significant differences were found for the various population measures of *C. rosaceana* in the center 2 ha versus the outer 14-ha area of the pheromone-treated orchards (Table 6). However, mean catch per lure-baited trap and percentage of fruit injury within the pheromone-treated orchards were significantly higher in the 2nd y of the study (Table 6).

All orchards were treated with 1–3 applications of *B. thuringiensis* in the spring for the overwintering leafroller generation during both years (Table 7). In 1996, some of the untreated control orchards were treated with 1 or 2 applications of an organophosphate insecticide. During 1995 the pheromone-treated orchards were not sprayed during the summer. However, in 1996 two of the orchards were sprayed with 1 application of *B. thuringiensis.* In comparison, all the untreated control orchards were sprayed with 1–3 sum-

Table 5. Mean catches of male *C. rosaceana* by lure and female-baited traps and mating of tethered virgin females in untreated control orchards (C) and orchards treated with 1,000 Hamaki-con dispensers per ha (P) during 1995–1996

Orchards	Mean moth catch per lure-baited trap		Female-baited traps catching >1 moth, %		Mating of virgin female moths, %	
	1995	1996	1995	1996	1995	1996
C1	222.3	149.3	52.0	71.4	25.0	6.2
C2	162.5	102.3	18.2	48.6	21.5	7.6
C3	409.3	23.3	38.3	11.4	16.0	0.0
Mean (SEM)[a]	264.7 (53.5)	91.6 (53.5)	36.2 (8.8)	43.8 (8.8)	20.8 (2.0)	4.6 (2.0)
P1	0.4	1.5	0.0	0.0	0.0	0.0
P2	0.9	7.5	0.0	1.4	2.8	0.9
P3	6.8	11.9	1.1	2.0	11.8	0.0
Mean (SEM)[a]	2.7 (43.5)	7.0 (53.5)	0.4 (8.8)	1.3 (8.8)	4.9 (2.0)	0.3 (2.0)
% reduction P/C	99.0	92.4	98.9	97.0	76.4	93.5
ANOVAs *P* values[b]						
Treatment	0.002		0.02		0.03	
Year	0.19		0.65		0.007	
Treatment × year	0.17		0.72		0.04[c]	

[a] Means are least squares means from repeated measures ANOVA.
[b] Degrees of freedom in repeated measure ANOVAs were 1, 4.
[c] Due to a significant interaction separate ANOVAs were calculated for each year: 1995: $F = 13.1$; df = 1, 4; $P = 0.02$. 1996: $F = 3.3$; df = 1, 4; $P = 0.14$.

Table 6. Comparison of population indices of *C. rosaceana* within the center 2 ha versus the outside 14 ha of replicated 16-ha orchards of apple treated with 1,000 Hamaki-con dispensers per hectare

Location	Mean moth catch per lure-baited trap		Female-baited traps catching >1 moth, %		Mating of virgin females, %		Summer larval count per 100 trees		Fruit injury per 2,000 fruits, %	
	1995	1996	1995	1996	1995	1996	1995	1996	1995	1996
Inside	0.0 (0.0)	6.0 (2.6)	0.37 (0.37)	1.3 (0.7)	6.4 (3.9)	0.0 (0.0)	20.3 (13.0)	14.0 (2.1)	0.6 (0.4)	1.6 (0.4)
Outside	3.0 (2.3)	7.1 (3.1)	0.37 (0.37)	1.3 (0.7)	3.3 (3.3)	0.6 (0.6)	26.3 (22.3)	14.0 (3.8)	0.6 (0.3)	1.5 (0.3)
ANOVA *P* values[a]										
Location	0.52		1.00		0.65		0.84		0.95	
Year	0.03		0.07		0.17		0.48		0.04	
Location × year	0.57		1.00		0.53		0.82		0.98	

[a] Degrees of freedom in repeated measure ANOVAs were 1, 4.

mer *B. thuringiensis* applications plus zero or 1 organophosphate spray during both years (Table 7). A mean of $250 less insecticide was used per hectare in the pheromone-treated versus untreated orchards over the 2-yr study.

Discussion

Despite the importance and specificity of the 3 minor pheromone components in the attractiveness of the sex pheromone blend for male *C. rosaceana* in western North America (Vakenti et al. 1988, Thomson et al. 1991), we failed in a series of both small-plot and field-cage studies to show any significant role of the minor components Z11-14:Ald and Z11-14:OH in disruption. Similarly, Agnello et al. (1996) found no difference in the level of disruption by using dispensers loaded with either a 94:6 Z:E11-14:OAc blend or a 90:5:5 Z:E11-14:OAc: Z11-14:OH blend in New York.

However, we may not have been using the most attractive blend for disruption of western populations of *C. rosaceana* because all dispensers in our tests initially included 4–6% E11-14:OAc (Table 1). Hill and Roelofs (1979) and Vakenti et al. (1988) found that E11-14:OAc comprised ~1–2% of female abdominal tip extracts. Maximal moth catches were with acetate blends, including 3–5% of this isomer with populations in New York (Hill and Roelofs 1979).

