Efficacy and Release Rate of Reservoir Pheromone Dispensers for Simultaneous Mating Disruption of Codling Moth and Oriental Fruit Moth (Lepidoptera: Tortricidae)

L. L. STELINSKI,[1,2] A. L. IL'ICHEV,[3] AND L. J. GUT[1]

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ABSTRACT Five formulations of controlled release, polyethylene tube dispensers of pheromone were evaluated during three field seasons for disruption of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), and the oriental fruit moth, *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae). Evaluations were conducted in replicated 4-ha plots of commercial apple in Michigan. Disruption of both *C. pomonella* and *G. molesta* male orientation to pheromone traps in plots treated with a dual-species formulation (Isomate CM/OFM TT), simultaneously releasing the pheromone components of both *C. pomonella* and *G. molesta*, was equivalent to that obtained by treating plots with separate formulations for each species (Isomate C Plus or Isomate C TT for *C. pomonella* and Isomate M Rosso for *G. molesta*) through mid-season. However, disruption efficacy of the dual-species formulation was significantly lower near the end of the season for *G. molesta* compared with the Isomate M Rosso formulation because of depletion of active ingredients and coincided with a slight increase in fruit injury. Effective disruption of *C. pomonella* and *G. molesta* also was obtained with a multispecies formulation (Isomate CM/OFM/LR) that releases the main pheromone components of *C. pomonella*, *G. molesta*, and several leafroller species. Each formulation type releasing (*E*,*E*)-8,10-dodecadien-1-ol (codlemone) also was found to release the E,Z- and Z,E-isomers of codlemone. Our data provide further evidence that simultaneous disruption of *C. pomonella* and *G. molesta* with dispensers releasing both species' pheromone components is possible; however, the controlled release formulations tested here require modification or postponed deployment coupled with early season control by other means to achieve season-long efficacy. Simultaneous disruption of several species with a single formulation will be economically advantageous in regions where control of multiple pests is needed given the need for hand application of this technology.

KEY WORDS *Cydia pomonella*, *Grapholita molesta*, mating disruption, Isomate, sex attractant pheromone

The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), and the oriental fruit moth, *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae), are worldwide pests of pome and stone fruits (Vickers and Rothschild 1991, Rothschild and Vickers 1991). Resistance to organophosphate insecticides has been documented for both species (Riedl et al. 1985, Varela et al. 1993, Pree et al. 1998, Reuveny and Cohen 2004), and mating disruption has been effectively integrated into management programs for both *C. pomonella* (Brunner et al. 2002) and *G. molesta* (Pree et al. 1994, Trimble et al. 2001). Implementation of mating disruption for these two key pests has led to reductions in the number of broad-spectrum insecticide sprays needed for adequate control, but has resulted in outbreaks of secondary tortricid pests such as leafrollers (Rice and Kirsch 1990, Gut and Brunner 1998, Walker and Welter 2001). In Michigan, a complex of tortricid pests including *C. pomonella* and *G. molesta,* as well as obliquebanded leafroller, *Choristoneura rosaceana* (Harris), and redbanded leafroller, *Argyrotaenia velutinana* (Walker) requires concurrent management in tree fruit. Application of separate mating disruption formulations for each species, particularly hand-applied dispensers, hinders adoption of this technology in Michigan (Gut et al. 2004).

Multispecies disruption formulations targeting several co-occurring pests are a potential solution to controlling outbreaks of secondary tortricids and the high cost of applying more than one species-specific formulation. Simultaneous disruption with a single formulation is effective for species sharing major pheromone components and for species with distinct components. For example, a reservoir dispenser formulation releasing a 93:7 blend of (Z)-11-tetradecenyl

[1] Department of Entomology, Michigan State University, East Lansing, MI 48824.
[2] Current address: Department of Entomology and Nematology, Citrus Research and Education Center, University of Florida, Lake Alfred, FL 33850 (e-mail: stelinski@ufl.edu).
[3] BioSciences Research Division, Department of Primary Industries, Tatura, 3616 VIC, Australia.

acetate and (*E*)-11-tetradecenyl acetate effectively disrupts three sympatric leafoller species [*C. rosaceana, Archips rosanus* (L.), and *A. argyrospilus* (Walker)] (Deland et al. 1994). Also, dispensers releasing a 98:2 blend of (Z)-11-tetradecenyl acetate and (*E*)-11-tetradecenyl acetate simultaneously disrupt *C. rosaceana* and *Pandemis limitata* (Robinson) (Evenden et al. 1999). Similarly, dispensers releasing (*E,E*)-8,10-dodecadien-1-ol and (Z)-11-tetradecenyl acetate simultaneously disrupt *C. pomonella* and multiple leafroller species (Judd and Gardiner 2004).

