This three-bed vacuum machine reduced Lygus bug abundance and strawberry damage to a greater degree than the smaller machines.

Vacuums provide limited Lygus control in strawberries

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Lygus bug* (Lygus hesperus) *feeding causes small strawberry size and weight, but the most serious damage is a deformation of the fruit called "cat-facing." Over two growing seasons, three grower-designed vacuum machines were evaluated for season-long control of Lygus bugs in production strawberry (var. 'Selva') fields on the coast. The Lygus bug control in fields vacuumed weekly and twice-weekly was compared to that in fields treated with malathion insecticide or an unregistered pesticide, bifenthrin. All vacuum machines significantly reduced Lygus bug damage when compared to the untreated control. However, the damage in plots treated only with the vacuum machines was high enough to be considered economically unacceptable.

California's strawberry crop is grown on over 22,000 acres, and is valued at $285 million annually. Quality standards for the fresh market are strict; small or cosmetically damaged strawberries are suitable only for processing. The Lygus bug, *Lygus hesperus* (Knight), is the key insect pest of strawberries on the Central Coast, including the Watsonville and Santa Maria growing regions. Lygus bugs rarely cause problems south of Oxnard, where harvest is earlier in the spring.

Strawberries are not a preferred host of Lygus bugs, but when weeds dry in the late spring, adults migrate into strawberry fields and establish populations. Lygus bug feeding causes small berry size and weight, but the most serious damage is a deformation of the fruit called "cat-facing." Lygus bugs damage berries by puncturing individual achenes of the flower or developing fruit, halting growth by removing growth hormones in the area around the affected achene. (Similar damage can be caused by lack of pollination in the early spring when plants are flowering during cold weather.) Lygus bugs may also feed on the receptacle of mature berries without damaging fruit. Cat-faced fruit cannot be sold fresh, but instead are salvaged for processing. Deformed berries increase the growers' harvest costs because they must be sorted from market-quality berries.

Many strawberry producers believe that relying solely on traditional insecticide control for Lygus bugs is not viable in the long term because of regulations, pest resistance and secondary pest outbreaks. These producers are experimenting with nonchemical approaches. In addition, several studies have shown that spraying broad-spectrum insecticides for Lygus bugs kills many naturally occurring beneficial insects as well as costly released predators. One approach to reducing Lygus bug populations is the use of tractor-mounted suction devices, which the growers refer to as "bug vacuums." These vacuums are patterned after the D-vac machine used for sampling insects in cotton and other crops. The objective of this study was to evaluate the relative efficacy for the control of Lygus bugs of three grower-designed bug-vacuum machines compared to a conventional pesticide regime, an unregistered pesticide applied as a treated control, and no treatment (untreated control).

Three suction machines

We conducted two separate tests in 1989 and 1990 on commercial strawberry fields near Watsonville in Santa Cruz County. The three suction machines tested were representative of machines used by growers. The machines were not directly compared to each other because the tests had to be conducted independently in each individual grower's field.

The first machine tested vacuumed a single bed and was valued at around $4,000, including the cost of a used Farm-All tractor. The suction apparatus was made by modifying an apple speed sprayer fan; it moved approximately 920 cubic feet of air per minute. In 1990 the grower-cooperator modified this vacuum machine so that it vacuumed two beds; this modified vacuum is regarded as the second machine in the study. The machine now moved 1,600 cubic feet of air per minute and was valued at $5,000. The third vacuum machine was tested in both years. It vacuumed three beds and moved approximately 3,000 cubic feet of air per minute. It cost approximately $60,000, including the dedicated tractor.

Air movement was measured using a hand-held wind-speed indicator (Turbometer) under the hood in the center of the vacuum area at the same level as the hood for each vacuum machine. To reduce the effect of varietal differences, all tests were conducted in fields planted with the day-neutral

TABLE 1. Mean number of Lygus nymphs and adults, and number of cat-faced fruit per 50 large green fruit in 1989 trial of single-row bug vacuum used weekly

	Mean (standard deviation) Lygus per 10-beat sample		
Treatment	Nymphs	Adults	No. damaged fruit per 50 fruit
Vacuum weekly	2.2 (0.5) b*	0.13 (0.1) b	16.3 (0.9) b
Bifenthrin†	1.4 (0.3) c	0.35 (0.1) ab	11.0 (1.1) c
Untreated	2.4 (1.2) a	0.45 (0.2) a	19.8 (1.9) a

*Means in columns followed by the same letter are not significantly different ($P > 0.05$).
†Bifenthrin, 0.1 lb. ai/acre, applied on 5/19/89.

