# MATING DISRUPTION OF CAROB MOTH, *ECTOMYELOIS CERATONIAE*[1], WITH A SEX PHEROMONE ANALOG

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## ABSTRACT

Mating disruption experiments were performed for two seasons using (*Z,E*)-7,9,11-dodecatrienyl formate, a formate ester analog of the major aldehyde component of the sex pheromone of the carob moth, *Ectomyelois ceratoniae* (Zeller). The pheromone analog, loaded into hollow fibers, was deployed in small, isolated date, *Phoenix dactylifera* L., orchards in the Coachella Valley of southern California. Experiments were conducted in both conventional, insecticide-treated fields and no-insecticide, organic fields. The formate analog disrupted mate location when the disruptant was initially deployed, as determined by greatly decreased catches of male moths in female-baited sticky traps. Biweekly trap catches of males in fields treated with disruptant were reduced up to 100% in several orchards compared with untreated check fields. However, the effect decreased between deployments as the disruptant was depleted and/or degraded under the harsh field conditions. In 1991, the field treated with disruptant recorded significantly less carob moth damage to date fruits than check fields for the insecticide-treated blocks. However, there were no differences in damage levels between pheromone-treated and check blocks in the organic orchards. In 1992, fewer point sources of pheromone which were deployed later in the season, coupled with logistical problems, resulted in no consistent reduction in carob moth damage to dates in pheromone-treated blocks as compared with untreated control blocks. During this season, date infestation levels appeared to be influenced most heavily by overriding cultural practices.

## INTRODUCTION

The carob moth, *Ectomyelois ceratoniae* (Zeller), is an exotic phycitine moth that has become a serious pest of dates, *Phoenix dactylifera* L., in the Coachella Valley of southern California (Warneret al. 1990a). The carob moth was first reported infesting dates in California in 1982 (Eichlin 1982), and it is now the most serious insect pest of the American date industry. The problem may be exacerbated in the near future because of re-registration problems with the malathion dust formulation typically used to control the moths. An alternative method of control, particularly one that does not use broad-spectrum insecticides,

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is urgently needed. One potential alternative is pheromone-based disruption of carob moth mating.

The sex pheromone of the female carob moth was identified as a 3-component blend of *Z,E*-9,11,13-tetradecatrienal (trienal), with two minor constituents (*Z,E*)-9,11-tetradecadienal and (*Z*)-9-tetradecenal, that were identified from pheromone gland extracts from female moths (Baker et al. 1989, 1991). However, the trienal is unstable, and polymerizes readily at room temperature (Todd et al. 1992), making it unsuitable for use in the harsh desert conditions of Coachella Valley date orchards, where daytime summer temperatures routinely exceed 40°C for prolonged periods.

Previous work had shown that formate analogs of aldehydes can be effective, biologically active mimics of pheromone components (Mitchell et al. 1975, 1976), and the efficacy of formate mimics of doubly-unsaturated aldehydes in disrupting insect sex pheromone communication has been demonstrated (Landolt et al. 1982). In preliminary studies, Todd et al. (1992) showed that (*Z,E*)-7,9,11-dodecatrienyl formate (henceforth formate) was as attractive to carob moth males as the real pheromone. The formate also appeared to stimulate the same receptor cells as the trienal in single sensillum electrophysiological recordings (Todd et al. 1992).

In preliminary field tests, both the 3-component aldehyde blend and the triene formate alone (loaded in 30-unit hollow fiber emitters surrounding female-baited traps) reduced or eliminated captures of male moths, and the disruptive effect of the formate lasted longer than that of the aldehyde blend (Baker et al., unpublished data). Our objective in the work reported here was to conduct larger scale, replicated trials to assess the potential for using the formate analog for mating disruption and control of carob moth in California date orchards.

## MATERIALS AND METHODS

*Trapping with Live Female Moths.* Pherocon 1C sticky traps (Trécé Inc., Salinas, California) with live virgin carob moth females were deployed in date orchards: 1) to track carob moth flight phenology throughout the year in control orchards, and 2) to assess the degree to which mating was disrupted in experimental orchards. Moths were obtained from a colony maintained for > 6 years at the University of California, Riverside. Five virgin females (1-5 days old) were placed in a screen cage (12 cm x 6 cm diameter), and the cage was then affixed to the bottom of a Pherocon 1C wing trap. A water source (a 3-dram glass vial stoppered with a cotton dental wick) was provided. The cage was wired to the vertical support wires of the trap to prevent the frequent strong winds from dislodging the cage.

Male moth flight phenology monitoring was initiated in January 1991 and continued until November 1992. Traps and live females were replaced twice per week from May through November 1991 and July 21 through November 1992; otherwise, traps were replaced weekly. From September through May, most females survived until traps were changed. However, in the warmer months, only 1-3 females usually survived the 3 or 4 day period of field exposure with occasional death of all females. Phenology data was determined from female-baited traps placed in three insecticide-treated fields in 1991 and 1992. Phenology in organic fields was determined from one field in 1991 and two fields in 1992. In conventional blocks, insecticide treatments were applied at grower discretion. Insecticide treatments consist of 75 pounds per acre per application of a malathion dust formulation (5% active ingredient; 3.75 pounds/acre a.i.) applied directly into the date bunches. Applications are made approximately biweekly, beginning at the "rutab" stage of date ripening (~ end of August) and continuing until harvest (November-December), with a maximum of 7 applications.

*1991 Chemicals.* The formate analog of the pheromone was synthesized as previously described (Todd et al. 1992) and diluted with methyl tridecanoate (Aldrich Chemical Co., Milwaukee, WI) in a 10:1 mixture to retard polymerization. The mixture was loaded into hollow, black Celcon™ fibers (16mm L x 0.2 mm id) by Scentry, Inc. (Billings, Montana), using vacuum to pull the pheromone mixture into the fibers. Filled fibers were sealed at one end and affixed to adhesive tape backings (10 fibers/tape). Fibers were stored at -20° C, and transported to the field on ice until deployment. When deployed as disruptants in the field, the fibers were placed open-end up in Pherocon 1C traps, which were used to shade the fibers from direct sunlight.

*1991 Field Sites.* Date orchards (one insecticide-treated and one organic) used for disruption experiments were ca. 1.5 hectare each and isolated (nearest date orchards were ~1 kilometer away) to minimize effects from migration of mated females from adjacent date orchards. Fields are designated by a 3-figure code: "I" or "O" for "insecticide-treated" or "organic", respectively, "D" or "C" for "disruption" or "check", respectively, and a specific identifying number. All fields were Deglet Noor variety dates unless otherwise noted.

