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Project Title: Development of alternative dispensing technologies for management of codling moth

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ABSTRACT

Overall, performance in puffer treated plots including pears and walnuts looked promising, yet faces the same limitations as other pheromone programs such as poor program performance against high pressure situations. High pressure situations were not adequately suppressed, whereas low to moderate situations experienced very low damage levels. Potential for cost reduction using more optimally spaced dispensing units also appeared feasible under controlled experimental conditions. While the economic gain from reducing the number of dispensers from 1 per acre to 1 unit per 1.5 to 3 acres can be quite significant, the current benefit may be offset in part by the documented high unit failure rate of 18%. When the distance between units is based on a conservative estimate of plume size and shape, then each unit is required to manage codling moth over a greater physical area without any redundancies between units. Because of documented difficulties with the units, the number of dispensers per acre should not be decreased beyond the current standards until issues of breakage are resolved.

The sprayable pheromone technologies performed less well than expected from 2001. Codling moth traps were consistently shut down in all trials, yet damage was still observed in one walnut location (Locke). In pears, where the sprayable formulations have looked less promising presumably due to the more open canopy, light penetration, and potential changes in codlemone stability, the sprayable plots produced commercially acceptable control, but increasing moth flight counts were also observed.

Initial efforts with aerial applications of sprayable formulations looked positive with equal trap suppression of sterile moths in areas treated with fixed wing plane or ground air blast sprayers. Monitoring with DA lures in walnuts also looked positive until late July after which moth trap counts were lower than pheromone baited traps in control plots. Late season monitoring for Azinphosmethyl resistance in codling moth in pear orchards did not indicate any dramatic increases in resistance, but high levels continued to be found in all tested orchards except an organic block.

INTRODUCTION

Two newer technologies were examined for their potential to contribute to pheromone mating disruption programs in pome and nuts crops. Different factors seem to be limiting our ability to implement mating disruption including cost, perceived program risk, and agronomic considerations that include characteristics of the orchard (tree size, canopy structure, light interception patterns, etc). The two approaches include utilizing a source of high pheromone doses with an aerosol emitter (or puffer) at densities of less than one emitter per acre, and alternatively, using encapsulated pheromone formulations that emit a low rate of pheromone from many tiny spheres applied to the foliage or bark.

The studies of high-rate emitters or puffers were predicated on expected plume size and apparent areas of effects estimated in previous years using releases of sterile codling moths. Previous data has suggested that the plume from a puffer conservatively would extend at least 500 feet downwind and 250 wide from the point source. Using this approach, a dramatically reduced number of dispensers could be used within an orchard, which ultimately would reduce program cost per acre. The final number of dispensers per acre would then depend on the geometry and size of the orchard rather than a fixed number of dispensers per acre. Cost savings are potentially quite dramatic given the proportional reduction in material costs as the number of units is decreased.

GENERAL METHODOLOGY

Puffer Unit Performance

One area that potentially could limit our ability to reduce the number of dispensers per acre is if the units malfunction and fail to deliver pheromone at a fixed rate over time. As the number of dispensers per acre is reduced, our reliance on each unit increases proportionally. Hence, failure by one unit that is relied upon to affect codling moth mating activity in 2-3 acres could prove disastrous. Puffer function was monitored at two to four week intervals by weighing units, checking battery power, checking that the unit would actually "puff", and inspecting the housing for excessive wear at the hang point. Emission rates were calculated from weight data to identify units blowing excessive amounts or low rates of pheromone. Poor-condition or dysfunctional units, batteries, and aerosol canisters were replaced as needed. The replacement of malfunctioning units was noted on each date so as to calculate unit failure rates.

Puffer Trials – Efficacy of Reduced Density Application

We evaluated the efficacy of aerosol emitters ("puffers") applied at reduced density in walnut and pear orchards. Data from both tree crops are included in the report such that a larger pattern can be more easily discerned. Standard application rates for the puffers that have proven successful in Lake County pears are 1-2 dispensers per acre. Depending on field dimensions and field geometry relative to predominant wind direction, we applied puffers at densities ranging from 1 unit per 1.5 acres to 1 unit per 3.2 acres. All trials used the Paramount Puffer (Suterra Inc., Bend, OR 97702) loaded with NOW/CM aerosol canisters. Trials were conducted with puffers set for an emission rate of 7.05mg ai (codlemone) /puff or 338.4 mg ai per day and were programmed to run 12 hours per day from 6 pm to 6 am in all sites. All puffers were hung in the upper canopy of the designated tree. The NOW material was included for potential control of navel orangeworm in the walnut trials.

A grid of traps (Pherocon® Delta VI, Trece, Inc., Salinas, CA) were placed in each trial site and monitored adult codling moth activity. In walnuts, traps baited with CM standard red lures (Trece 3111) or DA lures (Trece DA2313) hung low, while those baited with CM 10X lures (Trece 3160) were placed at about 12 to 15 feet. Traps were monitored weekly and lures changed every 2 weeks (CM standard and 10X) or 4 weeks (DA). In pears, initial use of Trece CM standard or 10X lures was changed to Biolure Codling Moth 1X or 10X lures (Suterra, Inc., Bend, OR) in mid-May. Traps were monitored weekly and lures changed every two weeks (Trece lures) until mid-May and every six weeks (Biolures) thereafter.

Codling moth damage assessments were conducted twice in pear sites (1000 DD and harvest), and three times in walnuts (1st generation, 2nd generation, harvest). Pear samples were conducted as follows: for each treatment orchard, the control and eight or nine sample sites within the treatment areas were surveyed for codling moth damage. All sites were sampled between June 11 and 13 (approximately 1000 DD), by inspecting 20 fruit from the lower canopy of 30 to 35 trees. Infested fruit were cut to determine age of the codling moth larva. At harvest (July 8 – 12), 1000 fruit were inspected from each sample site by surveying 20 fruit from each of 50 trees. Infested fruit were cut to determine age of larvae infesting the fruit. Walnut samples were conducted by the following general protocols: canopy samples were conducted from pruning towers for 1st and 2nd generation damage assessments from a grid of sample sites within the experimental plots. The 1st generation damage was evaluated mid-June by inspecting 450 –500 fruit from the controls and each of five (Vogel) or nine (Locke) sites within the treatment blocks of each orchard. 2nd generation damage was evaluated late July or early August by inspecting 500 – 800 fruit from control plots and each of five (Vogel) or ten sample sites (Locke) in the treatment area. Evaluations taken prior to harvest required the use of pruning towers to reach the upper portions of the tree canopy. Harvest samples were made by collecting 500 nuts per sample site after shake, either before or after being swept into windrows. In the Locke orchard, where some blocks have more than one walnut variety with different nut maturity dates, harvest samples were collected following each shake. Collected nuts were returned to the lab in Berkeley, cracked out and damage recorded.

Walnut sites.

Locke Orchard

The Locke Orchard is located in San Joaquin County adjacent the town of Lockeford, CA. Our puffer site encompassed several planting blocks that totaled 118 acres on the eastern side of this orchard. Blocks included Vina, Hartley, a mixed planting of Serr and

Chandler, and a mixed planting dominated by Vina and Serr but including Pedro and Tehema varieties. The trial site is roughly "half moon shape" running approximately 3500' on the long north-south boundary and 1900' across at the widest region. Dominant wind direction is from the northwest, thus, the control was assigned the northern 2.5-acre point of the area. A total of 34 puffers were deployed in the treatment plot at a rate of 1 puffer per 3.2 acres. Twelve were placed at approximately 280' intervals along the long west boundary and the remainder placed in a grid pattern as shown in Fig. 6. A grid of 24 traps baited with CM standard lures, 4 traps baited with CM 10x lures, and 4 traps baited with DA lures monitored codling moth activity. The 10X and DA baited traps were set up in pairs in each of the major planting blocks. In addition, three traps baited with CM standard lures, and one trap each of a 10X and DA lure were placed in the control area. Along the west boundary (the long edge), border sprays of 20 g ai/acre Checkmate CM-F (Suterra, Inc. Bend, OR) were applied May 2, June 14, and July 25. A single application of Confirm (24 oz/acre at 200 gal/acre) was made on July 12 to all 51 acres of the Vina block and 23 acres of the Vina-Serr mixed planting. Husk fly activity mandated a Lorsban treatment (4 pints/acre at 200 gal/acre) to the 101 acres of the Vina, Hartley, and Vina-Serr plantings between August 16-26. Canopy samples for damage after 1st and 2nd generation were made as described earlier. Harvest samples were made September 27 through October 14 with 1st shake, and October 10 and 28 following 2nd shakes in the south Vina-Serr and north Serr-Chandler blocks, respectively.

Vogel Orchard

The Vogel orchard is located in San Joaquin County, near Linden, CA. The orchard is planted to Vina variety walnuts except for the north nine rows (6.8 acre) that are Chandler variety. The puffer plot was placed in the south 25 acres of this 55-acre orchard. Predominant wind direction is from the northwest. A one-acre control block was placed at the northwest corner of the orchard, approximately 1000 feet upwind of the puffer treatment. Due to a misunderstanding, the control is in a different and less susceptible cultivar (Chandler) than the treated plots which renders the contrast less useful. Ten puffers were placed along the west and north boundaries of the treatment area for an application rate of one puffer per 2.5 acres. A total of 18 traps (12-CM standard, 3-10x and 3-DA) were set in a grid pattern in the puffer treated area. Two traps (1-CM standard and 1-DA) monitored codling moth activity in the control block. The north 5 rows (3.7 acres) and west edge of the puffer block were treated with Confirm on May 27 and July 7 as a border treatment. No other insecticide treatments were applied to the puffer area. Canopy samples for damage after 1st and 2nd generation were made as described earlier. Harvest samples were made October 8 (puffer treatment and two sites in the grower treated area) and October 21 (control).

Pear sites

Jaime Orchard

The Jaime orchard is a 19-acre site of Bartlett variety pears near Isleton, CA. It's long, narrow shape (approximately 1700 x 500 feet) oriented with predominant wind across the narrow dimension made it a challenging site for a puffer trial. Thus, the puffer density implemented at this site was the highest of our trials. Twelve puffers were set on April 17 in the 18-acre treatment area (one puffer per 1.5 acre). A one-acre untreated control was assigned the upwind southwest corner of the plot. A total of 18 traps (15-1X, 3-10X) placed in the puffer area monitored codling moth activity. Two traps (1-1X and 1-10X) were placed in the control. Two damage samples were conducted as described above. A single application of Confirm 2F (20 oz/acre) was made by the grower on June 4 to the entire orchard as a prophylactic treatment.

Barry Orchard

The Barry orchard was a 25-acre block of Bartlett pears near Courtland, CA. The predominant wind direction was in line with the long dimension of this block (approximately 1400 feet). Two rows of four puffers were deployed on April 12 in this site for a density of one puffer per 3.1 acres. A one-acre control plot was assigned in a nearby upwind block of the same orchard. A total of 18 traps (14-1X, 4-10X) placed in the puffer area monitored codling moth activity. Two traps (1-1X and 1-10X) were placed in the control. The orchard was treated with Agrimek at 12 oz/acre in mid-April. A border spray of Danitol at 21-1/3 oz/acre was applied mid-May to the northwest boundary and the first five rows of the upwind border (2 acres). Two damage samples were conducted as described earlier.

Hood Orchard

The Hood orchard is a 45-acre set blocks of Bartlett variety pears located near Hood, CA. Several blocks of this orchard have had a high codling moth population in recent years. We used approximately 20 acres of two adjacent blocks for a puffer treatment and an isolated upwind 0.5-acre block as a control. Thirteen puffers were placed in the treatment areas on April 10 for an overall density of one puffer per 1.5 acres. The large grower treated area in the eastern rectangular block was designated because tree canopy was minimal and probably not suitable for the puffer program. A total of 14 traps (12-1X, 2-10X) placed in the puffer area monitored codling moth activity. One trap (1-1X) was placed in the control and an additional trap (1-1X) was placed in the western grower treated area. Insecticide applications made in the grower treated areas were as follows: Danitol at 21.3 oz/acre on April 17, Imidan at 5 lbs/acre on May 8, and Imidan at 6.5 lbs/acre on July 3. In addition, Assail was applied to the entire orchard (including the puffer plot) July 18 when harvest was delayed beyond initial estimates. Thus, our harvest damage estimates preceded actual harvest by more than three weeks. Two damage samples were conducted as described earlier and included a sample taken from the grower treated area at the far west side of the orchard. Another researcher conducted a spray trial within the grower treated areas using Assail and Imidan/Danitol treatments. Six plots of 1.3 acres each were used for that study.

Peck Orchard

The Peck orchard is a 50-acre set of pear blocks in first year transition to an organic program located near Courtland CA. The acreage consists of one 25-acre rectangular block of Bartlett's we refer to as Peck-North. We grouped other adjacent Bartlett blocks forming a narrow strip along the levee into a 20-acre treatment plot we refer to as Peck-South. Peck-North was placed under pheromone treatment with the deployment of nine puffers (one per 2.8 acres) on April 10. A total of 20 traps (16-1X, 4-10X) placed in the puffer area monitored codling moth activity. Peck-South was placed under pheromone treatment using 11 puffers (one per 1.8 acres) on April 18. Estimating suitable puffer placement in Peck-South was difficult given the dimensions and orientation to wind direction. A total of 14 traps (12-1X, 2-10X) placed in the South block puffer area monitored codling moth activity. One upwind area on the south end of Peck-South served as control for both treatment areas (Peck-North and Peck-South). Two traps (1-1X and 1-10X) were placed in the control. The orchard received approximately eight treatments of oil and two treatments of Pyganic to supplement the pheromone coverage.

