Efficacy of Isomate-CM/LR for management of leafrollers by mating disruption in organic apple orchards of western Canada

GARY J.R. JUDD[1,2] and MARK G.T. GARDINER[1]

ABSTRACT

Results of a three-year study demonstrated that Isomate-CM/LR, a polyethylene, single tube-type pheromone dispenser releasing an incomplete mixture of several species' multi-component pheromones is an effective management tool that provides multiple-species mating disruption for *Choristoneura rosaceana* (Harris) and *Pandemis limitata* (Robinson). When applied at a rate of 500 dispensers / ha within the orchard and the equivalent of 2000 dispensers / ha to trees on the orchard perimeter, levels of control were adequate for production of organic apples in British Columbia, Canada. Trap catches with synthetic pheromone lures were reduced by 79 -99% and mating of females on mating tables was reduced by 87 - 98% in these species. At harvest, damage from leafrollers in pheromone-treated organic orchards was below organically-acceptable economic levels (5%) and similar to damage levels observed in insecticide-treated conventional orchards (2%). Over three years, total trap catches of these two leafrollers and their damage decreased in four of five orchards treated with pheromone, but catches and damage from leafrollers increased in one orchard. These indices remained relatively unchanged in paired insecticide-treated conventional orchards over the same three-year period. In pheromone-treated orchards, levels of damage from leafrollers at harvest were positively correlated with total leafroller catches in pheromone monitoring traps. Use of Isomate-CM/LR as a supplemental pest management tactic in organic orchards will help to reduce damage and economic losses from leafrollers that have been increasing under the area-wide codling moth sterile insect programme ongoing in this semi-desert, montane apple production region.

Key Words: leafrollers, multiple-species mating disruption, organic apples

INTRODUCTION

Over the last decade a new paradigm for integrated pest management in pome fruits has emerged in western North America. This transformation was driven by implementation of area-wide programmes to control codling moth, *Cydia pomonella* (L.), using sterile insect technique (SIT) in Canada (Dyck and Gardiner 1992) and pheromone-based mating disruption in the United States (Calkins 1998). Application of these species-specific controls for codling moth has resulted in increasing damage from secondary pests (Brunner *et al.* 1994, Knight 1995, Gut and Brunner 1998). Consistent with earlier prediction (Madsen and Morgan 1970), several species of leafrolling caterpillars (Lepidoptera: Tortricidae) have become an increasing problem when broad-spectrum insecticides that target codling moth, but which provide partial control of leafrollers, are removed from the production system (Madsen and Proctor 1985). Although the species complex varies across production regions, increasing damage from leafrollers in orchards using mating disruption for codling moth is a recur-

[1] Agriculture and Agri-food Canada, Pacific Agri-food Research Centre, Box 5000, 4200 Hwy 97, Summerland, British Columbia, Canada V0H 1Z0
[2] Author to whom correspondence should be sent. Tel.: +1 250 494 7711; fax.: +1 250 494 0755; E-mail: Gary.Judd@agr.gc.ca

ring problem seen around the world (Charmillot 1990, Wearing *et al.* 1995, Walker and Welter 2001).

The British Columbia (BC) organic apple industry is concentrated in the Similkameen Valley (Judd *et al.* 1997, Mullinix 2005). Although orchards in this region have been receiving sterile codling moth since 1994 as part of an area-wide SIT control programme (Dyck and Gardiner 1992), producers of organic fruit found it necessary to supplement this programme with codling moth mating-disruption technology in spring (Judd and Gardiner 2005). Because codling moth is presently under control but profit margins are shrinking under increased foreign competition, organic apple producers in BC are seeking alternative controls for leafrollers to improve quality of graded export fruit. Before 2005, *Bacillus thuringiensis* Berliner (Bt) was the only organic material available for controlling leafrollers in Canada. Although Bt is effective, its use is often limited by inclement spring weather in montane areas of BC, and while fairly benign to beneficial species, it can have a significant effect on parasites of leafrollers if applied at the wrong time (Cossentine *et al.* 2003).

Organic pome-fruit producers in BC have been interested in pheromonal control of leafrollers ever since pheromones were first applied to control codling moth (Judd *et al*. 1997). The idea of using one mating-disruption system to simultaneously control codling moth and leafrollers has been around for some time (van Deventer *et al.* 1992) but few commercial products exist. Isomate-CM/LR, a multiple-species mating-disruption product designed to control codling moth and leafroller species important in western North America, was registered in the United States in 1997 and in Canada in 2004 (Don Thomson, personal communication). When Isomate-CM/LR was used in conjunction with insecticides (Knight *et al.* 1997, Knight *et al.* 2001), apple orchards had 41% less leafroller damage and received one less spray per season. These same orchards consistently had less codling moth damage than orchards receiving Isomate-C^+ and supplemental insecticides. Whether leafrollers can be controlled effectively, or sufficiently, with Isomate-CM/LR when no supplemental insecticides are used remains untested.

Judd and Gardiner (2005) reported on the use of mating disruption as a supplementary tactic for spring control of codling moth in organic orchards that were part of the area-wide SIT programme. Herein we report results using Isomate-CM/LR to control damage from leafrollers while at the same time supplementing codling moth control in those same organic apple orchards. The primary objective of this study was to conduct season-long assessments on disruption of pheromonal communication and mating in the leafrollers, *Choristoneura rosaceana* (Harris) and *Pandemis limitata* (Robinson) in commercial, organic apple orchards where Isomate-CM/LR was used, and to report on levels of leafroller damage in the absence of insecticide inputs. Second, we wanted to collect data on the relationship between different measures of disruption and relative density of adult leafrollers as measured by pheromone traps, because questions about the efficacy of mating disruption and population density are rarely addressed experimentally. Third, we wanted to determine if pheromone trapping of *C. rosaceana* and *P. limitata* has the potential to be a predictive tool of potential damage in orchards under pheromone-based mating disruption (Walker and Welter 2001).

MATERIALS AND METHODS

Test orchards. All apple orchards used in this study are located at Cawston, BC, in the Similkameen Valley (latitude 49º 10.8′ N, longitude 119º 46.2′ W, elevation 401 m). The five organic orchards treated with Isomate-CM/LR and five paired conventional orchards treated with insecticides (Table 1) were described in detail by Judd

Table 1.
Management, monitoring and fruit sampling details for the leafrollers *Choristoneura rosaceana* and *Pandemis limitata* in each organic (O1 - O5) and paired conventional (C1 - C5) apple orchard studied in Cawston, BC, Canada, 1997 - 1999.