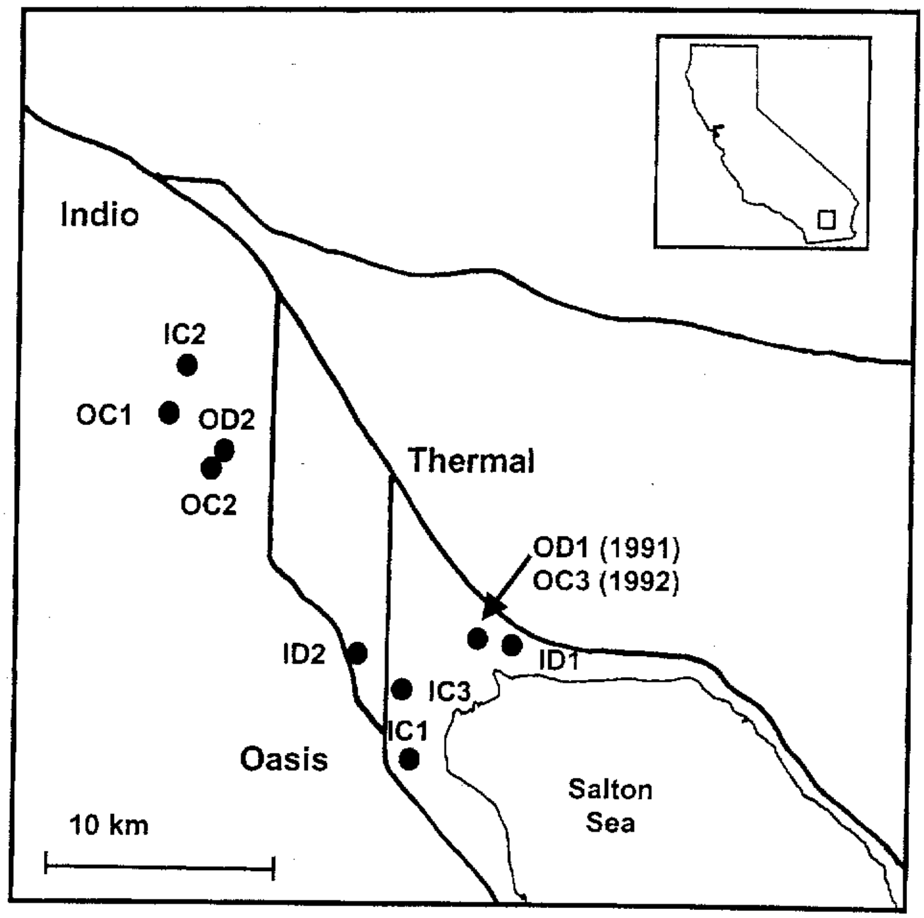


FIG. 1. Map showing the study sites in the Coachella Valley, California. A three-symbol code delineates each field; O = organic, I = insecticide-treated; C = check, D = disruption; and the number identifies the specific field. Thick lines designate major roads.

The fields used in 1991 (Fig. 1) were as follows:

ID1 - 1.5 hectare with 15-20 meter crop canopy height.

IC1 - 8 hectare with 7-15 meter crop canopy height, used also as one of the three phenology data fields.

OD1 - 1.5 hectare with 3-20 meter crop canopy height with date palms of ca. 20 different varieties, but predominantly Deglet Noor variety.

OC1 - 4 hectare with 2-10 meter crop canopy height, also used for organic phenology data.

Three sites were used to collect phenology data from insecticide-treated check orchards including IC1 described above, IC2 (32 hectare, 7 meter canopy height), and IC3 (20 hectare, 2-5 meter canopy height).

Each disruption site was equipped with two female-baited traps and each of the check orchards had one female-baited trap. In both disruption fields and OC1, female-baited trap monitoring was initiated on 14 June.

*1991 Disruption Experiment.* Previous work demonstrated that captures of carob moth males in Pherocon 1C traps were greater in the date palm canopy of 15-20 meter-tall trees than at 1 meter above ground (Baker et al. 1991). To facilitate deployment in the canopy of taller trees and the replacement of spent fibers throughout the season, a system of ropes and pulleys was installed before the experiment began. A screw hook and pulley were placed in a trimmed palm frond axil from the previous year's growth. A 6-mm diameter polyester rope was run through the pulley. At the base of the tree, another screw hook was fastened at ca. 1.5 meters above ground, and the rope ends were tied to form a loop around the hook with a tautline knot (Cassidy 1985) to keep the ropes from tangling in the strong desert winds. A Pherocon 1C trap was fastened to the rope, so the trap containing females or a formate disruptant dispenser could be hoisted to the bottom of the canopy.

Formate disruptant dispensers were deployed by placing three of the 10-fiber per tape formate dispensers in the adhesive bottom of Pherocon 1C traps, and hoisting one trap up into the canopy of every other tree for the entire field. If trees were small (date bunches at < 2 meter height), the canopy was easily reached from the ground and disruptant-fibers were deployed in Pherocon 1C traps, one trap for every two trees at the canopy level. Treatment started on 1 July (week 27) with fresh dispensers being added to each disruption station every 2 weeks. Disruption stations were neither cleaned nor replaced during the trial as long as there was sufficient adhesive in the bottom of the trap to affix a dispenser. A total of nine disruption deployments were made in the insecticide-treated field and eight in the organic field.

On two additional trees that did not contain a disruption station, a monitoring trap baited with live females was placed in the crop canopy at the north and south ends of the fields. Trees with female-baited traps were four rows from a corner and four trees into the field to reduce "edge-effects." Thus, each trap with females was surrounded by a formate dispenser 10 meters away (the next adjacent tree) in the four major compass directions.

To assess infestation levels, date samples (10 trees per field, ~200 dates per tree) were taken randomly throughout four fields (IC1, ID1, OC1, OD1) as the dates were harvested in mid- to late November. The formate dispensers were removed soon after harvest and monitoring with female-baited traps continued. Dates were stored at 10°C until they were dissected for inspection for carob moth damage.

Carob moth larvae are cream-colored, and pupae have two rows of conspicuous, paired dorsal spines. Another pyralid moth, the raisin moth, *Ephestia figulilella* (Gregson), is occasionally found in dates but is distinguishable from the carob moth by its mauve-striped larvae, and is lacking dorsal spines in the pupal stage (R. Vetter, personal observation). In addition, carob moth frass is usually bicolored whereas raisin moth frass is monochromatic. If lepidopteran frass was present but no positive identification could be made, it was assumed to be carob moth damage because carob moth infestation rates are invariably higher than those of raisin moth. Additional damage by nitidulid beetles, characterized by powdery frass, was seen occasionally. Only carob moth damage is presented in the infestation results.

