Mating Disruption for Suppression of Navel Orangeworm Damage in Almonds

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Executive summary

In 2004 we compared navel orangeworm (NOW) seasonal abundance in the absence of pheromone release to data from the same sites the previous year, and examined the hypothesis that mating disruption and hullsplit insecticide treatments together could offer greater protection from NOW damage than either treatment alone. The data collected in 2004 confirm that NOW are more abundant in pistachios than in almonds and exhibit different populations dynamics between the two crops, and confirm that mating disruption can significantly reduce NOW damage to Nonpareil almonds in locations where diligent orchard sanitation is practiced but is insufficient to prevent economically damaging populations.

Comparing flight trap data taken from June through August from three square miles of almonds and three square miles of pistachios, we found higher numbers of moths but the same trends as the previous year, when the traps at these sites were 200-300 yards from pheromone mating disruption blocks. NOW abundance in these almond sites was generally low through June and much of July and increased in August. In pistachios, in contrast, NOW abundance was high in June and July.

Within one square mile that had received heavy NOW pressure in 2003, we used 4 20-acre replicates each to compare the effects of mating disruption (Puffer), Imidan and Pounce at hullsplit (Imidian/Pounce), or both the mating disruption and hullsplit insecticide treatment (Imidan/Pounce/Puffer) with untreated control. Comparison of flight trap data within the treatment plots to traps between the treatment plots and in an adjacent section demonstrated that the mating disruption treatments reduced male capture in female-baited flight traps throughout the experimental section. We nonetheless captured significant numbers of males in the non-mating disruption treatment plots and showed complete trap shutdown in the mating disruption plots. NOW damage in this experimental section ranged from 2.5 to 6.5% in 2004, compared to 6 to 12% in 2003. There was significantly less NOW damage in the Puffer treatment plots than in the untreated controls, and also significantly less damage in the Imidan/Pounce than in the Puffer treatment plots. There was, however, no significant difference in NOW damage between the Imidan/Pounce and the Imidan/Pounce/Puffer plots, indicating that there is no additive benefit from using both the mating disruption and hullsplit insecticide treatments.

Introduction

Sex pheromones of moth species have long been used commercially for monitoring and control of pests such as the codling moth, oriental fruit moth, and peach twig borer. Control of moths using sex pheromones is typically via mating disruption, in which a synthetic blend of chemicals mimicking the female sex pheromone is released throughout an orchard in order to prevent mating and thereby prevent females from laying fertile eggs on fruit. Mating disruption has typically worked best with low initial populations and larger treated areas (Cardé and Minks 1995).

While the primary component of the NOW sex pheromone, (*Z*,*Z*)-11,13-hexadecadienal (Z11Z13-16Al), was identified 25 years ago (Coffelt et al. 1979), technical difficulties have delayed the development of monitoring or mating disruption systems based on this pheromone. For NOW, unlike some other moth species, the principle component is not sufficient to attract male moths to point source, such as a lure, and therefore is not suitable for monitoring. An early study demonstrated that treatment of 20 acre plots with this single component reduced both mating and NOW damage in almonds (Curtis et al. 1985). That study also found that this pheromone became inactive more quickly than others, requiring frequent re-applications. An aerosol timed release system, in which the pheromone was kept in a liquid solvent prior to release (Shorey and Gerber 1996), improved the field life of this material. A commercialized version of this system, the Suterra Puffer (Suterra LLC, Bend, OR) has received US and California EPA registration for use in almonds, pistachios, walnuts, and figs.

In 2003 we compare the effects of three different mating disruption release systems with untreated control plots and plots treated with aziphosmethyl (Guthion) at hullsplit (Burks et al. 2003). We compared the effect of these treatments on ability of males to locate unmated females in flight traps, on the mating of status unmated females placed in the field, and on damage to almonds and pistachios. While comparing the effects of mating disruption treatments on males capture in traps, we also compared seasonal abundance in the areas between the mating disruption plots in the four 640-acre almond sections and four of pistachios.

There were very different trends in seasonal abundance of NOW between almonds and pistachios. In almonds there was generally very low abundance in June and July, where in pistachios there was high abundance throughout the growing season. The previous year we found very low NOW abundance and damage in three of four almond ranches examined. Within these three ranches damage in mating disruption and insecticide-treated areas was not significantly different from that in the control, and damage in the untreated control plots was not economically significant. In the fourth ranch both the most effective mating disruption treatment and insecticide treatment resulted in a ~50% reduction in NOW damage. A comparison, between Nonpareil almonds and pistachios, of NOW harvest damage at harvest and abundance in the weeks preceding harvest suggested that damage in Nonpareil almonds is the result of a relatively low NOW population in a very susceptible crop, whereas damage in pistachios results from a very abundant population in a less susceptible crop.