	No. of pheromone dispensers / ha applied each year[2]			Yearly insecticide treatments for leafrollers[3]			Yearly number of traps for each leafroller species[4]			Number of fruit sampled for damage at harvest each year		
Orchard[1]	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**	**1997**	**1998**	**1999**
O1	500	500	500	0	0	0	4	4	4	3368	2145	2000
O2	500	500	500	0	0	0	6	6	6	5006	1756	2000
O3	500	500	500	0	0	0	4	4	4	4298	2100	2000
O4	500	500	500	0	0	0	2	2	2	4300	2223	2000
O5	500	500	500	0	0	0	4	4	4	3031	1939	2000
C1	0	0	0	0	1	1	–	2	2	2270	1698	2000
C2	0	0	0	3	3	4	–	2	2	2000	2000	2000
C3	0	0	0	2	2	3	–	2	2	2000	2000	2000
C4	0	0	0	1	1	0	–	2	2	2100	2000	2000
C5	0	0	0	2	3	4	–	2	2	2000	1883	2000

[1] Orchards O1 to O5 were cited by Judd and Gardiner (2005) as orchards A1 - A4 and B1, respectively, and orchards C1 - C5 remain the same across studies. Six untreated, organic, comparison orchards not listed were monitored but not sampled for damage (Cossentine *et al.* 2004).
[2] All trees on the perimeter of each orchard received the equivalent of 2000 dispensers / ha.
[3] Leafroller sprays consisted of spring (April) sprays of methidathion in dormant oil and summer (July - August) sprays of Confirm ® (tebufenozide).
[4] No leafroller monitoring was done in conventional comparison orchards in 1997 but they were sampled for damage at harvest. Six untreated, organic, comparison orchards (Cossentine *et al*. 2004) were each monitored with two traps in 1998 and 1999. Each species was monitored with a septal lure loaded with 3 mg of a multi-component blend described by Deland *et al*. (1994).

and Gardiner (2005). Six organic apple orchards that received no treatments for control of leafrollers were described in detail by Cossentine *et al*. (2004) as part of a study on parasitism of leafrollers in 1998 and 1999. The latter untreated orchards were used to compare relative trap catches of leafrollers only, as no damage data were collected in the original study. Briefly, all orchards ranged in size from 0.5 - 2 ha and were composed of mixed apple varieties planted at densities of 267 - 938 trees/ha with tree x row spacing of 2.4 - 6.1 x 3.0 - 6.1 m, respectively. Trees ranged in height from 2.5 - 3.5 m and were pruned using a pyramid shape training system.

No synthetic insecticides were applied to any of the organic orchards examined in this study (Table 1), but one orchard (O3) received Bt sprays (Dipel 2X DF) in 1998 and this is noted in the Discussion. All but one conventional orchard also received at least one application of Guthion® (azinphosmethyl at 0.84 kg a.i./ha) for codling moth control in 1997, but in later years growers used Confirm® (tebufenozide) during both spring and summer usually timed for control of leafroller larvae. One caveat is that conventional orchards did not necessarily receive similar or optimal insecticide spray programmes because these orchards were chosen by Judd and Gardiner (2005) as local comparisons not controlled treatments.

Pheromone disruption treatment. Isomate-CM/LR is a brownish red, single-tube, polyethylene dispenser, manufactured by the Shin-etsu Chemical Company Ltd. (Tokyo, Japan) and marketed by Pacific Biocontrol Corporation (Vancouver, Washington). Each Isomate-CM/LR dispenser contains a 285 mg blend of 36.9% (*E,E*)-8,10-dodecadien-1-ol (codlemone), 1.8% isomers of codlemone, 6.0% dodecanol and 1.2% tetradecanol for disruption of codling moth, and 43.5% (*Z*)-11-tetradecenyl acetate (Z11-14:Ac) and 2.4% (*E*)-11-tetradecenyl acetate (*E*11-14:Ac) for disruption of leafrollers, plus 8.2% inert ingredients and pheromone stabilizers (Don Thomson, personal communication). Isomate-CM/LR dispensers were deployed in five organic apple orchards at a rate of 500/ha, however each perimeter tree received the equivalent of 2000 dispensers/ha (Table 1). Dispensers were attached to branches in the upper third of tree canopies ca. 1 m below the top of the central leader, or on the first lateral branch beneath the central leader. All pheromone dispensers were deployed a few days before codling moths were expected to emerge and no later than 8 May each year (Judd and Gardiner 2005).

Monitoring seasonal flight activity of moths. In all orchards, seasonal flight activity and capture of adult leafrollers were assessed using traps baited with synthetic pheromones. Disruption of pheromone communication in leafrollers was calculated by expressing catches of moths in pheromone-treated organic orchards as a percentage of catch in either insecticide-treated conventional orchards or untreated organic orchards in 1998 and 1999. No comparisons were made in 1997 as the latter sets of orchards were not monitored that season.

Depending on orchard size and shape, 2 - 6 Pherocon 1-C style open (5-cm side spacers) wing traps (Pherotech International, Delta, BC) baited with each species' multi-component pheromone blend (Deland *et al.* 1994; described below) were deployed evenly throughout each orchard (Table 1). One trap for each species was hung ca. 1.5 - 2.0 m above ground on different sides of the same tree in 2 - 6 separate trees. Positions for all traps remained fixed within and across years. In 1997 only the five Isomate-CM/LR-treated organic orchards were monitored with pheromone traps. On 30 May 1997, wing traps were deployed in each of these organic orchards and checked weekly from 6 June until 18 September. In 1998, wing traps were deployed in these same five Isomate-CM/LR-treated organic orchards, five paired insecticide-treated conventional orchards and six untreated organic orchards on 8 May, and checked weekly from 15 May until 25 September. In 1999, wing traps were deployed in all orchards on 27 May and checked weekly from 3 June until 30 September. Moths were counted and removed weekly with trap bottoms replaced as needed and pheromone lures changed every three weeks.

Synthetic multi-component pheromone lures for each leafroller species were prepared with chemical components (Aldrich Chemical Company Inc., Milwaukee, Wisconsin) of known purity, as confirmed by gas chromatographic analysis (*Z*11-14:Ac, 98% with 2% *E*11-14:Ac; (*Z*)-11-tetradecenal 96%; (*Z*)-11-tetradecanol; 97%, (*Z*)-9-tetradecenyl acetate, 96%) using published ratios (Roelofs *et al.* 1976, Vakenti *et al.* 1988). In making pheromone lures for each species, 200 µl of each multi-component pheromone blend was dissolved in dichloromethane and 3 mg of the pheromone blend was loaded into each red rubber septum (Aldrich Chemical Company Inc., Milwaukee, Wisconsin). After loading, septa were air-dried for ca. 18 h at 23 ^{o}C in a fume hood and stored at 0 ^{o}C until pinned to the inner side of trap lids in the field.

Assessment of mating in leafrollers. Mating was assessed using laboratory-reared, virgin, female moths placed in Teflon®-lined mating tables described by McBrien and Judd (1996). Both *C.*

rosaceana and *P. limitata* were reared on a modified pinto bean-based diet (Shorey and Hale 1965) at 24 °C and 16:8 h L:D photoregime. Female pupae of each species were placed individually in 150-ml plastic cups provided with moist cotton wicks until eclosion. Female moths aged 24 - 72 h were immobilized at 0.5 °C and one forewing and a tarsal tip were removed with fine forceps to prevent escape from mating tables. Females were kept chilled and transported to field sites in small ice chests.

In 1998, mating activity of both leafroller species was assessed weekly from 2 June until 3 September in each pheromone- and insecticide-treated orchard. During each weekly assessment, one female of each species was placed in 5 or 10 separate trees in each, insecticide- or pheromone-treated orchard, respectively, on Tuesdays, Wednesdays and Thursdays (n = 15 or 30 females/species/orchard/week). Two mating tables, each containing an individual female of each species, were placed in opposite sectors of the same tree, in the upper third of the canopy, several rows and trees distant from any pheromone traps. Females were placed in the field during the afternoon and removed the following morning to minimize predation and escape. Females recovered from the field <24 h after deployment were returned to the laboratory and each was dissected and examined for the presence of a spermatophore in the *bursa copulatrix* which indicates females have mated. Any females that were dead when collected from the field were omitted from the data.