*1992 Chemicals.* The formate, synthesized as before (Todd et al. 1992) was formulated as a 5:1 mixture with mineral oil before loading into the Celcon™ fibers (26 mm x 0.2 mm ID) because field tests in early 1992 showed that the formate diluted in mineral oil attracted males for several days longer than the formate/methyl tridecanoate mixture of 1991 (T.C. Baker et al., unpublished data). Three dispensers with 10 fibers per dispenser were prepared as in 1991 and secured together to make a 30-fiber dispenser.

*1992 Field Sites.* In 1992, the goal was to reduce the number of formate disruptant dispenser stations per field and the number of applications in order to decrease the cost and time involved in deployment while maintaining sufficient disruption of pheromone communication in the fields. Isolated orchards used in disruption were split into half-fields and disruptant was deployed as listed below. Two female-baited traps were placed in trees which did not contain a formate dispenser, at least four trees in from the field edges. Check fields contained one female-baited trap each. Plots (Fig. 1) were as follows:

ID1 - same field as 1991, with formate dispensers deployed in every second tree in the south half (similar to 1991) and every fourth tree in the north half. Each half-field consisted of approx. 16 x 8 trees.

ID2 - 7 hectare with a canopy height of 1-5 meter. This field (40 x 21 trees) was split into two blocks of 20 x 21 trees each. Formate dispensers were deployed in every eighth tree in the west half and in every second tree around the perimeter of the east half. In addition, after 25 August, in the perimeter-treated half-field, a female-baited trap was placed in the center of the field where the pheromone should have been least effective.

IC1 - same field as 1991.

IC2 - same field as 1991.

OD2 - 4 hectare field (22 x 21 rows) of 90% Deglet Noor and 10% Medjool dates at a canopy height of 1-5 meter. The field was split into 11 x 21 tree blocks. Formate dispensers were deployed in every second tree in the south half and every fourth tree in the north half.

OC2 - 9 hectare at 1 meter or 20 meter height. This property had pecans interplanted between the date palms; carob moth also infests pecans. An insecticide-treated date orchard was adjacent. One female-baited trap was placed in the middle of the field to avoid edge effects.

OC3 - this was field OD1 from the 1991 study. One female-baited trap was placed away from the field edge.

An additional field, IC3, was monitored with one female-baited trap for phenology data but no date samples were collected.

*1992 Disruption Experiment.* Formate dispensers were deployed at the canopy level only. The total number of fibers in a field was similar to the number used in 1991, but the distribution patterns were changed. The first pattern (one 30-fiber dispenser in every second tree) was identical to 1991. Additional patterns used treatments of two 30-fiber dispensers placed in every fourth tree, four 30-fiber dispensers placed in every eighth tree or five 30-fiber dispensers placed in every second tree around the perimeter of the plot.

Fibers were deployed 28 July. The second deployment of disruptant was made 2 weeks later and was allowed to remain in the field for 3 weeks to determine whether a longer field life was possible. Because this lengthened time of deployment resulted in decreased disruption as determined by numbers of male moths caught per trap per week, we reverted back to deployments at 2-week intervals. We made five deployments of disruptant in 1992. Additional deployments were not possible because of unforeseen difficulties in obtaining sufficient formulated material. Fortuitously, 1992 was a hot year and the dates were harvested from most fields much earlier than normal (early October instead of November or later).

Date samples from check fields or disruption half-fields were taken at harvest. In the mating disruption blocks, samples were taken near each corner and from the middle of the block. Corner samples were taken from the second or third row, two or three trees into the field, to minimize possible edge effects. One thousand dates per field or block were taken where possible.

*Statistics.* For both years, disruption efficiency was determined by comparison of number of males caught in female-baited traps in disrupted fields vs. check fields. Data were compared with 95% confidence intervals. Statistical significance was determined between an experimental disruptant-treated treatment and that of the check fields (the latter being collectively defined as the 100% value). No comparisons were made between or amongst differing disruption treatments and the degree of disruption efficiency.

In 1991, the date infestation data were not normally distributed, so ANOVA tests could not be run. Data were analyzed in regard to proportion of dates infested for the 10 or 15 samples from each field and 95% confidence intervals were calculated. In 1992, infestation data were normally distributed, and were transformed by arcsin square root transformation before analysis. For fields that were split into two blocks and treated with different pheromone disruption deployments, t-tests were performed on the transformed infestation data. If there were no differences between the different treatments within a field, data were pooled for that field. Similarly, t-tests were performed on check fields for organic and insecticide-treated conditions and pooled, within each field type, if statistically indistinguishable. ANOVA was then used to distinguish date damage differences between the disruptant and check fields.

## RESULTS

*Phenology.* Carob moth flights began in February and moths were present throughout the year until ca. mid-December (Figs. 2, 3). In 1991, the numbers of male moths caught in traps peaked in July-September for both the insecticide-treated and the organic fields. In early 1992, the numbers increased similarly to 1991, but the moth populations decreased during June-July before rising again to a maximum in September-October.

*1991 Disruption.* Prior to deployment of formate disruptants, the numbers of moths caught in fields to be treated with disruptant were 30-50% of those of the control plots (Figs. 4, 5). After disruptants were deployed, numbers of moths caught in fields treated with the disruptant declined to near zero (Figs. 4, 5). In field ID1 (Fig. 4), almost no moths were caught in traps for 7 weeks after the disruptant was initially deployed. It appeared that the disruptant decreased in efficacy in August-September during each 2-week period following the placement of fresh pheromone dispensers, because the number of moths trapped increased in the second week following deployment, then dropped to near zero again after fresh dispensers were put out (Fig. 4, weeks 33-41). In field OD1 (Fig. 5), disruption was less effective, but the numbers of moths trapped were still lower than those in the check fields for many of the weeks of the trial. Many of these comparisons were not statistically significant due to high variation in the numbers of moths trapped in control fields (Fig. 2) where one of the two female-baited traps often recorded zero or few males, possibly due to premature death of the virgin females. In both disruptant fields, when the disruptant was