Sprayable Trials

We used the sprayable pheromone Checkmate CM-F (Suterra, Inc., Bend, OR) for a) rate trials in walnuts and pears, and b) an aerial vs ground application trial in walnuts. The walnut orchards included the Locke Orchard in Lockeford, CA, and an orchard near Wheatland, CA in the central Sacramento Valley. The pear orchard was the Wiseman ranch in the Sacramento delta. Codling moth monitoring techniques followed the trapping protocols indicated for puffer trials.

Rate Trials

Walnuts – Locke Orchard
The 50-acre block of Chandler and Serr varieties was divided into quadrants as well as a smaller untreated control block (0.95 acres) in one corner. Three treatments were applied at 10 ai/acre. Two plots were treated at 10g ai/acre with every row sprayed. The third plot had every other row treated with twice the concentration (equivalent to 20 gm per acre) to achieve the 10 gm per acre application rate. The fourth treatment had 20 gm per acre applied to every row in the plot. We located the untreated 0.95-acre control in the upwind corner of the northwest quadrant. A total of three applications of pheromone were made on the following dates: May 1-2, June 13-14, and July 25. All sprays were performed with a 500 gal speed sprayer at 100 gallons per acre. On Aug. 5-6, the grower applied Lorsban (4 pt/acre at 200 gal/acre) to the entire block for walnut husk fly control.

The trap layout in each quadrant consisted of six traps laid out in two parallel rows of three traps spaced a minimum distance of 200 feet apart. In each treatment, two CM 1x, two 10X and two DA lures were randomly assigned to traps. Three traps were placed in the control (1-1X, 1-10X, and 1-DA). We monitored traps weekly and changed lures bi-weekly, except for the DA lures, which were changed on a 4-week basis.

Canopy samples were taken at two times to assess damage. The 1st generation sample made on June 12-13 consisted of 30 trees per treatment area, 10-15 nuts per tree. Sample areas included the central region of each quadrant, as well as the upwind edge of the two northern treatment blocks. The control was also sampled, with a two-tree boundary from the treated area maintained. The nuts, collected at varying canopy levels in the center of each block, were cut on-site if there was evidence of damage and larval development was recorded at that time. The second generation sample on July 24 consisted of a 600-800 nut sample conducted by inspecting 30-40 nuts from 20 trees in each treatment and the north edge of two sites. Our final damage assessments at Locke were a pair of harvest samples on Sept. 28 (predominantly Serr variety) and Oct. 21 (predominantly Chandler). We collected 500 nuts per sample site per treatment for each of the 1st and 2nd shakes. Nuts were returned to the lab, cracked-out, and damage was recorded.

Leaf samples were collected twice from the 20g ai/acre treatment block for testing to detect application coverage and longevity. The first sample was collected the day following the third pheromone application; the second sample was collected about three weeks later. Leaves were collected from the top, middle, and bottom of the canopy from each of four trees. We hope to use these samples to develop a detection technique using an electro-antennagram (Syntech, Netherlands). The leaflets remain frozen for future evaluation.

Pears – Wiseman Orchard

The 31-acre Wiseman plot contains both Bartlett (17 ac) and Bosc (14 ac) variety pears. The orchard itself is pie-shaped and narrows to a point inside the Bosc planting. The broad end of the plot planted to Bartlett's was divided into two treatment blocks of 20g ai/acre and 10g ai/acre, with an untreated control placed in the northern corner of the 20g block. Because of the narrow formation of the Bosc plot, we assigned it a single treatment (10g ai/acre achieved by spraying the 20 g rate on alternate rows only) with a control along the southwest end.

Codling moth flight activity was monitored by a total of twenty traps placed as follows: Bosc - four traps baited with 1X lures and two with 10X lures; Bartlett 10 g ai/acre rate – three traps with 1X and two with 10X lures; Bartlett 20 g ai/acre rate – three traps with 1X and two with 10X lures; control – one each of 1X and 10X lures.

Supplemental insecticide applications were made to the 17 acres of Bartlett's in response to high trap catches. Danitol 2.4EC was applied June 4 at the rate of 0.4 lb ai/acre in a 125 gal/acre spray. Following harvest, Assail 70WP was applied July 28 at a rate of 0.15 lb ai/acre in a 125gal/acre spray.

Codling moth damage was assessed twice: first with a 1000 DD sample on June 11, then before harvest on July 9. Ten sites were designated as sample areas in the first sample, and 20 fruit from 30 trees in each site were inspected for evidence of codling moth. At harvest, 11 sites were evaluated and 20 fruit from 50 trees in each site were inspected. Pears showing codling moth damage were cut to determine stage of infestation.

Aerial application

Walnuts - Wheatland

We compared an aerial application to standard ground application of Checkmate CM-F (Suterra, Inc., Bend, OR) in this block of Chandler variety walnuts east of Marysville, CA. Three 2.5-acre test areas were set up within the orchard for the aerial application, ground application, and the control (Fig. 45). The aerial application was made on 2.5 acres at one end of the block. A five-row, 150-foot border was left between the 2.5 acre ground application and the aerial application. The untreated control was placed at the opposite end of the block, approximately 600 feet away from the ground treatment border. Pheromone applications were made at the rate of 20 g ai / acre on Sept. 19 for both aerial and ground sprays.

Efficacy of aerial versus the ground application was assessed solely by the ability of the treatment to shut down 1X-baited traps. Traps baited with DA lures were placed to demonstrate presence of codling moth. As this trial was conducted at the end of the season, the codling moth population was created by the release of sterile moths (Sterile Insect Release Program, Osoyoos, BC CANADA). Eight traps set in two rows of four traps were place in each of the treatment blocks and the control. Traps were baited with CM1X or DA lures (Trece Inc., Salinas, CA) with lure placement in trap pairs randomly assigned. Five trees in a diamond pattern between trap rows were assigned as release point trees for the sterile moths. At each point 800 moths were released by placing them into a Pherocon Delta VI trap without the sticky liner. This permitted the moths to warm, recover and disperse at their own timing. The sterile release was made on September 20. Traps were read weekly for two weeks.

Leaf samples were collected from the three test areas on Sept. 26, a week after the pheromone application and again on Nov. 5. All samples were frozen, and will be tested for indications of pheromone coverage. Leaves were collected from the top, middle, and bottom canopy of each of five trees from each treatment block and the control.

DA Sprayable Formulation

Walnuts – Pittel Orchard

A small quantity of a microencapsulated formulation of the pear ester (DA) compound was made available for trial in July. We proceeded with a trial consisting of single-tree treatments at rates of 0.1 and 1.0 g ai/100 gal to evaluate whether female moths could be induced to oviposit on treated trees. The trial was conducted at the 75-acre Pittel Orchard, near Farmington, CA. This is a mixed block of Eureka and Chandler varieties with Chandlers as an interplant and replacing Eureka trees in decline. We selected the Chandler's to treat in this study, as trees were generally smaller, crop smaller, and this was a crop-destruct trial. Nine blocks of three trees were established with all treatment trees and controls separated by approximately 200 feet (Fig. 46). Rates (1.0 or 0.1 g ai/100 gal, or control) were randomly assigned to the three trees in each block. Two applications were made (August 1 and August 29) using a hand-gun sprayer calibrated to 100 gal/acre.

Impact of treatments was assessed by evaluating damage on nuts from treated trees. A 100-nut sample was collected from each sprayed tree and control on Oct 14 prior to harvest. The nuts were taken back to the laboratory, cracked and checked for damage. At the same time, a 200-nut sample was taken from Eureka variety trees adjacent the south side of experimental trees. This was done for four blocks of three trees. These were also returned to the lab and inspected for codling moth damage.

Resistance Survey

A late season survey of Azinphosmethyl resistance was conducted in response to grower and PCA concerns about difficulties with codling moth control. As such, codling moth populations from 3 potential problem orchards plus an organic apple orchard were surveyed. The organic apple orchard has been used historically since the early 1990s as a baseline for resistance in that resistance levels have recently been similar to levels first reported in the 1960s. Data from the organic orchard are used as a relative comparison with historical data and between orchards.

Adult moths are trapped in pheromone baited pheromone traps (Delta 1C) which have a modified lower liner which uses less adhesive to minimize moth mortality. Traps are placed in the evening and recollected the next morning at daybreak. The traps with the live moths are transported back to Berkeley and assigned to various insecticide dosages that are expected to span the levels of resistance found in the past. Total number of moths per trial ranged from 126-605 moths, which were all collected in a single night. The moths are treated topically with a fixed dose of Azinphosmethyl and held at 60°F for 48 hours. After 48°hours, the moths are scored as alive or dead and the percent mortality calculated. Data were analyzed using probit analysis.

RESULTS

Lure efficacy in walnuts: DA and 1x standard lures

The cumulative counts for the 1 mg pheromone lures, the DA lure in control plots and the CA in pheromone treated plots did not differ significantly over the entire season for any contrast (Figures 1-2). However, the relative patterns did shift dramatically during the season with higher counts in the DA baited traps compared to the pheromone baited lures. Because of the small plot size for the control and the immediate adjacency of the pheromone treated plots, it is unclear if drift from these plots also suppressed the pheromone-baited traps. The DA and pheromone lures indicated the same overall patterns in flight in the control and pheromone treated areas until the third flight. While the results were not significant at $P = 0.07$, the DA lures did not detect any flight compared to the 1x pheromone baited traps, whereas higher counts had been observed for in DA baited traps for the 1st and 2nd flights. If this pattern is repeated in further studies, the DA lure will not be a good fit as a monitoring tool for estimating late season flights.

Puffer Trials

Results from individual orchards are presented rather than just summarized versions in that the patterns within the data are relatively unique per orchard. Similarly, the overall pattern from both the walnut and pear orchards are similar, yet pressure levels and issues of outside sources of codling moth also varied tremendously.

Evaluation of puffer unit performance

The results of the periodic review of the puffer units over the season are shown in Figures 3-5. Figure 3 shows that 82% of the units were never replaced, while 18% of the units were replaced for a variety of different problems. The most common issue was excessively discharge rates (“ blow-outs”) due to apparent changes in programming or in valves sticking in the open position. The second problem of structural failure may be due to the high winds in the trial regions in that the opening for the hanger system would wear away under the swinging resulting from windy conditions, The plastic opening would wear through on the top and the unit would fall from its location for 4% of the units. The puffers would also emit too low of rate in about 2% of the units.

In addition, the rates of replacements varied by part as would be expected (Fig. 4). The batteries fail to last the duration of the season for 90% of the units, whereas 32% of the pheromone cans had to be replaced during the season due to insufficient pheromone content resulting from high delivery rates. The increasing rates of cumulative replacement of the dispensing units to 19% also shows that units were being replaced sporadically throughout the entire season with the most intensive rates of replacement between weeks 10 and 14.

The emission rates of the units per day were relative varied (Figure 5). A fairly significant percentage of the units failed to emit at rates (2 gm per day or less) that would allow the units work for the entire season.

These data become especially acute when designing a program that relies on the minimum distribution of units per acre (e.g. 1 per 3 acres). Each unit is required to cover a swatch of orchard without backup assumed. The failure rates of 18% of the units and the 32% replacement rate for the cans can be dealt with 2 ways: 1) increase the reliability of the dispenser in qualities of release rates and durability or 2) build redundancy into your deployment pattern such that unit failure becomes less catastrophic.

Puffers – Walnuts

Locke Orchard

The plot design is shown in Figure 6 including puffer deployment spacing. The seasonal counts for codling moth are shown in Figures 7 and 8 for both traps baited with 1 or 10 mg lures. Traps baited with 1 mg lures were effectively suppressed throughout the season in the puffer treated interiors. However, the edges of the orchard were not suppressed with maximum average counts of ca. 5 moths per trap in late July or early August. The control plots also had low counts with the 1 mg lures, which may reflect some pheromone movement throughout the plots. This is supported by higher counts in the control plots for the 10 mg lures that normally are less active in non-pheromone treated areas. Counts peaked early in the season in the control plot at ca. 13 moths per trap. Traps baited with 10 mg lures also detected very low populations in the interior of the orchard.

The DA baited traps caught moths consistently in the control and treated plots until late July (Fig. 9). The DA lure did not detect the spike in the counts for the control plots which were noted in the 1 mg lures in late July-early Aug. However, the DA lure did provide flight insights in the plot earlier in the year.

The damage results for the first harvest sample had the highest infestation in the control plot at 2.4% in September (Figure 10). Most other sites were less than 0.5% and often had 0% detectable damage except for areas along the edge of the orchard. The downwind edge had damage averaging 0.6-1.2% despite having low cumulative counts of 1 moth for the season in the 1 mg loaded traps, whereas cumulative counts as high as 23- 28 moths per season were found along the upwind edge of the plot. The 2nd shake sample of late variety cultivars had no clear detectable pattern in damage, but damage was very low at less than 1.0% throughout the plot (Fig. 11). The spatial distribution of the DA counts indicated higher seasonal averages (range 19-30 moths per season) than pheromone trap counts (Fig. 12) though no clear relationship between trap catch and damage was observed. A similar pattern was observed for the second harvest (Fig. 13).

Vogel Ranch

Trap counts were somewhat higher in the control plots of the Vogel Ranch (Fig. 14) with peaks of 10 moths in 1 mg baited traps, and a more consistent flight throughout the season. However, all pheromone traps placed in the puffer treated areas, regardless of lure load, were effectively suppressed. In the control plot, a similar peak to the Locke orchard was observed in late July. The DA traps detected similar flight patterns early in the season, yet again failed to detect any flight in later July or August (Fig. 15). The counts in the treated plots are difficult to interpret since low levels were recorded with a similar flight pattern as the control plots, but any potential interactions between the pheromone treatment and the DA trap cannot be determined.