In 2004 we replicated mating disruption and insecticide treatments within the most heavily infested ranch. We also compared seasonal abundance trends in three remaining almond ranches and an arbitrary selection of three of the four pistachio ranches examined in 2003, in order to be certain that the difference in seasonal abundance seen the previous year was not an anomaly and also occurred in the absence of mating disruption. Our objectives for the 2004 field season were: 1) to examine seasonal abundance of NOW in almonds and pistachios a second season and in the absence of pheromone permeation; and 2) to confirm the efficacy of reduction in NOW damage in almonds using mating disruption with Puffers containing the single principle component. We also used the latter experiment to examine the hypothesis that the combination of insecticide and mating disruption could provide improved control over either separate treatment. The results are discussed in consideration of historical data on crop volume and NOW damage in almonds and pistachios.

Materials and Methods

Monitoring techniques Male abundance and the ability of males to locate calling females were monitored using unmated females. Groups of three females were sealed in a mesh bag, which was then suspended from the top of a wing trap (Pherocon IC, Trécé Inc., Adair OK) as described by Burks and Brandl (2004). Briefly, larvae were maintained until the last larval instar, then males were separated out and discarded and females were allowed to pupate. Newly eclosed females were placed in plastic mesh bags, 3 females per bag, and the bags were heat-sealed and distributed for placement in traps in the field within 24 hours. We have previously shown that, under mid-summer conditions in Central California, NOW females prepared this way survive for and call for 4-6 days, and that 60% of the total trap capture occurs on the first night (Burks and Brandl 2004). Local abundance of females within treatment plots was examined using universal moth traps baited with ground almond and pistachio, and containing a dichlorvos No-Pest strip (Spectrum Group, St. Louis, MO) as a killing agent.

Seasonal abundance in almonds and pistachios We used female-baited flight traps to compared NOW abundance in three 640-acre almond and three 640-acre pistachio ranches weekly for 14 weeks, from the week of May 24 to that of August 23, 2004. Two of the almond ranches (344, 374) were located within a 5-mile radius south of the town of Lost Hills, and a third (394) was located ~30 miles to the east, along Highway 99 between Highway 46 and McFarland. The three pistachio ranches (401, 484, 451) were located within a 5-mile radius along Highway 33 between Highway 46 and Twisselman road. Nine traps were placed in each ranch, one the center and one 440 and 880 yards from the center in each cardinal direction. The total number of moths captured was compared to data taken from the ranches and positions between the weeks of May 26 and August 25, 2003, when the mating disruption treatment blocks were located in the center of each quarter-section and between 220 and 311 yards from each trap position. Because of missing data, the weeks of August 11 and 18, 2003 and August 9 and 16, 2004 were not included in the analysis.

In order to compare these data with prior phenological models, degree day (DD) accumulations were calculated with DDU (DNAR 1990), using the double triangle and vertical cut-off options, and presuming 1093 DD °F for flights (i.e., cohorts) in which oviposition occurred prior to hullsplit, and 738DD °F for subsequent flights (Sanderson et al. 1989). Climate data were for stations 5, Shafter; 54, Blackwell's Corner; 138, Famoso; 146, Belridge; and 172, Lost Hills were obtained from the California Department of Water Resources, http://wwwcimis.water.ca.gov/. March 1, 2003, and March 7, 2004 were used as biofix dates based on our flight trap data from these sites and others in the vicinity.

Mating disruption and insecticide treatments We used Ranch 371, the almond ranch where we observed the greatest NOW abundance and damage in 2003, to further examine the effect of mating disruption with gridded puffers alone or with a hullsplit insecticide treatment. Treatments were: 1) untreated controls; 2) mating disruption with Puffers; 3) a hullsplit spray of phosmet and permethrin (Imidan/Pounce); and 4) a combination of both the mating disruption and hullsplit insecticide treatments (Imidan/Pounce/Puffer). Response variables were: 1) the count of males flight traps baited with unmated females, 2) the count of females captured in traps baited with an oviposition attractant, and 3) NOW damage to Nonpareil almonds.

The square 640-acre site, ~2 miles south of Shafter, was divided into 16 square 20-acre treatment plots (i.e., 311 x 311 yards) separated from each other by 129 yards, and from the sides of the section by 64 yards (Fig. 1A). Treatment plots were arranged as a Latin square, with each treatment represented once in each east-west row and once in each north-south column. The allies between the rows of trees in this ranch were oriented in a north-south direction. This section was bordered by additional sections of almonds to the north and east, and by highways to the south and west. Puffers (Suterra LLC, Bend, OR) were placed evenly throughout the treated plots at a density of 2 per acre, and at two-thirds canopy height. Mating disruption was began on March10, 2004 and continued until after October 15. Each Puffer was programmed to release 0.2 mg AI each 15 minutes from 7:00PM until 7:00AM Pacific Daylight time, thus releasing 19.2 mg AI per acre per night. Hullsplit treatments, comprising phosmet (5 lb. Imidan 70WP) plus permethrin (4 oz. Pounce 3.2 EC) in 200 gallons of water per acre, were applied on July 10. Areas between the treatment plots received a hullsplit insecticide treatment with phosmet as previously described, but without permethrin.

