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Organic farming research project report submitted to the Organic Farming Research Foundation:

Project Title:

Control of the western tarnished plant bug, Lygus hesperus (Knight) in an organic strawberry production system using trap crops, mass-released parasitoids, and tractor-mounted vacuums

FINAL PROJECT REPORT

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Project Summary

Strawberry growers on the Central Coast of California have long observed that the principal cosmetic pest of their crop, the western tarnished plant bug (WTPB) or lygus bug, *Lygus hesperus* (Knight) establishes populations in strawberry fields in mid-season in relation to the proximity and flowering status of weedy, broadleaved hosts in adjacent areas. WTPB is known to be hosted in winter and early spring by numerous wild hosts which serve as a bridge to the infestation of strawberry fields when strawberry host flowers and small green fruit become abundant. Organic strawberry growers do not use the chemical pesticides registered for conventional lygus bug control nor can they routinely use any organically-compliant materials economically, due to the expense and low efficacy of these products. Instead, organic strawberry growers on the Central Coast rely on field isolation from hosts, adjustment in fresh-market harvest schedules, and whole field deployment of tractor-mounted insect vacuums, or "bug vacs". Recently, organic strawberry growers have become interested in experiments with plantings of attractive non-crop vegetation as trap crops which might simultaneously attract WTPB away from strawberry fields (where they can be removed by the use of a bug vac) *and* increase levels of WTPB-associated predators and parasitoids. This project attempted to gather evidence in support of these trap crop uses in terms of the potential for the release of a mass-reared a selective WTPB egg parasite, conservation of native natural enemies, and use tractor-mounted vacuums on the trap crop vegetation for WTPB control in organic strawberry fields.

In the 2001 field season, a completely randomized block design alfalfa trap crop vacuuming experiment with four treatments (n= 4 replicates) was established on the row edges of organic strawberry fields. Treatments consisted of no vacuuming (tractor driven over the alfalfa trap crop row only) and single, double, and triple vacuuming, with samples taken pre-vacuuming, and after one, two, and three successive passes of a tractor-mounted vacuum. This experiment was performed on three dates in July. When vacuumed in this fashion, a significant difference in WTPB counts from the alfalfa trap crop was always was detected after the first vacuuming treatment when compared with the pre-treatment counts, and the average adult WTPB reduction was 70%. The average single vacuuming WTPB nymphal reduction was 72%. Subsequent vacuum passes 2 and 3 reduced adult and nymphal WTPB numbers further, but not significantly when compared with the effects of the first vacuum pass. Control passes of the tractor machinery (without using the mounted vacuum) did not reduce WTPB density. This experiment demonstrated that a tractor-mounted vacuum machine could remove over 2/3 of WTPB from an alfalfa trap crop in a single pass.

In 2001, the WTPB egg parasitoid *Anaphes iole* was made available by a commercial insectary in May. This parasitoid was released into 4 alfalfa trap crop replicates and average parasitism of WTPB eggs was measured in both the alfalfa trap crop and adjacent strawberry rows. Thirty-five percent egg parasitism of WTPB eggs was detected in the trap crop within 10 days of release of 2,000 parasitoids. Forty percent parasitism was detected in the first adjacent strawberry row, but average parasitism decreased rapidly outward to row 4 (4%) and no parasitism was detected in row 8. This project was discontinued due to rearing difficulties at the commercial insectary and subsequent unavailability of parasitoids due to expense and a limited market demand.

In 2002, a randomized complete block design trapping experiment with three treatments (n= 4 replicates) was established on the row edges of an organic strawberry field. Treatments consisted of a market/culinary radish and wild mustard mix, alfalfa, or strawberry planting. When given this choice during the spring, WTPB was significantly more attracted to alfalfa than to either radish/mustard or strawberry from January-July. Subsequently, a completely randomized block design with two treatments (n= 4 replicates) was established on an organic strawberry farm at Eagle Tree/Pacific Gold Farm in Salinas, California. Treatments included: (1) planting of a field edge alfalfa trap crop, vacuumed twice weekly with a tractor-mounted vacuum device and (2) no trap crop, whole field weekly vacuuming (grower's program). Results indicate that in June and July the vacuumed trap crop treatment significantly reduced damage due to WTPB bug feeding in associated strawberry rows (38-47%) compared with the grower's whole field vacuuming program. This is an important result because trap crop vacuuming constitutes a 75% reduction in machine energy/effort usually expended by organic strawberry growers in whole-field vacuuming programs. Our results show that treatment significance could not be detected in August, and that trap crop attractiveness may have been compromised by lack of irrigation water. A native predacious natural enemy of WTPB (*Geocoris spp*.) was more abundant in the trap crop and trap crop treatment strawberry rows in June and July, indicating that trap crops can also increase the abundance of this beneficial insect in organic strawberries.

Introduction

Strawberries are damaged by the western tarnished plant bug (WTPB) or lygus bug, *Lygus hesperus* Knight (*Hemiptera: Miridae*) in California (Allen and Gaede 1963). This insect is a native species and it feeds on a broad range of winter broadleaved weeds in coastal central California, including wild radish, mustards, chickweed, shepard's purse, common groundsel, lupine and other legumes, and knotweed (Strand, 1994; Barlow et al, 1999). More than 100 species in 24 plant families have been listed as WTPB hosts (Scott, 1977; Barlow et al. 1999). Leguminous cover crops (vetches, clover, and especially alfalfa, etc.) can also host WTPB in spring and summer. Alfalfa is consistently listed in these host inventories as a preferred host. Only the adult form of WTPB can fly from one plant to another, and they appear to move from one host plant to another as each plant begins to flower. In central coastal California, *L. hesperus* overwinters as an adult in winter broadleaved hosts. In the spring when the rains cease and the weeds dry out, the adults rapidly colonize flowering crops, including strawberries. Strawberries are not a preferred host of WTPB in California, but the absence of other more attractive host plants in early summer stimulates the colonization of strawberries. Based on heat unit accumulations typical of the central coast, two-three generations of WTPB develop between April and November in strawberries

WTPB adults are about 6 mm. long and variable in color. They are characterized by a conspicuous yellow or pale green 'v' on the scutellum. Females insert eggs into host plant tissues and often only the operculum or tip of the egg is visible externally and thus the eggs are not easily detectable. The first and second instars are tiny and pale green with a distinct red terminal antennal segment. The third through fifth instars are larger and have five black dots on the back (Sorensen, 1939).

Feeding by all five nymphal stages and by adults causes distortion of the berries, known as catfacing, rendering the fruits unacceptable for fresh market sale. Distortion of the berries occurs when feeding by WTPB destroys developing embryos in achenes (seeds) during early fruit development, preventing growth of the fruit tissue beneath and surrounding the damaged achenes (Handley and Pollard, 1993).