Early season canopy counts using pruning towers (June 14 and Aug. 8) failed to detect any significant infestations throughout the orchard (Fig 16 and 17). In the August sample, damage peaked at 0.4% in the southwest corner of the orchard at a site that may have had insufficient pheromone coverage due to orientation of wind direction and puffer placement (Fig.17).

At harvest the results remained consistent overall with 0% damage being found in almost all locations. Low levels of damage for the grower treated areas at 0% and 0.2% were similar, but the control also had 0% damage (Fig. 18 and 19). As noted earlier, the miscommunication which resulted in placement of the controls in the Chandler rows undermines the interpretation of the pressure from codling moth. While counts as high as 21 moths for the season were detected in a DA trap in the puffer plot, they did not seem to reflect any real risk at these levels given the low damage levels.

Puffers – Pears

Overview

The overall pattern across plots does not reflect the patterns within many of the orchards in that different local issues confounded particular plots. For the first sample (Figure 20) at 1000°D, the highest levels of damage were observed in the control, whereas all treated areas (edge and center). However, as the season progressed the patterns became less clear and all plots experienced low damage levels at less than 1%. Control plots failed to generate any damage in some orchards (e.g. Jaime), whereas areas of the Peck ranch that were treated with pheromone appeared to experience pressure from moths outside of the ranch, which may have spilled over into the body of the ranch. However, the true source of the moths cannot be determined from these data.

Jaime Orchard

The seasonal counts for the Jaime Pear Orchard are shown in Fig 21 for all types of pheromone traps. Counts were extremely low throughout the season with a peak of ca. 2 moths per week in traps baited with 10 mg lures after the harvest was complete. The single Confirm application may have influenced our results and were not suggested by the PI. The low trap counts would have predicted almost no damage and this was reflected in 1st generation and harvest evaluations (Fig. 22 – only harvest data shown).

Barry Orchard

Seasonal codling moth counts for traps baited with 1 mg lures were also very low in all treated areas of the orchard as well as the untreated control (Fig. 23). A late season spike of less than 4.0 moths per trap was observed in mid-August as is typical in many years in the Sacramento Delta. However, the 10 mg lures caught high numbers of moths at 20-25 moths per trap late in the season in the control site. Given that the trap placed in the orchard fell during the peak of the flight, the highest potential counts cannot be determined (Fig 24).

Damage levels remained low all season with slightly higher infestation levels observed on the upwind edge and control plots, yet these differences were small at harvest (Fig. 25).

Hood Ranch

Several factors were identified relatively early in the season: the orchard had considerable pressure from codling moth as indicated by an early flight peak of almost 25 moths in April in the untreated control (Fig. 26). The mixed canopy structure of the orchard and the apparent high pressure from codling moth made this a difficult site for control. Late season flight continued to increase to very high levels, peaking at more than 60 moths per trap per week in the untreated control, but between 10-15 per week in the pheromone treated plots. As such, uniform treatment with Assail to the overall plot was more than warranted.

Damage and flight totals to date for the first evaluation on June 11-12 followed a pattern predicted by the counts (Fig. 27). Damage was 1.0% in the control plot where the 1 mg trap had caught 29 codling moths. As the season progressed, both count totals and damage increased throughout the orchard. At harvest, the control plot had the highest damage at 2.3% and a cumulative count of 40 moths, whereas the highest count of 89 moths in the insecticide treatment plot only had 0.1% damage (Fig. 28). Damage in the pheromone treated area before expected harvest remained low at less than 1.0%, but high trap counts were noted along the border containing the pheromone traps.

A sample of more than 500 fruit on August in the untreated control found that the plot had erupted in damage with more than 50% of the fruit remaining on the tree infested. The plot was not harvested commercially, whereas the remainder of the orchard contained too few fruit because of the fruit harvest to effectively measure codling moth damage at this time. While no data were collected, anecdotal data from the management personnel also suggested that the damage in the puffer treated plots continued to increase with some fruit loads being rejected. Data from the insecticide treated portions of the plot also showed that these plots were not adequately suppressed by one application of Danitol and two of Imidan, thus, damage was observed in all parts of the orchard.

The plot represents a very difficult situation for mating disruption to be effective: a high moth pressure situation, large edge areas, and poorly developed canopy in parts of the orchard. Fortunately, the puffer treatments were able to suppress the populations sufficiently within most of the plot and for most of the season despite these difficulties. However, they were not sufficient to provide commercially acceptable control given these conditions. Future efforts with orchards under similar conditions would require a more uniform treatment of the entire orchard with both the pheromone plus supplemental insecticide applications.

Peck Orchard

The seasonal codling moth counts in pheromone traps baited with 1 mg lures are shown in Fig. 29. The highest counts were observed in the control plot, which peaked at 25-30 moths per trap late in the growing season. Traps baited with 10 mg lures exceed 10 moths per trap throughout much of the early part of the season, which suggested fairly significant pressure for the organic orchard (Fig 30). Extremely high counts were detected later in the season with more than 70 moths per trap per week later in August. Despite continued pheromone emission, counts reaching almost 25 moths per trap were also observed in the pheromone treated plots.

Damage levels in the south block were very low in early June with no detectable damage and a maximum cumulative 1 mg trap catch of 7 moths in the south plots. The control also indicated 0% damage with a cumulative catch of 2 moths in a 1 mg trap. Figure 31 shows this pattern continued for the duration of the season in the south plot with 0.7% being the highest damage level observed.

However, this pattern was not repeated for the northern block of the same orchard, which was adjacent to a commercial orchard experiencing some difficulty in control of codling moth. Counts in the northwest corner of the plot had already accumulated 63 moths per trap by early June in 1 mg baited lures. While damage levels were overall low at the 1000 DD sample, with 0.2% damage being the highest levels detected, the trap counts suggested a potential problem (Fig. 32).

By July, the same corner had reached 142 moths cumulatively for the season, which translated into 3.7% damage. In addition, the numbers of moths in the block had continued to increase and spread throughout the block with cumulative counts as high as 95 moths found in a 10X trap along the eastern edge. Damage levels typically ranged from 1-4% throughout the orchard (Fig. 33). Damage levels in the commercial plots adjacent to the orchard were documented at 3.0% in late July.

Sprayable Pheromone Trials

Locke Orchard - Walnuts

The seasonal counts for codling moth in the standard 1 mg baited traps were suppressed throughout the entire orchard except for late July, regardless of the application rate (Fig. 34). Sporadic catches were made yet no consistent pattern of catch was observed. However, the control plot did catch the most moths with low, but consistent catches early in the season, and ca. 8 moths per trap later in the season. The 10 mg baited traps caught more than the 1 mg lures in the control, which again suggests some “bleed-over” of pheromone into these plots (Fig 35). Low counts were found throughout the season, yet the numbers were too low to see clear peaks. The DA baited traps did much better in catching moths early in the season and similar patterns could be found in all treatments (Fig 36). However, the same pattern observed in other locations indicated that the DA lures did not catch later in the season compared to the peaks in the 10 mg lures.

The damage from codling moth in the first harvest of Serr variety nuts was highest in the 10 gm plot at 4.8%, but the other replicate of 10 gm per acre had 1.6%. The highest application rate of 20 gm per acre had 1.8%, whereas the lowest damage at 0.4% was found in the plot of 10 gm per acre applied to every other row. The untreated control had 2.9% damage. As such, the pattern for damage does not seem to follow any clear trend (Fig 37).

For the second harvest (Chandler variety), the pattern was the same, but some plots shifted in their relative position with the highest damage found again in the 10 gm plot adjacent to the control, but the lowest found in the 20 gm per plot. However, a strong difference between the 2 10-gm per acre plots (1.2% vs 0.4%) indicated the level of variance in the plot (Fig. 38).

These same data are presented again for the 2 harvests (Serr and Chandler) but with the cumulative counts for the various traps superimposed on the figure. While the DA counts were certainly higher (Fig 39 and 40), using the Serr data in Figure 39 as an example, the plot appeared to have a gradient in pressure with the 2 southern plots having 66 and 74 seasonal totals compared to 45 and 11 moths in the 2 northern plots. However, any correlations between trap counts and damage are difficult to make with such small number of examples.

Wiseman Pear Orchard

The seasonal counts for all three plots using 1 mg lures are shown in Fig. 41. While no dramatic counts were observed prior to harvest, the control plots spiked to more than 30 moths per trap in late July to early August. Using the 10 mg lures, counts were much higher in all plots with more than 20 moths being caught at peak in late May in all treatments. This resulted in a Danitol application to the entire orchard to prevent excessive damage. The numbers continued to swell late in the season with more than 100 moths caught in late August in the control. Suppression of codling moth in this orchard appeared to be failing such that problems would be expected next year with any type of pheromone management program (Fig. 42).

Early in the season, no clear pattern of damage was observed in any plot nor was there any spatial pattern of trap catch (Fig. 43). However, as the season progressed, the control had the highest level of damage from codling moth at 3.0%, but the adjacent plots treated with sprayable pheromone remained under commercially acceptable damage levels (Fig. 44). Average damage levels of 0.76 and 1.0% were observed in the Bartletts for 10 g and 20 g application rates, respectively, but specific locations nearest the upwind edge and control had higher levels at 2.1 or 1.2% damage. The Bosc pears failed to develop any significant population pressure presumably due to differences in cultivars.

Wheatland Aerial Application

The results of this trial are shown below:

Treatment	Lure	Average number of codling moth recaptured / trap	
		Week 1	Week 2
Aerial	DA	0.25	0
	1mg	0	0
Ground	DA	0	0
	1mg	0	0
Control	DA	0.25	0.5
	1mg	0.5	6.5

The rates of recovery for the sterile insects were quite low and disappointing. However, the highest counts were found in the control plot, whereas virtually no moths (1) were recaptured in the areas treated with sprayable pheromone regardless of application method. Given the preliminary nature of this study, we were encouraged that aerial applications might prove feasible for walnut orchards and would merit further replicated studies next year.

The EAG work with the leaf discs still needs to be completed and discs are currently stored in a –80°C freezer.

Pittel Orchard – Sprayable DA Trial

Nut damage evaluations of the treated Chandler variety has been completed and 0% of the walnuts were infested, thus no conclusions can be suggested from these data. The Eureka cultivar damage sample also failed to find significant infestation, thus rendering the data unusable. The late applications relative to a codling moth flight may have impacted this study.

Resistance Assays

As shown in Table 1, the sites varied considerable between the organic and non-organic orchards with up to 6.6 fold differences observed. However, resistance levels remained at levels similar to levels observed within the past few years. Resistance levels first reported in 1989 with an LC50 of 0.24 mg / ml was noted as problematic, whereas the orchard with an LC50 of 0.59 mg /ml represents better than a doubling in resistance. All orchards were statistically different from the organic with resistance ratios of 4.0-6.3.

While these levels are typically problematic, the levels are not different enough from recent resistance levels to explain the problems with codling moth control experienced in 2002. The strong late season flight was not expected in some orchards, and we are still looking for alternative explanations.

Table 1. Summary of adult codling moth dose mortality trials conducted August 2002. Resistance levels of field populations measured following 48 hours exposure to azinphosmethyl.

Site	# tested	LD50 (95% CL)	slope	Hetero-geneity	"g" value	Resistance Ratio LD50 (95% CL)
Organic apples	126	0.089 (0.072 – 0.112)	3.65	0.95	0.117	--
Hood	491	0.591 (0.474 – 0.700)	3.306	1.52	0.074	6.6 (5.1 – 8.6)
Walnut Grove	605	0.359 (0.251 – 0.454)	2.951	1.63	0.101	4.0 (3.0 – 5.4)
Steamboat Slough	258	0.386 (0.309 – 0.451)	4.333	0.87	0.108	4.3 (3.3 – 5.7)

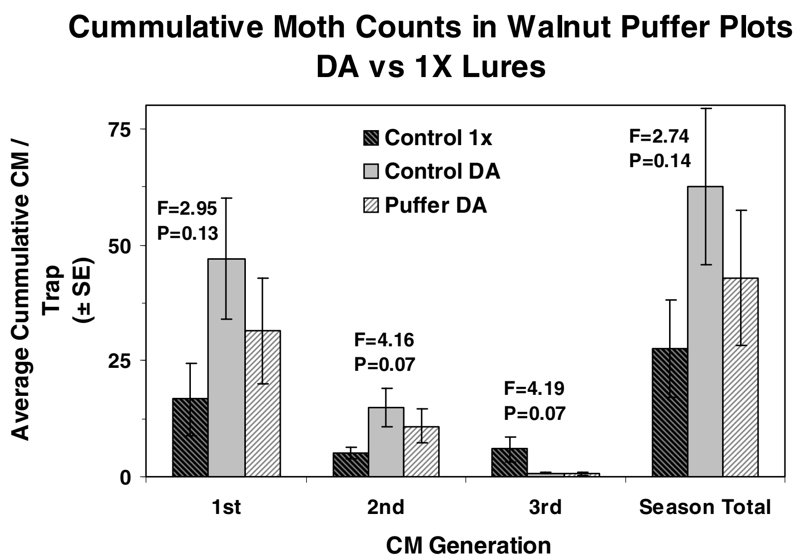

Figure 1. Average cumulative codling moth counts for DA and 1x baited traps from four puffer trial plots in 2001-2002.