The goal of this study was to compare the effectiveness of experimental and commercial multispecies reservoir dispensers for simultaneous disruption of *C. pomonella* and *G. molesta* with commercial dispensers designed for species-specific disruption of these tortricid pests in Michigan apple orchards. The effectiveness of treatments was assessed by inhibition of moth catch in pheromone traps and fruit injury evaluations. In addition, release rates of individual pheromone components from dispensers were quantified by gas chromatography to relate efficacy data with seasonal pheromone release.

Materials and Methods

Formulations Tested. Five formulations of controlled release sex pheromone dispensers were evaluated for mating disruption of *C. pomonella* and *G. molesta.* These were all made of polyethylene tubing and manufactured by Shin-Etsu Chemical Co. Ltd. (Tokyo, Japan).

Species-Specific Formulations. The formulations tested that specifically target *C. pomonella* were Isomate C Plus and Isomate C TT. The Isomate C Plus dispenser contained a total of 205 mg of 53.0% (*E,E*)-8,10-dodecadien-1-ol (codlemone), 29.7% dodecanol (12OH), 6.0% tetradecanol (14OH), and 11.3% inert ingredients per dispenser. Isomate C TT is a twin-tube design dispenser that contained a total of 440 mg of 48.9% codlemone, 27.3% 12OH, 6.3% 14OH, and 17.6% inert ingredients per dispenser. The species-specific formulation for *G. molesta,* Isomate M Rosso, contained 250 mg of 88.5% (Z)-8-dodecen-1-yl-acetate, 5.7% (*E*)-8-dodecen-1-yl-acetate, 1.0% Z-8-dodecen-1-ol, and 4.8% inert ingredients per dispenser.

Multispecies Formulations. The Isomate CM/OFM TT is a twin tube dispenser, simultaneously targeting both *C. pomonella* and *G. molesta,* containing a total of 424.1 mg (including 7.4% inert ingredients) of material per dispenser. The *C. pomonella* pheromone components were 58.3% codlemone, 9.2% 12OH and 1.9% 14OH per dispenser. The *G. molesta* pheromone components were 21.3% (Z)-8-dodecen-1-yl-acetate, 1.6% (*E*)-8-dodecen-1-yl-acetate and 0.3% (Z)-8-dodecen-1-ol per dispenser. The Isomate CM/OFM/LR dispenser is also a twin tube design targeting *C. pomonella, G. molesta,* and several leafroller species. These dispensers contained 450 mg (including 7.3% inert ingredients) of material per dispenser. The *C. pomonella* pheromone components were 34.0% codlemone, 5.0% 12OH, and 1.0% of 14OH per dispenser. The *G. molesta* pheromone components were 11.8% (Z)-8-dodecen-1-yl-acetate, 0.8% (*E*)-8-dodecen-1-yl-acetate, and 0.1% (Z)-8-dodecen-1-ol per dispenser. The leafroller components were 37.4% (Z)-11-tetradecenyl acetate, 0.6% (*E*)-11-tetradecenyl acetate, and 2.0% (Z)-11-tetradecenol.

Field Sites. Three experiments were conducted during consecutive field seasons (2001–2003) in commercial apple (*Malus* spp.) orchard plots in Grand Rapids, MI. Orchards were planted on a 4.6- by 5.5-m tree row spacing (441 trees per ha) with 4.9–5.5-m tall 'Delicious' apples. Replicate plots were four ha in size and separated by 70-m buffers at minimum. All plots on each farm were also treated with identical insecticide programs to prevent unacceptable levels of fruit damage at harvest. During the first generation of *C. pomonella* flight there were two applications of azinphos-methyl at 2.2 kg of formulated product/ha, and during the second generation there were two applications of thiacloprid at 0.43 liters/ha.

Experiment 1. The objective of this experiment was to compare the effectiveness of Isomate CM/OFM TT dispensers for simultaneous disruption of both *C. pomonella* and *G. molesta* with species-specific dispensers deployed simultaneously. The dual-species dispensers were deployed at 500 dispensers per ha. The single-species dispenser treatment consisted of a combination of Isomate C Plus (1,000 dispensers per ha) for *C. pomonella* and Isomate M Rosso (500 dispensers per ha) for *G. molesta.* The two single species dispensers were always deployed at least 3 m apart from one another. All dispensers were deployed in the upper third of the tree canopy. Plots not treated with pheromone served as a control. The experimental design was a randomized complete block with four replicates per treatment. Disruption was evaluated with four pheromone traps (LPD Scenturian Guardpost, Suterra, Bend, OR) per plot per species. Traps for *C. pomonella* were baited with Suterra CM 1X (1 mg of codlemone) red septum lures. Traps for *G. molesta* were baited with red septa loaded with 0.1 mg of a three component blend of (Z)-8-dodecenyl acetate: (*E*)-8-dodecenyl acetate:(Z)-8-dodecen-1-ol in a 100: 6:10 ratio. All traps were placed in the upper third of the tree canopy at least 15.2 m away from plot borders and separated from one another by at least 6 m. Midseason and harvest assessments of fruit injury were conducted by evaluating 30 randomly selected fruit (15 high and 15 low in the canopy) from each of 20 randomly selected trees per plot. The experiment was conducted season-long from 6 April to 28 September.