WTPB damage is often called cat-facing and is characterized by berry deformities including severe distortion of the berry due to depressed areas where all achenes are contiguous. Damage can also be centered on the apical area of the berry and for that reason is sometimes referred to as “apical seediness”. Allen and Gaede (1963) first showed that WTPB damage was not due to a toxic action but rather that feeding inside the achenes and the subsequent destruction of the enclosed embryo and endosperm was the reason for the deformed berries. Hormones responsible for receptacle enlargement are produced in the achenes and then translocated to the surrounding tissue. When WTPB feeds on the achenes, hormone synthesis and translocation is disrupted. Several studies indicate that WTPB feed on strawberry achenes from the time that the flower opens until the beginning of enlargement, when the achenes become too hard for their stylets (mouthparts) to penetrate. Handley and Pollard (1985) conducted electron microscope observations of WTPB feeding and damage and found that the holes in damaged achenes were consistent with the size of WTPB stylets. They also found that after selecting a feeding site, WTPB punctures the achene several times, causing considerable damage that results in a hollow achene. Damaged achenes range in size from completely undeveloped to fully developed. Allen and Gaede (1963) hypothesized that because WTPB bugs are able to feed on the achenes from 4 days before pollination to approximately 10 days after pollination that there should be more large hollow achenes than small ones on a damaged strawberry. Both WTPB adults and nymphs feed on developing achenes, but because nymphs appear to be quicker to select a site and are unable to fly, they tend to stay on a single seed/plant longer and thus cause more damage than adults.

In their electron microscope observations, Handley and Pollard (1985) found that after achenes become too hard for WTPB to penetrate, they begin to feed on the receptacle near the achenes. Once feeding on the receptacle, WTPB targets the vessel conducting nutrients to the developing achene. Digestive enzymes from WTPB saliva can cause necrosis, deformation, and fruit abscission. Udayagiri and Welter (2000) observed that WTPB preferred to oviposit on the strawberry receptacle because of the complexity of its surface and the small distance between achenes on an enlarging berry. This reduces the accessibility of WTPB eggs to *Anaphes iole*, an egg parasitoid. WTPB oviposition into the receptacle alone can cause damage to the receptacle because of the wound created. WTPB adults that oviposit in strawberry may also feed at the same time, resulting in additional damage to the strawberry.

Insufficient pollination can also be responsible for the non enlargement of some achenes, but these achenes are small with their embryo and endosperm intact. Riggs (1990) found that non-pollination alone did not have a significant effect on fruit deformity, but that the interaction between WTPB feeding and pollination was highly significant. He showed that that WTPB feeding at the early stages of achene development had an effect on fruit deformity. After 16-17 days of development, WTPB feeding mostly affected only fruit weight. These sources suggest that the main criteria for distinguishing WTPB damage from other types of damage in strawberries are: (1) the emptiness of the damaged achenes, (2) the non or partial enlargement of the surrounding receptacle, and (3) the color of the achenes: green (possibly damaged) or brown (damaged).

WTPB nymphal densities in strawberry fields can be consistently and most economically estimated by beating plants onto a clean enclosed surface, such as a white pan or white sheet of paper or cloth. Since adults are very mobile, their numbers are more accurately estimated by vacuuming plants using a leaf blower modified to act as a vacuum (Zalom et al. 1993). Economic damage is estimated to occur at densities of 1 or 2 WTPB per 20 strawberry plants sampled (Strand, 1994).

WTPB densities should be monitored throughout the season in organic strawberries. No organically acceptable insecticides are very effective against the early instars; hence preventive control measures must be undertaken. These preventive measures must be timed especially to coincide with periods soon after egg hatch in each generation. Since WTPB adults migrate to strawberries from weeds in the spring, when strawberry flowering commences, plants need to be monitored in spring to determine the first appearance of WTPB adults. Egg hatch can be estimated using a degree-day (DDU) model (Pickel et al. 1990). Using a base temperature of 54 F, egg hatch is estimated to occur at 252 F DDU's, and on the central coast in California this translates to approximately 3 - 4 weeks after the first appearance of the adults in the trap crop, weeds or strawberries under cool spring temperatures. The second hatch of nymphs is predicted to occur 779°DDU's after the first nymphs are found in surrounding weedy host plants. The third hatch of nymphs is predicted to occur 799°DDU's after the first adults are found in the strawberries (Strand, 1994).

Naturally occurring native predators of WTPB eggs and nymphs include big-eyed bugs, *Geocoris spp*., minute pirate bugs, *Orius spp*., green and brown lacewings, *Chrysoperla* and *Hemerobius spp.,* damsel bugs, *Nabis spp*., the convergent lady beetle, *Hippodamia convergens* Gurin-Mneville and several species of spiders, which feed on aphids, white flies and lepidopteran pests besides feeding on WTPB nymphs and eggs (Clancy and Pierce, 1966). Monitoring should take the presence of these beneficial insects into account. While these predators feed on WTPB eggs and nymphs, they often do not keep summer populations below the economic injury level. *L. hesperus* is also parasitized by a few native parasitoids including the egg parasitoid, *Anaphes iole* Girault (Hymenoptera: Mymaridae). *A. iole* appeared to have the greatest potential for suppressing WTPB populations in strawberries. Adult wasps are minute (0.6 mm) and black. The wasps were commercially available and have been released for WTPB suppression in strawberries and on small acreages in organic strawberries in California. In experimental plots in conventional strawberries augmentative releases of adult wasps @ 37,500/ha/wk provided a 43 % WTPB reduction and a 22% reduction in berry damage (Norton and Welter 1996). However, efforts to modify release strategies and enhance performance of the parasitoid by integration of Anaphes releases into trap crops has not been recently feasible due to commercial unavailability and high cost of parasitoids.

Efforts to suppress WTPB populations using tractor mounted vacuum devices, including the "bug vac" technology originating on the California central coast, have been successful in lowering adult and nymphal densities and reducing damage (Pickel et al. 1994, Vincent and LaChance, 1993). Depending on suction force generated and operational method, vacuum machines are an important and common tool for suppression of WTPB in organic strawberries in coastal Central California. Since most vacuum machines remove larger instars and adults, but may have limited impact on the early instars, weekly use of the vacuum is necessary for effective control, and repeat vacuuming during each week may be necessary. WTPB adults are mobile and can rapidly move back into strawberries after passage of the vacuum. Growers should routinely check that under the airflow and speeds of operation of their weekly vacuuming the use of the machine is effective in reducing WTPB numbers and damage, and make adjustments in their vacuuming program according to field sampling information. Vacuuming should begin as soon a fields are dry in the spring, and can be timed to coincide with intervals in which nymphs and adults are abundant, according to degree-day unit calculations mentioned above.

A WTPB bug suppression strategy that has been tested in cotton in the San Joaquin Valley of California (Stern et al. 1964, 1969; Sevacherian and Stern 1974; Godfrey and Leigh 1994) is the establishment of alfalfa trap crops adjacent to cotton. Since alfalfa is a preferred host for WTPB, cotton is protected by close proximity to alfalfa when properly managed.

We hypothesized that this relationship could also be true for an alfalfa/strawberry association for organic strawberry production, given the necessity to employ non-chemical cultural methods for control of WTPB. A non-crop plant trap crop (alfalfa) could be planted on beds at the field border or within the field to attract WTPB. Once the insects are concentrated in the trap crop, we hypothesized that they could be controlled by increased numbers of beneficial insects and/or they could be vacuumed with a tractor-mounted vacuum machine which generates a suction force sufficient to remove the insects from the trap crop, killing them in the fan housing. This strategy would also seek to avoid vacuuming the in-field adjacent strawberry rows as much as possible, since the vacuum machines are non-selective in their effect and also remove beneficial insects from the strawberry crop (Vincent and LaChance, 1993). Repeated in-field vacuuming may also increase problems with mold and mildew by spreading spores of these diseases (Strand, 1994). Our hypothesis included the theory that since WTPB adults do not prefer strawberries compared with alfalfa, and it should be possible to concentrate and remove adults in a preferred (more attractive) trap crop, thereby reducing WTPB numbers and damage in associated strawberry rows. Any control measures (vacuuming, release of beneficial insects and pathogens, etc.) would be concentrated in the trap crop vegetation. Previously, Easterbrook and Tooly (1999), in England, reported that trap crops of alfalfa and plants in the family Asteraceae did not consistently reduce *Lygus rugulipennis* in strawberries. However, they did not incorporate vacuum treatments of the trap crop into their experiment. We report here our evaluation of our management hypotheses in replicated studies in a certified organic strawberry field in Salinas in the 2002 production season (with an additional study of natural enemy release into the trap crops in 2001).