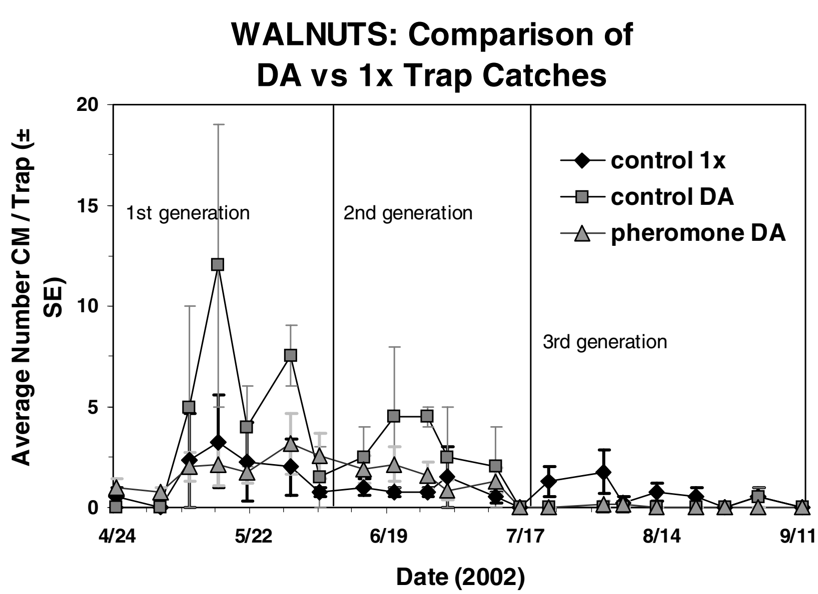

Figure 2. Seasonal codling moth counts for DA and 1x baited traps from four puffer trial plots in 2001-2002.

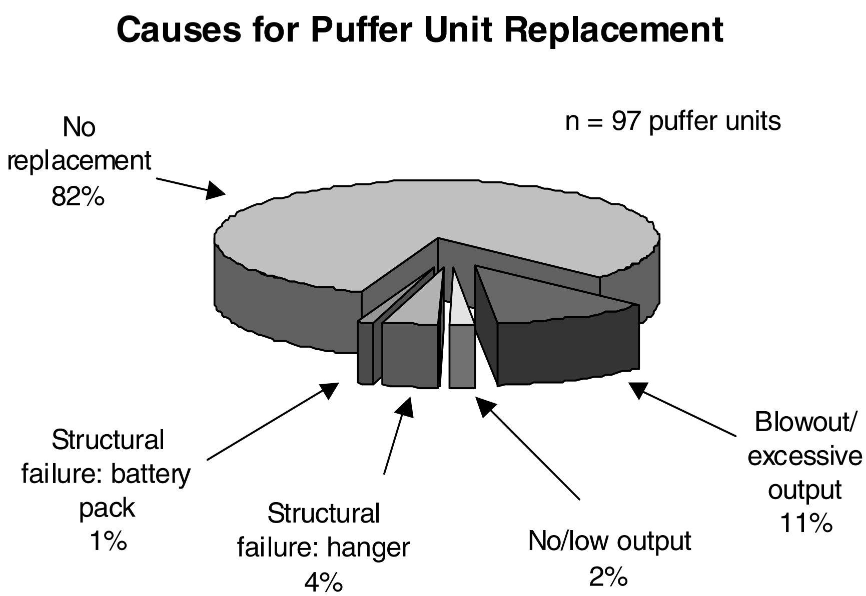

Figure 3. Summary of reasons puffer units were replaced during the growing season.

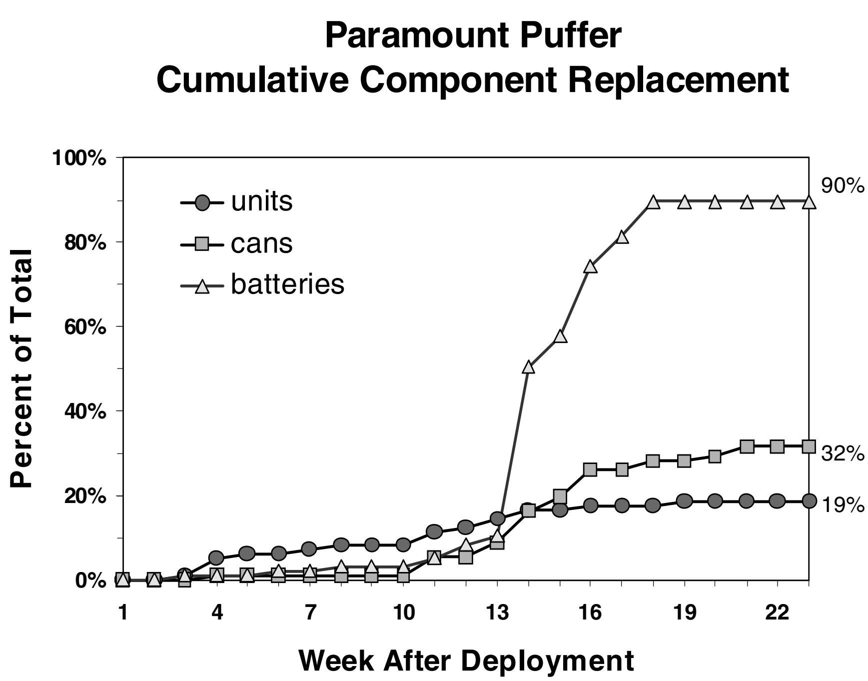

Figure 4. Cumulative replacement rate for components of the Paramount Puffer over time.

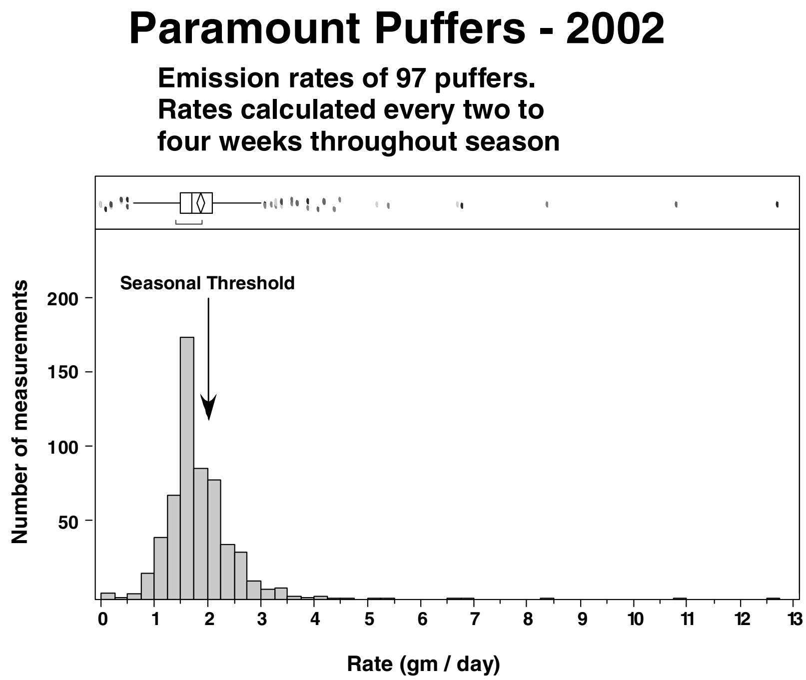

Figure 5. . Mean emission rates per day of Paramount Puffer Pheromone Dispensers (codlemone plus solvents).

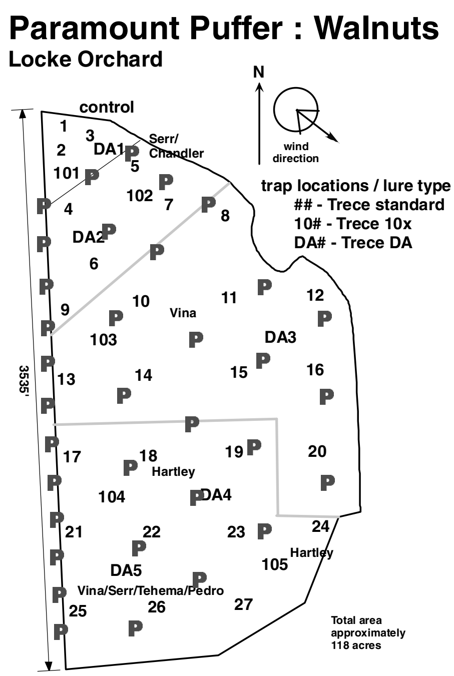

Figure 6. Plot map for Puffer treated regions of Locke Walnut Orchard, Locke, CA. P = Puffer Site

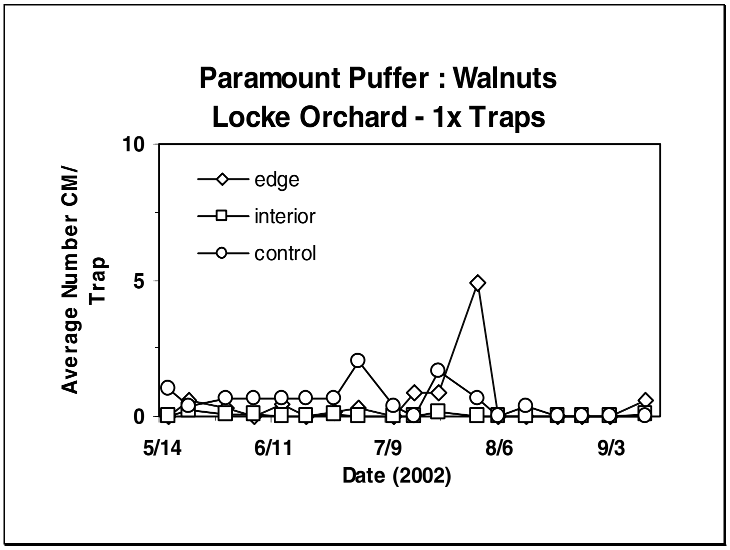

Figure 7. Seasonal codling moth counts in Puffer treated and control plots for 1 mg lures.

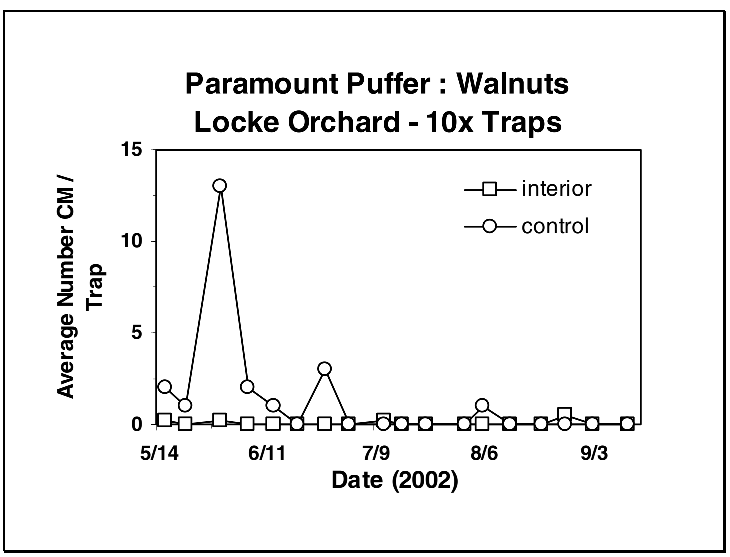

Figure 8. Seasonal codling moth counts in Puffer treated and control plots for 10 mg lures.

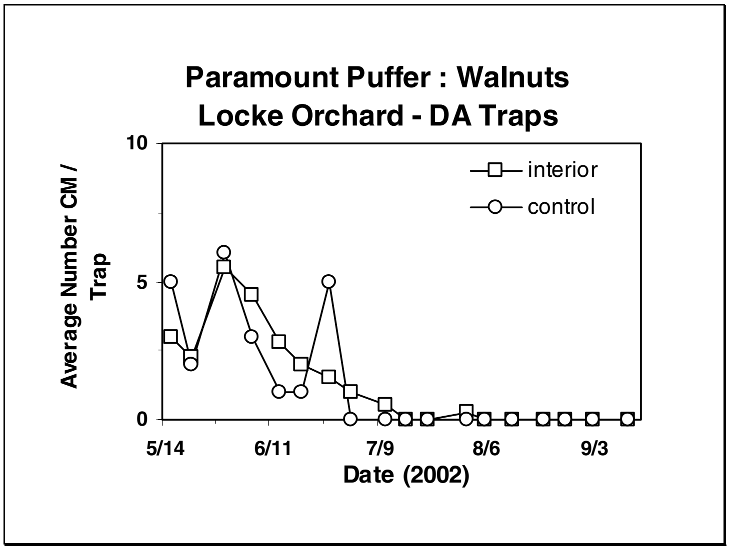

Figure 9. Seasonal codling moth counts in Puffer and control plots for DA baited traps.