Four female-baited flight traps were placed within each treatment plot, 155 yards from each other and 78 yards from the side of the treatment block (Fig. 1B). In order to examine male abundance and response to females outside the treatment plots, additional flight traps were placed outside and within the experimental section (Fig. 1A). Outside the section, four traps were placed 550 yards north of the north edge and parallel with the center of each of the four columns of treatment plots. Within the section, a trap was placed center of the section and one each in the middle of the west, north, east and south sides of the section ~50 yards from the edge. Females were placed in the flight traps on February 24, 2004 and replace weekly until August 24. As the traps were serviced weekly, liners were removed and replaced if they contained moths or were dirty, and old liners were taken to the laboratory to identify and count NOW adults.

To monitor female abundance, a universal moth trap containing an oviposition attractant (previously described) was placed at the center of each treatment plot (Fig. 1B) and checked weekly starting the week of March 2, 2004 and continuing until August 24. Starting the week of May 11, female traps were also placed at each of the five flight trap positions between the treatment plots within the experimental section. Of 1036 NOW captured between March 11 and May 20, 2004 in a concurrent study in almond and pistachio orchards distant from 371, all but 20 were females. Examining moths captured on March 16, one or more spermatophore was found in the bursa of 98 of 100 female dissected. These observations confirm that this ovipositional attractant is attractive primarily to mated females.

Samples of Nonpareil almonds were taken from windrows on August 20, 2004 in the east half of Ranch 371, and on August 23, 2004 in the west half. Sixteen samples were taken from a four by four grid within each treatment plot, approximately 78 yards apart and 39 yards from the edge of the plot (Fig. 1C). In order to compare experimental treatments with the Imidan treatment used in the portion of Ranch 371 outside of the treatment plots, eight samples of ~500 nuts each were taken outside the 20-acre treatment plots, 2 per side and 64 yards outside the edge. The pooled sample comprised ~5,800 nuts each for the within-plot and outside plot samples associated with each treatment plot. All nut samples were examined by Paramount Farming research personnel for NOW damage. The effects of treatments on pollinator varieties are not considered here because the presence of different pollinator varieties in different parts of the experimental section resulted in inadequate replication for such comparisons.

Historical trend in NOW damage in almonds Data comparing harvest damage (percent inedible) and harvest volume for Nonpareil almonds for 1986 to 2004 were obtained from the Almond Board of California. Linear regression was used to examine the influence of crop volume and long-term trends on almond quality and to describe long term trend in changes in quality in Nonpareil almonds.

Statistical procedures We analyzed these data using the SAS System (Cary, NC). NOW counts from flight traps were transformed as $\log_{10}(x+1)$, and proportional harvest sample data were transformed as the arcsine of the square root of the observation. Means and standard errors of the untransformed data are presented in all figures and tables. The 2-year seasonal abundance data were analyzed as a 2-way factorial design with year and crop as main effects, the sum of counts at each ranch as the response variable, and week as a repeated measure. The effects of mating disruption and insecticide treatments on male captures in flight traps and nut damage and difference between treatment plot and surrounding damage were analyzed as a Latin square using PROC GLM; with rows, columns, and treatments as main effects. Flight trap data were analyzed with weeks as repeated measures. We used pair-wise comparison of means (LSMEANS) with a Bonferroni adjustment in analyses of seasonal abundance over two years and effects of mating disruption and insecticide treatments on flight trap counts in 2005, and a contrast to compare the NOW count in flight traps of the two mating disruption treatments with the two non-mating disruption treatments. In analysis of treatment effects on NOW damage to almonds, we used Tukey's protected LSD because of the small number of means involved and the large number of nuts pooled. In order to compare damage to almonds outside the treatment plots within the experimental section to those north of the experimental section, we used a one-way ANOVA. We considered individual replicates for that purpose, because we did not wish to infer results of that comparison beyond the present test. Comparisons of treatment means with a control level were performed using Dunnett adjustment. Since the mean number of females in bucket traps was <5 and the frequency distribution was highly skewed, these data were analyzed by generalized linear modeling rather than ANOVA, using PROC GENMOD with a log link and Poisson distribution. Regression of damage of Nonpareil almonds on crop volume and year was performed using the REG procedure of SAS, and the Durbin-Watson statistic (option DWPROB) was used to examine these data for autocorrelation.