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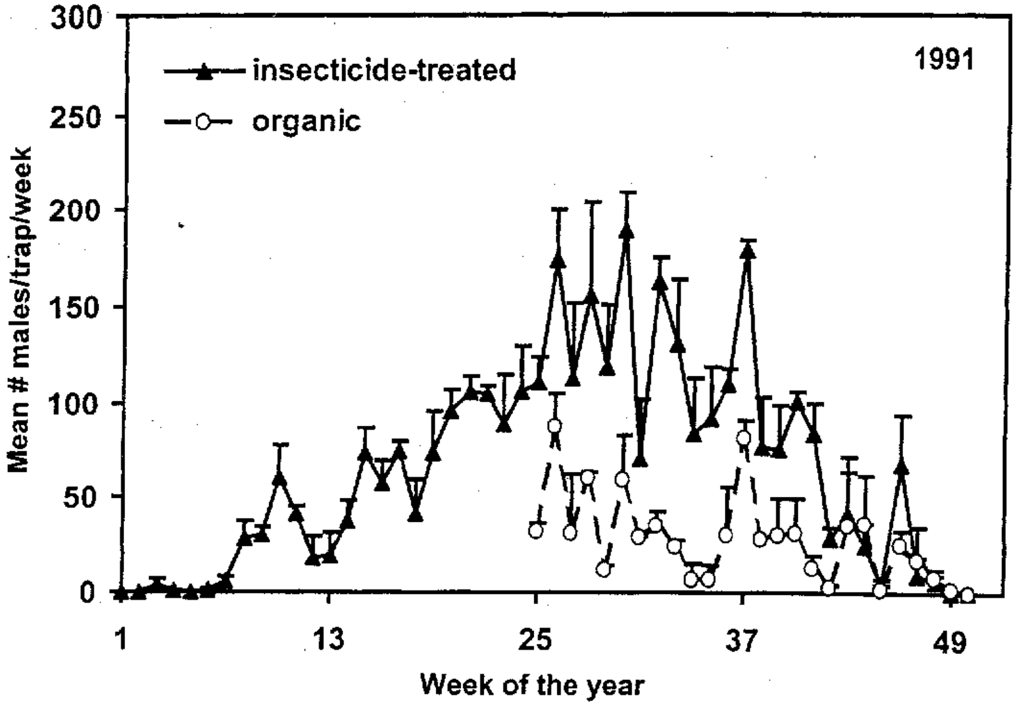



FIG. 2. Carob moth flight phenology, as determined by numbers of male moths caught in pheromone-baited traps in 1991 deployed in the control plots from insecticide-treated orchards (based on three orchards) and an organic orchard. Each data point represents mean weekly catches of male moths in three female-baited traps for Weeks 1-18, and 6 female-baited traps per week from Weeks 19 to 48 in the insecticide-treated field. Trapping started on Week 25 in the organic field, where each data point represents mean weekly catches of males from two female-baited traps per week until Week 48. Thereafter data points represent one trap only.

removed after harvest, the numbers of moths trapped increased to levels similar to or greater than the checks (Fig. 4, 5).

*1991 Damage Assessment.* Carob moth damage to dates was significantly greater in the insecticide-check field (IC1) than in each of the other three fields (Table 1). Damage levels in the disruptant fields (ID1 and OD1) were not significantly different from each other, nor were damage levels different between both organic fields (OC1 and OD1). The organic check field (OC1) sustained significantly more damage than the insecticide-treated disruption field (ID1) (Table 1).

*1992 Trials: Disruption.* The numbers of moths caught in pheromone-baited traps in disruption plots before deploying the disruptant (Figs. 6, 7, 8) were not statistically different from those in control plots. Following application of the disruptant, very few moths were trapped in any of the disrupted orchards, for all deployment patterns in all orchards (Figs. 6, 7, 8). Once again, occasional zero and low readings in one check-plot trap obscured likely differences because of the confidence interval being greater than the mean, even though few or no males were captured in disruption fields. Also, as the season progressed, the results in 1992 were much more variable than in 1991.

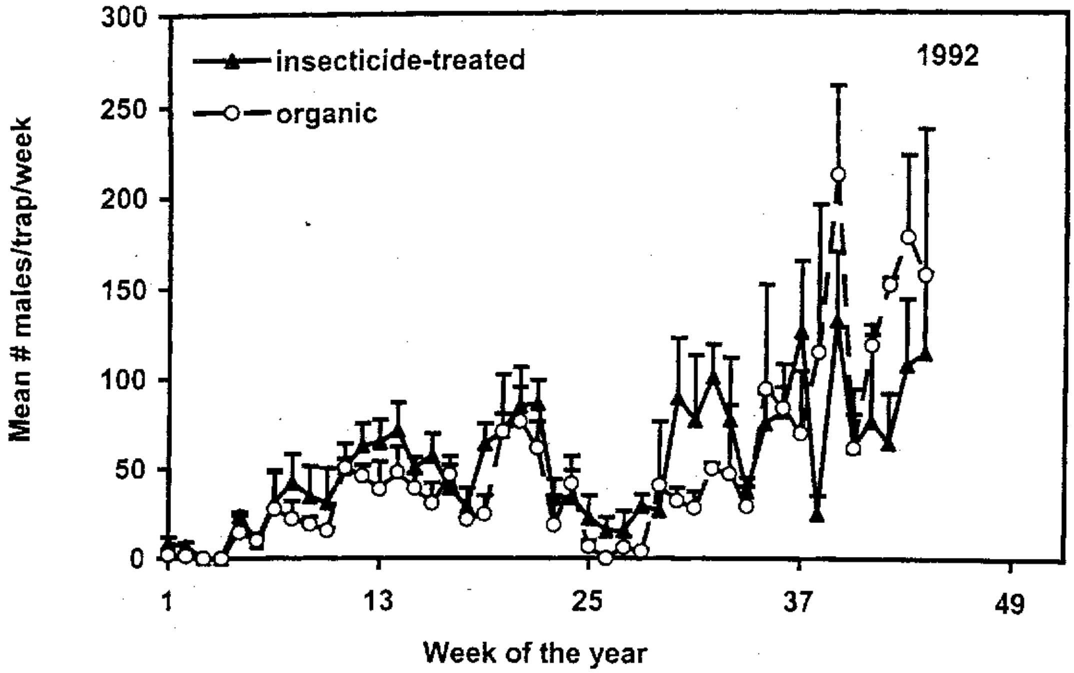


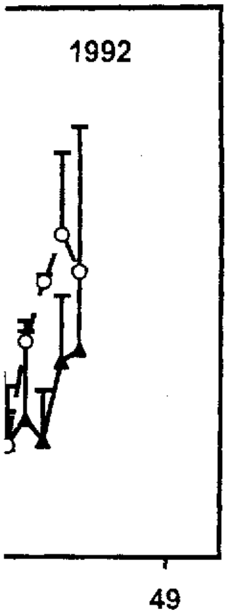

FIG. 3. Carob moth flight phenology, as determined by numbers of male moths trapped in 1992 in the control plots from three insecticide-treated fields and two organic fields. Traps were checked weekly from week 1 to 29, then biweekly for week 30 to 44, for all fields. Each data point represents mean number of male moths caught in three female-baited traps for insecticide-treated orchards, and two female-baited traps for organic fields, for Week 1 to 29. Each data point represents six traps per week from the insecticide-treated control orchards and four traps per week from the organic control orchards for Week 30 to 44.