In 1999, we conducted an experiment during flight of the first summer generation to determine if the probability of mating increased with the length of time (24 - 96 h) females were exposed in the field in either pheromone- or insecticide-treated orchards. Starting on Monday, 21 June, 100 female *P. limitata* were deployed in one pheromone-treated orchard and another 100 females were placed in an insecticide-treated orchard. At 24-h intervals for four consecutive days, 25 females were recovered from each orchard and returned to the laboratory where their mating status was assessed as before. This procedure was repeated for several consecutive weeks.

Fruit damage sampling. Depending on year and orchard, we examined fruit from 18 to 48 trees in the paired, pheromone- and insecticide-treated orchards (Table 1) using a stratified, cluster sampling procedure, where the outer row of trees and all interior trees represent two strata, and each tree represents a cluster of fruit, respectively (Judd *et al.* 1997). Sample trees were chosen systematically by crossing each orchard from corner to corner and edge to edge, ensuring that each variety and stratum was sampled. It was necessary to sample irregular numbers of trees and fruit from year to year because biennial bearing in organic orchards resulted in large annual differences in fruit set. All orchards were sampled during normal periods of harvest for each variety as fruit maturity and growers dictated. In most cases, a minimum of 100 fruit were removed from each sample tree by picking 50 low and 50 high fruit from south side branches. If there were fewer than 100 fruit on a tree, all fruit were removed from the sample tree. Early- or late-season leafroller damage, caused by either overwintering or summer larvae, respectively, can be distinguished by the degree of surface tunneling and scarring of fruit. Only late-season damage caused by summer-feeding larvae is scored in this study. All leafroller damage observed in this study was caused by either *C. rosaceana* or *P. limitata*, as no other species were previously found in this region (Madsen and Madsen 1980, Judd and Gardiner 2004). Our damage comparisons were limited to pheromone *vs*. insecticide-treated orchards because no damage samples were taken in the untreated organic orchards examined by Cossentine *et al*. (2004).

Statistical analyses. For each species, moth captures from all traps in the same orchard were pooled and transformed ($\log_{10}$ [x +1]) to normalize the data. Annual mean total number of moths caught per trap in untreated, Isomate-CM/LR-treated, and insecticide-treated orchards were compared using an analysis of variance (ANOVA) followed by a Student Neuman Keuls' multiple comparisons test (Zar 1984), where orchards are treated as replicates (n = 5 or 6). Mean weekly and seasonal total percent mating of each species in pheromone- and insecticide-treated orchards in 1998 were compared using two-sample *t*-tests (n = 5). Linear regression analysis was used to relate mean weekly percent mating and mean weekly trap catches in 1998. The frequency of mating among females placed in the field for varying lengths of time in either a pheromone-treated or insecticide-treated orchard was compared weekly and seasonally using contingency tables and χ^2 tests or a binomial *Z*-test (Zar 1984). Mean percent leafroller damage at harvest for pheromone- and insecticide-treated orchards was compared annually using a two sample *t*-test following an arcsine $\sqrt{p}$ transformation of raw data. Linear regression analysis was used to relate mean percent damage at harvest in pheromone-treated orchards with mean seasonal cumulative moth catches using all three years of data (n = 15 data pairs) and to examine changes in moth catches and damage over time in organic orchards. All statistical tests were performed using SigmaStat® (Version 3.0.1, SPSS Software Inc., San Jose, California) and an experimental error rate of $\alpha = 0.05$.

RESULTS

Seasonal flight activity of leafrollers. Mean weekly catches of *C. rosaceana* and *P. limitata* in orchards under different treatment regimes in 1999 are shown in Fig. 1. Similar weekly catches were seen in 1997 and 1998 but for brevity data are not shown. Catches of both species reflect two adult flight periods representing the first and second generations in this region, respectively. Weekly catches of *C. rosaceana* under all treatment regimes tended to be smaller during second generation than those during first generation, but this trend was often reversed in *P. limitata* (Fig. 1). *P. limitata* appeared to be the most abundant leafroller species in conventional orchards, but the relative species makeup reversed itself annually in untreated and pheromone-treated organic orchards (Table 2).

Disruption of leafroller pheromone trap catches. Weekly catches of *C. rosaceana* were reduced 70 - 100% in the Isomate–CM/LR treatment relative to both untreated and insecticide-treated orchards in 1999 (Fig. 1), and relative reductions averaged 90.4 and 92.1%, respectively, across years in 1998 and 1999 (Table 2). Weekly catches of *P. limitata* were reduced 67 - 100 % by treatment with Isomate-CM/LR compared to untreated and insecticide-treated orchards (Fig. 1), and relative reductions averaged 92.5 and 87.2 %, respectively, across years (Table 2). Catches of *P. limitata* were always higher in insecticide-treated conventional orchards compared with untreated organic orchards (Table 2).

Mating in leafrollers. During the entire 1998 season, 35.1% of female *C. rosaceana* (n = 757 females recovered) and 57.4% of female *P. limitata* (n = 702) mated on mating tables hung in the insecticide-treated orchards (Fig. 2). If 1 August is used as an approximate starting point for second-generation flight activity in both species (Fig. 2), then mating of both species tended to increase during the second-generation flight period. In the insecticide-treated orchards mating of *C. rosaceana* during the first (26.8%) and second generation (54.3%) was significantly different (χ^2 = 23.01, df = 1, $P < 0.001$). However, mating of *P. limitata* during first (53.6 %) and second generation (65.3%) was not significantly different (χ^2 = 2.05, df = 1, P = 0.152).

During the entire 1998 season only 1.6% of female *C. rosaceana* (n = 1610) and 7.4% of female *P. limitata* (n = 1522) mated on mating tables hung in the Isomate-CM/LR-treated orchards (Fig. 2). As seen in the absence of pheromone disruption (Fig. 2), significantly more *C. rosaceana* mated during second generation (3.5%) than during first generation (0.75%)