Methods

Performance of a tractor-mounted vacuum machine in reducing WTPB in alfalfa trap crops associated with organic strawberries

In July 2001, we evaluated the performance of the tractor-mounted vacuum on the four trap cropped organic strawberry farms (Clint Miller, Reiter Berry, Coke, and Eagle Tree/Pacific Gold

Farms). In the trap-cropped replicates, two edge beds were designated to remain unplanted to strawberries, and instead of strawberry crowns, were planted to seeds of a planted trap crop consisting of market/culinary radish and mustard mix (outside trap crop bed) and alfalfa (inside trap crop bed). A second, nearby identical planting was maintained as an untreated control. All beds were weeded and drip irrigated with a single sub-surface tape, as needed. All strawberry and trap crop beds of the experiment were planted by October 15, 2000, and germination and development with fall rains was excellent.

To assess the impact of vacuuming the trap crop on populations of WTPB, we sampled insects in the trap crop in a randomized, complete block (block=each of four farms) in the total of eight trap crop plots on four dates. Four plots in each of two treatments on each farm were either 1) treated with the tractor-mounted vacuum 2) or left unvacuumed (running the tractor only through the trap crop without using the vacuum). In the vacuumed replicates, we sampled insects immediately before vacuuming, then once after each of three passes of the vacuum (1/2 hour interval between passes). The unvacuumed control treatments were sampled immediately prior to and immediately after each vacuuming of the vacuum-treated plots on the same day. Trap crop vegetation was sampled with a hand-held vacuum suction device (modified reversed Stihl BG75 leaf blower) with a 5-inch insect-netted intake orifice secured by rubber bands. Each week, a whole sample consisting of 50 one-second suction points was taken from a continuous line walked along the trap crop vegetation. Alfalfa plants with flowers were targeted. All samples were frozen, then sorted in the laboratory and all insects (pest and beneficial) were counted.

Effects of the release of a WTPB egg parasitoid in trap-cropped organic strawberries

In May 2001, we conducted an experiment to measure the impact of releases of the WTPB egg parasitoid *A. iole* into an alfalfa trap crop. We released the parasites into four un-vacuumed alfalfa trap crops (planted as previously described) on the four different organic strawberry farms described previously. Plots were also planted to strawberries as described above. In each of the alfalfa trap crop rows and adjacent strawberry rows 1,4, and 8, we selected three plants. On May 6, on each plant, one leaf was bagged, down to the base of the petiole, with a small organdy sack. Bags were put on 10 days in advance of the release experiment to allow any WTPB to emerge. No WTPB emerged into the sacks during the ten-day period. 8-12 female WTPB were
enclosed in each bag on May 16 for 48 hours. On May 18, the bags were removed and 2,000 *A. iole* adults purchased from BioTactics Inc. in Perris, CA) were immediately released into each alfalfa trap crop. On May 26, we harvested the leaves and petioles and dissected any WTPB eggs detected under a microscope. Parasitized eggs can be determined by the color and consistency of the egg on being punctured with a pin. Total number of WTPB eggs and parasitized eggs were counted.

Controlling damage of WTPB to organic strawberries with trap crop vegetation with a tractor-mounted vacuum machine

In 2002, we used an experimental design that was a completely randomized block array consisting of two treatments on an organic strawberry farm: 1)un-vacuumed, non-trap cropped control strawberry, as the grower's whole field vacuumed strawberry program; one vacuuming per week), and 2) trap cropped strawberry, with the sixteen adjacent rows un-vacuumed (vaccumed twice daily, two days per week). This experiment was carried out at Eagle Tree/Pacific Gold Farm in Prunedale. Each replicate consisted of 16 rows of strawberries (numbered 1 through 16 based on proximity to the trap crop vegetation; row 1 directly adjacent), and each row was approximately 150 ft. in length. Strawberry beds were planted on 48-in. centers, and were 18 in. in width and 12 in. in height. The strawberry variety planted was Seascape. Each treatment was replicated 4 times, and plots were distributed over an area of approximately 10 acres. Plots were separated by at least 25 feet in all cases. In the trap-cropped replicates, two edge beds were also designated to remain unplanted to strawberries, and instead of strawberry crowns, were planted to seeds of a planted trap crop consisting of market/culinary radish and mustard mix (outside trap crop bed) and alfalfa (inside trap crop bed). A "control" strawberry row at the edge of an adjacent un-trap cropped strawberry block, was also designated. All beds were drip irrigated with a single sub-surface tape and weeded, as needed. All strawberry and trap crop beds of the experiment were planted by October 30, 2001, and germination and development with fall rains was excellent.

Beginning in January 2002, we monitored the trap crop plants in each replicate weekly with the hand-held vacuum suction device (modified reversed Stihl BG75 leaf blower) with a 5-inch insect-netted intake orifice secured by rubber bands. Each week, a whole sample consisting of 50 one-second suction points was taken from a continuous line walked along the trap crop vegetation. Samples were frozen, and insects (pest and beneficial) were counted under a dissecting microscope as detailed above. We also monitored only adjacent strawberry row 1 in the same fashion.

On May 11, the collaborating grower began treating the replicates in the described fashion, with a 65 hp tractor mounted with three rectangular vacuum collector inlets (6X20 in). The inlets were mounted on 48 in. centers in order to match up with strawberry bed dimensions. Each inlet had an associated fan which generated an average negative pressure at each inlet surface of approximately 28 mi/hour (40 km/hr) based on measurements taken with a portable wind speed indicator. The tractor was driven at a speed of approximately 1.5 mi/hour (3 km/hour) when vacuuming the rows. In the vacuumed trap crop treatment, two of the three inlets were passed over the radish and/or alfalfa trap crop row two times (30 minutes between passes), two days a week between 10 a.m. and noon each week until September 11. In the growers whole field vacuuming treatment without the trap crop vegetation, all rows were vacuumed once a week. On all vacuumed strawberry rows, the tractor-mounted vacuum was passed over the strawberries at canopy height. On May 15, we additionally began monitoring insects in rows 2, 4, 8, and 16 with the hand-held insect vacuum net as previously described. On July 1, the radish trap crop plants were completely removed and the drip irrigation to that row tied off, due to senescence and termination of flowering. On June 1, we established three randomly selected clusters of four strawberry plants as permanent "pick plots" in rows 1, 2, 4, 8, and 16. Each week, developing berries that showed signs of distinct WTPB damage (empty, small, discolored achenes, unevenness of enlargement of the receptacle around empty achenes, apical damage or "seediness") were counted and removed. New berries with no evidence of damage were tagged with a colored twist-tie to avoid double counting, and then counted as undamaged upon maturity.

Percent damaged berries were calculated as a cumulative percentage by month of harvest during the WTPB "damage season" (June= early, July=mid, August=late).