Results

Seasonal abundance in almonds and pistachios Abundance was low in the almond ranches in June and July, and increased considerably in August, whereas in pistachios high abundance was observed in July and August (Fig. 2). The year and crop effects on NOW flight trap counts were both significant (F = 156.37, df = 1, 8; P < 0.0001; and F = 140.25, df = 1, 8; P < 0.0001, respectively), as was the year by crop interaction was also significant (F = 9.63, df = 1, 8; P = 0.0146). Comparison of weekly means for individual crop/year combinations showed that there were significantly more NOW captured in pistachios than in almonds (P < 0.05) in nine of the 12 weeks examined in 2003 and five of the 12 weeks examined in 2004, including, in both years, the period of 15 June to 15 July. Comparing within crops between years, the NOW count in flight traps was significantly higher in 2004 compared to 2003 in nine of the 12 weeks in almonds, and in three of the 12 weeks in pistachios. Accumulation of 1093 DD°F after biofix (required for development from egg to adult on old crop almonds) occurred on June 18 in 2003, and on June 6 in 2004. An additional 738 DD accumulation (sufficient for development from egg to adult on new crop) occurred on July 24, 2003, and July 13, 2004; and accumulation 1093 DD after beginning of the calculated second flight (in June) was achieved on August 9 and July 29, respectively, of these two years.

Mating disruption and insecticide treatments Over the period of March 2 to August 24, 2004, the mean NOW count in flight traps was 1.7±0.6 (n = 125) in the between plot traps and 51 ± 4 (n = 100) in the traps in the adjacent orchard to the north. Treatment means were 0.015 ± 0.008 and 0.003 ± 0.003 moths per trap for traps in Puffer and Puffer/insecticide treatment plots, and 3.9 ± 0.72 and 7.5 ± 1.0 for traps in untreated control and insecticide-only treatment plots (n = 400 for each treatment). This comparison demonstrates that the mating disruption treatments within the experimental section affected the entire section, including non-mating disruption treatments (Fig. 3A). The effect of treatment on NOW counts in female-baited flight traps was not quite significant (F = 4.03, df = 3, 6; P = 0.069) and the effects of row and column were not significant. The interaction of the row, column, treatment effects (used as the error term for those factors) was itself highly significant (F = 14.02, df = 6, 54; P = <0.0001), indicating that much of the variation in trap catch was within treatment plots. The effect of week was also highly significant (F = 57.58, df = 6, 54; P < 0.0001), as was the interaction of week and treatment (F = 4.35, df = 75, 100; P < 0.0001). This week by treatment interaction is evident in comparing Fig. 3B and 3C, in which flight trap counts increase in August in the non-mating disruption treatment but not in the mating disruption treatments. The contrast between the two mating disruption and two non-mating disruption treatments was not significant for the four weeks from March 1 to 22, 2004, but was significant (*P* < 0.05) for the 22 subsequent weeks from March 29 to August 23, 2004. The mean trap capture in treatment plots receiving Puffer or Puffer and insecticide treatments was not significantly different from 0 for any of the 25 weeks analyzed, and in fact the season total for 16 traps over 25 weeks was six moths for the former treatment, and one for the latter.

A plot of weekly treatment means of bucket trap captures shows that the seasonal trends are similar between the treatments, but that more females were captured in the two treatments involving Puffers than in the two not involving pheromone release (Fig. 4). Examining the effects of row, column, mating disruption (present or absent), and hullsplit insecticide (present or absent) with Poisson linear regression, we obtained a Value to degrees of freedom ratio of 0.8923 (Pearson $\chi 2 = 6.2463$, df = 7). Type 3 likelihood ratio statistics indicated that the effects of mating disruption and row were significant ($\chi 2 = 6.25$, df = 1, P = 0.0124; $\chi 2 = 18.38$, df = 1, P = 0.0004), whereas the effects of column and insecticide were not ($\chi^2 = 7.43$, df = 3, P = 0.0594; $\chi^2 = 0.24$, df = 1, P = 0.6212).

Examination of NOW damage from the treatment plots indicated significant variation due to column (F = 8.12, df = 3, 6; P = 0.0156) and treatment (F = 18.99, df = 3, 6; P = 0.0018), whereas the effect due of row was not significant (F = 3.53, df = 3, 6; P = 0.0884). The damage in the treatment plots ranged from 2.5 to 6.5%, compared to 6 to 12% NOW damage at this site the previous year. There was significantly less damage in almonds from the Puffer plots compared to the untreated controls, and both the nuts in both the Imidan/Pounce treatment and the Imidan/Pounce/Puffer treatment had significantly less NOW damage than those from the Puffer plots (Fig. 5A). The overall ANOVA for comparison of NOW damage to samples taken outside the treatment plots with damage taken in an adjacent ranch was significant (F = 2.94, df = 4, 131; *P* = 0.0288), but Dunnett's post-test revealed that none of the means of the nuts collected from outside of any of the treatment plots differed significantly from that of the nuts collected from the locations far north of the experimental section (deemed the control for this comparison). The overall mean NOW damage to these nuts was 4.4±0.2% (n=136).