Table 1. Carob moth damage in the disruption and control date gardens in Year 1. Data were analyzed with confidence intervals; means that are significantly different do not share a letter. Percentage damage is presented as mean ± SD.

| Block | Treatment | (%) damage | # of dates |
|---|---|---|---|
| ID1 | (insecticide + disruptant every second tree) | 0.9 ± 1.0 a | 3000 |
| IC1 | (insecticide control) | 13.2 ± 4.2 c | 2000 |
| OD1 | (organic + disruptant every second tree) | 3.8 ± 4.1 ab | 1743 |
| OC1 | (organic control) | 6.8 ± 2.9 b | 2000 |

In field ID1 (dispensers every second or fourth tree), female-baited traps captured high levels of males toward the end of the season (Fig. 6), with numbers of males trapped rising to 20-50% of those in the check plots for a 4-week period in September-October in the block with disruptant every second tree.

In disrupted field ID2 (dispensers every eighth tree, or around the perimeter in every second tree), very few moths were trapped for almost the entire season in the section treated with dispensers every eighth tree (Fig. 7). However, when a female-baited trap was placed in the center of the perimeter-treated disruption plot (ca. 100 meters from the perimeter), this

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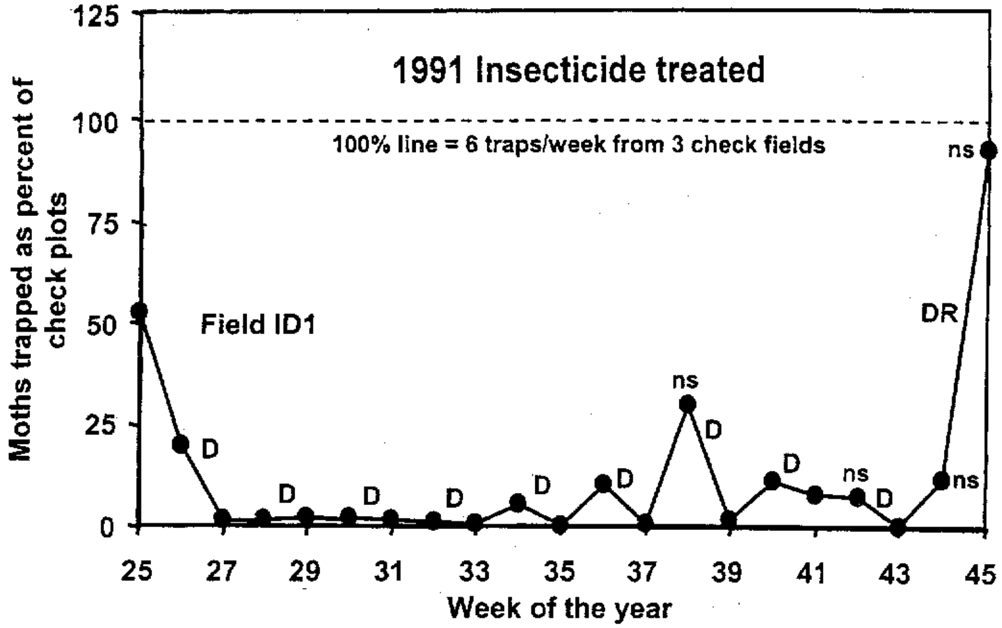


FIG. 4. Numbers of male moths trapped in the pheromone-disruption field as a percentage of the males caught in the control plots for the 1991 disruption season; all fields were treated with insecticide. D = fresh disruptant deployed, DR = disruptants removed from field. Weekly disruption data points that are not significantly different from those of the control plot are labeled "ns", otherwise, unlabelled experimental points were significantly different from the control using 95% confidence intervals.

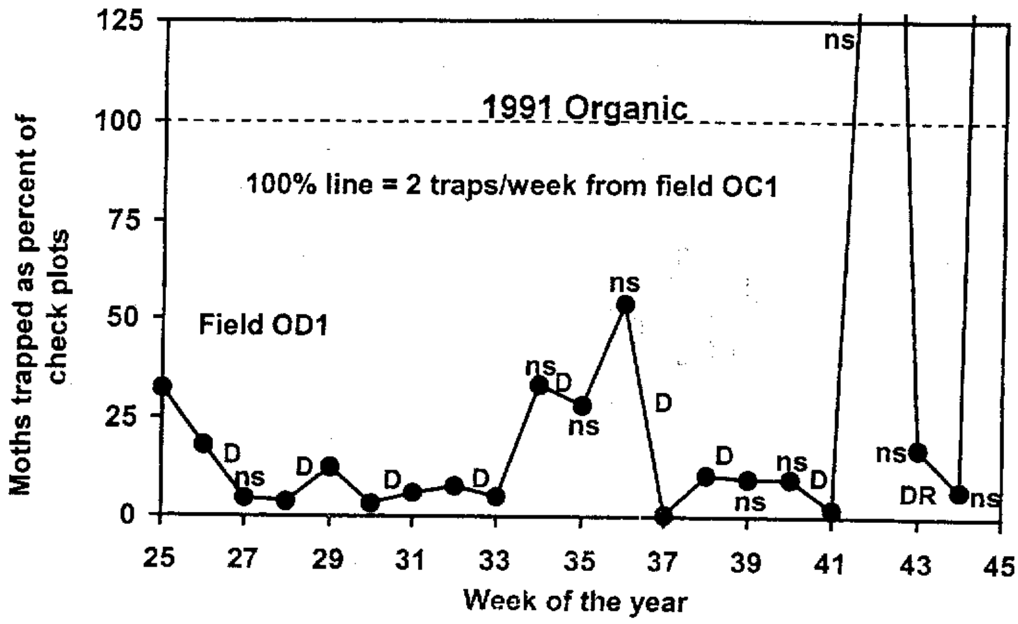


FIG. 5. Numbers of male moths trapped in the pheromone-disruption field as a percentage of moths caught in the control plots for the 1991 season; all plots were organic. D = fresh disruptant deployed, DR = disruptants removed from field. Weekly disruption data points that are not significantly different from that of the control plot are labeled "ns", otherwise, unlabelled experimental points were significantly different from the control using 95% confidence intervals.