All statistical analyses of these experiments were performed with the ANOVA (repeated measures) program of STATISTICA software, by Stat Soft Inc., Tulsa, OK at an alpha level = 0.05. A least significant difference test was performed to separate means except where indicated. All insect counts were transformed by the log transformation and percent damage estimates by the arcsine transformation before statistical analysis.

Results

Performance of a tractor-mounted vacuum machine in reducing WTPB in alfalfa trap crops associated with organic strawberries

Figure 1 shows that vacuum treatment of an alfalfa trap crop can reduce adult WTPB numbers by 70% after a single pass of the tractor with the mounted vacuum. Control treatment did not result in any measurable difference in WTPB numbers. Successive vacuum passes 2 and 3 lowered WTPB numbers approximately 20% more, however the statistical significance of this difference was below p<0.05.

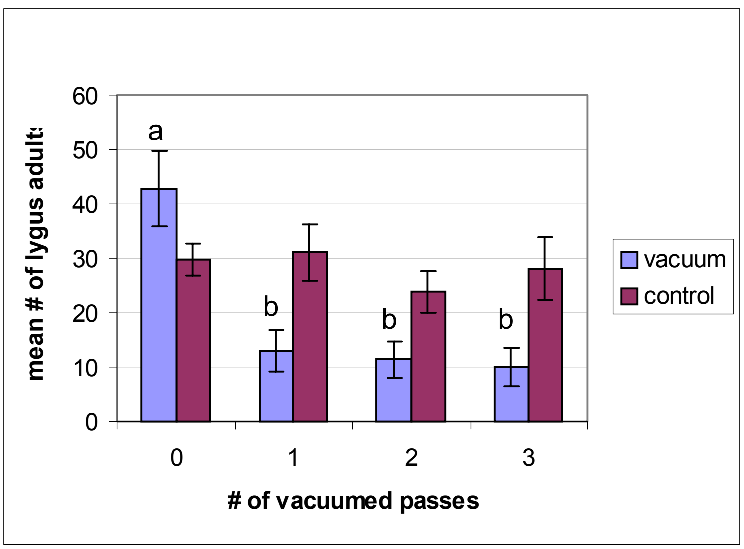

Figure 1. Effect on single and multiple vacuumings on WTPB adults in an alfalfa trap crop (0= prior to vacuum treatment; 1,2,3=number of sequential times the trap crop was vacuumed in the same day). Control means are not significantly different from each other. Means followed by different letters within the vacuum treatment are different; ANOVA, least significant difference test, p< 0.05

Figure 2 shows that vacuum treatment of an alfalfa trap crop can reduce nymphal WTPB numbers by 72% after a single pass of the tractor with the mounted vacuum. Control treatment did not result in any measurable difference in WTPB nymph numbers. Successive vacuum passes 2 and 3 lowered WTPB numbers approximately 15% more, however the statistical significance of this difference was below p<0.05.

Figure 3 shows that vacuum treatment of an alfalfa trap crop reduces beneficial insects (generalist predators and hymenopterous parasitoids) by 40% after a single pass of the tractor with the mounted vacuum. Control treatment did not result in any measurable difference in beneficial insect numbers. Successive vacuum passes 2 and 3 lowered beneficial insect numbers approximately 11% more, however the statistical significance of this difference was below $p<0.05$.

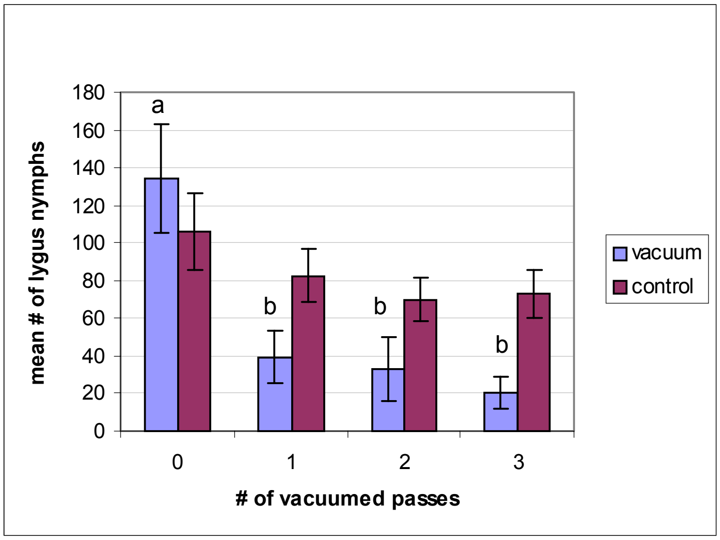

Figure 2. Effect on single and multiple vacuumings on WTPB nymphs in an alfalfa trap crop (0= prior to vacuum treatment; 1,2,3=number of sequential times the trap crop was vacuumed in the same day). Control means are not significantly different from each other. Means followed by different letters within the vacuum treatment are different; ANOVA, least significant difference test, $p< 0.05$

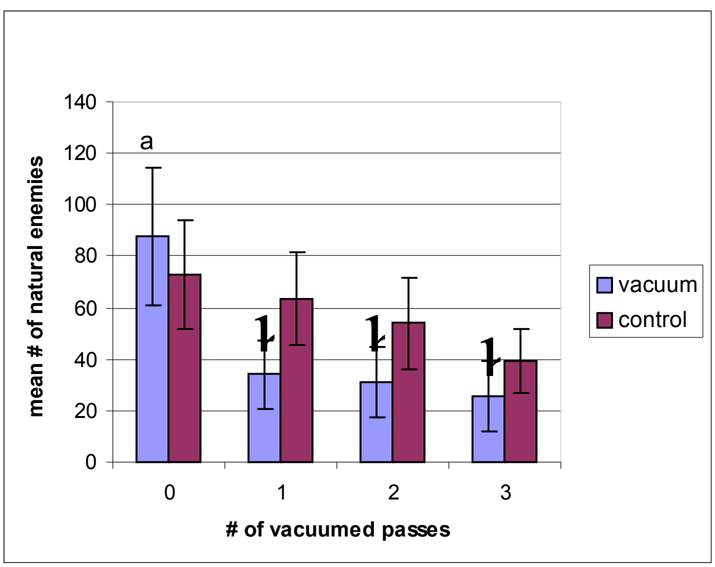

Figure 3. Effect on single and multiple vacuumings on beneficial insects in an alfalfa trap crop (0= prior to vacuum treatment; 1,2,3=number of sequential times the trap crop was vacuumed in the same day). Control means are not

significantly different from each other. Means followed by different letters within the vacuum treatment are different; ANOVA, least significant difference test, $p < 0.05$

Controlling damage of WTPB to organic strawberries with trap crop vegetation with a tractor-mounted vacuum machine

The 2002 pattern of adult WTPB presence in the trap crop vegetation is shown in Figure 4. The first WTPB adults were found in the radish trap crop vegetation on February 10, and radish trap crop flowering began in January. The alfalfa trap crop vegetation began flowering in mid-April, coincident with the first adults found in the hand-held vacuum sample. A WTPB heat unit accumulation model initiated on February 10 predicted that in this trap crop vegetation, a second-generation adult would not mature at the earliest until August 19. This calculation indicates that these adults shown in Figure 4 were all migratory in origin before August, 2002. This result suggests that there was a six-month period in which migrant WTPB adults are attracted to trap crop vegetation on the edge of the strawberry fields. Figure 5 shows the pattern of WTPB nymphal counts. The first in-season hatching (indicated by the beginning of nymphal counts) began in April in the trap crop vegetation.