Experiment 2. This experiment was conducted identically to experiment 1 except that Isomate C TT dispensers deployed at 500 dispensers per ha were substituted for Isomate C Plus dispensers as the single species disruption treatment for codling moth. The experiment was arranged as a randomized complete block design with three replicates. Moth monitoring protocols and fruit injury analysis were conducted as described previously. The experiment was conducted season-long from 30 April to 24 September.

Experiment 3. A multicomponent dispenser (Isomate CM/OFM/LR) containing the pheromone components of *C. pomonella, G. molesta,* and the main pheromone components of several leafroller species was evaluated against a no pheromone control. *C. rosaceana* and *A. velutinana* can occur as important secondary pests of apples in Michigan and a dispenser simultaneously targeting *C. pomonella, G. molesta,* and leafroller moths is desirable. The experiment was arranged as a randomized complete block design with four replicates. Disruption of moth orientation and evaluation of fruit injury was as described for experiment 1. The experiment was conducted season-long from 30 April to 24 September.

Release Rate Analyses. All five dispenser types were deployed in the upper third of the tree canopy in apple trees not used for disruption trials on 11 May 2003. Six samples of each dispenser type were collected immediately after application to determine the amount of pheromone at test onset. Thereafter, samples were collected every 7–11 d until 19 September, 2003. During each collection, six replicate dispensers of each formulation were collected and analyzed.

Each dispenser was cut into 1–1.5-cm pieces and placed in a 125-ml flask. Ninety milliliters of acetone solvent and 2 ml of methyl tetradecanoate (50 mg/ml) as an internal standard were added per flask. The flasks were tightly sealed and left overnight at room temperature. The next day, the solvent was transferred to a 100-ml volumetric flask and the final volume adjusted to 100 ml. One milliliter of each extract was placed in a 15-ml centrifuge tube along with 2 ml of additional acetone. The tube was vortexed and the contents placed in a GC vial (Supelco, Bellefonte, PA).

Residual pheromone collected from dispensers was quantified using a gas chromatograph (GC) (HP-6890, Hewlett–Packard, Palo Alto, CA). The GC was fitted with a DBWAXETR polar column (model 122-7332, J &W Scientific, Folsom, CA) of length 30 m and internal diameter of 250 μm. The initial GC temperature was held at 130°C for 2 min and then ramped up at a rate of 2.5°C/min to 160°C where it was held for 2 min. The program then ran at 40°C/min to a final temperature of 230°C. The carrier gas, helium, entered the column at 20 psi.

Calibration standards for all of the pheromone components were developed and a conversion factor was calculated. The amount of each pheromone component was calculated based on the response to these standards. A set of calibration standards were injected onto the GC for each replicate set of dispensers analyzed. The percentage of loss due to extraction methods was determined by the loss of the methyl tetradecanoate internal standard.

Statistical Analyses. To normalize the distributions and homogenize variance, seasonal catches were transformed to ln $(x + 1)$ before analysis of variance (ANOVA). Fruit injury data were arcsine transformed before ANOVA. Tukey's honestly significant difference Test was used to compare treatment means (PROC GLM, SAS Institute 2000).

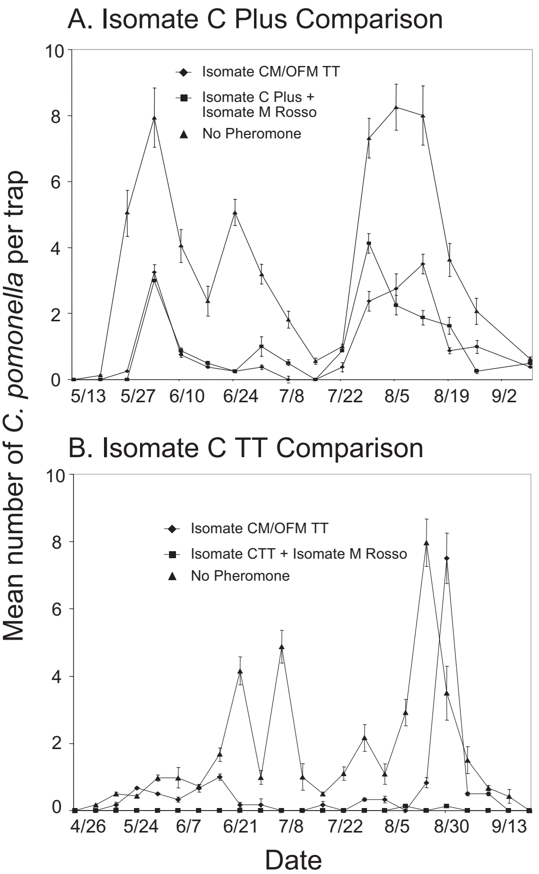

Fig. 1. Mean catch of *C. pomonella* males in pheromone traps in plots treated with Isomate CM/OFM TT dual dispensers or in no pheromone control plots compared with catch in plots simultaneously treated with Isomate C Plus and Isomate M Rosso (A) or Isomate C TT and Isomate M Rosso (B).