<u>Imidan with and without Pounce</u> In examining difference in damage between nuts in the treatment plots and nuts in the surrounding area, which had been treated with Imidan at hullsplit, the effects of column and treatment were significant (F = 6.96, df = 3, 6; P = 0.0222; and F = 30.81, df = 3, 6; P = 0.0005; respectively), and that of row was not quite significant (F = 3.56, df = 3, 6; P = 0.0869). The almonds in the treatment plots had significantly more NOW damage than the surrounding Imidan-treated area in the case of the control and Puffer treatments, whereas those in treatment plots receiving Imidan/Pounce treatments with or without mating disruption had significantly less damage than the nuts in the surrounding Imidan-treated area. In all cases these differences were significantly different from 0 (Fig. 5B). The difference between the differences between treatment plot and surrounding area was not significantly different between the control and Puffer treatments, or between the Imidan/Pounce and Imidan/Pounce/Puffer treatments.

<u>Historical Almond Damage Data</u> The equation for regression of proportion inedible Nonpareil almonds on crop volume and year is:

1) $\text{Damage} = 1.140 - 9.186 \times 10^{-3} * (\text{Pounds} * 10^{6}) - 5.430 \times 10^{-4} * \text{Year}$

This model is highly significant (F = 28.05, df = 2, 16; *P* < 0.0001), the goodness of fit coefficient $r^2 = 0.78$, the estimates of the intercept and the two independent variables are significant (*P*<0.05), and there is no indication of collinearity between the independent variables. The Durbin-Watson statistic was not significant (P>0.05), indicating that autocorrelation could not be detected on the scale on which these data were collected (i.e., statewide).
The equation for simple linear regression of damage on year is

2) $\text{Damage} = 2.095 - 1.001 \times 10^{-3} * \text{Year}$

This model is also significant (F = 8.33, df = 1, 17; *P* = 0.0103) with $r^2 = 0.33$. The relation between year and damage to Nonpareil almonds is illustrated in Fig. 6.

Discussion

These data confirm our findings from the previous year that there are consistent differences between NOW abundance in well-managed almonds and pistachios, and that mating disruption can significantly reduce damage in Nonpareil almonds in which NOW is abundant.

The regression analysis presented here demonstrates that, independently of crop volume, there has been a significant decline in defects in Nonpareil almonds delivered to handlers from 1986 to 2004. A negative correlation between crop load and NOW damage has been described anecdotally (Zalom 1984). The negative parameter estimate found here for volume is consistent with that report, and the fact that r^2 for the two variable model which includes crop load (volume) is over twice that of the simple regression of damage on year indicates that crop volume explains a larger portion of year-to-year variation in damage than does a general trend of improving quality. This analysis that there is, nonetheless, a significant trend of less damage to Nonpareil almonds over the last 15 years, and this trend is still evident after accounting for the effect of volume.

From 1977 to 1981 the damage to California almonds by NOW averaged 5.3% (Curtis et al. 1984). At that time pistachios were a recent crop in California, and some observations suggested that NOW dispersal from mature almonds was a source of infestation for young pistachios

(Andrews and Barnes 1982). Since then the Almond Board of California and the University of California have continuously communicated to almond growers the importance of orchard sanitation for the control of NOW. Even though the "inedible" category includes many types of damage, reduced NOW damage is probably a factor in the statistically described above. From 1994 to 2003 the bearing acreage of pistachio orchards in California have increased by 53%, from 57,500 to 88,000 bearing acres (CDFA 2003). These observations suggest important changes in the environment for NOW in recent decades, and corresponding changes in relative abundance in these two crops.

The present data demonstrate that, under current circumstances, there is a consistent trend of greater NOW abundance and different population dynamics of NOW in pistachios compared to almonds. Comparing data between the two years, it is evident that the 2003 pheromone trap counts were reduced in both crops, even though the monitoring traps were 220 to 311 yards from the edges of the pheromone treatment plots. It is, nonetheless, evident that in both years abundance was low during the second flight in almonds, but high during much of this period in pistachios. In pistachios the cohorts appear to overlap after the second flight, and there is high abundance through much of the year.