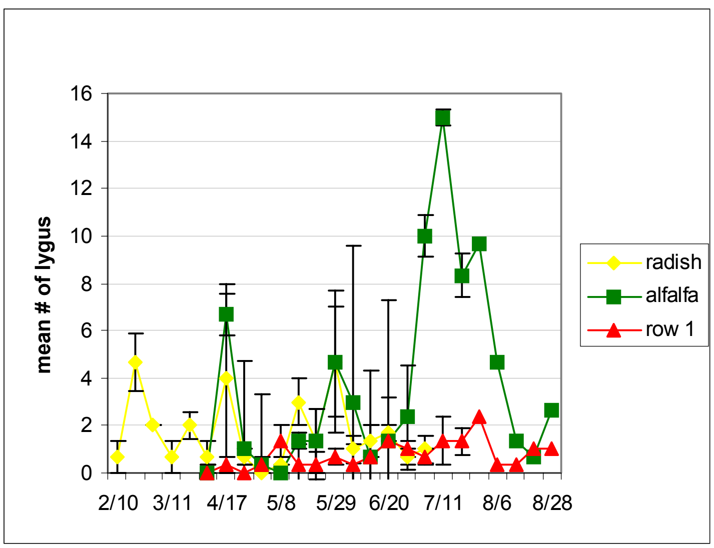

Figure 4. Adult WTPB in trap crops and adjacent strawberry row treatments, by date, 2002. Trap crop treatments not vacuumed until May. Bars indicate 1MSE.

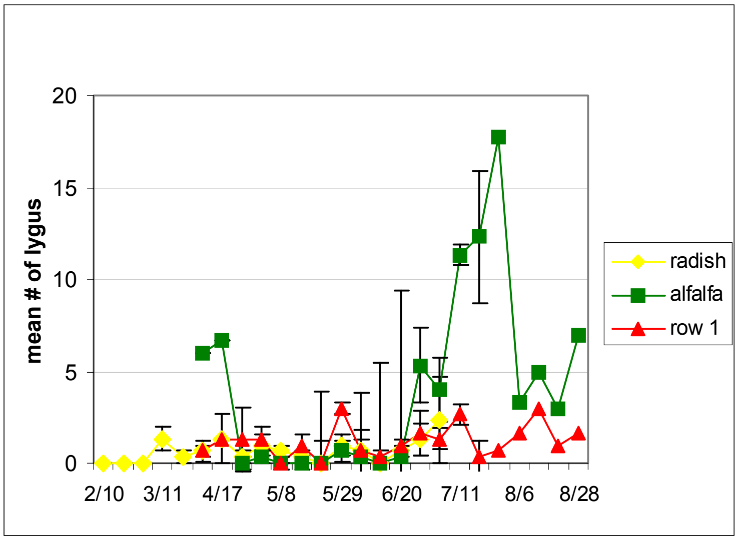

Figure 5. Nymphal WTPB in trap crops and adjacent strawberry row treatments, by date, 2002. Trap crop treatments not vacuumed until May. Bars indicate 1MSE.

Figure 6 shows mean total (adult and nymph) accumulation per sample of WTPB in the trap crop treatments from February 10-July 1. A highly significant difference in both total accumulated adult and nymphal WTPB was found when the radish, alfalfa, and strawberry treatments are compared. Alfalfa attracted 4 times more total WTPB on average, per sample, than radish. Radish was not significantly more attractive than the strawberry row. Although flowering and maturing somewhat later in the spring, alfalfa was a significantly better trap crop. This is a fundamental result, because tractor-mounted vacuum management of a trap crop can only begin in May, when all drainage ditches are closed and the threat of heavy spring rain and muddy row conditions has diminished, and alfalfa is flowering.

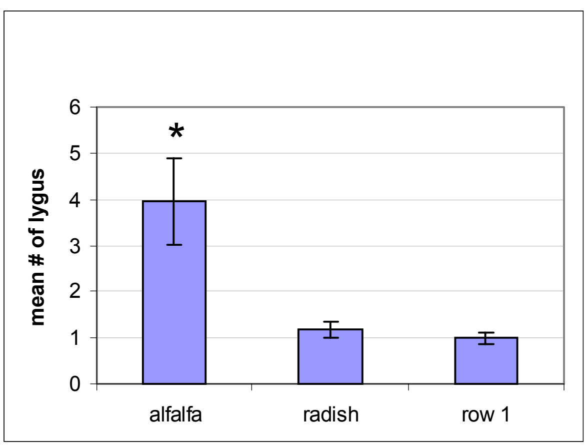

Figure 6. Mean total accumulated WTPB per sample in alfalfa, radish, and strawberry row 1, February 10- July 1 2002. Treatment mean marked with (*) is significantly different from other treatment means ($p<0.05$; Kruskal Wallis ANOVA).

Figure 7 shows accumulated total WTPB by treatment and row in June. The alfalfa trap crop accumulated more than 3X more WTPB than a control edge strawberry row in June. In the rows, the vacuumed trap crop treatment had the same accumulated WTPB as the grower's whole-field vacuuming treatment. Vacuuming only a field-edge alfalfa trap crop in June does not result in significantly increased in-field WTPB counts, when compared with the growers whole-field vacuuming program.

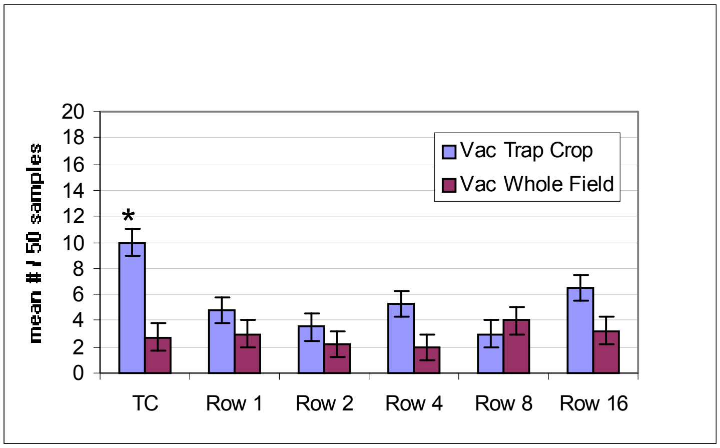

Figure 7. Accumulated WTPB by treatment and row, June 6-June 25, 2002.
Treatment means followed by a (*) letter are significantly different within the trap crop or row, ANOVA least significant difference test ($p<0.05$).

Figure 8 shows accumulated WTPB by treatment and row in July. The alfalfa trap crop accumulated more than 20X more WTPB than a control strawberry edge row in July. In the rows, the vacuumed trap crop treatment did not have significantly different accumulated WTPB compared with the grower's whole-field vacuuming treatment. Vacuuming only a field-edge alfalfa trap crop in July does not result in significantly increased in-field WTPB counts, when compared with the growers whole-field vacuuming program.

Figure 9 shows accumulated WTPB by treatment and row in August. The alfalfa trap crop accumulated only about 3X more total WTPB than a control strawberry edge row. In contrast to the monthly trend of increased total numbers of WTPB in the trap crop, the August samples showed a *declining* number of WTPB in the trap when compared with the previous month. For the first time, in the rows 2, 4, 8, and 16, there is a numerical trend toward increased total WTPB in the vacuumed trap crop treatment. Although the vacuumed trap crop treatment did not accumulate a *significantly different* number of WTPB at these distances, in August, the trend toward higher WTPB numbers is a reversal of earlier results. This result may be due to the condition of the trap crop vegetation in August (discussed below).