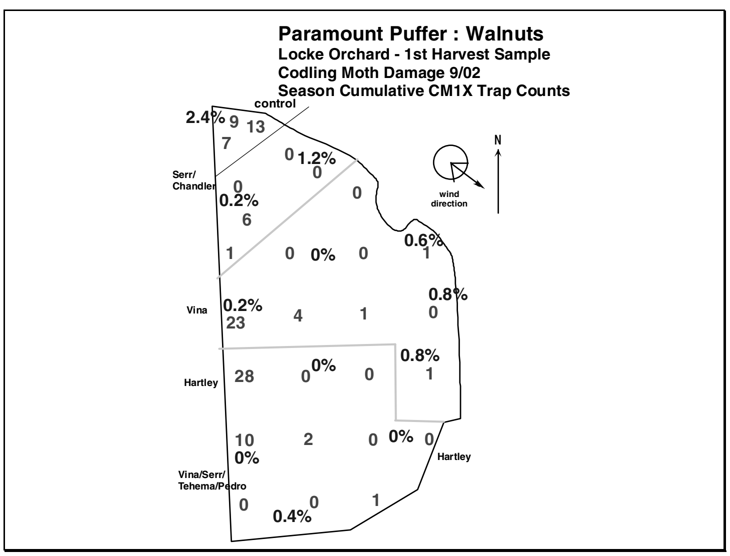

Figure 10. Spatial distribution of damage and cumulative codling moth counts for 1 mg lures in Locke puffer treated walnut orchard at first harvest. Samples from the north block were dominated by Serr variety, and those from the south block by Serr and Vina variety nuts in the 1st shake.

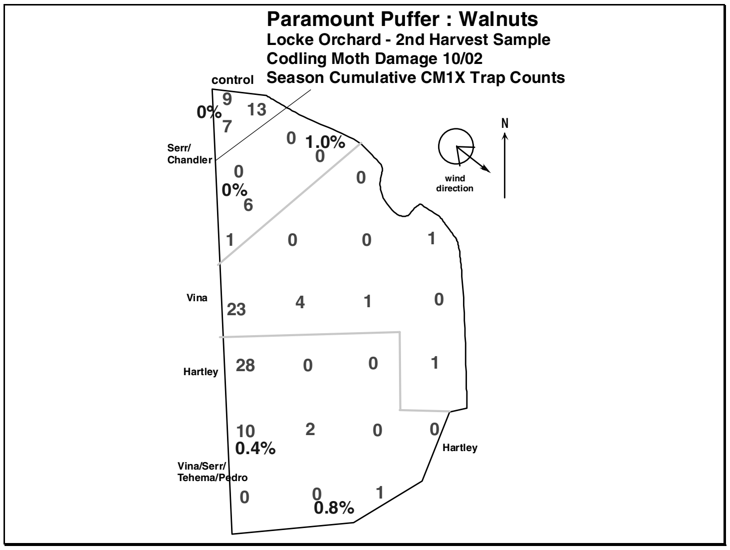

Figure 11. Spatial distribution of damage and cumulative codling moth counts for 1 mg lures in Locke walnut orchards for puffer treated orchard at second harvest. Samples from the north block were dominated by Chandler variety, and those from the south block dominated by Vina and Serr varieties in the 2nd shake.

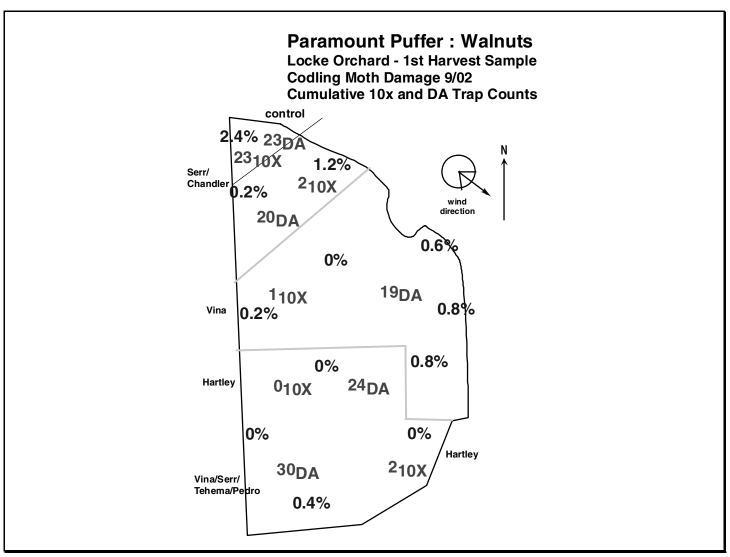

Figure 12. Spatial distribution of damage and cumulative codling moth counts for DA and 10 mg lures in Locke walnut orchards for puffer treated orchard at first harvest. Samples from the north block were dominated by Serr variety, and those from the south block by Serr and Vina variety nuts in the 1st shake.

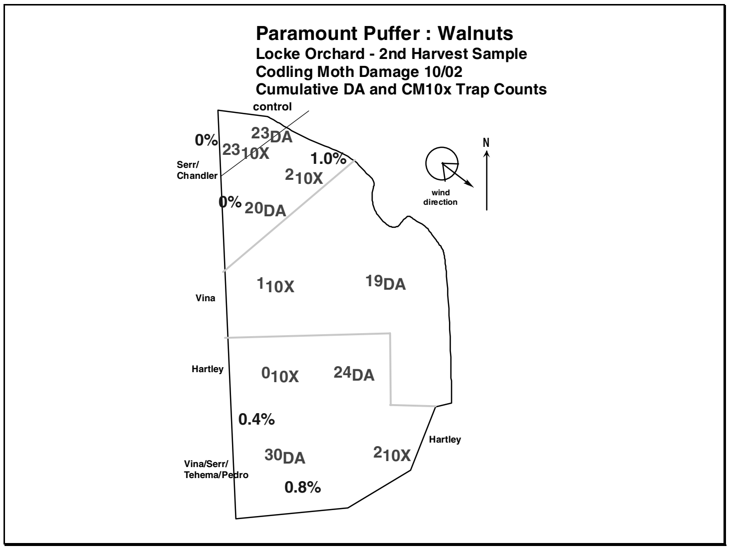

Figure 13. Spatial distribution of damage and cumulative codling moth counts for DA and 10 mg lures in Locke walnut orchards for puffer treated orchard at second harvest. Samples from the north block were dominated by Chandler variety, and those from the south block were dominated by Vina and Serr varieties in the 2nd shake.

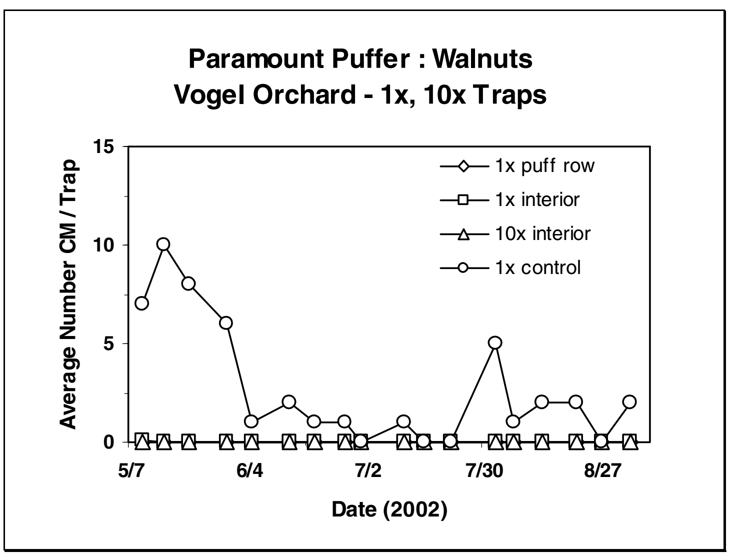

Figure 14. Seasonal codling moth counts in 1 mg and 10 mg lure baited pheromone traps in Puffer treated walnut orchard, Vogel Orchard.

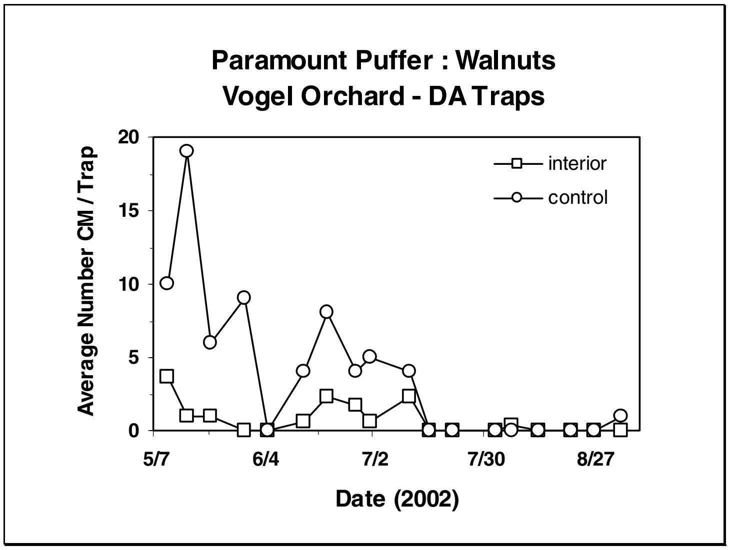

Figure 15. Seasonal codling moth counts in 1 mg and 10 mg lure baited pheromone traps in Puffer treated walnut orchard, Vogel Orchard.

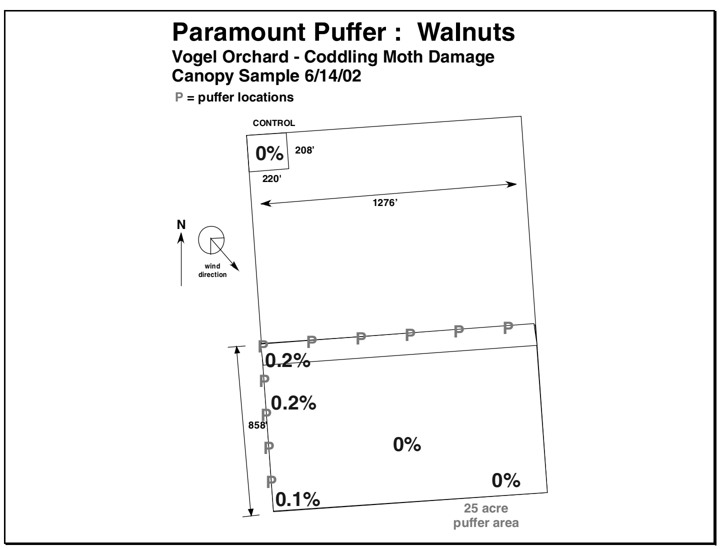

Figure 16. Codling moth damage distribution for first canopy sample in Vogel Orchard.

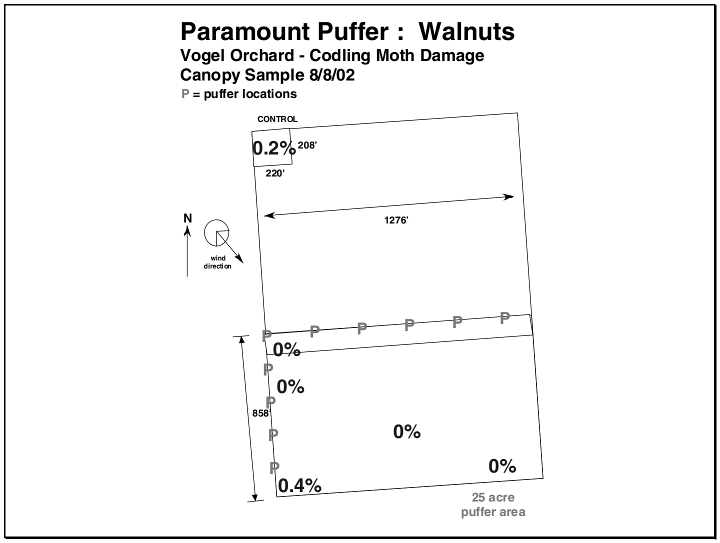

Figure 17. Codling moth damage distribution of second canopy sample in Vogel Orchard.

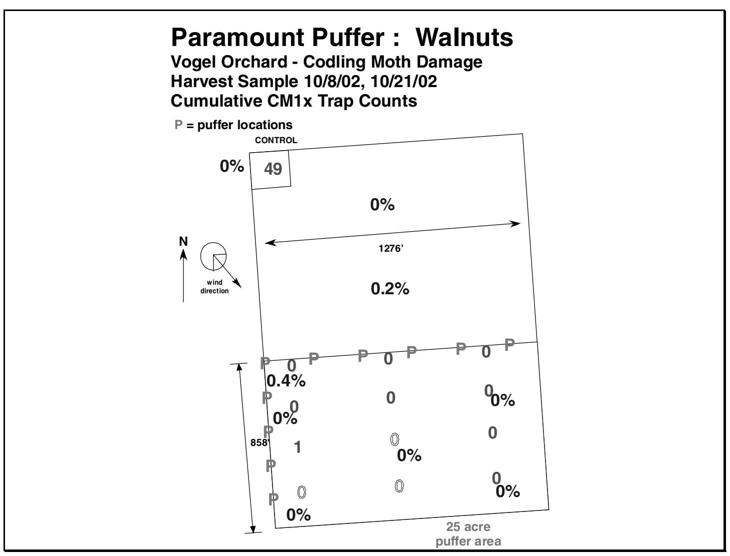

Figure 18. Codling moth damage distribution for harvest sample and cumulative trap counts for 1 mg baited pheromone traps in Vogel Orchard.