TABLE 2. Mean number of Lygus nymphs and adults, and number of cat-faced fruit per 50 large green fruit, in 1989 trial of three-row bug vacuum used weekly or after reaching the treatment threshold

	Mean (standard deviation) Lygus per 10-beat sample		
Treatment	Nymphs	Adults	No. damaged fruit per 50 fruit
Vacuum weekly	3.9 (1.7) b	0.5 (0.2) b*	14.7 (2.0) b
Vacuum at threshold	4.9 (0.9) ab	0.7 (0.3) ab	18.1 (3.5) ab
Bifenthrin†	0.4 (0.3) c	0.1 (0.1) b	5.8 (0.9) c
Untreated	6.8 (1.9) a	1.9 (0.6) a	23.3 (0.3) a

*Means in columns followed by the same letter are not significantly different ($P > 0.05$).
†Bifenthrin, 0.1 lb. ai/acre, applied on 5/19/89 and 7/10/89.

TABLE 3. Mean number of Lygus nymphs and adults, and number of cat-faced fruit per 50 large green fruit, in 1990 trial of two-row bug vacuum

	Mean (standard deviation) Lygus per 10-beat sample		
Treatment	Nymphs	Adults	No. damaged fruit per 50 fruit
Bifenthrin*	9.0 (0.3) d	1.7 (0.04) a	4.4 (0.3) d
Vacuum weekly	26.7 (0.4) a	1.3 (0.1) a	10.8 (1.3) bc
Vacuum twice weekly	18.0 (0.5) bc	2.3 (0.1) a	11.8 (1.7) ab
Vacuum + malathion†	14.5 (0.4) cd	1.0 (0.2) a	9.2 (1.3) bc
Malathion†	21.2 (0.2) ab	2.3 (0.2) a	8.1 (0.9) c
Untreated	19.5 (0.4) bc‡	2.8 (0.2) a	13.0 (1.5) a

*Bifenthrin, 0.1 lb. ai/acre, applied on 5/8/90 and 6/13/90.
†Malathion, 1.25 lb. ai/acre, applied on 5/30/90 and 7/11/90 at treatment threshold.
‡Means in columns followed by the same letter are not significantly different ($P > 0.05$).

TABLE 4. Comparison of weekly vacuuming, twice weekly vacuuming, vacuuming plus malathion, malathion, and bifenthrin treatments on mean number of Lygus bug nymphs and adults, and number of cat-faced fruit in 1990 trial of three-row bug vacuum

	Mean (standard deviation) Lygus per 10-beat sample		
Treatment	Nymphs	Adults	No. damaged fruit per 50 fruit
Bifenthrin*	0.8 (0.5) a	2.0 (0.8) b	5.3 (2.1) c
Vacuum weekly	24.2 (5.9) b	6.0 (1.6) ab	17.2 (3.3) b
Vacuum twice weekly	26.0 (3.7) b	7.5 (1.3) a	18.1 (3.7) b
Vacuum + malathion†	20.7 (7.6) b	3.7 (0.9) ab	17.5 (4.0) b
Malathion†	24.7 (3.3) b	4.3 (0.9) ab	16.0 (2.0) b
Untreated	52.5 (18.4) a‡	9.5 (2.1) a	27.3 (3.0) a

*Bifenthrin, 0.1 lb. ai/acre, applied on 5/6/90 and 7/10/90.
†Malathion, 1.25 lb. ai/acre, applied on 5/6/90 and 7/10/90.
‡Means in columns followed by the same letter are not significantly different ($P > 0.05$).

cultivar 'Selva' in 48-inch beds with two rows of plants per bed.