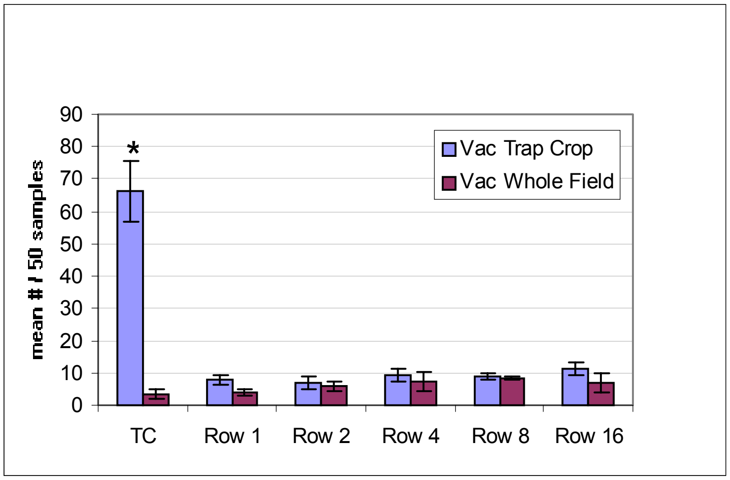

Figure 8. Accumulated WTPB by treatment and row, July 2-July 25, 2002. Treatment means followed by a (*) letter are significantly different within the trap crop or row, ANOVA least significant difference test ($p<0.05$).

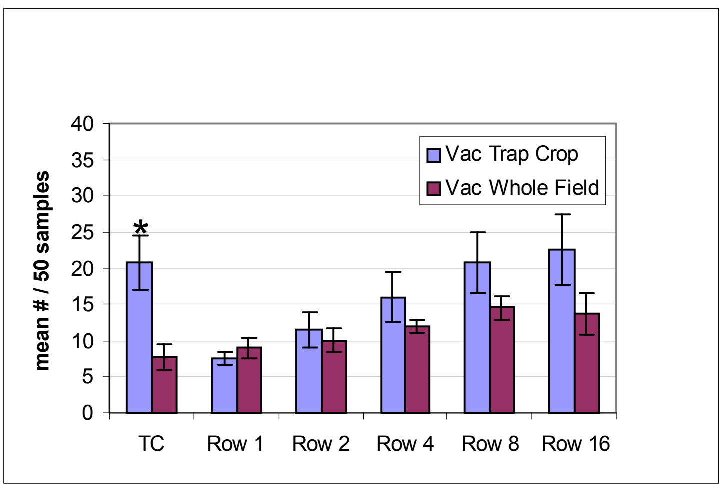

Figure 9. Accumulated WTPB by treatment and row, August 6-August 29, 2002. Treatment means followed by a (*) letter are significantly different within the trap crop or row, ANOVA least squares difference test ($p<0.05$).

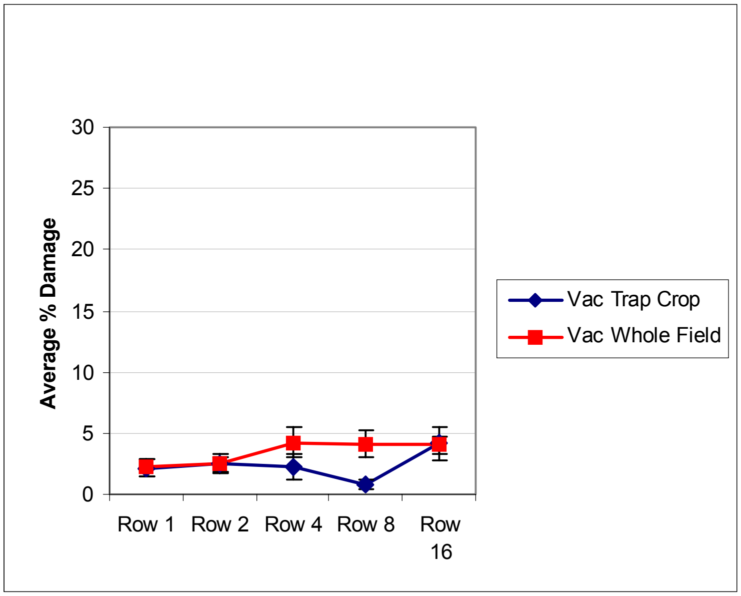

Figure 10. Accumulated WTPB damage by treatment and row, June 6-June 25, 2002. Treatment means were not significantly different within the rows.

Figure 10 shows accumulated WTPB damage to the strawberries, by row, in June. No significant differences could be detected, although a numerical trend exists showing lower damage in rows 4 and 8 in the vacuumed trap crop treatment.

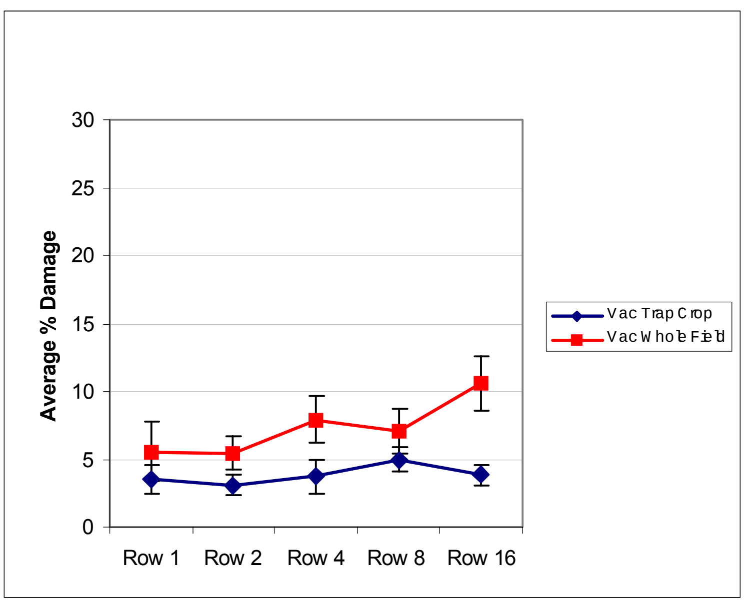

Figure 11. Accumulated WTPB damage by treatment and row, July 2-July 30, 2002.

Treatment means were not significantly different within the rows.

Figure 11 shows accumulated WTPB damage to the strawberries, by row, in July. No significant differences could be detected, although a numerical trend exists showing lower damage in all rows in the vacuumed trap crop treatment.

Figure 12 shows accumulated WTPB damage to the strawberries, by row, in August. No significant differences could be detected, although a numerical trend exists showing *higher* damage in several rows in the vacuumed trap crop treatment. This is a marked reversal of the trends seen in the first two harvest months.