Results

Experiment 1. The mean ± SE number of male *C. pomonella* captured in traps in control plots (3.6 ± 0.3) was significantly ($F = 7.1$; df = 2, 6; $P = 0.05$) greater than in plots treated with Isomate C Plus dispensers (along with Isomate M Rosso for *G. molesta*) (1.0 ± 0.1) or with Isomate CM/OFM TT dual dispensers (1.0 ± 0.1); there was no significant difference among the latter two treatments. Disruption of *C. pomonella* was consistently similar over the course of the entire field season for both multi- and single-species formulation treatments (Fig. 1A).

Both the dual-species and species-specific dispenser treatments significantly ($F = 8.2$, df = 2,6, $P = 0.04$) reduced the number of male *G. molesta* captured in pheromone traps compared with the mean number captured over the course of the season in control plots (4.6 ± 0.3). Significantly fewer male *G. molesta* were captured in plots treated with Isomate M Rosso dispensers (along with Isomate C Plus for *C. pomonella*) (0.05 ± 0.02) compared with that in plots treated with

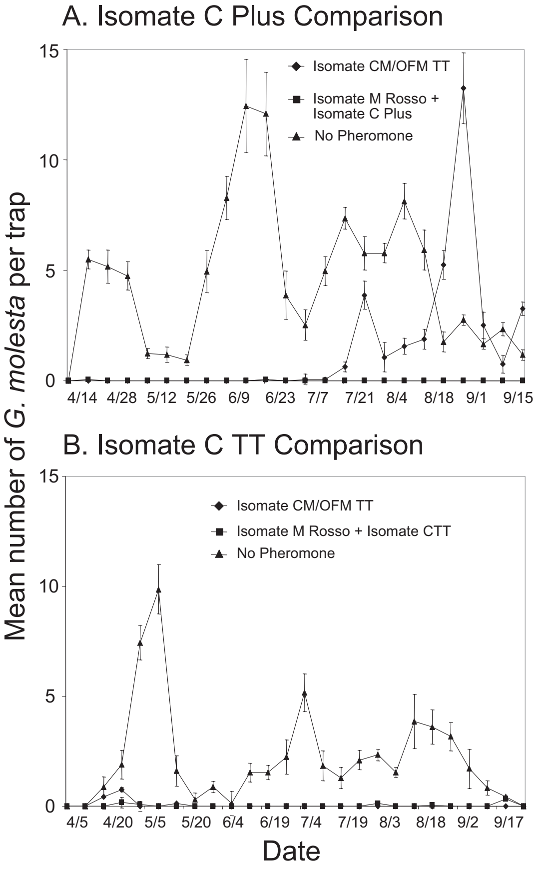

Fig. 2. Mean catch of male *G. molesta* in pheromone traps in plots treated with Isomate CM/OFM TT dual dispensers or in no pheromone control plots compared with captures in plots simultaneously treated with Isomate M Rosso and Isomate C Plus (A) or Isomate M Rosso and Isomate C TT (B).

Isomate CM/OFM TT dual dispensers (1.4 ± 0.3). Both pheromone treatments performed equally well until mid July, after which catch of male *G. molesta* in traps in plots treated with the Isomate CM/OFM TT dual dispensers was comparable or higher to that observed in control plots (Fig. 2A).

Fruit injury in control plots at mid-season and preharvest evaluations averaged 0.1 ± 0.1 and 0.2 ± 0.1%, respectively. There were no significant differences in fruit injury among the three treatments at mid-season ($F = 1.2$; df = 2, 6; $P = 0.3$) and at preharvest ($F = 0.9$; df = 2, 6; $P = 0.5$). At mid-season, no fruit injury could be detected in plots treated with separate species-specific Isomate dispensers, whereas 5.0 ± 0.3% fruit injury was recorded in plots treated with Isomate CM/OFM TT dual dispensers. At preharvest, fruit injury in plots treated with species-specific and dual-species dispensers averaged 0.2 ± 0.2 and 3.0 ± 0.9%, respectively.