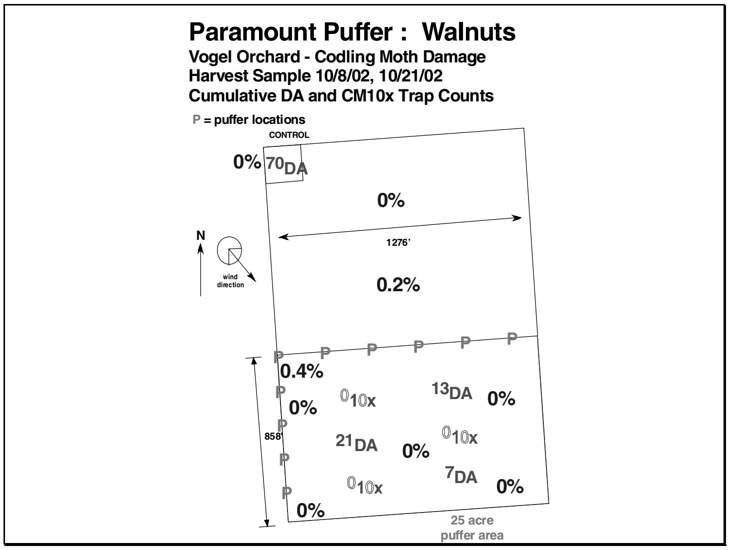

Figure 19. Codling moth damage distribution for harvest sample and cumulative trap counts for 10 mg and DA baited pheromone traps in Vogel Orchard.

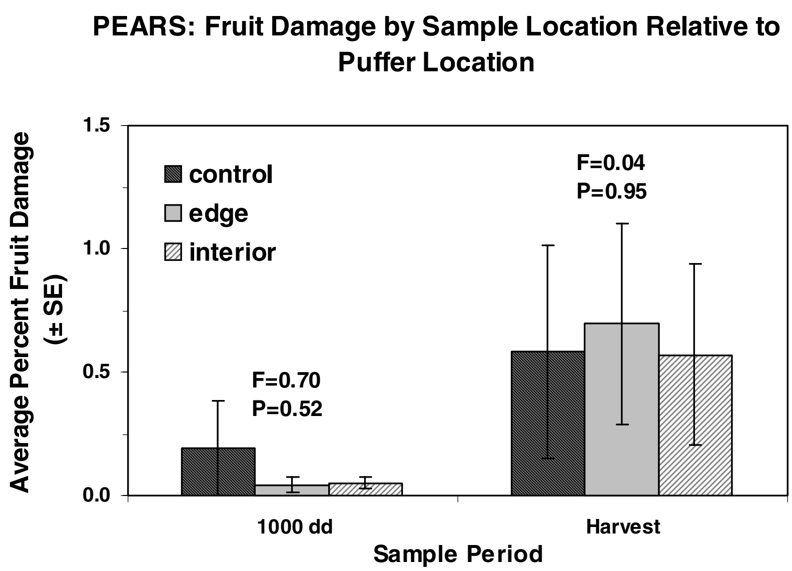

Figure 20. Average percent damage relative to puffer location for five puffer treated orchards.

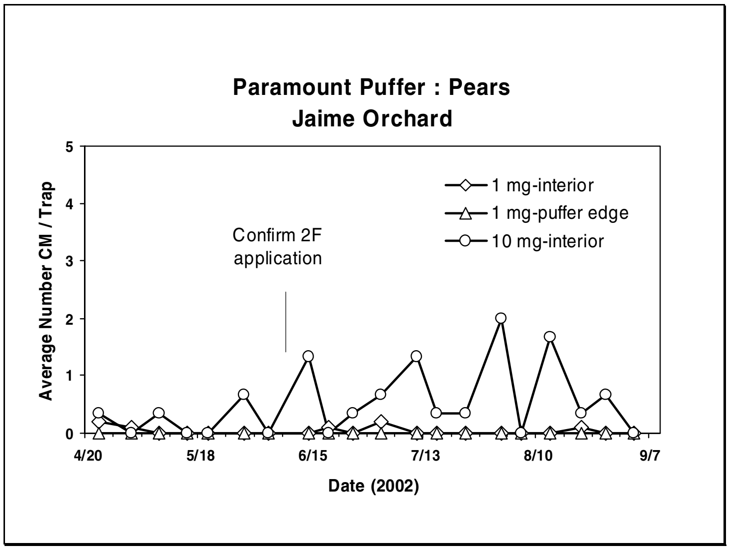

Figure 21. Seasonal counts for 1 and 10 mg baited lures in Puffer treated regions of the orchard.

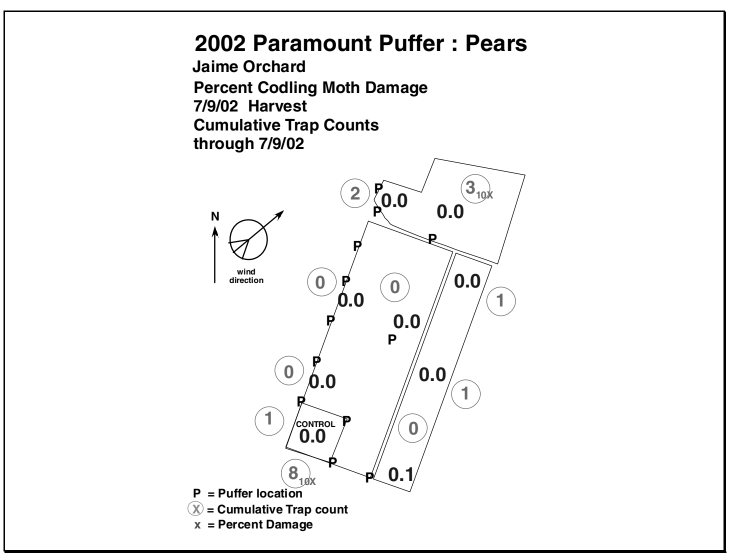

Figure 22. Cumulative codling moth counts at sample sites and fruit damage in Jaime Orchard at harvest on July 9, 2002.

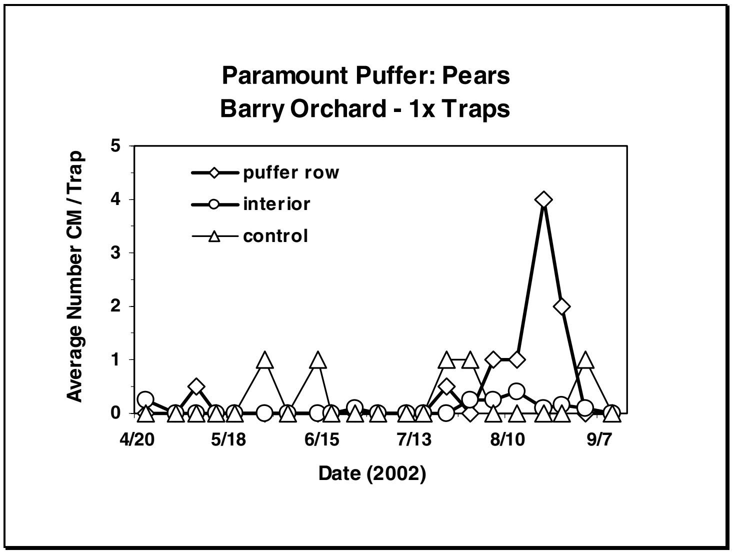

Figure 23. Seasonal codling moth counts in traps baited with 1 mg lures in puffer treated plots and control in Barry Pear Orchard.

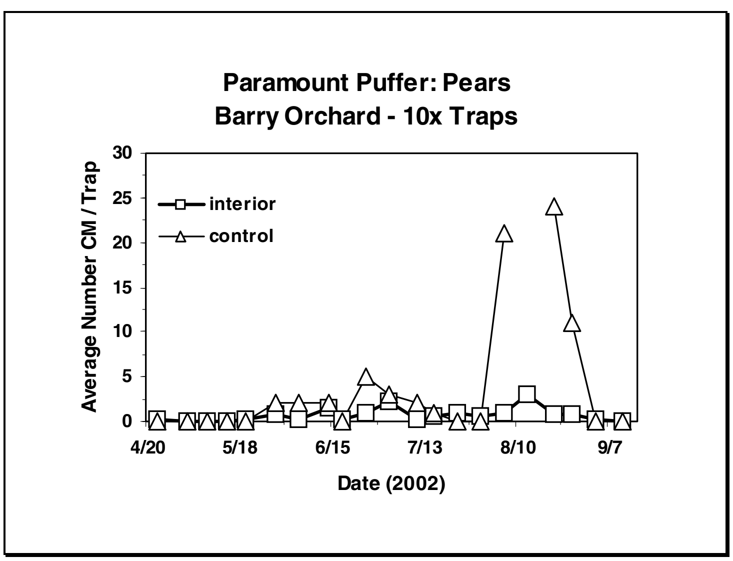

Figure 24. Seasonal codling moth counts in traps baited with 10 mg lures in puffer treated plots and control in Barry Pear Orchard.

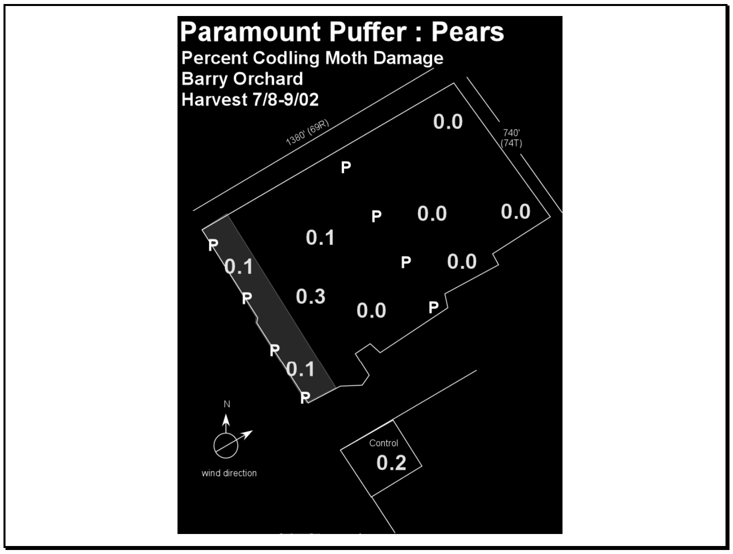

Figure 25. Spatial distribution of codling moth damage in Barry pear orchard at harvest in July, 2002.

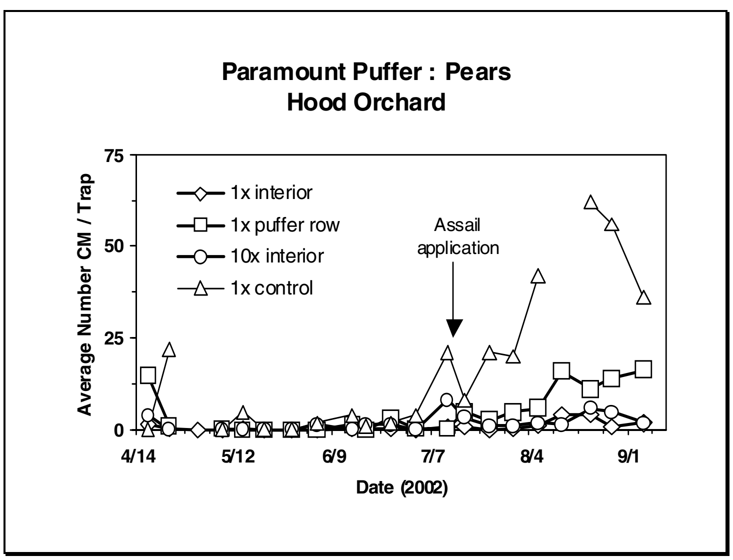

Figure 26. Seasonal codling moth counts for 1x and 10x traps in treatment plots in Hood pear orchard.

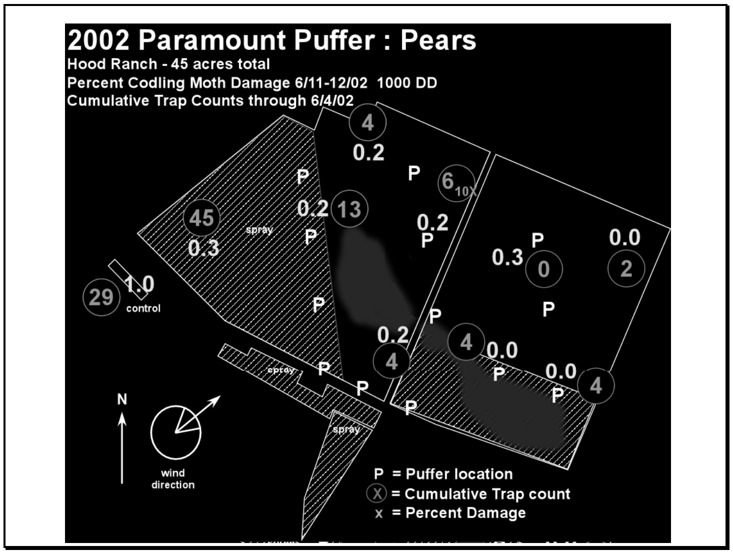

Figure 27. Spatial distribution of codling moth damage and cumulative trap counts in 1 mg baited pheromone traps in Hood pear Orchard in June 2002.

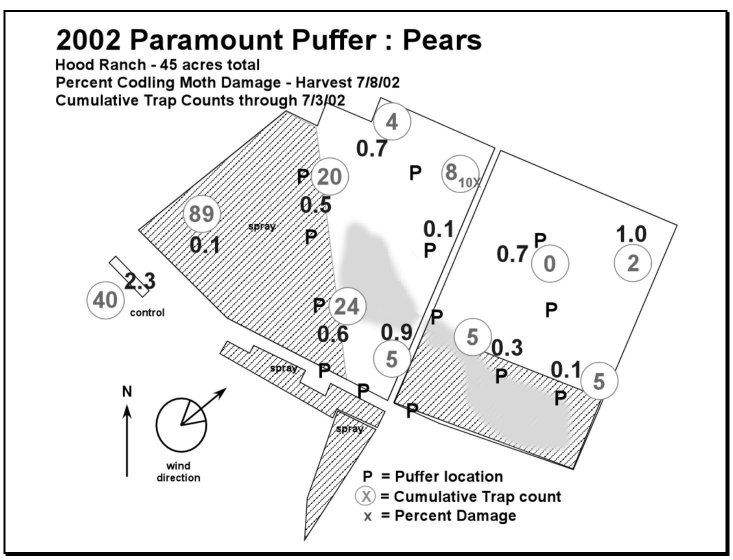

Figure 28. Spatial distribution of codling moth damage and cumulative trap counts in 1 mg baited pheromone traps in Hood pear Orchard in July 2002.