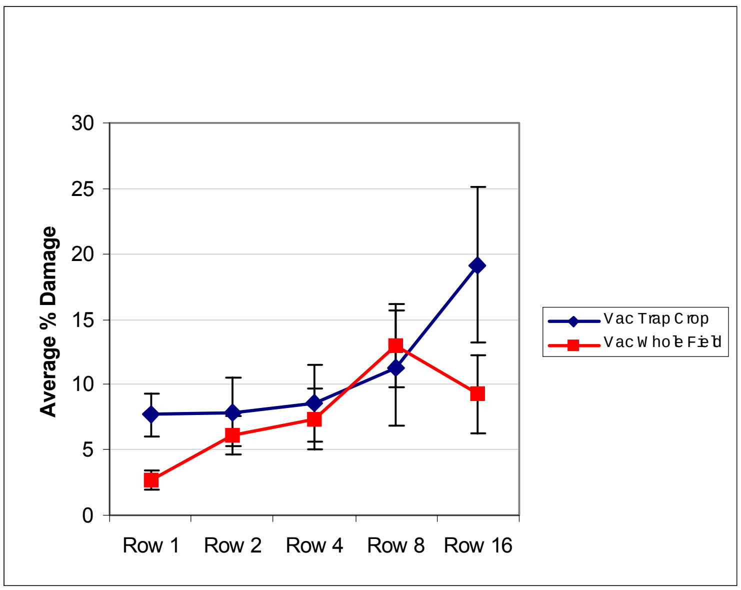

Figure 12. Accumulated WTPB damage by treatment and row, August 6-August 27, 2002. Treatment means were not significantly different within the rows.

Figure 13 shows a summary of overall strawberry damage in all rows by WTPB due to treatment in June, July and August. The vacuumed trap crop treatment accumulated 2.4% damage in June, 3.9% damage in July, and 10.9% damage in August, compared with 3.4%, 7.3%, and 7.7% damage respectively in the whole field vacuuming treatment. In June, the vacuumed trap crop damage (2.4%) is significantly lower than the whole field vacuumed damage (3.4%). In July, the vacuumed trap crop damage (3.9%) is also significantly lower than the whole field vacuumed damage (7.3%). No difference was detected between treatments in August. The vacuumed trap crop treatment significantly reduced strawberry damage by 38% in June and by 47% in July when compared with the grower's whole field vacuuming treatment. No significant difference in damage could be detected in August, however during that month, WTPB damage in the vacuumed trap crop showed a numerical reversal of the June and July trends, showing a higher damage level than the whole field vacuumed treatment.

A native predacious natural enemy of WTPB, the big-eyed bug (BEB), *Geocoris spp*., is the most abundant beneficial insect in our samples. Figure 14 shows average total BEB per sample, by row and treatment in June. The vacuumed trap crop treatment had significantly more BEB in the trap crop and in all rows. This result indicates that the trap crop vegetation increased the numbers of the most numerous generalist WTPB predator in the strawberry rows at the furthest distance sampled. A similar result was found in rows 2 and 8 in July (Figure 15). The effect is greatly diminished in August (Figure 16), with only row 1 showing a significant difference due to treatment. BEB populations declined markedly in August. We do not know the reason for this decline, because WTPB prey are abundant in August. It is possible that the BEB enters diapause (genetically pre-determined quiescence) at this time.

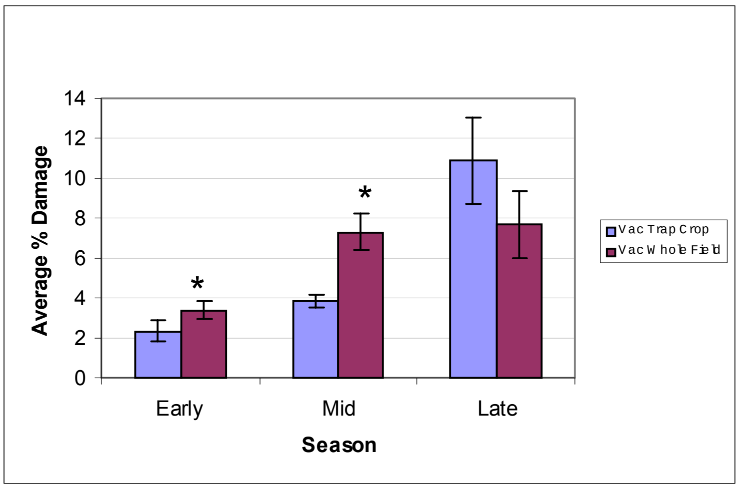

Figure 13. Accumulated WTPB damage by treatment, in early (June), mid (July) and late (August) Samples. Means followed by (*) within season are significantly different. ANOVA, least significant difference test ($p<0.05$).

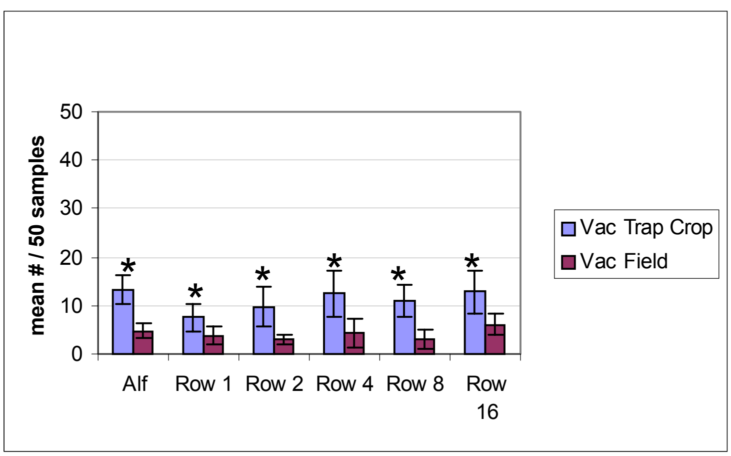

Figure 14. Accumulated big-eyed bug abundance in the trap crop and strawberry rows by treatment in June. Means followed by (*) within trap crop or rows are significantly different. ANOVA, least significant difference test ($p<0.05$).

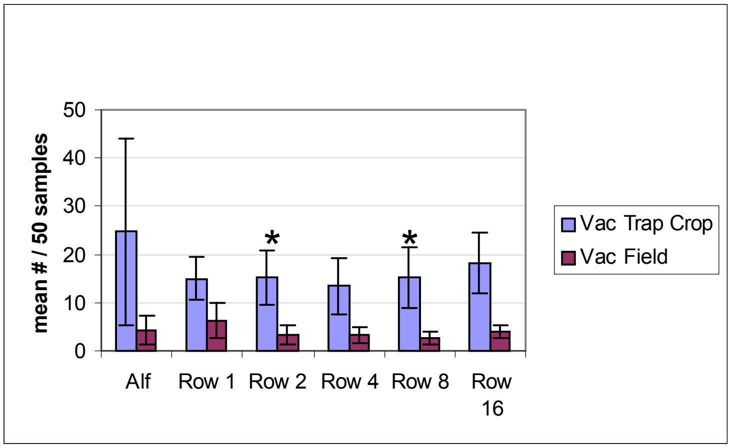

Figure 15. Accumulated big-eyed bug abundance in the trap crop and strawberry rows by treatment in July. Means followed by (*) within trap crop or rows are significantly different. ANOVA, least significant difference test (p<0.05).