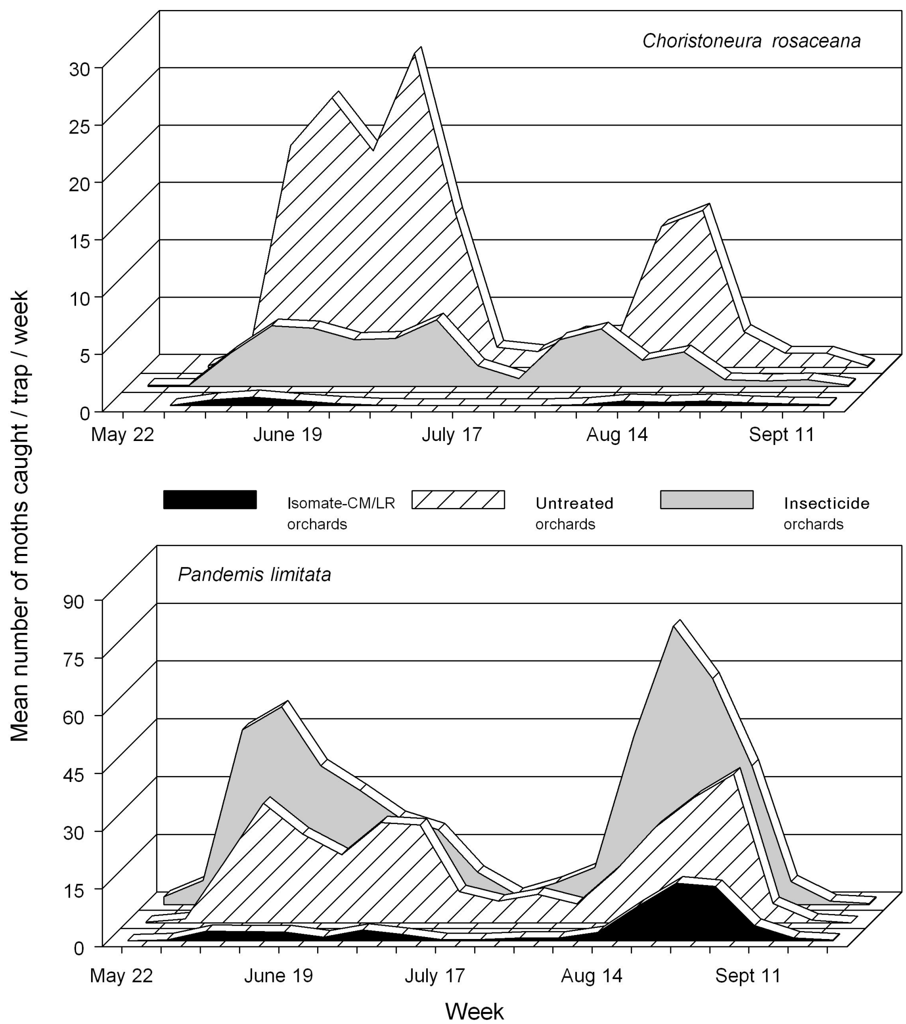

Figure 1. Mean weekly catches of two leafroller species in their species-specific synthetic pheromone-baited traps hung in untreated organic apple orchards (n = 6), Isomate-CM/LR-treated organic apple orchards (n = 5) and insecticide-treated conventional apple orchards (n = 5) in 1999.

(χ^2 = 14.74, df = 1, P < 0.001) and mating of *P. limitata* was also significantly greater in the second generation (15.4%) than in the first generation (2.9%) in pheromone-treated orchards (χ^2 = 65.14, df = 1, P < 0.001).

Regression analyses (Fig. 3) indicate that weekly differences in mating of *C. rosaceana* and *P. limitata* in the insecticide-treated orchards were partially correlated with the differences in weekly catches of males in pheromone-baited traps, respectively. In the Isomate-CM/LR-treated orchards, weekly differences in mating of female *P. limitata* were explained (see r^2 values) by differences in weekly catches of males (Fig. 3), but both mating and catches of *C. rosaceana* were too low in pheromone-treated orchards to ascribe any significant relationship to these variables (P = 0.06).

Estimates of mating in *P. limitata* did not appear to increase with increasing time deployed in the orchard (Table 3). Comparing results in Table 3 (1999) and Fig. 2 (1998), it appears that percent mating of

Table 2.
Seasonal total number of male leafroller moths, *Choristoneura rosaceana* and *Pandemis limitata*, caught in synthetic pheromone-baited traps placed in untreated organic orchards (n = 6), insecticide-treated conventional orchards (n = 5) and Isomate-CM/LR-treated organic orchards (n = 5) and relative percent disruption of trap catches.

Year	Species	Mean ± SE total number of moths / trap / year / treatment[1]			Relative % trap catch reduction[2]	
		Untreated	Insecticide	Isomate-CM/LR	Untreated	Insecticide
1997	*C. rosaceana*	–	–	124.2 ± 187.6	–	–
	P. limitata	–	–	84.7 ± 103.7	–	–
1998	*C. rosaceana*	137.0 ± 45.1a	56.3 ± 21.6b	3.8 ± 2.1c	93.3	97.2
	P. limitata	282.6 ± 33.5b	460.3 ± 173.7a	66.2 ± 35.3c	85.6	76.6
1999	*C. rosaceana*	211.7 ± 37.1a	150.1± 73.1a	27.8 ± 11.3b	87.5	86.9
	P. limitata	101.7 ± 28.5b	386.8 ± 155.2a	2.3 ± 0.8c	99.4	97.7
Mean	*C. rosaceana*	174.4 ± 37.4a	103.2 ± 46.9a	51.9 ± 36.8b	90.4 ± 4.6	92.1± 5.1
1998-1999	*P. limitata*	192.2 ± 90.5b	423.6 ± 36.7a	51.1 ± 24.9c	92.5 ± 4.8	87.2 ± 10.6

[1] Means within a row a followed by different letters are significantly different (P < 0.05) by Student Neuman Keuls' multiple comparisons test following significant (P < 0.05) ANOVA.
[2] Percent trap catch reduction in Isomate-CM/LR-treated organic orchards relative to catches in untreated organic orchards or insecticide-treated conventional orchards.

female *P. limitata* in the insecticide-treated orchards was higher during the first generation in 1999 (82.9%) compared with 1998 (53.6%), while percent mating (2.9%) during the first generation in the Isomate-CM/LR-treated orchards was identical in 1998 (Fig. 2) and 1999 (Table 3).

Disruption of mating in leafrollers. When the entire 1998 season is considered (Fig. 2), Isomate-CM/LR significantly reduced mating of *C. rosaceana* by 95.4% (χ^2 = 378.47, df = 1, P < 0.001) and mating of *P. limitata* by 87.1% (χ^2 = 376.78, df = 1, P < 0.001) relative to their mating in insecticide-treated orchards, respectively. Disruption of mating in both species tended to be lower during the second-generation flight period, dropping to 93.5% in *C. rosaceana* and 76.4% in *P. limitata*, respectively. Even though percent mating of *P. limitata* in the insecticide-treated orchards was lower during the first generation of 1998 (Fig. 2) than 1999 (Table 3), disruption of mating by treatment with Isomate-CM/LR was similar in 1998 (95.7%) and 1999 (96.4%).

Fruit damage. Summer leafroller damage in pheromone-treated organic orchards ranged from 1.7 - 24.8% in 1997, 0.4 - 4.2% in 1998, and 0.4 - 13.7% in 1999 (Fig. 4A). From 1997 - 1999 leafroller damage declined in 4 of the 5 organic orchards and in 12 out of 15 orchard-years damage was less than 5% at harvest under Isomate-CM/LR treatment. Downward trends in leafroller damage over three years appeared correlated with downward trends in total catches of leafrollers in each orchard, respectively (Fig. 4B). There was a significant correlation (r = 0.65, P < 0.009) between total leafroller trap catches and damage at harvest, but catches of leafrollers only explained 42.3% of the variation in harvest damage (Fig. 4C). Comparison of leafroller damage in five organic orchards under management with Isomate-CM/LR, and five conventional orchards under various insecticide programmes is shown in Fig. 5. Damage levels were not significantly different between the two groups of pheromone- and insecticide-treated orchards in 1998 and 1999 (Fig. 5).