The fourth almond ranch examined in 2003 was used for the mating disruption experiment in 2004. This was done because, in 2003, low NOW pressure in the other three almond ranches resulted in no significant differences between treatments within those ranches. Replicating the mating disruption treatments within an area of high NOW abundance and damage provided more uniform variation in trap capture and damage, and therefore better confirmed the efficacy of mating disruption in reduction of damage in almonds. While removing this ranch from the comparison of seasonal abundance accentuated differences between the two crops, the fact remains that all four of the 640 acre pistachio ranches we examined for two years had high abundance through most of the second flight, whereas three of the four almond ranches we examined had overall low abundance and very low abundance during the second flight.

The NOW seasonal abundance in the fourth almond ranch in 2004 (where the mating disruption experiment was conducted) resembled that in pistachios; i.e., abundance was high in the second flight. We believe that, in both cases, this is because intense sanitation efforts were ineffectual. In the case of almonds we believe that age was one factor. Ranch 371 was established in 1993, and adjacent almond ranches were established in 1990. The remaining almond ranches were established between 1996 and 1999. It seems likely that mummy almonds high in the canopy of larger and/or older trees escape attempts to dislodge them, and escape the notice of those assessing the results of sanitation efforts. In the case of pistachios, we believe that this is because spilled and dislodged mummy nuts have the tendency to stick in the soil, particularly on the berm, and therefore to escape attempts to destroy them.

The data from the mating disruption experiment at the fourth almond ranch demonstrated that the Puffers in the treatment plots at this ranch substantially reduced NOW sexual communication throughout the section, and that there were nonetheless significant differences in NOW damage between the Puffer treated plots and the untreated control plots. This contrast further suggests that a very high level of reduction of sexual communication is required to reduce damage in almonds. That is consistent with the flight trap data from this study and well as previous data (Burks et al. 2003), which indicated that shut down of flight traps baited with virgin females must be complete to reduce damage. That is logically consistent with the conclusion from that previous study that NOW damage to Nonpareil almonds is due to the highly susceptibility of that crop, and that damage can be accomplished by a relatively low NOW population.

While replicating mating disruption treatments within a single 640 acre ranch better allowed us to confirm the efficacy of mating disruption with Z11Z13-16Al, there were also disadvantages to that approach. The principal disadvantage is that the difference between the damage in the Puffer and the untreated control plots is probably understated. The previous year damage in this same ranch ranged from ~12% in untreated control plots to ~6% in plots receiving either the insecticide treatment or the Puffer treatment used in the current study. A second disadvantage is that it remains possible that all insecticide treatments within the experimental section received at least some added benefit from the reduced sexual communication throughout the experimental section. On the other hand, while it is possible that a greater difference between insecticide and insecticide/mating disruption treatments would be seen in widely separated 40 acre plots, the data from this and our previous study (Burks et al. 2003) generally demonstrate that residual insecticides such as azinphosmethyl and phosmet more consistently reduce NOW damage when NOW populations exceed a threshold for economic damage. Logically, the results of such residual treatments would be less dependent on environmental factors such as initial abundance or the size of the treatment block.

In this study, more mated females were captured in traps baited with an oviposition attractant in mating disruption treatment plots than in plots not receiving mating disruption treatments. While previous studies have suggested behavioral effects of pheromone permeation on other lepidopteran females, it is not clear why we captured more mated females in oviposition attractant traps in plots under mating disruption treatments, even as damage in those plots is reduced.

This study, and our previous mating disruption research, examined whether mating disruption treatments applied during a growing season reduce damage within a growing season, and how that reduction in damage compares to that obtained with residual insecticides. The data to date indicate that, while reduced damage in Nonpareil almonds can be obtained, residual insecticides achieve the same or superior results, and these results depend less on circumstances such as the size of the block under protection or initial populations. Thus, the advantages of residual insecticides (more reliable reduction of damage) accrue primarily to the producer, whereas the advantages of mating disruption (less toxic residue entering the ecosystem) accrue primarily to others. What has not been tested in this species is whether mating disruption can reduce population abundance from one season to the next and, if so, what size of treatment block would be needed to achieve that effect. These are questions that need to be addressed to use mating disruption in the context of an area-wide approach. Given the proximity of large blocks of pistachios and almonds in the southern San Joaquin Valley, an area-wide approach would be appropriate.