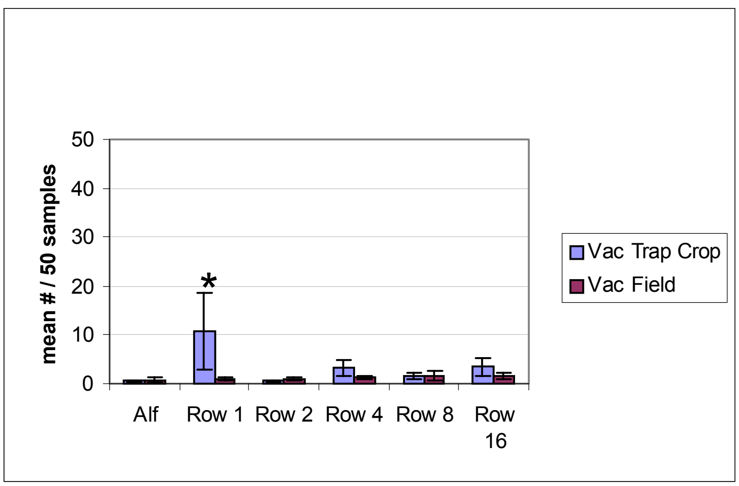

Figure 16. Accumulated big-eyed bug abundance in the trap crop and strawberry rows by treatment in August. Means followed by (*) within trap crop or rows are significantly different. ANOVA, least significant difference test (p<0.05).

Effects of the release of a WTPB egg parasitoid in trap-cropped organic strawberries

Forty percent of the caged plants with WTPB adults showed oviposition into the leaf blade or petiole area. Of these leaves/petioles with WTPB eggs, forty percent overall had one or more eggs parasitized by *A. iole*. Of the plants that had WTPB eggs present, the average percent parasitism per "lygus egg/leaf" was 16% overall and ranged from 4 to 24%, depending on the farm site. Figure 17 shows the pooled average parasitism in the trap crop and adjacent strawberry rows. On average, (by row averaged across all farm sites) 35% of the eggs in the alfalfa trap crop were parasitized; 39% of the eggs in row 1 were parasitized, 5% of the eggs in row 4 were parasitized and 0% of the eggs in row 8 were parasitized. Although this egg mortality was not sufficient to have a suppressive population impact, it is important to note that a selective WTPB natural enemy could be released and colonized in the trap crop, and recovered from the adjacent strawberry rows at a short distance. This finding has motivated us to continue evaluation of the dispersal of other mass-reared natural enemies from the trap crop, although *A. iole* is no longer commercially available.

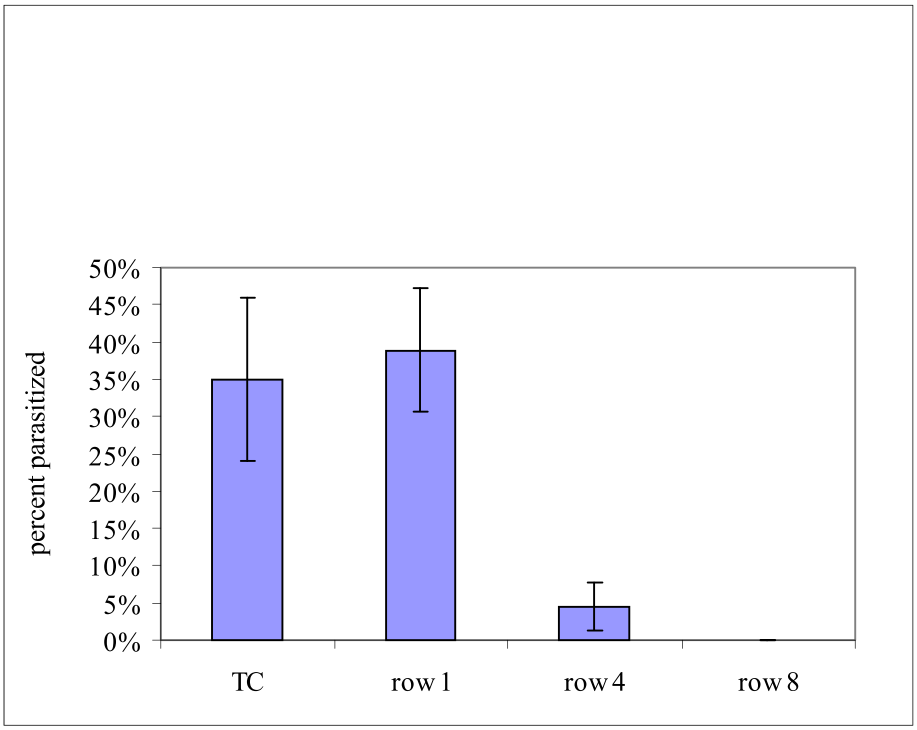

Figure 17. WTPB egg parasitism by mass-released Anaphes iole, May 2001. TC=alfalfa trap crop; rows 1, 4, 8 = strawberry beds adjacent to the trap crop. Bars indicate +/- 1 SEM. Data pooled from 4 release sites.

Discussion

Our results from the 2001 and 2002 seasons indicate that organic strawberry field edge alfalfa trap crops attract 4X more WTPB than either radish/mustard or strawberry plants in the spring. Alfalfa trap crops can be planted on a designated bed (otherwise prepared for strawberry planting) in October and will grow slowly through the winter and early spring, until they flower and grow rapidly in the late spring and early summer. Alfalfa can also be effectively vacuumed to remove at least 70% of total WTPB from the trap crop with a single pass of the tractor-mounted vacuum machine. Additional sequential vacuum use can further diminish WTPB numbers in the trap crop, but the significance of this additional treatment could not be determined. Beneficial insects are also impacted by the vacuuming treatment of the trap crop, showing an approximate 40% reduction with the same single vacuum pass. A program of field-edge trap cropping and vacuuming four times weekly did not increase numbers or damage of

WTPB when compared with a grower's whole field vacuuming program. This is a significant result, because the field edge trap crop vacuuming program requires 75% less vacuuming effort in our experiments, and restricts the vacuuming to the trap crop only. Organic strawberries also showed a significantly lower level of damage in the vacuumed trap cropped treatment when compared with a whole field-vacuuming program in June and July. In August, difficulties with water supply to the trap crop row in one replicate affected trap crop attractiveness negatively, and we could not detect a reduction in damage due to trapcrop treatment. In fact, the unattractiveness of the under-watered replicate caused an average *reversal* of the trend toward lower damage in the trap crop, although this was not a statistically significant effect. This result indicates that it is extremely important to maintain the horticultural quality of the trap crop throughout the production season, and especially to maintain irrigation water supply. The trap crop treatment also increased the abundance of an import generalist predator over the entire area of organic strawberry adjacent to the trap crop in June. While the effect diminished in July and August (possibly due to predator diapause), this is an important "natural enemy effect" of trap-cropping organic strawberries with alfalfa. A similar effect was demonstrated in a release experiment with the mass-reared WTPB egg parasitoid *A. iole,* however, the distances from which the parasitoid was recovered were shorter and closer to the alfalfa trap crop than the effect observed with the generalist BEB. Although experimentation with the use of *A. iole* was discontinued due to high costs and commercial unavailability, these results with natural enemy introduction and conservation have stimulated our continuing work with the introduction of other selective parasitoids and generalist predacious natural enemies into the alfalfa trap crop.

Based on these experimental results and other more recent (2003 and 2004) field observations, one grower-collaborator (Larry Eddings, Eagle Tree/Pacific Gold) has expanded his alfalfa trap-cropping program to over 75 acres of organic strawberry production on two farms in Monterey County. He has repeatedly expressed great satisfaction with the project (see enclosed article). We are currently evaluating sample size hypotheses and statistical methods for increased power of our analyses, and we are still analyzing new 2003 and 2004 data sets. We intend to continue to replant trap crop experiments and we are currently evaluating the economic impact of these results in terms of reduced vacuuming and pest control costs, and increased protection of yield from WTPB damage. It is expected that the results reported here and our subsequent research activities will show increased and multiple benefits of trap-cropping organic strawberries with alfalfa in coastal central California.

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