Experiment 2. Both pheromone treatments significantly ($F = 8.5$; df = 2, 4; $P = 0.03$) reduced catch of male *C. pomonella* in pheromone traps compared with season-long catch in control plots (1.7 ± 0.2). Significantly fewer male *C. pomonella* were captured in plots treated with Isomate C TT dispensers (along with Isomate M Rosso for *G. molesta*) (0.01 ± 0.04) compared with plots treated with Isomate CM/OFM TT dual dispensers (0.6 ± 0.2). Efficacy of both multi- and single-species treatments was similar until mid August, after which catch of male *C. pomonella* in traps in plots treated with the Isomate CM/OFM TT dual dispensers was comparable to that observed in control plots (Fig. 1B).

The mean number of male *G. molesta* captured in control plots (2.2 ± 0.2) was significantly ($F = 7.2$; df = 2, 6; $P = 0.05$) greater than in plots treated with Isomate M Rosso dispensers (along with Isomate C TT for *C. pomonella*) (0.03 ± 0.04) or with Isomate CM/OFM TT dual dispensers (1.0 ± 0.1); there was no significant difference among the latter two treatments (Fig. 2B).

Fruit injury in control plots was 0.3 ± 0.2 and 2.0 ± 0.9% on average at mid-season and preharvest, respectively. There were no significant differences in fruit injury between the three treatments at mid-season ($F = 2.3$; df = 2, 6; $P = 0.1$) and at preharvest ($F = 1.4$; df = 2, 6; $P = 0.4$). At mid-season and preharvest, no fruit injury could be detected in plots treated with separate species-specific Isomate dispensers, whereas 0.3 ± 0.1% and 2.2 ± 1.2% fruit injury was recorded in plots treated with Isomate CM/OFM TT dual dispensers at mid-season and preharvest, respectively.

Experiment 3. The mean number of male *C. pomonella* captured in traps in plots treated with Isomate CM/OFM/LR dispensers was significantly ($F = 22.5$; df = 1, 3; $P = 0.01$) lower during the first (7.5 ± 4.2) and second (2.5 ± 1.8) generations of moth flight compared with captures in control plots (61.5 ± 18.7 and 67.5 ± 12.3, respectively). In these same plots treated with Isomate CM/OFM/LR, no *G. molesta* were captured season-long, whereas 108.5 ± 45.6 and 192.5 ± 65.3 were captured on average in control plots during the first and combined second and third generations, respectively.

There were no significant ($F = 3.2$; df = 1, 3; $P = 0.08$) differences in fruit injury between pheromone-treated (0.4 ± 0.2%) and control (0.5 ± 0.3%) plots at mid-season. No fruit injury was detected in any of the treatments at harvest.

Release Rate Analyses. The release rate profiles of pheromone components from Isomate C Plus and Isomate C TT dispensers are shown in Fig. 3A–D. Relatively stable release rates of 0.55 and 0.63 mg/d codlemone were observed over the course of the season for the Isomate C Plus and Isomate C TT dispensers, respectively (Fig. 3A and C). Although not declared as active ingredients, both E,Z- and Z,E-isomers of codlemone were detected from these dispensers over the course of the season (Fig. 3B and D).

Release of E,E-codlemone from the Isomate CM/OFM TT dual dispenser was also relatively stable over the course of the season at ≈1.14 mg/d (Fig. 4A). As with the species-specific dispensers for *C. pomonella*, both E,Z- and Z,E-codlemone were detected over the