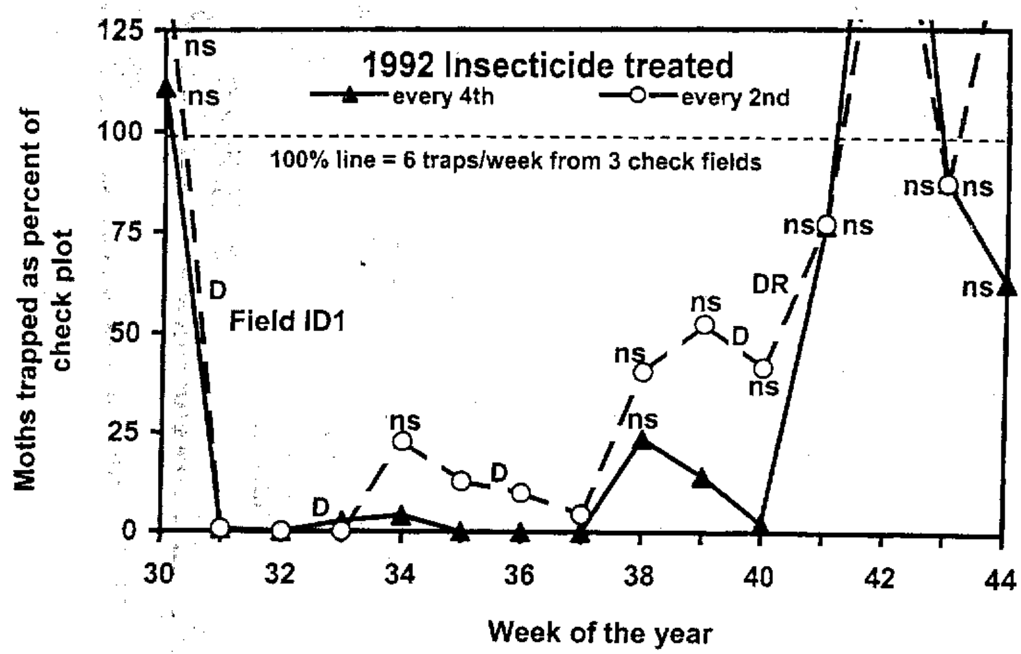


FIG. 6. Numbers of male moths trapped in the pheromone-disruption plot as a percentage of the moths caught in the control plots for the 1992 season; all fields were insecticide treated. Field ID1 consisted of disruptant placed in every second or in every fourth tree. D = fresh disruptant deployed, DR = disruptants removed from field. Weekly disruption data points that are not significantly different from that of the control are labeled "ns", otherwise, unlabelled experimental points were significantly different from the control using 95% confidence intervals.

trap captured many moths (Fig. 7). Similar to 1991, removal of the disruptant from the field was followed by a tremendous increase in numbers of male moths trapped.

In organic field OD2 (dispensers every second and fourth tree), the numbers of male moths trapped hovered close to zero for the entire season (Fig. 8). Unlike the large industrial orchards that are harvested in a few days, this small plot was harvested over a long period of time. Thus, the disruptant was not removed until after the experiment was terminated instead of at harvest.

*1992 Damage Assessment.* Data were pooled for the following block treatments within a field because there were no significant differences between the infestations: ID1 (disruptant on every second or fourth tree; $t = 1.51$, df = 8, $P = 0.17$), ID2 (every eighth tree vs. perimeter trees; $t = 1.51$, df = 7, $P = 0.18$), OD2 (every second or fourth tree; $t = 1.21$, df = 8, $P = 0.99$). Data were pooled between check fields of similar category because there were no significant differences between the damage levels: OC ($t = 0.78$, df=8, $P = 0.45$), IC ($t = 0.96$, df = 8, $P = 0.36$).

When the pooled data and the infestation data from the insecticide-treated check fields were analyzed by ANOVA, one insecticide-treated disruption field (ID1) sustained significantly more damage than all of the other fields (F = 13.3, df = 4, $P < 0.001$, Table 2). Infestation levels in all of the remaining fields were statistically indistinguishable (Table 2).

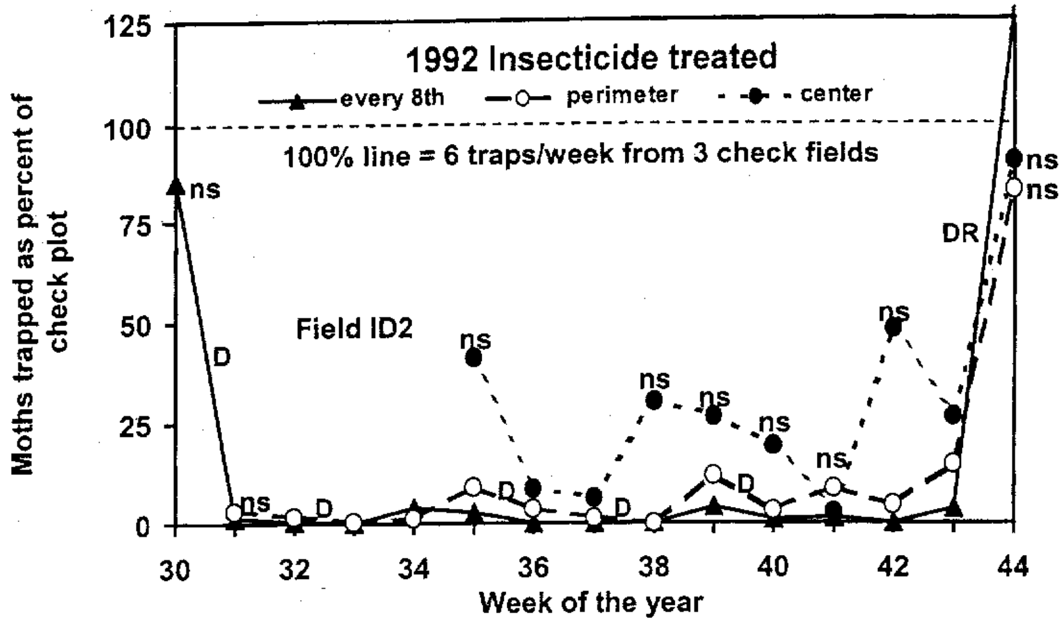


FIG. 7. Numbers of male moths trapped in the pheromone-disruption field as a percentage of the moths caught in the check plots for the 1992 disruption season; all fields were treated with insecticides. Field ID2 consisted of disruptant placed in every eighth tree or in every second tree around the perimeter of the field. On Week 35, an additional female-baited trap was placed in the middle of the field, at the furthest point from the perimeter disruptants. D = fresh disruptant deployed, DR = disruptants removed from field. Weekly disruption data points that are not significantly different from that of the check are labeled "ns", otherwise, unlabelled experimental points were significantly different from the control using 95% confidence intervals.

## DISCUSSION

Our experiments showed that the formate ester analog of the major component of the carob moth pheromone can disrupt attraction of male moths to females in the canopy of date palms. Tests that involved reducing the number of point sources while increasing the strength of these sources were generally inconclusive due to high variability and a small number of replicates. However, at the highest strength, the lowest density of disruptant stations per hectare, each containing 150 fibers per tree (the perimeter treatment in field ID2), female-baited traps 100 meters away in the center of the field caught significant numbers of moths (Fig. 7), indicating that disruption of male moth orientation to females was not complete, using this array in this size of block. Greater reduction in the numbers of males trapped (i.e., better disruption) was demonstrated in the adjacent half-field (120 fibers every eighth tree) suggesting that a grid-like deployment pattern of point sources using a high release rate may be more effective.