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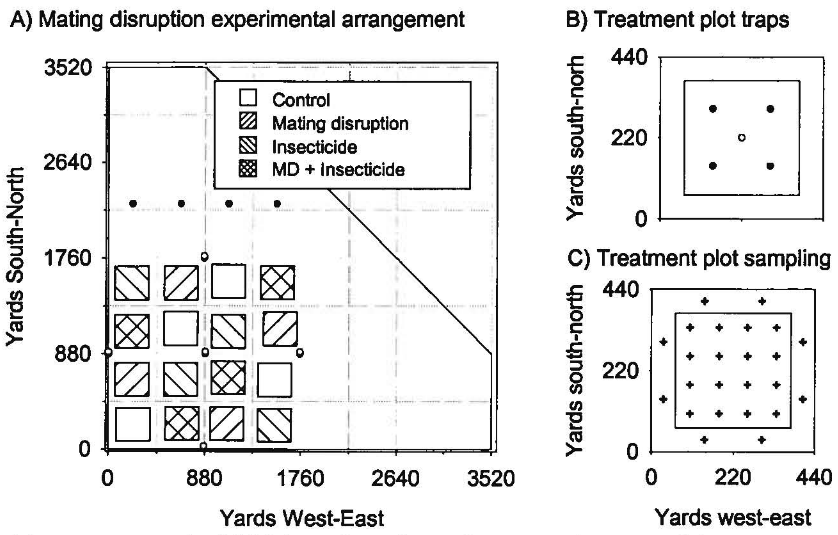


Figure 1. Field arrangement of 2004 mating disruption experiment. A) Latin square arrangement of treatment plots. One square mile of a contiguous planting of >4 square miles of was divided into 16 20-acre treatment plots, each centered in a 40-acre subdivision of the square mile. Female-0baited flight traps (●) were used to examine male response outside the experimental area, and flight traps and bucket traps (O), attractive to mated females, were used to examine NOW abundance and response between the treatment plots. The solid line represents field boundaries and a railroad track on the northeast side, and the entire 4 square mile area depicted was planted in almonds. B) Illustration of placement of female-baited flight traps (●) and bucket traps (O) within the individual treatment plots. C) Illustration of nut sampling points (+) within and around individual treatment plots. Approximately 5,800 nuts were sampled inside each of the 16 treatment plots, and an equal number was sampled outside each of the treatment plots.

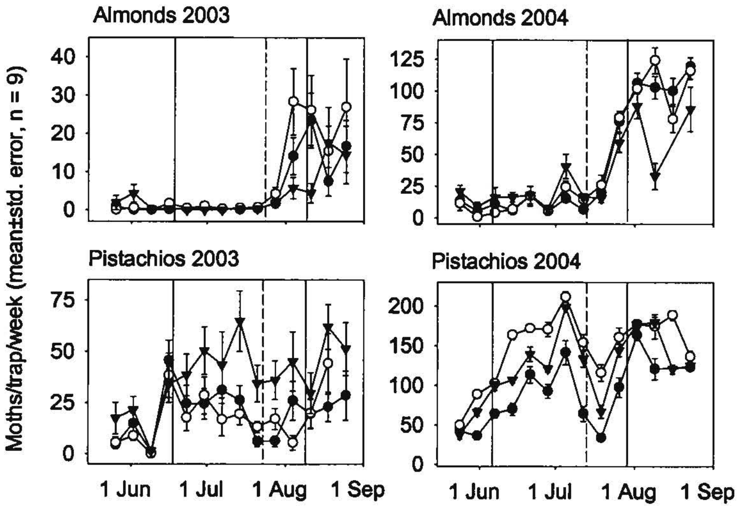


Figure 2. Seasonal abundance of NOW from June to August, as indicated by males captured in female-baited flight traps in three sections of almonds and three sections of pistachios in the southern San Joaquin Valley in the vicinity of mating disruption (2003) and in the absence of mating disruption (2004). The vertical bar on the right represent the predicted beginning of the 2nd flight based on 1093 DD°F from biofix. The dashed and solid vertical bars to the right represent 738 and 1093 DD, respectively, from the bar on the left.