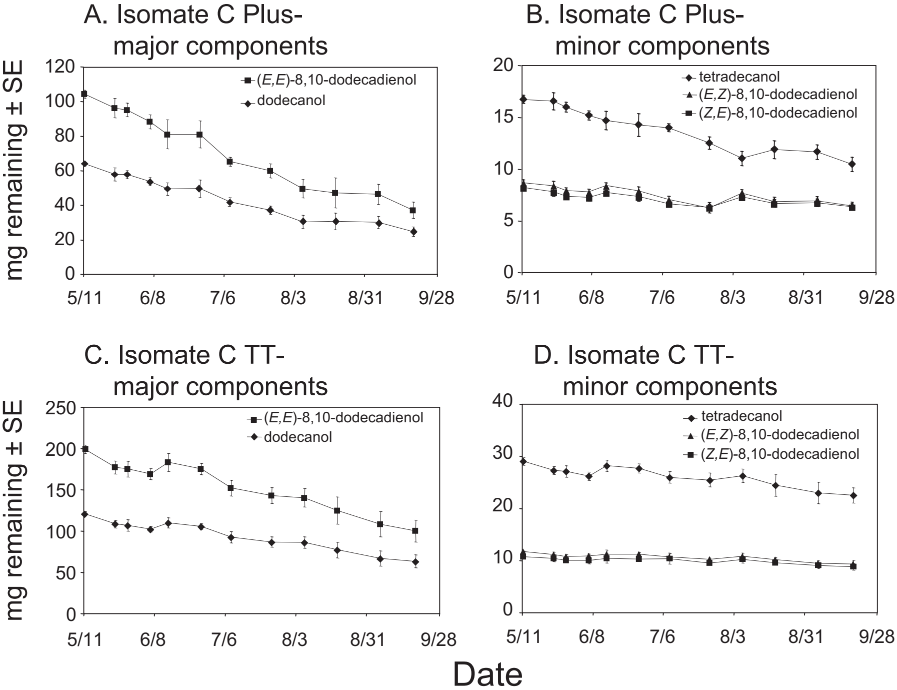

Fig. 3. Seasonal release rate of major and minor *C. pomonella* pheromone components from Isomate C Plus dispensers (A and B, respectively) and Isomate C TT dispensers (C and D, respectively).

course of the season (Fig. 4B). The release rate of the major component of the *G. molesta* blend [(Z)-8-dodecenyl acetate] was higher during the first 2 mo of deployment at ≈1.06 mg/d than for the remainder of the season, during which time it leveled off at 0.19 mg/d (Fig. 4C). In contrast, the release of (Z)-8-dodecenyl acetate from the Isomate M Rosso species-specific dispenser was quite steady season long at ≈1.15 mg/d (Fig. 4D).

The release rate of codlemone from the Isomate CM/OFM/LR dispenser was relatively steady during the first month of deployment at ≈0.55 mg/d, increased to ≈1.84 mg/d in late June and leveled off at ≈0.45 mg/d from August to late September (Fig. 5A). As before, the isomers of codlemone were detected season-long (Fig. 5B). The release rate of (Z)-8-dodecenyl acetate from these dispensers was 0.89 mg/d until 8 July and then decreased to 0.21 mg/d by 8 August; dispensers were completely depleted of *G. molesta* pheromone components by mid-August (Fig. 5C). The release rate of the major component of the leafroller pheromone [(Z)-11-tetradecenyl acetate] was relatively steady season long at ≈1.06 mg/d (Fig. 5D).

Discussion

The species-specific nature of pheromones for pest control in temperate tree fruit is beneficial given that nontarget organisms are not affected, but it is also one of the greatest challenges to adoption of this technology for pest control in locations where multiple pests require simultaneous disruption (Witzgall et al. 2008). If pheromones are to replace or substantially supplement broad-spectrum toxicants for control of moth pests in pome fruit growing regions such as Michigan, where a complex of several tortricid species co-exist, formulations will need to be available that simultaneously disrupt multiple species. *C. pomonella* remains the most important tortricid apple pest in Michigan (Gut et al. 2004) and throughout the world (Witzgall et al. 2008). However, *G. molesta* has recently also emerged as a major pest of apple in the eastern and midwestern United States (Kovanci et al. 2005; Myers et al. 2006). In addition, several leafroller species are sporadic secondary pests in North American pome fruit production (Hull et al. 1995, Agnello et al. 1996, Stelinski et al. 2005a). The cost associated with hand application of separate formulations for each species is a serious obstacle to adoption of mating disruption (Gut et al. 2004). Fortunately, multispecies formulations have proven effective. For example, the Isomate CM/LR dispenser effectively disrupts both *C. pomonella* and the leafroller, *P. limitata* (Judd and Gardiner 2004). Furthermore, simultaneous disruption of *C. pomonella* and *G. molesta* has been shown with the Isomate CM/OFM TT formulation in Australian pear orchards (Il'ichev et al. 2007) and with Puffer aerosol dispensers in North American apple orchards (Stelinski et al. 2007). The current results are consistent with previous findings showing that both dual species (Isomate CM/OFM TT) and multispecies (Isomate CM/OFM/LR) formulations simulta-