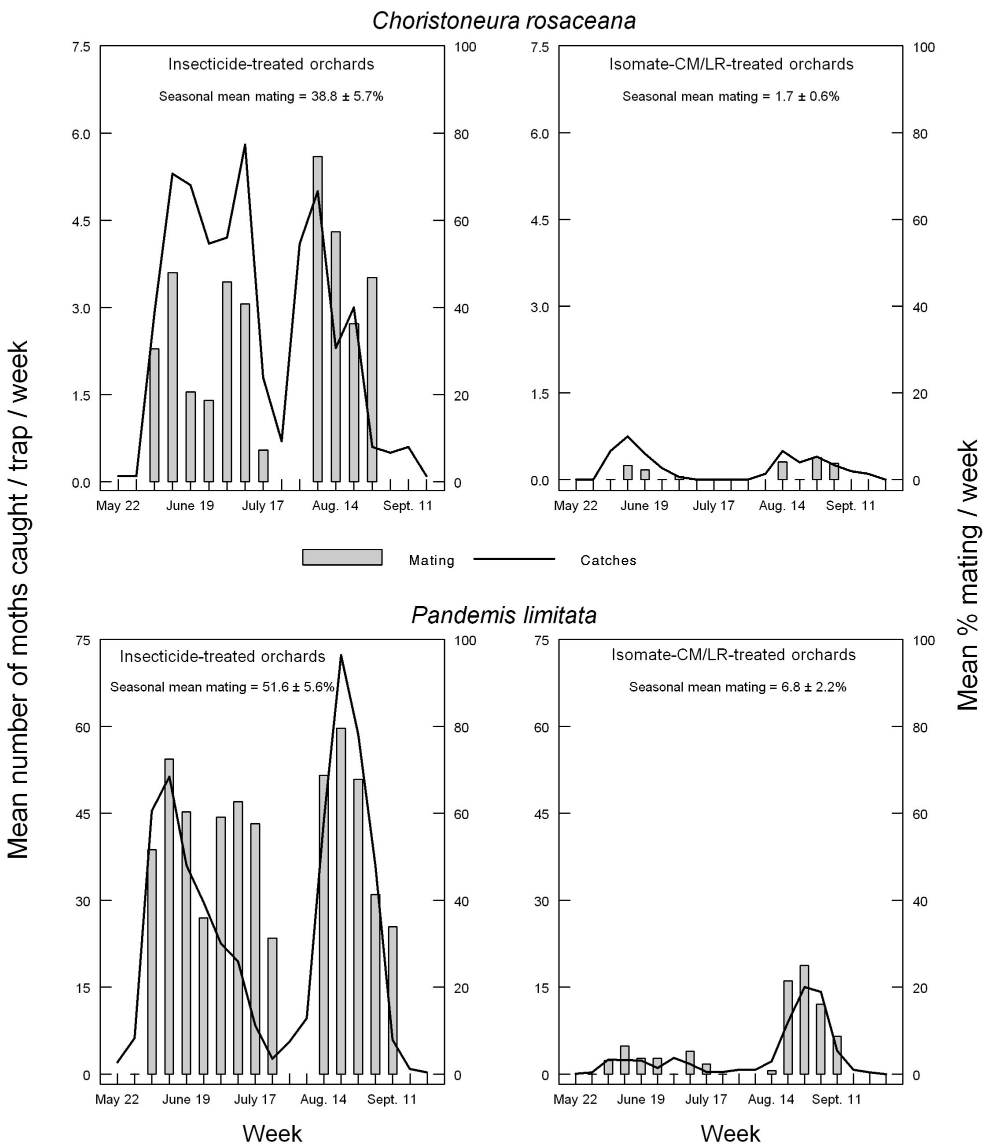

Figure 2. Observed mean weekly percent mating of two leafroller species on mating tables hung in Isomate-CM/LR-treated organic apple orchards (*n* = 5) and insecticide-treated conventional apple orchards (*n* = 5) and mean weekly catches of moths in synthetic pheromone traps in the same orchards in 1998.

DISCUSSION

Previously we showed that Isomate-CM/LR was a useful spring-time supplement for the codling moth SIT programme in BC (Judd and Gardiner 2005), but its additional benefits as a supplement for control of leafrollers in organic orchards was not described. This study has demonstrated that pheromone communication and mating in sympatric leafroller moths commonly found infesting organic apples in the Similkameen Valley of BC can be effectively and simultaneously disrupted by releasing a mixture

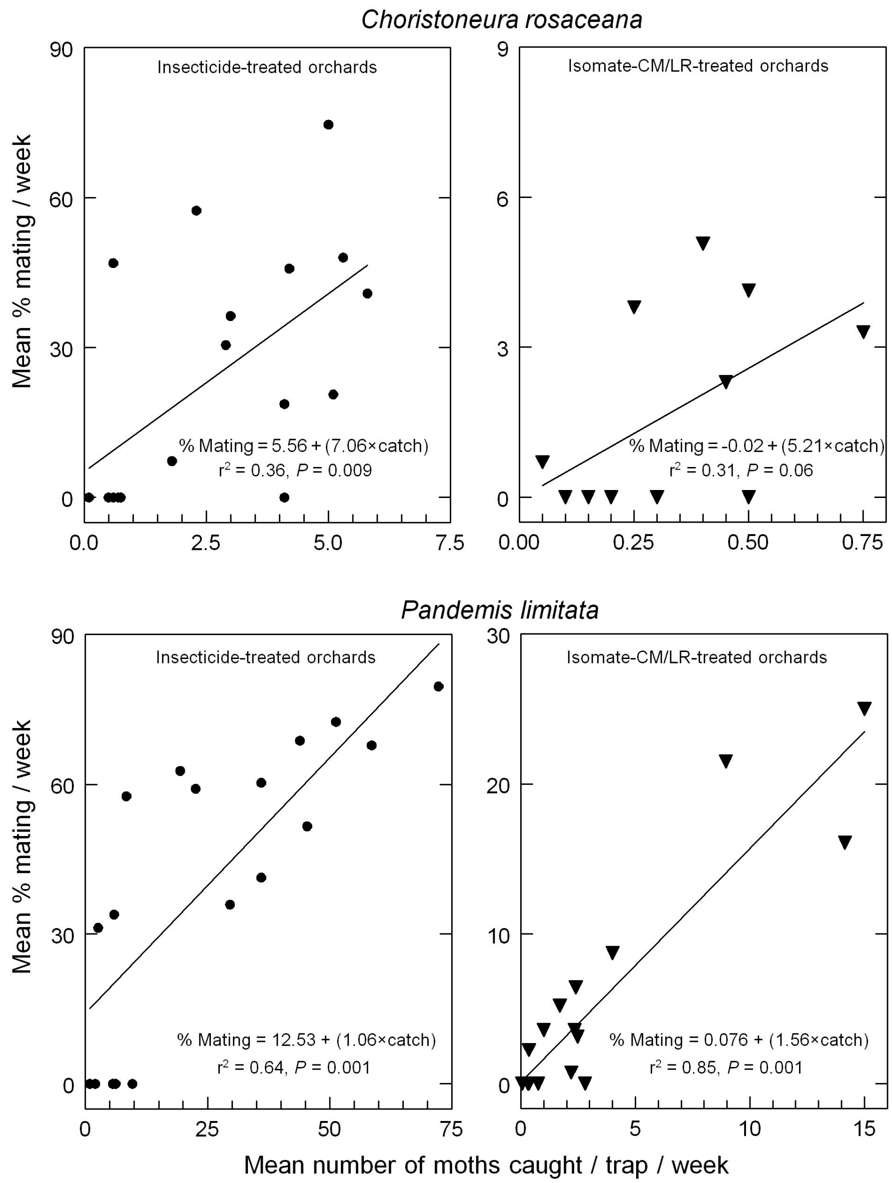

Figure 3. Regression analyses showing relationships between relative moth density (trap catches) and mating in two leafroller species in Isomate-CM/LR-treated organic apple orchards (n = 5) and insecticide-treated conventional apple orchards (n = 5) in 1998.

of their major pheromone components from Isomate-CM/LR. Season-long reductions of pheromone trap catches of both *C. rosaceana* and *P. limitata* with Isomate-CM/LR were comparable to levels seen in several studies examining each species individually (Deland *et al.* 1994, Agnello *et al.* 1996, Knight *et al.* 1998, Knight and Turner 1999, Trimble and Appleby 2004) and greater than levels observed in other studies (Lawson *et al.* 1996). There is no generally accepted level for the reductions in pheromone trap catches often observed using mating disruption that correlate with crop protection, but the observation has been made that this reduction is usually 97 - 100% in species where disruption appears to be an effective crop-protection tool

Table 3.
Percentage of female *Pandemis limitata* mating in mating tables when placed in insecticide-treated conventional and Isomate-CM/LR-treated organic apple orchards for increasing lengths of time during first-generation flight in 1999.