Table 7. Insecticide use and average material costs per hectare in 3 orchards treated with and without Hamaki-con dispensers for mating disruption of *C. rosaceana* during 1995 and 1996

Time period	Total no. of insecticide applications			
	Mating disrupted orchards		Untreated control orchards	
	OP	Bt	OP	Bt
Spring 1995	0	7	0	5
Summer 1995	0	0	0	4
Spring 1996	0	6	4	8
Summer 1996	0	2	2	9
Mean 2-yr cost per ha	$244		$497	

Organophosphate (OP) insecticides applied for leafrollers during this study per hectare included: 2.3 liter of chlorpyrifos (Lorsban 4 E) at $13.50/liter and 2.8 kg of azinphosmethyl (Guthion 50 WP) at $17.50/kg. The Bt insecticides included 0.9 kg of Dipel 2× at $21.90/kg.

However, highest moth catches in British Columbia were obtained with blends containing 1–2% E11-14:OAc. Blends with 3–6% E11-14:OAc were significantly less attractive. Thomson et al. (1991) found that decreasing the percentage of E11-14:OAc from 5.0 to 2.5% significantly improved attraction. Reissig et al. (1978) found that including E11-14:OAc in the pheromone blend marginally improved disruption; however, its proportion in the blend was not specified. Our results showed that E11-14:OAc alone or a 88:12 E:Z mixture were not effective disruptants (Table 3). Further studies with *C. rosaceana* in western orchards should examine if disruption could be improved with blends that include 1–2% E11-14:OAc.

Efforts to develop mating disruption for tortricid pest species of tree fruits have evaluated both complete and partial sex pheromone blends. Minks and Cardé (1988) first suggested that the complete blend should provide the most efficacious disruption. However, there is no conclusive evidence for either approach being superior for all species where mating disruption has been attempted (Cardé and Minks 1995). Comparisons of complete and partial pheromone blends for disruption of tortricid species by using Z11-14:OAc as their major pheromone component have been inconclusive. Disruption of *A. citrana* with rope dispensers was improved by using its 2-component blend versus Z11-14:OAc alone (Knight 1996). Yet, studies with *Pandemis pyrusana* Kearfott found no difference in either Z11-14:OAc or a 94:6 blend with Z9-14:OAc (A.L.K., unpublished data). Fitzpatrick et al. (1995) found little improvement by adding 2 minor components to the major sex pheromone component, Z11-14:OAc, of the blackheaded fireworm, *Rhopobota naevana* (Hübner), in spiral dispensers. Studies with the summerfruit tortrix, *Adoxophyes orana* Fischer von Röslerstamm, in Switzerland indicated that disruption with Z11-14:OAc from plastic and rubber tubing was as good as the complete 2-component blend (Charmillot 1989). The Z11-14:OAc is used to disrupt several tortricid pest species of tea and apple in Asia that all have multiple component sex pheromones (Ogawa 1990).

The use of a generic approach to manage the suite of leafroller species attacking tree fruits has been an important issue because sympatric leafroller species are common in tree fruits and because they tend to share a small number of chemicals as their sex pheromones (Arn et al. 1992, Cardé and Minks 1995). A 3rd reason to develop a generic blend for mating disruption of leafrollers may be economics. Companies may not be interested in developing a multitude of specific products each with a small market potential for the various species of leafrollers.

Several studies have tested whether developing a generic disruptant is an effective approach. Pfeiffer et al. (1993) and Felland et al. (1995) found that a proposed 5-component generic leafroller blend for 4 leafroller species [*C. rosaceana*, *Argyrotaenia velutinana* (Walker), *Platynota flavedana* (Clemans), and *Platynota idaeusalis* (Walker)], present in orchards in the eastern United States was not as effective as the 2-component species-specific blends for the 2 major *Platynota* pest species. However, subsequent research by Hull and Felland (1995) demonstrated that a 3 component generic blend (3:3:4 ratio of E11-14:OH, E11-14:Ac, and Z11-14Ac) was equally effective as the specific pheromone for *P. idaeusalis* and also shut down traps for 3 other species. Our data showed that the sex pheromone [12:88 blend of (Z:E) 11-14:OAc] of the omnivorous leafroller, *Platynota stultana* (Walsingham) (Hill and Roelofs 1975), would not be an effective generic disruptant for species such as *C. rosaceana* (Table 3). Alternatively, Knight (1996) hypothesized that a multispecies generic approach in the western United States may be possible using only Z11-14:OAc or with the addition of Z11-14:Ald to disrupt 3 leafroller species: *C. rosaceana*, *A. citrana*, and *P. pyrusana*. Deland et al. (1994) proposed that Z11-14:OAc also could be a generic disruptant for 2 univoltine species common in many orchards in western North America, the fruittree leafroller, *Archips argyrospila* (Walker), and

European leafroller, *Archips rosana* (Robinson). Across several European countries, Z11-14:OAc has been used to disrupt 5 species of leafrollers: *A. orana*, *Archips podana* Scopoli, *P. heperana* Denis & Schiffermüller, *A. rosana*, and *Argyrotaenia pulchellana* (Fernald) (Charmillot 1989).