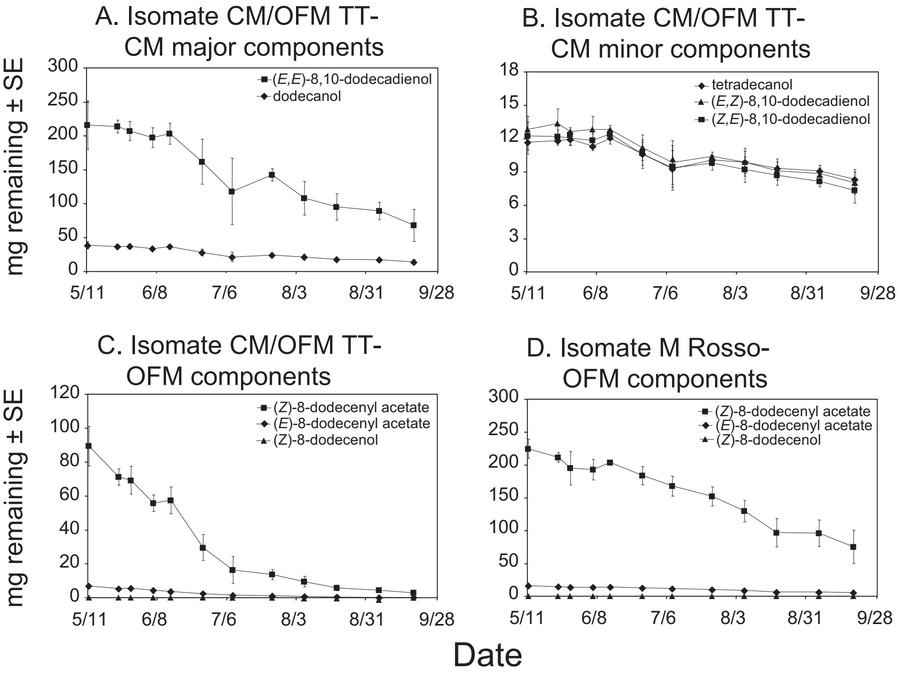

Fig. 4. Seasonal release rate of major (A) and minor (B) *C. pomonella* pheromone components and *G. molesta* pheromone components (C) from Isomate CM/OFM TT dual-species dispensers as well as seasonal release rate of *G. molesta* pheromone components from Isomate M Rosso dispensers (D).

neously disrupt orientation of both *C. pomonella* and *G. molesta.*

A drawback of the Isomate CM/OFM TT formulation, compared with the single-species formulations tested for both *C. pomonella* and *G. molesta,* was that the *G. molesta* pheromone components were depleted faster (Fig. 4C and D). Similarly, codlemone and the three *G. molesta* pheromone components exhibited a faster release rate and were depleted sooner from the multispecies Isomate CM/OFM/LR formulation compared with the three single-species formulations tested (Figs. 3A–D, 4D, and 5A and C). For the multispecies dispenser, the *G. molesta* components were completely depleted just after mid-season. Not surprisingly, efficacy of disruption was lower late in the season with dual-species dispensers compared with single species dispensers; this was particularly evident for *G. molesta* (Fig. 2A). Although equivalent application of insecticides to all treatment plots was necessary for this on-farm study to prevent unacceptable levels of fruit injury, infestation tended to be higher at preharvest in plots treated with the dual species CM/OFM TT dispensers compared with the coapplication two single-species formulations. This is consistent with the hypothesis that injury occurred as disruption began to fail due to insufficient release of the active ingredient from dual-species dispensers. This drawback of the dual- and multispecies dispensers warrants caution for late season control of *C. pomonella* and *G. molesta.* Timing of dispenser application may need to be adjusted such that dispensers are deployed 2–4 wk after *G. molesta* emergence to promote pheromone release until after fruit harvest. The first generation flight of *G. molesta* in this case may require targeted control with insecticides. By postponing application of the pheromone formulation rather than targeting pest outbreaks late in the season after potential pheromone depletion, postapplication reentry intervals are less likely to affect management decisions. Alternatively, perhaps the dispenser formulation can be improved by increasing loading rate or appropriately adjusting surface porosity to decrease release rate and prolong efficacy.

Each formulation evaluated for codling moth in the current investigation released the *E,Z* and *Z,E* isomers of codlemone which are known to isomerize on the surface of polyethylene-tube mating disruption dispensers similar to those evaluated in this study (Brown et al. 1992). These isomers are behavioral antagonists for *C. pomonella* males at sufficient release rates (El-Sayed et al. 1998). *C. pomonella* males are known to approach Isomate C Plus dispensers (Knight et al. 1999, Stelinski et al. 2005b) and thus competitive attraction is a likely contributing mechanism to disruption with such formulations. Isomerization of codlemone and subsequent emission of behavioral antagonists is likely an undesirable side effect of UV light and air exposure. Release of these antagonists could reduce the attractiveness of such dispensers or reduce the time that males spend orienting to or near these synthetic sources of pheromone. Chemical stabilization of codlemone on the surface of these dispensers