Hours females were in field	Insecticide-treated orchard		Isomate-CM/LR-treated orchard		% mating reduction[3]
	n females[1]	% mated[2]	*n* females[1]	% mated[2]	
24	274	86.5a	246	2.03a	97.6*
48	274	75.9a	252	4.36a	94.3*
72	242	80.6a	224	3.12a	96.1*
96	220	79.5a	220	2.27a	97.1*
Total (24 - 96 h)	1010	82.9	942	2.97	96.4*

[1] *n* = total number of live females recovered from field in test period.
[2] Percentages within a column followed by the same letter are not significantly different ($P > 0.05$) based on a χ^2 test of the null hypothesis of equal mating frequencies across time categories.
[3] Asterisk indicates a significant ($P < 0.001$) reduction in mating based on a comparison of paired proportions of mating within a row using a binomial *Z*-test (Zar 1984).

(Trimble and Appleby 2004). In many mating-disruption studies on *C. rosaceana* (Reissig *et al.* 1978, Deland *et al.* 1994, Agnello *et al.* 1996, Lawson *et al.* 1996, Knight *et al.* 1998, Trimble and Appleby 2004), pheromone treatments have resulted in less than 97% reduction in pheromone trap catches relative to catches with the same traps in insecticide-treated orchards. In our study, a reduction of this magnitude was achieved in 1998 when fewer than 4 moths were caught / trap / year (Table 2) and a similar reduction was observed for *P. limitata* in 1999 when catches of this moth averaged fewer than 3 moths / trap / year. Knight and Turner (1999) found a significant negative relationship between mean catches of *Pandemis* spp. / trap and percent reduction of catches in synthetic pheromone traps. A similar relationship has not been reported for *C. rosaceana*, but our data (Table 2) reflect this type of trend for both species.

Presumably, reductions in pheromone trap catches are correlated with reductions in mating, but this is almost never confirmed in mating-disruption studies because measures of mating are often missing. Actual reductions in female mating should be more directly correlated with reductions in damage from larvae than reductions in males caught in pheromone traps. We found relatively large correlations between trap catches, a relative measure of population density, and mating of *P. limitata* on mating tables (Fig. 3), but only a weak correlation was found for *C. rosaceana* in the insecticide-treated orchards, and no correlation was found for this species in the pheromone-treated orchards (Fig. 3). Given that catches of *P. limitata* represented about 50% of the total leafroller catch in organic orchards during 1997 - 1999, and total catches of leafrollers declined in Isomate-CM/LR-treated orchards each year (Table 2), a significant, albeit weak, relationship between total leafroller catches and damage may be expected (Fig. 4C). A better relationship might be observed in orchards having populations of *P. limitata* only. Nevertheless, the relationship shown in Fig. 4C is consistent with the view that the reduction in trap catches needs to be close to 99% (ca. 6 moths / trap / season) to ensure damage from leafrollers is 1% or less, an acceptable level for organic apple producers in BC.

We acknowledge that the relationship we have shown between trap catches in pheromone-treated organic orchards and damage from summer-feeding leafrollers may not hold true for conventional orchards in this region, because there are significant

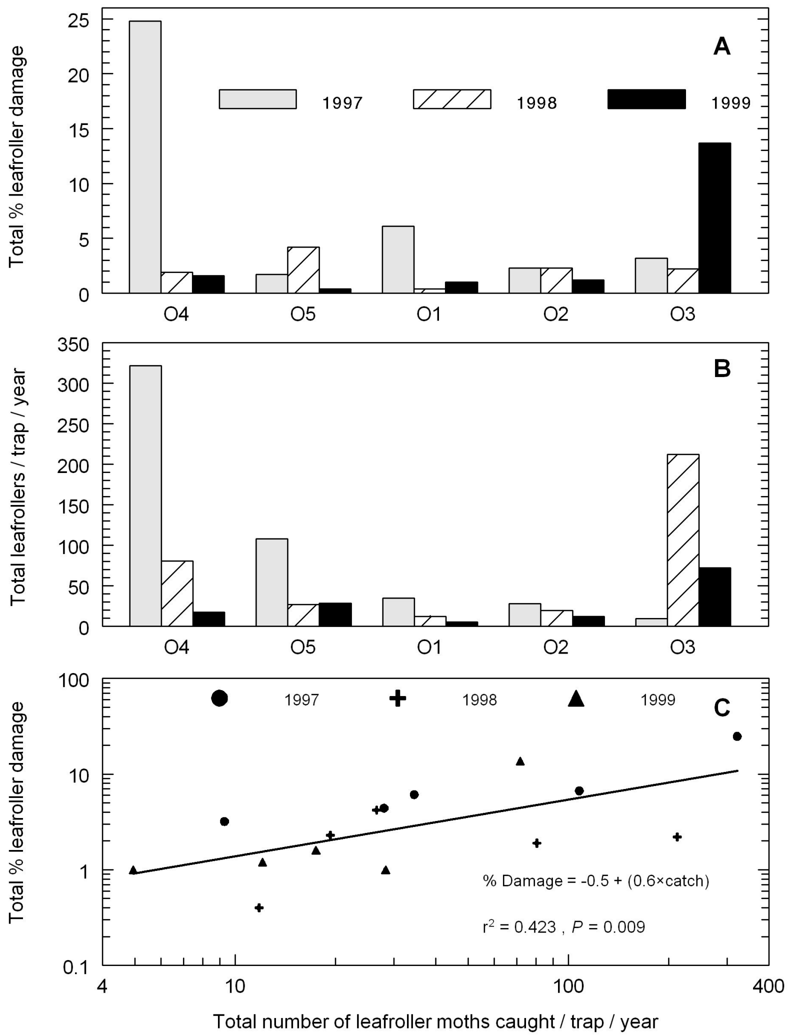

Figure 4. Percentage of damage at harvest caused by summer-feeding leafroller larvae in each Isomate-CM/LR-treated organic apple orchard by year (A), total number of leafroller moths (*Choristoneura rosaceana* and *Pandemis limitata*) caught in synthetic pheromone traps in each Isomate-CM/LR-treated organic apple orchard by year (B), and linear regression of the observed relationship between damage and total leafroller catches (log scales) in 1997 - 1999 (C).

differences in the levels of biological control in these different production systems. In a study running parallel to ours, Cossentine *et al*. (2004) found that summer larval populations of both *C. rosaceana* and *P. limitata* in untreated organic apple orchards in the Similkameen Valley experienced parasitism rates as high as 68% during 1998 and 1999, and higher levels of parasitism were observed as leafroller populations declined. Given these observations, if mating disruption was causing leafroller populations to decline then it might be expected to increase the impact of parasitoids and reduce damage. The general absence of these natural control agents in local conventional orchards (Joan Cossentine, personal communication) may invalidate any application of an established relationship between trap catches and damage from organic orchards where natural controls are also acting. Mating disruption of leafrollers in conventional orchards may have to be augmented with insecticides,