The level of disruption that has been achieved in various studies of *C. rosaceana* using the incomplete (Z:E) 11-14:OAc blend have generally been moderate. Reissig et al. (1978) obtained poor trap shutdown (<65%) in plots treated with hollow fibers releasing only Z11-14:OAc. Disruption was significantly improved when the minor components Z11-14:OH alone and when Z11-14:OH and E11-14:OAc were added (88–95%). Deland et al. (1994) obtained 90% disruption of lure-baited traps in small plots by using a rope dispenser similar to the one used in our trials (except, their dispenser was loaded with 90 mg of pheromone). They hypothesized that disruption of *C. rosaceana* with this incomplete blend is poor because the dispenser competes poorly with the natural pheromone released by females and because the ratio of Z11-14:OAc in the natural blend is too high for sensory imbalance to be a primary mechanism affecting disruption (Deland et al. 1994). We suggest that the much higher levels of trap shutdown achieved in our studies (92–99%) do not support their conclusion that further testing of the Z:E11-14:OAc blend is unwarranted. However, additional studies of *C. rosaceana* are needed to elucidate the mechanisms of mating disruption and test their hypotheses. Identification of the specific cues that each of the sex pheromone components within the blend provides in eliciting sexual behavior in *C. rosaceana* will help identify the major mechanisms of disruption occurring in pheromone-treated orchards.

Moth population density and dispersal are 2 major factors impacting mating disruption of *C. rosaceana*. The importance of moth immigration, especially mated female moths, into pheromone-treated orchards remains unclear. In orchards with a high overwintering population of *C. rosaceana*, the lack of complete trap shutdown, mating of tethered moths, and catch of mated females in bait pans or on interception traps in the center of pheromone-treated orchards suggests that mating is occurring within the orchards. In our study, data for orchard P3 showed this in 1995 (Tables 4 and 5). These types of orchards will require that supplemental control actions. However, in another orchard with a low overwintering population density, larval populations developed during the summer even within their center despite 100% disruption of female-baited traps and tethered females (see data for P1 in Tables 4 and 5). This is probably due to immigration of mated females dispersal of larvae, or both.

Integration of mating disruption with selective spray programs can reduce within orchard moth densities and increase the level of mating disruption attained; however, immigration of mated females and ballooning larvae from outside the orchard could still remain an intractable problem. Factors affecting larval dispersal and host acceptance have been investigated for *C. rosaceana* (Carrière 1992), but dispersal distances of neonates or adults have not been reported. Knight et al. (1990) found that 90% of *P. idaeusalis* egg masses was laid within 65 m from their experimental release sites and the most distant egg mass was deposited at 250 m. Larval *P. idaeusalis* dispersal is limited (<30 m) and survivorship is low (Simelane et al. 1992). Female *C. rosaceana* are larger than those of *P. idaeusalis* (pupal weights, 100 mg versus 42 mg, respectively) and lay more eggs but in fewer egg masses (300–900 eggs within 2–6 masses versus 100–500 eggs in 2–13 egg masses, respectively) (L. Hull, unpublished data). Whether the population dispersal of *C. rosaceana* between generations can occur over a scale larger than the 400 by 400 m areas treated with sex pheromones in our study is unknown. Further studies are needed to assess the scales of adult and larval movement of *C. rosaceana* within and among orchards.

Implementation of mating disruption for leafrollers will probably involve integration of mating disruption with limited insecticide use. Orchard trials assessing mating disruption of *C. rosaceana* in New York typically found a small additive effect of combining mating disruption with insecticides versus insecticide use alone (Agnello et al. 1996, Lawson et al. 1996). However, fruit injury was often not acceptable with either program (2–25%) due to high population densities and the occurrence of insecticide resistance (Lawson et al. 1996). In comparison, fruit injury in our study was kept below an acceptable threshold (<2%) for 2 yr with a savings of $250/ha due to reduced insecticide material costs. However, the increases in trap catch and injury levels in the pheromone-treated orchards from the 1st to 2nd yr are of concern and suggest that not enough insecticides were used to supplement mating disruption in 1995. Studies of 3–5 yr are needed to more completely assess the economic viability of mating disruption. Registration of a dual dispenser that releases the pheromone of both codling moth and leafrollers could minimize the additional cost of controlling a 2nd pest (Cardé and Minks 1995). Areawide adoption of mating disruption for leafrollers also may improve its effectiveness by minimizing the edge effect and reducing the importance of moth immigration.

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