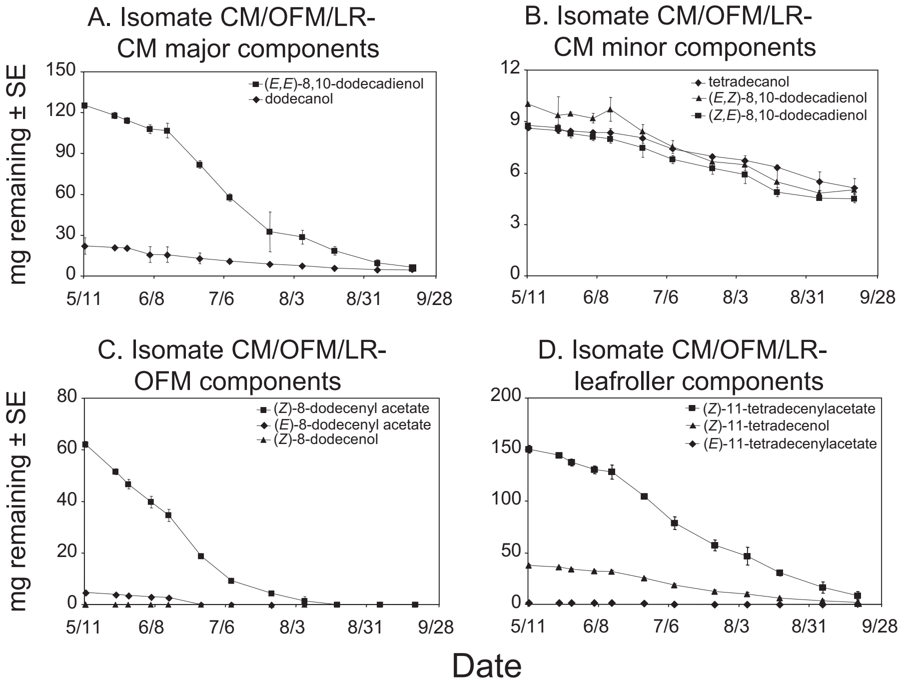

Fig. 5. Seasonal release rate of major (A) and minor (B) *C. pomonella* pheromone components, *G. molesta* pheromone components (C), and leafroller sp. pheromone components (D) from Isomate CM/OFM/LR dispensers.

may hold promise for improving efficacy of *C. pomonella* disruption with polyethylene-tube formulations. Disruption of *G. molesta* with multi- and single-species dispensers in this study seemed superior to that obtained with *C. pomonella.* This has been observed previously with several other types of disruption formulations (Gut et al. 2004). It is possible that formation of behavioral antagonists by chemical degradation of codlemone on the surface of mating disruption dispensers targeting *C. pomonella,* as observed in this study, contributes to the lesser efficacy of disruption for this species compared with other species, such as *G. molesta,* where this does not occur.

Addition of *G. molesta* pheromone components to an attracticide formulation containing codlemone reduced its attractiveness to male *C. pomonella* compared with formulations with codlemone alone (Evenden and McLaughlin 2005). Conversely, codlemone acts as a pheromone synergist for *G. molesta* (Allred et al. 1995, Evenden and McLaughlin 2005). In the current investigation, the dual-species Isomate CM/OFM TT formulation seemed consistently equivalent in efficacy to the species-specific formulations as long as pheromone active ingredients were being released. There was no clear evidence of negative or positive interactions of the combined *C. pomonella* and *G. molesta* pheromone components on disruption of either species, which is consistent with other recent investigations of dual *C. pomonella* and *G. molesta* disruption formulations (Il'ichev et al. 2007, Stelinski et al. 2007).

Although the efficacy of the Isomate CM/OFM/LR dispenser was not directly compared with single-species dispensers applied concurrently, as was done with the dual-species dispenser studies, the level of disruption for both *C. pomonella* and *G. molesta* was comparable to that seen with the dual species CM/OFM TT dispenser, and thus the multispecies dispenser should be effective for management of *C. pomonella* and *G. molesta* in areas where leafrollers also would require management. Although we did not specifically investigate the efficacy of the Isomate CM/OFM/LR dispenser on disruption of leafrollers in this study, a similar dispenser was shown to be effective against the leafroller *P. limitata* (Judd et al. 2004). Given the relatively constant season-long release rate of leafroller pheromone components from the Isomate CM/OFM/LR dispensers (Fig. 5D), this formulation should provide efficacy against *C. rosaceana* and *A. velutinana* equivalent to that seen with formulations specifically targeting these species. Further investigations will be required to confirm this hypothesis.

The Isomate CM/OFM/LR formulation is not yet registered, but represents a potential new alternative for control of multiple internally and externally feeding tortricid pests in production areas challenged by a complex of multiple pests. Although production regions such as Michigan may provide only a niche market for such formulations currently, the need for multispecies control by pheromones may increase to other regions as broad-spectrum insecticides are phased out, and as pests such as *G. molesta* continue expanding their range and pest status within commercial pome fruit production. An economic assessment of mating disruption for *C. pomonella* alone using hand applied pheromone dispensers during four consecutive years revealed a 60% reduction in pesticide sprays for this pest and a total cost savings of $570–840/ha based on the combination of reduced sprays and reduced fruit injury compared with conventional apple production without mating disruption (D. L. Epstein and L. J. Gut, unpublished data). Concurrent control of multiple tortricid species also may prove effective with machine applied formulations such as wax drops (Stelinski et al. 2005c) or sprayable microcapsules that should further improve the economic benefit of this technology (Knight and Larsen 2004).

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