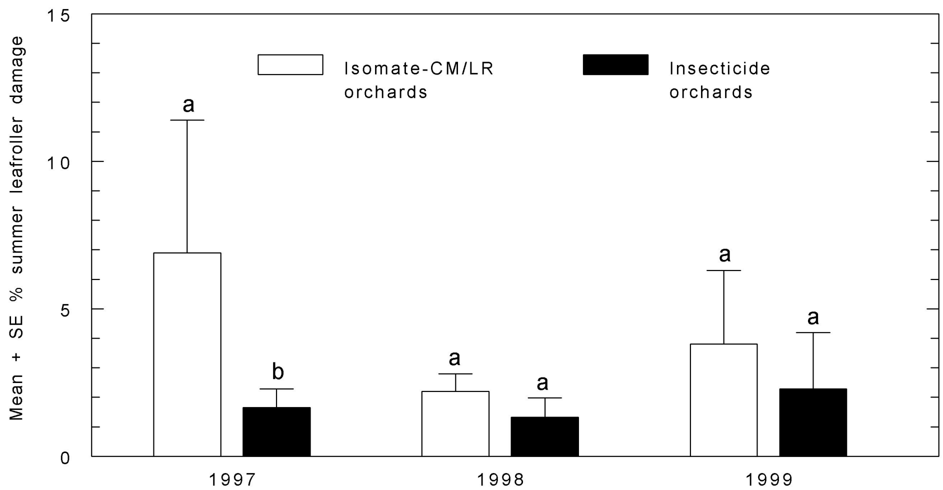

Figure 5. Comparison of mean (+ SE) percent damage at harvest caused by summer-feeding leafroller larvae in Isomate-CM/LR-treated organic apple orchards (*n* = 5) and insecticide-treated conventional apple orchards (*n* = 5) in 1997 -1999. Paired means with the same letter superscript are not significantly different ($P > 0.05$) by two-sample *t*-test.

particularly where *C. rosaceana* is the dominant species. With one exception (Trimble and Appleby 2004), limited use of selective insecticides in combination with mating disruption has provided a small improvement in the control of *C. rosaceana* over mating disruption alone (Agnello *et al.* 1996, Lawson *et al.* 1996, Knight *et al.* 1998, Knight *et al.* 2001).

To the best of our knowledge this study is the only evaluation of mating disruption of *C. rosaceana* and *P. limitata* with Isomate-CM/LR in organic production systems where no insecticides were applied. This technique holds promise for organic pome fruit producers in the Similkameen Valley, especially if *P. limitata* is the dominant species. Our results are in sharp contrast to a failure of mating disruption to keep damage from *C. rosaceana* below economic levels in other regions even when used in conjunction with pesticides (Agnello *et al.* 1996, Lawson *et al.* 1996). This failure has been attributed to high population density and potential immigration of adults and larvae into treatment areas. Population density should be an important factor in limiting the efficacy of mating disruption, but this has seldom been shown experimentally. Our data certainly point to a strong relationship between relative adult numbers, mating success and harvest damage, but moth catches in our pheromone-treated orchards were often greater than those reported elsewhere so it is difficult to reconcile our results on the basis of adult population differences alone. Four of the five organic orchards in this study were somewhat isolated by having other orchards located on only one border. Orchard O3 was the only one that was surrounded by adjacent orchards, particularly cherries, which were not treated for leafrollers, and it was the one orchard in which we saw a significant increase in catches of *P. limitata* late in 1998 and damage in 1999 (Fig. 4). Interestingly this was the only orchard that received a petal-fall spray of Bt in spring of 1998. As noted by Knight *et al.* (1998), immigration may be an important constraint on use of mating disruption for leafrollers, but monitoring may help to allay some of this concern if it can predict immigration of adults, as it did in orchard O3.

Although damage in the organic orchards was comparable to that seen in some comparison insecticide-treated orchards (Fig. 5), we make no claim that mating disruption is as effective as an optimal insecticide-based control programme. However, we are of the opinion that the efficacy of mating disruption against any species is best evaluated over several years. Mating disruption is certainly a less robust control technique than most insecticides, and more constrained by population density than the latter. Suppression of codling moth populations using mating disruption often takes several years and this will probably be true of leafrollers (Fig. 4). Depending on the comparison orchards chosen, it is possible for mating-disruption technology to look very effective, or highly ineffective; a better approach may be to examine its long-term effects in the same locations over several years and compared with standard systems as has been used for codling moth (Charmillot 1990, Judd *et al.* 1997). The long-term impact of mating disruption on biological control of leafrollers in orchards (Cossentine *et al.* 2004) relative to standard controls also needs to be considered.

In areas of BC outside the Similkameen Valley, control of leafrollers using pheromone-based mating disruption requires a multi-species approach if different complexes of sympatric leafrollers are to be controlled effectively (Judd and McBrien 1995). For example, in the Okanagan and Creston Valleys of BC, eye-spotted bud moth, S*pilonota ocellana* (Denis and Schiffermüller), European leafroller, *Archips rosanus* (L.) and fruit-tree leafroller, *Archips argyrospilus* (Walker) are also important pests of apple. The latter two species use *Z*11-14:Ac as the major component in their multi-component pheromone blends (Arn *et al.* 1982) and small-plot studies (Deland 1992) demonstrated that pheromone communication and mating in *A. rosanus* and *A. argyrospilus* could be disrupted effectively with a pheromone blend similar to that used in Isomate-CM/LR. *Spilonota ocellana*, however, uses (*Z*)-8-tetradecenyl acetate as its major pheromone component (Arn *et al.* 1982) and would not be controlled by Isomate-CM/LR, but can be controlled by mating disruption (McBrien *et al.* 1998). An Isomate dispenser containing this added ingredient is currently under study as a mating-disruption system for control of the entire leafroller complex found in organic pome fruit orchards in BC. With an organic formulation of spinosad (Entrust®) registered in Canada during 2005, the combined use of this insecticide and mating disruption in organic orchards also warrants study, because the impact of spinosad on parasites of leafrollers in these systems needs to be considered carefully.

ACKNOWLEDGEMENTS

We thank the Similkameen-Okanagan Organic Producers' Association (SOOPA) and its cooperating members for allowing us to conduct trials in their orchards. We thank Janine Gartrell, Lila DeLury, Karen Todd, and Nicole Verpaelst for technical assistance. We especially thank Joan Cossentine for providing trapping data on leafrollers in untreated orchards, and Don Thomson of Pacific Biocontrol Corporation for making Isomate-CM/LR available for testing and sharing technical data on this product. This research was partially funded by the Washington State Tree Fruit Research Commission, SOOPA and the Agriculture and Agri-Food Canada Matching Investment Initiative.

REFERENCES

Agnello, A.M., W.H. Reissig, S.M. Spangler, R.E. Charlton, and D.P. Kain. 1996. Trap response and fruit damage by obliquebanded leafroller (Lepidoptera: Tortricidae) in pheromone-treated apple orchards in New York. Environmental Entomology 25: 268-282.

Arn, H., M. Tóth, and E. Priesner. 1982. List of sex pheromones of Lepidoptera and related attractants, 2nd Edition. International Organization for Biological Control, Montfavet.

Brunner, J.F., L.J. Gut, and A.L. Knight. 1994. Transition of apple and pear orchards to a pheromone-based pest management system. Proceedings of the Washington State Horticultural Association 88: 169-175.