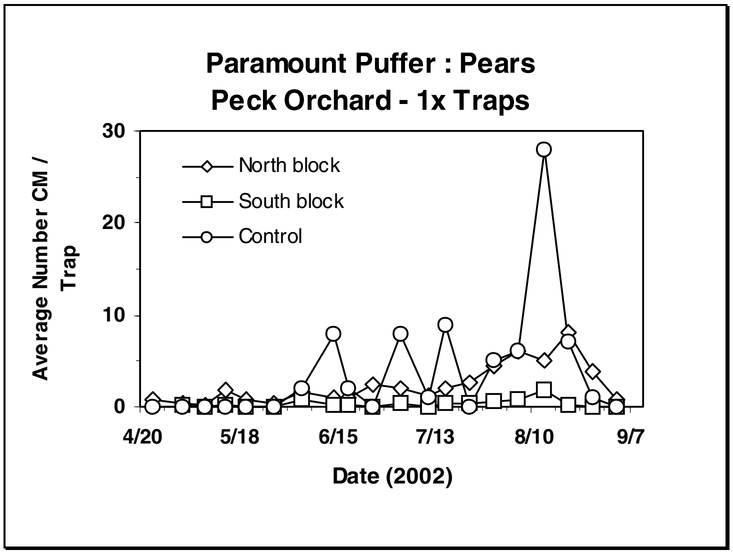

Figure 29. Seasonal codling moth counts in treatment plots in 1 mg baited traps in Peck pear orchard.

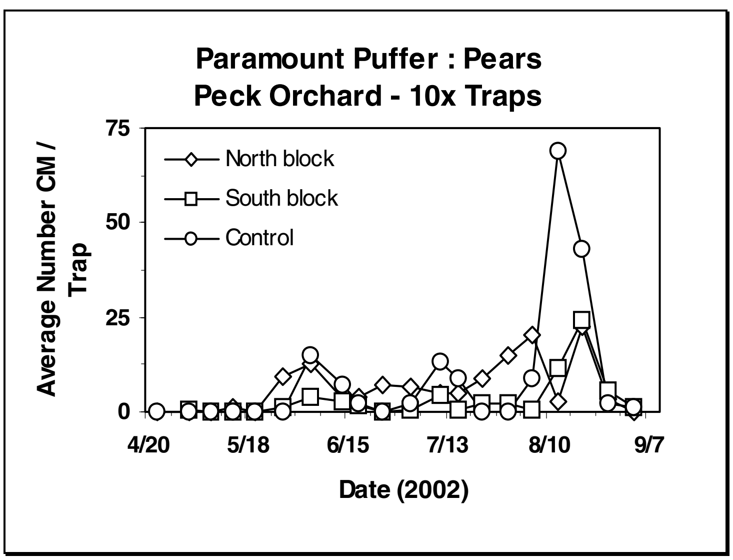

Figure 30. Seasonal codling moth counts in treatment plots in 10 mg baited traps in Peck pear orchard.

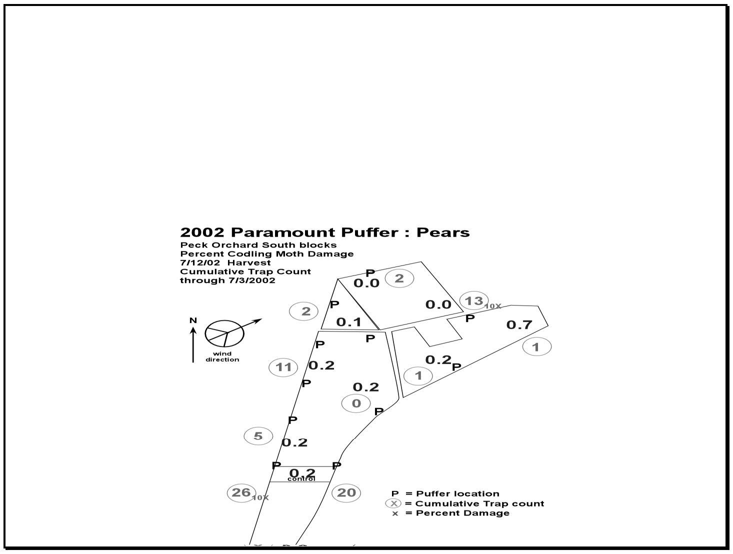

Figure 31. Spatial distribution of codling moth damage and cumulative trap counts in 1 mg baited pheromone traps in Peck pear orchard (South) in July 2002.

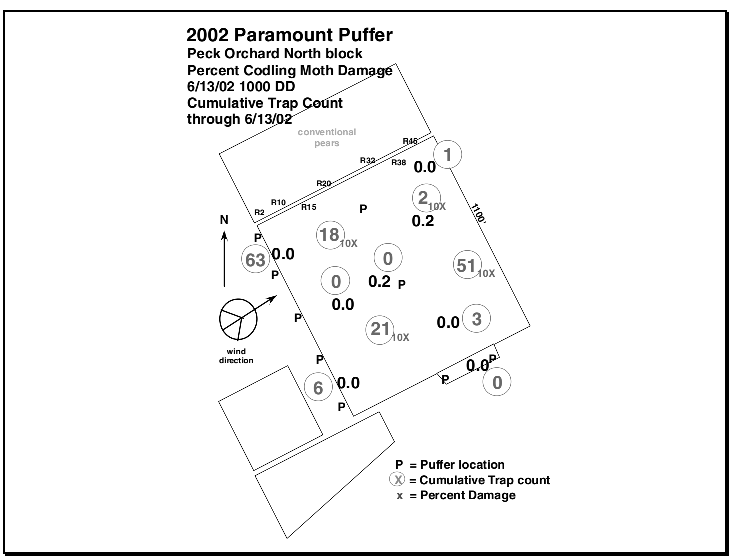

Figure 32. Spatial distribution of codling moth damage and cumulative trap counts in 1 mg baited pheromone traps in Peck pear orchard (North) in June 2002.

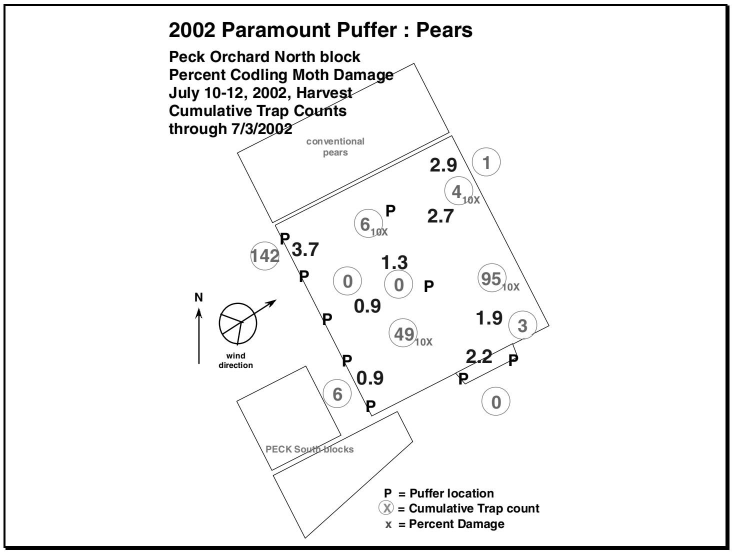

Figure 33. Spatial distribution of codling moth damage and cumulative trap counts in 1 mg baited pheromone traps in Peck pear orchard (North) in June 2002.

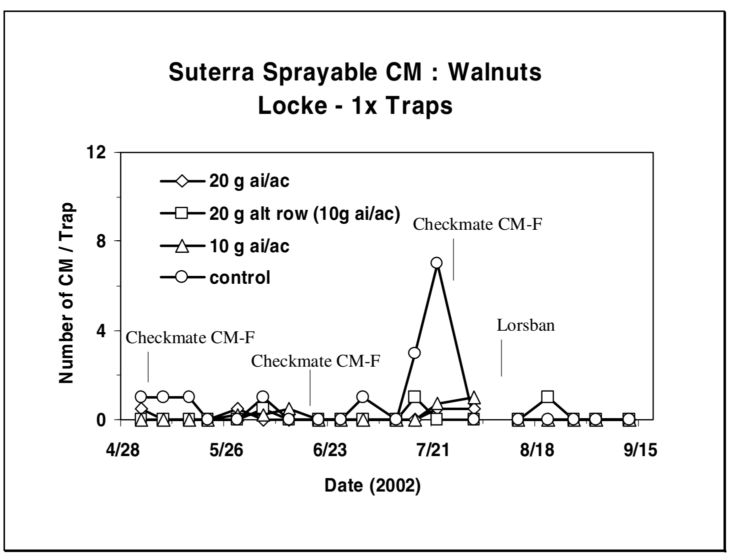

Figure 34. Seasonal codling moth counts in treated and control plots using 1 mg lure baited pheromone traps.

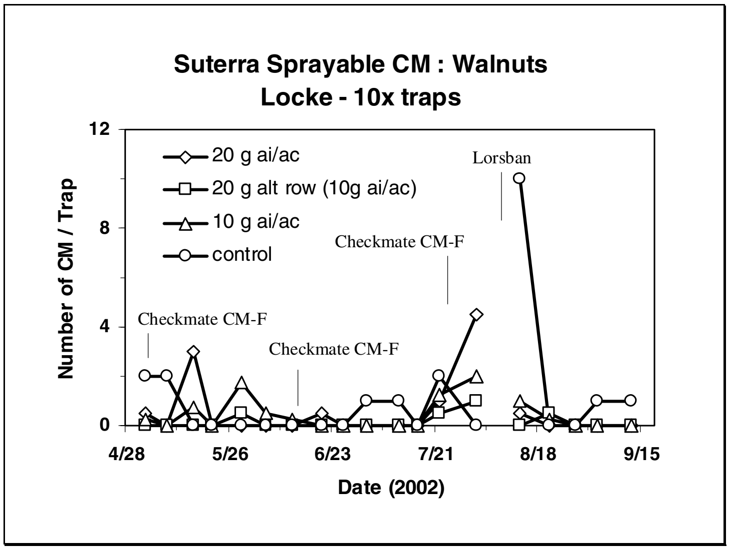

Figure 35. Seasonal codling moth counts in treated and control plots using 10 mg lure baited pheromone traps.

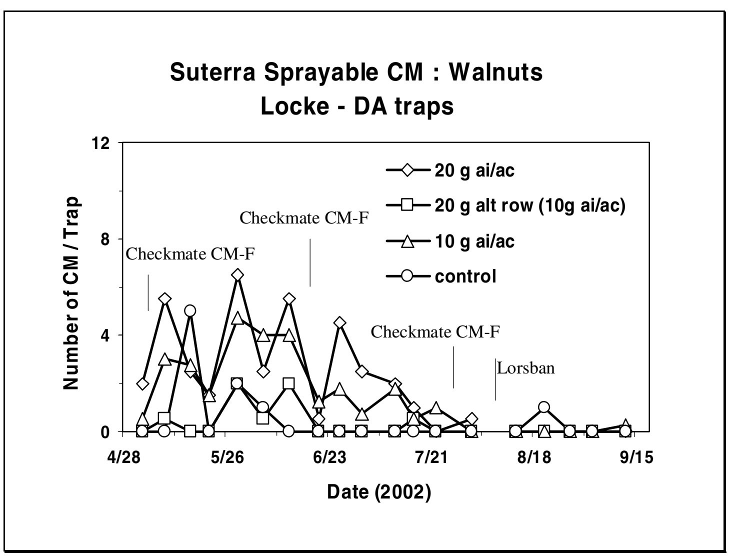

Figure 36. Seasonal codling moth counts in treated and control plots using DA baited traps.

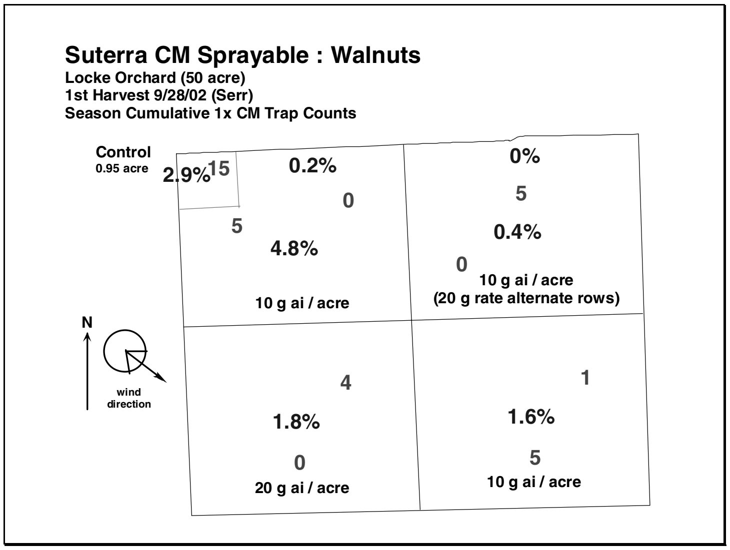

Figure 37. Spatial distribution of codling moth infestation in first harvest sample of predominantly Serr variety walnuts and cumulative counts in 1x traps of the Locke Sprayable plots.