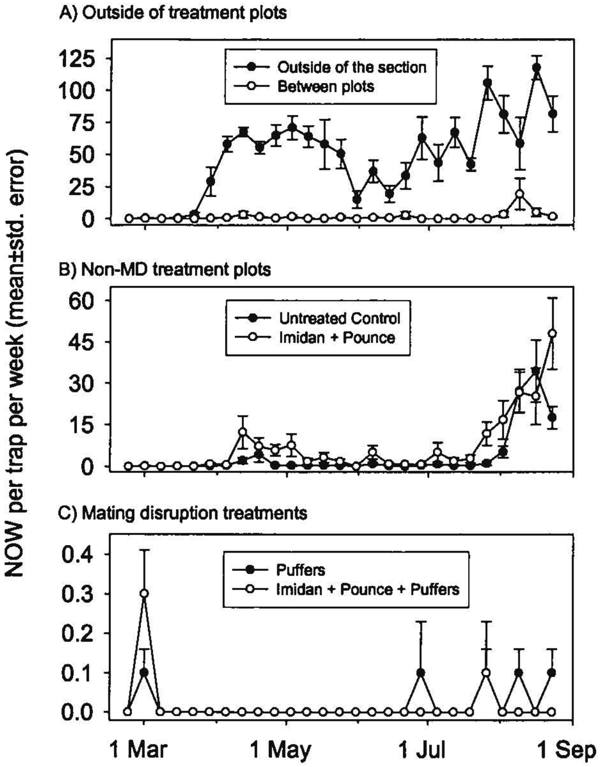


Figure 3. Effect of mating disruption and insecticide treatments on NOW males captured in female-baited flight traps. A) The outside flight traps demonstrate high NOW abundance in the area, whereas those between treatment plots in the experimental section demonstrate that male orientation to females was affected throughout the experiment section. B) Significant numbers of moths were, nonetheless, captured in non-mating disruption treatment plots within the experimental section. C) No weekly treatment means in the two mating disruption treatments was significantly >0.

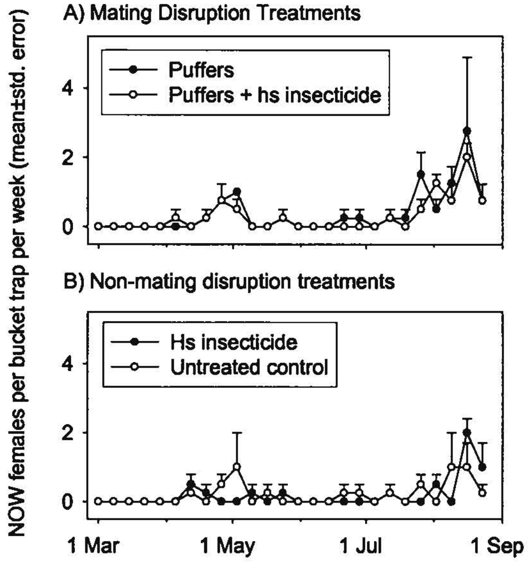
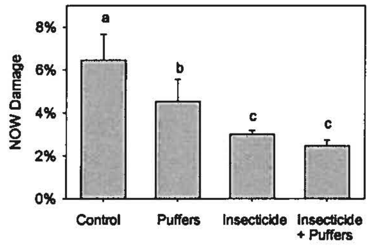


Figure 4. Effect of mating disruption and insecticide treatments on NOW females captured in treatment plots in A) mating disruption and B) non-mating disruption treatment plots. The effect of mating disruption on females captured in treatment plots was significant (Poisson linear regression, $\chi^2 = 5.30$, $P = 0.02$).

A) Effect of treatments on NOW damage



B) Comparison between experimental treatments and Imidan only

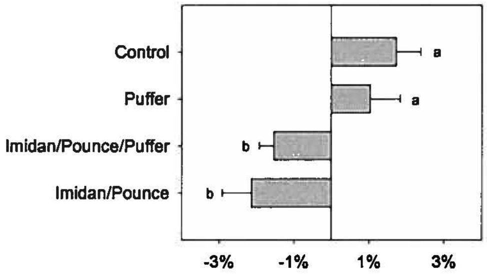


Figure 5. Effect of treatments on NOW damage to almonds. Mean and std. error, n = 4. Means with different superscripts are significantly different ($P < 0.05$). A) Effect of mating disruption and insecticide treatments on NOW damage in Nonpareil almonds. Means with different superscripts are significantly different ($P < 0.05$). B) Diffference between damage in treatment plots and surrounding area treated with only Imidan at hullsplit. All mean differences are significantly different from 0 ($P < 0.05$).

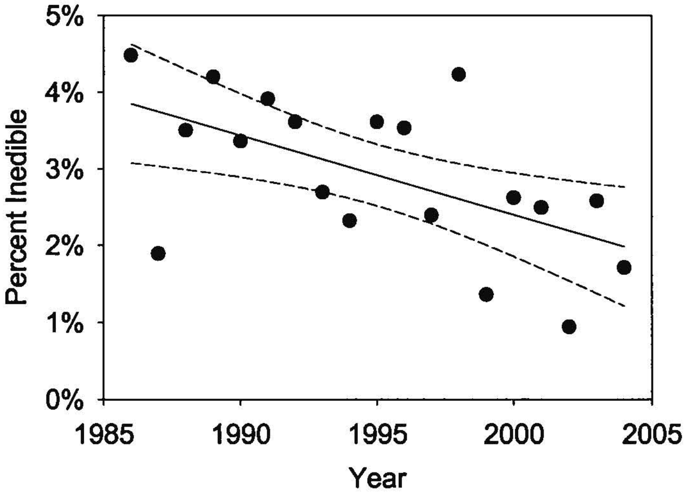


Figure 6. Twenty year trend in postharvest damage in Nonpareil almonds received by handlers. The goodness of fit coefficient $r^2 = 0.3228$, and the slope is significantly different from 0 ($P < 0.05$).