Calkins, C.O. 1998. Review of the codling moth area-wide suppression program in the western United States. Journal of Agricultural Entomology 15: 327-333.

Charmillot, P.-J. 1990. Mating disruption technique to control codling moth in western Switzerland, pp. 165-182. *In* Ridgway, R.L., Silverstein, R.M., Inscoe, M.N. (Eds.), Behavior-Modifying Chemicals for insect Management: applications of pheromones and other attractants. Marcel Dekker, Inc., New York and Basel.

Cossentine, J., L. Jensen, and K. Deglow. 2003. Strategy for orchard use of *Bacillus thuringiensis* while minimizing impact on *Choristoneura rosaceana* parasitoids. Entomologia Experimentalis et Applicata 109: 205-210.

Cossentine, J., L. Jensen, K. Deglow, A. Bennett, H. Goulet, J. Huber, and J. O'Hara. 2004. The parasitoid complex affecting *Choristoneura rosaceana* and *Pandemis limitata* in organically managed apple orchards. BioControl 49: 359-372.

Deland, J.-P. 1992. Mating disruption of fruittree leafroller, *Archips argyrospilus*, and effects on other leafroller species. Master of Pest Management Thesis. Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, Canada.

Deland, J.-P., G.J.R. Judd, and B.D. Roitberg. 1994. Disruption of pheromone communication in three sympatric leafroller (Lepidoptera: Tortricidae) pests of apple in British Columbia. Environmental Entomology 23: 1084-1090.

Dyck, V.A. and M.G.T. Gardiner. 1992. Sterile-insect release programme to control the codling moth *Cydia pomonella* (L.) (Lepidoptera: Olethreutidae) in British Columbia, Canada. Acta Phytopathologica et Entomologica Hungarica 27: 219-222.

Gut, L.J. and J.F. Brunner. 1998. Pheromone-based management of codling moth (Lepidoptera: Tortricidae) in Washington apple orchards. Journal of Agricultural Entomology 15: 387-405.

Judd, G.J.R. and M.G.T. Gardiner. 2004. Simultaneous disruption of pheromone communication and mating in *Cydia pomonella, Choristoneura rosaceana* and *Pandemis limitata* (Lepidoptera: Tortricidae) using Isomate-CM/LR in apple orchards. Journal of the Entomological Society of British Columbia 101: 3-13.

Judd, G.J.R. and M.G.T. Gardiner. 2005. Towards eradication of codling moth in British Columbia by complimentary action of mating disruption, tree-banding and sterile insect technique: five-year study in organic orchards. Crop Protection 24: 718-733.

Judd, G.J.R. and H.L. McBrien. 1995. Pheromone-based management of pome fruit pests in British Columbia: a multiple-species approach, pp. 9-17. *In* Research, development and commercialization of semiochemicals in insect pest management in Canada. Proceedings of The Entomological Societies of Manitoba and Canada, Workshop, Winnipeg, Manitoba, 1994.

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.

Knight, A.L. 1995. 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.

Knight, A.L. and J.E. Turner. 1999. Mating disruption of *Pandemis* spp. (Lepidoptera: Tortricidae). Environmental Entomology 28: 81-87.

Knight, A., S. Cockfield, D. Thomson, and D. Neff. 1997. Developing mating disruption for leafrollers. *In* Proceedings of the 71st Annual Western Orchard Pest and Disease Management Conference, Portland, Oregon, U.S.A. January 8-10, 1997. Western Orchard Pest and Disease Management Conference 71: 112-114.

Knight, A.L., D.R. Thomson, and S.D. Cockfield. 1998. Developing mating disruption of obliquebanded leafroller (Lepidoptera: Tortricidae) in Washington State. Environmental Entomology 27: 1080-1088.

Knight, A.L., B.A. Christianson Jr., S. Cockfield, and J. Dunley. 2001. Areawide management of codling moth and leafrollers. Good Fruit Grower 52(11): 31-33.

Lawson, D.S., W.H. Reissig, A.M. Agnello, J.P. Nyrop, and W.L. Roelofs. 1996. Interference with the mate-finding communication system of the obliquebanded leafroller (Lepidoptera: Tortricidae) using synthetic sex pheromones. Environmental Entomology 25: 895-905.

Madsen, H.F. and B.J. Madsen. 1980. Response of four leafroller species (Lepidoptera: Tortricidae) to sex attractants in British Columbia orchards. The Canadian Entomologist 112: 427-430.

Madsen, H.F. and C.V.G. Morgan. 1970. Pome fruit pests and their control. Annual Review of Entomology 15: 295-320.

Madsen, H.F. and P.J. Procter. 1985. Insects and mites of tree fruits in British Columbia. British Columbia Ministry of Agriculture and Food. Publication 82-6. Victoria, BC.

McBrien, H.L. and G.J.R. Judd. 1996. Teflon®-walled mating table for assessing the efficacy of pheromone-based mating disruption. Journal of the Entomological Society of British Columbia 93: 121-125.

McBrien, H.L., G.J.R. Judd, and J.H. Borden. 1998. Development of pheromone-mediated mating disruption for control of the eye-spotted bud moth, *Spilonota ocellana*. Entomologia Experimentalis et Applicata 88: 101-107.

Mullinix, K. 2005. Pacific Northwest / Colorado / British Columbia - Regional Report, pp. 24-30. *In* Proceedings of the third national organic tree fruit research symposium, June 6-8, 2005, Chelan, WA, USA.

Reissig, W.H., M. Novak, and W.L. Roelofs. 1978. Orientation disruption of *Argyrotaenia velutinana* and *Choristoneura rosaceana* male moths. Environmental Entomology 7: 631-632.

Roelofs, W., A. Cardé, A. Hill, and R. Cardé. 1976. Sex pheromone of the threelined leafroller, *Pandemis limitata*. Environmental Entomology 5: 649-652.

Shorey, H.H. and R.L. Hale. 1965. Mass-rearing of the larvae of nine noctuid species on a simple artificial medium. Journal of Economic Entomology 58: 522-524.

Trimble, R.M. and M.E. Appleby. 2004. Comparison of efficacy of programs using insecticide and insecticide plus mating disruption for controlling the obliquebanded leafroller in apple (Lepidoptera: Tortricidae). Journal of Economic Entomology 97: 518-524.

Vakenti, J.M., A.P. Guance, K.N. Slessor, G.G.S. King, A.A. Allan, H.F. Madsen, and J.H. Borden. 1988. Sex pheromone components of the oblique-banded leafroller, *Choristoneura rosaceana* in the Okanagan Valley of British Columbia. Journal of Chemical Ecology 14: 605-621.

van Deventer, P., A.K. Minks, L.H.M. Blommers, U. Neuman, and K. Jilderda. 1992. Mating disruption utilizing lepidopterous sex pheromones: three years of testing in apple orchards in The Netherlands. Brighton Crop Protection Conference — Pests and Diseases 3: 1193-1198.

Walker, K.R. and S.C. Welter. 2001. Potential for outbreaks of leafrollers (Lepidoptera: Tortricidae) in California apple orchards using mating disruption for codling moth suppression. Journal of Economic Entomology 94: 373-380.

Wearing, C.H., J.T.S. Walker, W.P. Thomas, J.R. Clearwater, D.M. Suckling, J.G. Charles, P.W. Shaw, V. White, and G. Burnip, G. 1995. Pest control for organic apple production in New Zealand. The Orchardist July: 22-27.

Zar, J.H. 1984. Biostatistical Analysis, Second edition. Prentice Hall, Englewood Cliffs, USA.