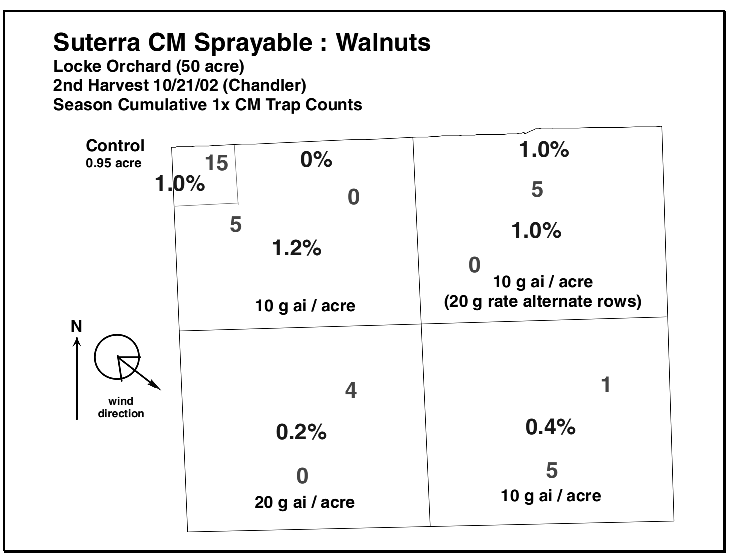

Figure 38. Spatial distribution of codling moth infestation in second harvest sample of predominantly Chandler variety walnuts and cumulative moth counts in 1x traps, Locke Sprayable plots.

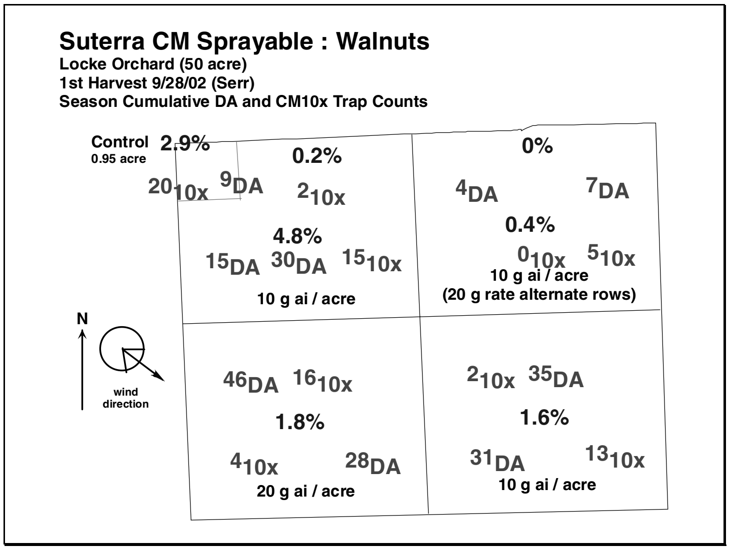

Figure 39. Spatial distribution of codling moth infestation and cumulative moth counts in 10 mg lure and DA baited traps at first harvest of predominantly Serr variety nuts, Locke Sprayable plots.

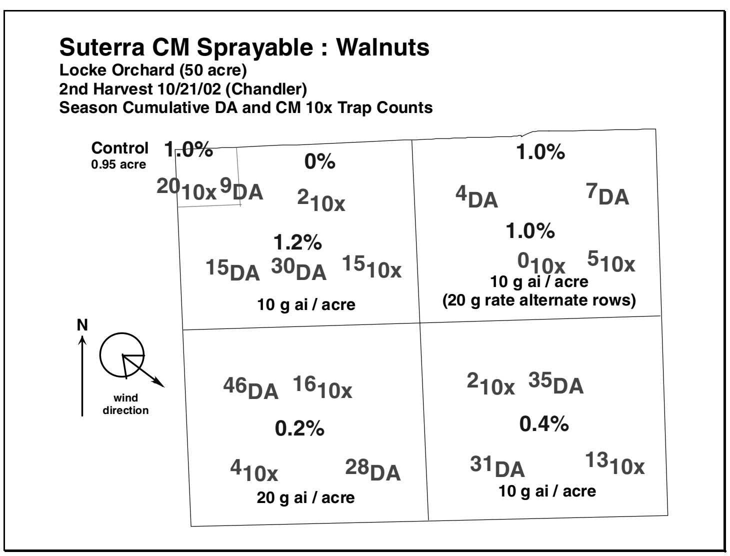

Figure 40. Spatial distribution of codling moth infestation and cumulative moth counts in 10 mg lure and DA baited traps at second harvest of predominantly Chandler variety nuts, Locke Sprayable plots.

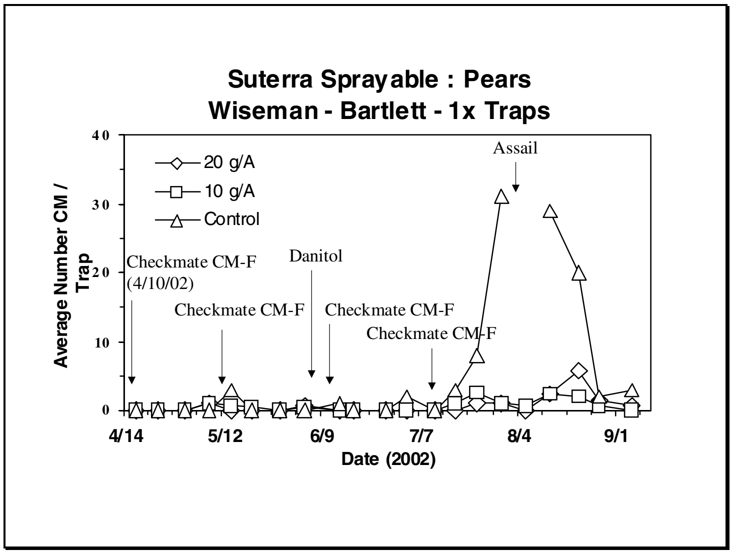

Figure 41. Seasonal codling moth counts in 1 mg pheromone lure baited traps in treatment and control plots.

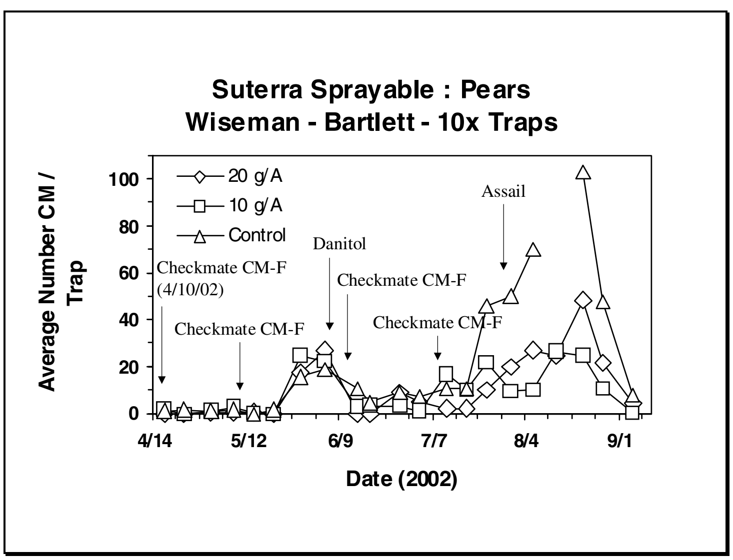

Figure 42. Seasonal codling moth counts in 10x pheromone lure baited traps in treatment and control plots

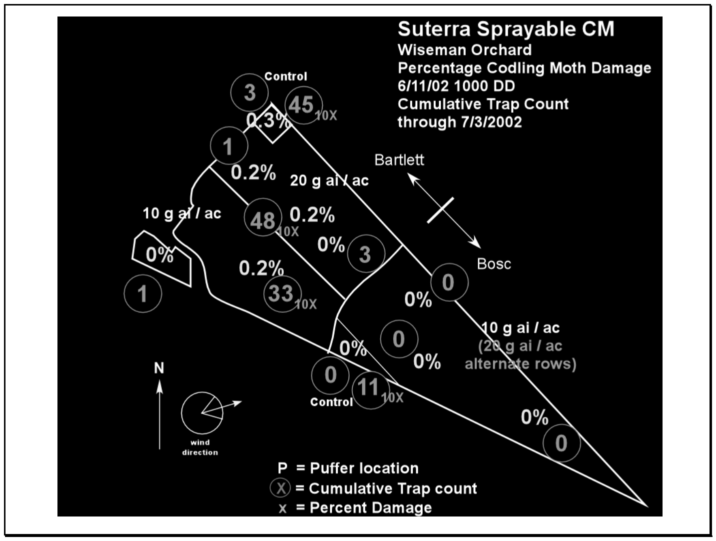

Figure 43. Spatial distribution of cumulative codling moth counts in 1x lure baited traps and codling moth infestation in June 2002 in Wiseman pear orchard.

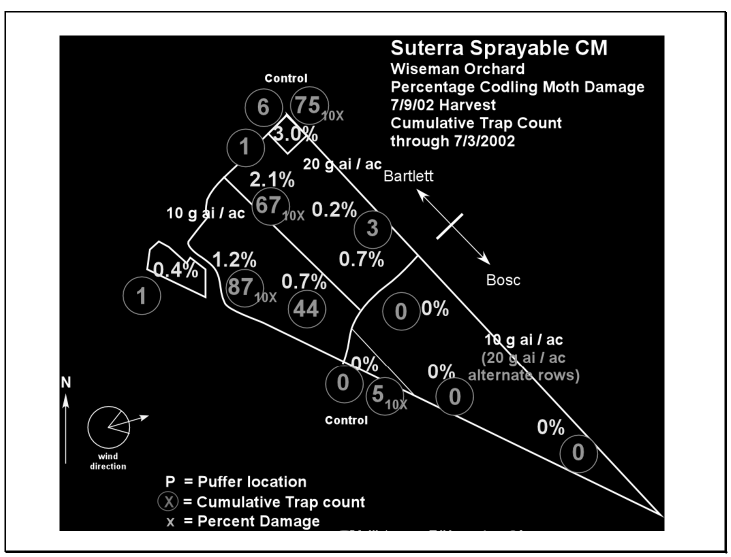

Figure 44. Spatial distribution of cumulative codling moth counts in 1x lure baited traps and codling moth infestation in July 2002 in Wiseman pear orchard.

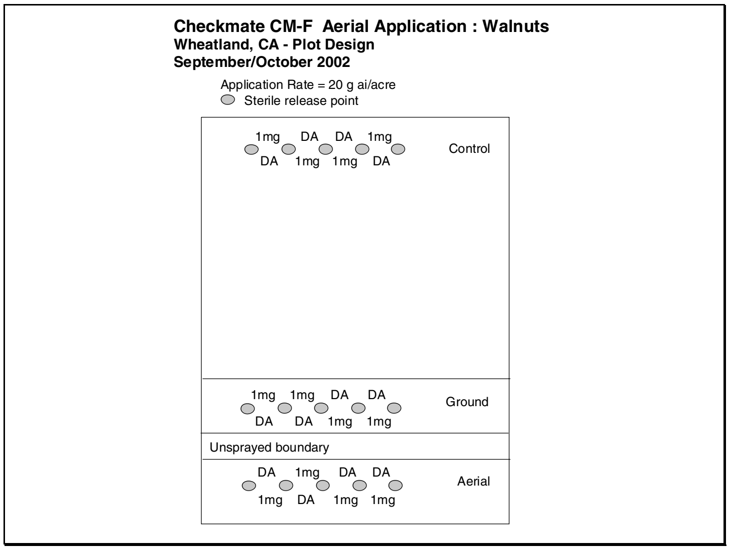

Figure 45. Plot map for Wheatland Walnut orchard using aerial and ground application of sprayable pheromone formulation.

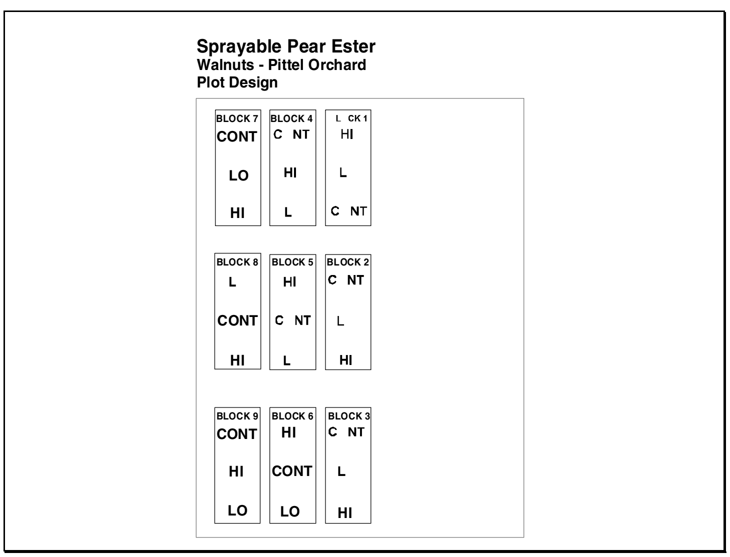

Figure 46. Plot map for Pittel Walnut orchard using sprayable DA formulation.