One-bed vacuum

In the 1989 study using the one-bed vacuum, three treatments were compared for the harvest season in plots. The treatments, including (1) weekly vacuuming; (2) one application of bifenthrin (Brigade) applied May 19 at 0.1 pound active ingredient per acre (ai/acre); and (3) untreated (control), were replicated four times. The vacuum treatments were 120 feet long separated by a one-bed (two-row) buffer between plots. Plot size was minimized to keep the costs to the grower-cooperator down; damage costs the grower about $10 per foot. Lygus bug adults are strong fliers, but previous studies have shown that much of the damage in strawberries comes from the more stable nymph population rather than from the adults.

For the second and third treatments, a 120-foot bed was divided into four lengths and treatments were assigned randomly along the 30-foot lengths of bed. Samples in the vacuum treatment plot were taken in an equal 30-foot section of the bed. The bifenthrin treatment, which is not currently registered for use in strawberries, was included as a treated check to provide a reference for potential Lygus bug control in case a more effective pesticide becomes available.

Three-bed vacuum

The 1989 study using the three-bed vacuum had four treatments, which were replicated four times. The treatments included (1) weekly vacuuming; (2) threshold treatments: vacuuming twice per week, starting after Lygus bug treatment threshold (1 Lygus/10-foot row) was reached; (3) treated control: bifenthrin applied May 19 and July 10 at 0.1 pound ai/acre; and (4) untreated control. Each replicate consisted of three 150-foot beds for all treatments, separated by a one-bed (two-row) buffer between plots. Samples were taken from the middle bed of the treatment, leaving the two side beds as an additional buffer in an effort to minimize treatment effects.

1990 studies

In 1990 we expanded the studies to evaluate applications of malathion, the pesticide most commonly used for Lygus control by California strawberry growers. One study used the two-bed vacuum; the other used the three-bed vacuum. In both tests the same treatments were replicated four times: (1) untreated control; (2) treated control: bifenthrin at 0.1 pounds ai/acre; (3) weekly vacuuming; (4) twice-weekly vacuuming; (5) weekly vacuuming with malathion (1.25 lb. ai/acre) sprays timed to nymphal hatches; and (6) malathion sprays timed to nymphal hatches. The bifenthrin was applied on May 8 and June 13; the malathion was applied on May 30 and July 11. Treatment beds were 120 feet long in the field with the two-bed vacuum and 150 feet long in the field with the three-bed vacuum. Samples were taken from the middle bed.

Lygus populations were monitored using the beat-sheet technique, which we recommend to growers. Lygus bug nymphs and adults were counted weekly. Damage was evaluated every two weeks in 1989 and weekly in 1990 by randomly inspecting 50 large green berries for cat-facing. We monitored twospotted spider mite abundance by sampling 10 leaves from each treatment replicate and brushing the mites onto glass plates, using a mite-brushing machine.

Lygus bug adults and nymphs and cat-faced fruit from each replicate were summed across weeks and divided by the total number of samples to obtain the average number per replicate per year. Data were subjected to analysis of variance (M-STATC), and means were separated by Duncan's new multiple-range test.

Damage reduced, but still high

Table 1 shows the results of the test using the single-bed vacuum machine. The mean numbers of Lygus bug adults and nymphs were reduced significantly by the vacuum machine ($P < 0.05$). However, although damage was reduced significantly compared to the untreated control ($P < 0.05$), it was still quite high. Average damage in the vacuum treatment was 32.6% for the season, as opposed to 39.6% for the untreated control. Lygus damage in the bifenthrin treatment was 22%; however, most of the damage in this treatment occurred after July. A second bifenthrin treatment might have further reduced damage. Differences in damage between the untreated (control) and vacuum treatments appeared to be greatest earlier in the season; after mid-July differences between the two treatments were less apparent.

Twospotted mite abundance one month after the bifenthrin application reached 244.6 mites per leaflet. In contrast, mite abundance in the untreated plot averaged 12.0 mites per leaflet and in the vacuumed plot 9.3 mites per leaflet.