The numbers of males trapped were reduced to near zero in most of the disruption plots in comparison to the check plots, most commonly in the week following deployment of fresh lures. However, after one week in the desert heat, the dispensers appeared to lose their efficacy, with females attracting low levels of males in 1991 with the formate:methyl tridecanoate formulation, and higher numbers of males in some fields in 1992 with the

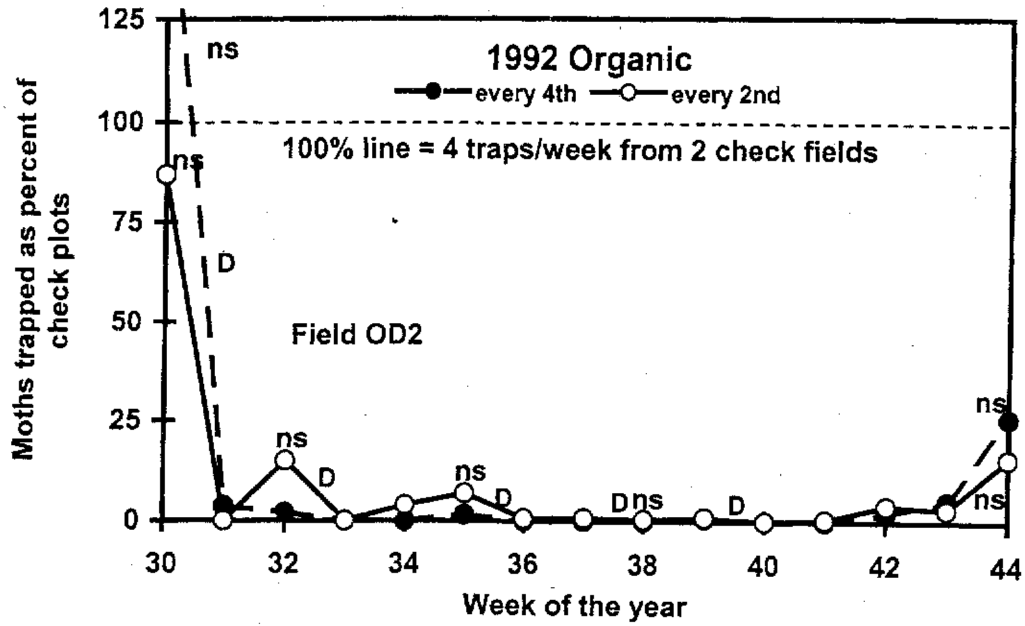


FIG. 8. Numbers of male moths trapped in the pheromone-disruption field as a percentage of the moths caught in the control plots for the 1992 season; all fields were organic. Field OD1 consisted of disruptant placed in every second or in every fourth tree. D = fresh disruptant deployed. Weekly disruption data points that are not significantly different from that of the control are labeled "ns", otherwise, unlabelled experimental points were significantly different from the control using 95% confidence intervals.

Table 2. Carob moth damage in the disruption and control date gardens in Year 2. Data were transformed and analyzed with ANOVA. Means that are significantly different do not share the same letter. Percentage damage is presented as mean ± SD. Field OC3 in Year 2 was field OD1 from Year 1.

| Block | Treatment | | (%) damage | # of dates |
|---|---|---|---|---|
| ID1 | (insecticide + disruptant every second tree) | | 20.2 ± 8.2 | 1000 |
| ID1 | (insecticide + disruptant every fourth tree) | | 12.6 ± 7.6 | 1000 |
| | | ID1 mean | 16.4 ± 8.5 a | |
| ID2 | (insecticide + disruptant every eighth tree) | | 4.3 ± 1.6 | 974 |
| ID2 | (insecticide + disruptant around perimeter) | | 2.4 ± 1.9 | 658 |
| | | ID2 mean | 3.4 ± 1.8 b | |
| IC1 | (insecticide control) | | 3.6 ± 3.0 | 1000 |
| IC2 | (insecticide control) | | 2.2 ± 1.1 | 632 |
| | | control mean | 2.9 ± 2.2 b | |
| OD2 | (organic + disruptant every second tree) | | 6.7 ± 2.8 | 803 |
| OD2 | (organic + disruptant every fourth tree) | | 6.4 ± 5.2 | 799 |
| | | OD2 mean | 6.3 ± 3.9 b | |
| OC2 | (organic control) | | 5.8 ± 4.0 | 1000 |
| OC3 | (organic control) | | 7.3 ± 1.4 | 632 |
| | | control mean | 6.6 ± 2.9 b | |

formate:mineral oil formulation. Thus, the more viscous mineral oil did not appear to improve the longevity of the fibers' disruptant activity. Furthermore, the decreased levels of disruption seen in 1992 may have been due in part to the fact that four fewer applications of pheromone were made than in 1991. In addition, in 1992, labor problems in field ID1 resulted in only one insecticide application, whereas four applications typically are made in conventionally managed date orchards.

Overall, the infestation of dates by carob moth appeared to be influenced more by agricultural practices than by pheromone disruption applications. The most extreme example was insecticide-treated field ID1 which, in 1991, had the lowest of all date infestation rates for any field in either year (0.9%) and then, in 1992, when labor problems affected insecticide application, had the highest infestation rate (16.4%) of any field in either year (Table 1, 2). There were no significant differences in damage in any of the 1992 split-field pheromone deployments within an orchard (Table 2).

One of the goals of these experiments was to determine whether the disruptant could reduce the resident population of carob moths within a date orchard. This may have been an unreasonable goal given the relatively small plots, the relatively high moth population levels, and the fact that in both years we started disruption treatments after 1 July, when populations had a chance to build up for several generations (beginning in February). Removal of the disruptant from the plots after harvest resulted in large increases in numbers of male moths trapped. Whereas this rapid increase verified the disruptant effect of the formate, it also suggested that over the months of disruption, the population density had not been appreciably reduced. Alternatively, immigration of moths from nearby date gardens may have replenished the population of moths in the experimental plots.

Despite the lack of evidence that we substantially affected carob moth populations in these experiments, it was apparent that the formate pheromone mimic had a profound effect on the attraction of male moths to caged females, with trap catches reduced by an average of over 90%, even in these high-density moth populations. These somewhat contradictory results can possibly be resolved by further research. First, and of the utmost importance, is the need to improve the pheromone dispensers to increase their longevity. Our data showed that fresh dispensers suppressed trap catch nearly 100% even in the hottest months, but that two weeks after deployment, their efficacy had waned. Commercial implementation of mating disruption will not be realized until dispensers can be developed that provide pheromone release rates sufficient for continuous, effective disruption for at least 100 days in these desert conditions.