The second test in 1989 used the three-bed vacuum machine. The weekly vacuum treatment averaged 29.4% cat-faced fruit throughout the season as compared to 46.6% for the control treatment (table 2). Lygus bug nymphal populations were reduced by 43% and adults by 74%; however, the difference for Lygus bug adults was not significant ($P > 0.05$) because variability was high. Lygus bug damage was somewhat higher in the plots vacuumed twice weekly after reaching treatment thresholds than in those vacuumed weekly following the start of Lygus migration, but the difference between vacuum treatments was not significant ($P > 0.05$).

As table 3 shows, in 1990 the two-bed vacuum machine did not significantly reduce the number of Lygus bug nymphs or adults compared to the untreated control ($P > 0.05$). However, damage was lower in all treatments than in the untreated control except for the twice-weekly vacuuming treatment. The treated control, bifenthrin, significantly reduced lygus populations and damage in comparison to all other treatments ($P < 0.05$). Both the bifenthrin and malathion applications were timed to nymphal hatch, using a degree-day phenology model for Lygus. Vacuuming in combination with malathion did not reduce damage significantly below that of vacuuming alone.

Lygus bug abundance was much greater in the field where the three-bed vacuum was tested in 1990 (table 4), resulting in more damage than in any of our other experimental fields (54.6% in untreated plots). All treatments significantly reduced Lygus bug nymphs and damage compared to the untreated control ($P < 0.05$). There was no significant difference between the vacuum treatments and the malathion treatments. It is possible that additional malathion treatments could result in less damage. However, it is likely that more applications would result in outbreaks of other pests such as mites.

This single-bed vacuum machine, made by a grower-cooperator, uses an apple sprayer fan. It was modified in 1990 to vacuum two beds.

Three-bed vacuum performs best

Weekly use of the three vacuum machines reduced damage when compared to the untreated control in all of our field tests. Use of the three-bed machine resulted in a greater reduction of damage than the other machines. In most cases the vacuum machines provided control similar to that achieved by the registered pesticide malathion. Applying bifenthrin at Lygus nymphal emergence consistently provided better control than the other treatments. Bifenthrin is not registered for use on strawberries, but its performance in this study illustrates better control could be achieved if alternative materials or tactics were available. A side effect we observed following bifenthrin application was the large increase in mite abundance.

Both years of our study (1989 and 1990) provided similar results for similar treatments, but the additional treatments (in 1990) of increasing the number of vacuum trips per week and combining the vacuumings with malathion did not reduce damage compared to weekly vacuuming or malathion alone. Two seasonal applications of malathion timed to Lygus bug nymphal hatches did not provide better control than did weekly vacuuming.

Observations of Lygus bug behavior indicated that nymphs were easily disturbed by wind, picking and spraying. Once the nymphs were disturbed they dropped to the crown, making it difficult to vacuum them or to contact them with spray. Once nymphs dropped, they stayed on the crown for about 4 hours before returning to the flowers and foliage. This behavior suggests that a good strategy for vacuuming or spraying to control Lygus might be to employ both methods under calm conditions and at least 4 hours after picking.

Costs were compared for using the three-bed vacuum once per week and the standard malathion for chemical applications. Vacuuming once per week requires 20 trips per season, resulting in a total cost of $172.20, including tractor and vacuum operation and labor to run the vacuum. This does not include the initial purchase price of the vacuum machine, which varies considerably, as mentioned earlier. The cost of two malathion sprays per season is $82.39, including tractor and sprayer operation and labor.

In both years, the larger three-bed vacuum machine reduced Lygus abundance and damage to a greater degree than did the other machines, and their relative efficiency appeared to be related to amount of air flow. This study tested three vacuum machines, which were representative of models used by growers at the time of the study. There is a great deal of variability among vacuums in cost, size and power. A few models are produced commercially and some are built by growers. At present, only a few strawberry growers use vacuum machines for Lygus control. Those who do use these machines typically begin vacuuming weekly when adult Lygus begin to migrate into the fields, and continue vacuuming until populations increase following nymphal hatch.

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This study was supported in part by the California Strawberry Advisory Board and the California Energy Commission. We thank Jon Becker and Robert Curtis for their assistance on the project.