Second, further experiments with the deployment pattern and release rates of disruptant dispenser stations are warranted. Our results show that reducing the numbers of disruptant stations per hectare while increasing the disruptant release rate per station (every fourth tree; every eighth tree) resulted in disruption efficacy levels comparable to the every-second-tree grid system. The concept of using a few widely-separated large point sources of pheromone for disruption was first demonstrated by Shorey et al. (1972) for the cabbage looper moth, and this concept appears to be supported by our results.

Third, the basic bionomics of the carob moth need to be better understood in order to develop a holistic approach to implementing mating disruption within this system. For example, we do not know where mating occurs within a date orchard. Presumably it can happen anywhere within or below the canopy, as demonstrated by the capture of male moths in female-baited traps placed near ground level, on the trunks 10 meters above ground level, and in the palm canopy (R. Vetter and T.C. Baker, unpublished data). However, where females actually attract males for mating is unknown.

Fourth, due to difficulties in obtaining sufficient quantities of the pheromone mimic to carry out the mating disruption trials described above, disruptant was deployed relatively late in the season, after moth populations had increased over four or five generations. Our disruptant applications were made after 1 July, when moth population densities were high, as evidenced by numbers of male moths trapped in the check plots after week 26 (Fig. 2, 3). The ripening date fruits are susceptible to penetration and feeding by carob moth larvae beginning at the "rutab" stage, in middle to late August (Warner et al. 1990b). This is when damage to the date crop begins to occur, and it is the critical time period on which to focus for crop protection. Hence, given the limited amount of disruptant available to us, we sought to reduce oviposition on the ripening crop by bracketing this period with disruptant treatment from midsummer onward. It is possible that trying to reduce the winter and early spring generations by deploying the disruption dispensers beginning in January, for instance, would be more effective.

Because abundant moth populations build up in February through September (Fig. 2, 3), other sources of food must be available for the developing larvae of these four or five early-season generations. Warner (1988) showed that ample alternative food sources are provided by the abundant rotting dates from the previous year's harvest that litter the ground, as well as those that have become stuck in the cut axils along the entire height of the palm trunks. Also, even native plants such as mesquite, *Prosopis* sp., are capable of supporting carob moth populations (Warner 1988), but it is not known to what degree these plants provide alternative sources of gravid females capable of affecting population densities within the orchards.

Overall, date orchards represent one of the most challenging environments in which to develop effective pheromone-based mating disruption. In mature, high-yielding orchards the canopies are typically 15 - 20 meters high, and thus the volume of air that needs to be permeated with disruptant is large. Temperatures in the orchards routinely exceed 40°C daily, and pheromone will be emitted from dispensers at the highest rates during the day, when carob moths are not reproductively active (Vetter et al. 1997). Furthermore, the major component of the carob moth pheromone, (*E*,*Z*)-9,11,13-14:Ald, is very labile, and even the more stable formate analog's structure renders it amongst the most difficult lepidopteran pheromone structures to protect and emit in controlled-release fashion. Even synthesis of this analog (or the major pheromone aldehyde itself) is challenging and expensive (currently ~$40,000/kilo) relative to other pheromone components currently in use. Although the methodology needs improvement, mating disruption of carob moth may still prove to be a useful tool for control of this pest, particularly if disruption is used in an integrated program that includes improved date orchard sanitation techniques (Warner 1988).

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# LITERATURE CITED


Baker, T.C., W. Francke, B. Hansson, C. Löfstedt, J-W. Du, P.L. Phelan, R.S. Vetter, and R. Youngman. 1989. Identification of carob moth pheromone, *Ectomyelois ceratoniae*. Tetrahedron Letters 30: 2091-2092.

Baker, T.C., W. Francke, J.G. Millar, C. Löfstedt, B. Hansson, J-W. Du, P.L. Phelan, R.S. Vetter, R. Youngman, and J.L. Todd. 1991. Identification and bioassay of sex pheromone components of carob moth, *Ectomyelois ceratoniae* (Zeller). J. Chem. Ecol. 17: 1973-1988.

Cassidy, J. 1985. The Klutz Book of Knots. Klutz Press, Palo Alto, California 20pp.

Eichlin, T.D. 1982. Carob moth in California: new state record. California Department of Food and Agriculture Memo: Nov 26.

Landolt, P.J., C.E. Curtis, J.A. Coffelt, K.W. Vick, and R.E. Doolittle. 1982. Field trials of potential navel orangeworm mating disruptants. J. Econ. Entomol. 75: 547-550.

Mitchell, E.R., A.H. Baumhover, and M. Jacobson. 1976. Reduction of mating potential of male *Heliothis* spp. and *Spodoptera frugiperda* in field plots treated with disruptants. Environ. Entomol. 5: 484-486.

Mitchell, E.R., M. Jacobson, and A.H. Baumhover. 1975. *Heliothis* spp.: disruption of pheromonal communication with (*Z*)-9-tetradecen-1-ol formate. Environ. Entomol. 4: 577-579.

Shorey, H.H., R.S. Kaae, L.K. Gaston, and J.R. McLaughlin. 1972. Sex pheromones of Lepidoptera. XXX. Disruption of sex pheromone communication in *Trichoplusia ni* as a possible means of mating control. Environ. Entomol. 1: 641-645.

Todd, J.L., J.G. Millar, R.S. Vetter, and T.C. Baker. 1992. Behavioral and electrophysiological activity of (*Z,E*)-7,9,11-dodecatrienyl formate, a mimic of the major sex pheromone component of carob moth, *Ectomyelois ceratoniae*. J. Chem. Ecol. 18: 2331-2351.

Vetter, R.S., S. Tatevossian, and T.C. Baker. 1997. Reproductive behavior of the female carob moth (Lepidoptera: Pyralidae). Pan-Pac. Entomol. 73: 28-35.

Warner, R.L. 1988. Contributions to the management of the carob moth, *Ectomyelois ceratoniae* (Zeller) in 'Deglet Noor' date orchards in the Coachella Valley of California. Ph.D. dissertation. University California, Riverside, California.

Warner, R.L., M.M. Barnes, and E.F. Laird. 1990a. Reduction of insect infestation and fungal infection by cultural practice in date orchards. Environ. Entomol. 19: 1618-1623.

Warner, R.L., M.M. Barnes, and E.F. Laird. 1990b. Chemical control of a carob moth, *Ectomyelois ceratoniae* (Lepidoptera: Pyralidae) and various nitidulid beetles (Coleoptera) on 'Deglet Noor' dates in California. J. Econ. Entomol. 83: 2357-2361.