Economics of Integrating the Predaceous Mite *Phytoseiulus persimilis* (Acari: Phytoseiidae) with Pesticides in Strawberries

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ABSTRACT Weekly yields and control costs were used to calculate the economic benefits of *Tetranychus urticae* Koch suppression by a variety of chemical, predaceous mite (*Phytoseiulus persimilis* Athias-Henriot), and chemical plus predaceous mite treatments. Although three or four releases of *P. persimilis* at 4,050/ha in the 1988–1989 or 1990–1991 seasons, respectively, provided a net benefit per hectare of $2,170–$4,315 above the untreated controls, the economic returns from two applications of abamectin ($5,062–$15,802) or fenbutatin-oxide ($4,401–$9,146) ranged from nearly twice to approximately three times higher than the *P. persimilis* treatments alone. The best returns were generated by abamectin in combination with releases of *P. persimilis*. In both seasons, the additive net benefits of abamectin alone and *P. persimilis* alone were essentially equal to the net benefit from the combination (1988–1989, $6,890; 1990–1991, $19,705), thereby indicating compatibility. Both sampling and economic data indicated that neither fenbutatin-oxide nor hexythiazox were consistently compatible with the use of *P. persimilis*. The implications of these results for the development of integrated pest management programs for strawberries are discussed.

KEY WORDS integrated pest management, biocontrol, economics

THE TWOSPOTTED SPIDER MITE, *Tetranychus urticae* Koch (Acari: Tetranychidae), is the major arthropod pest of California's one-half billion dollar strawberry industry (Oatman et al. 1967, 1982). *T. urticae* feeding on foliage of strawberry causes chlorosis (Jeppson et al. 1975), suppresses photosynthetic activity (Sances et al. 1981), and reduces yields (Wyman et al. 1979, Butcher et al. 1987). Unfortunately, high fecundity and multiple generations per season have allowed this pest to develop resistance to a variety of pesticides including chlorinated hydrocarbons, organophosphates, cabamates, sulfones, organotins, and others (Wolfenbarger 1968, Carbonaro et al. 1986, Flexner et al. 1988). Thus, considerable research effort has been devoted to finding alternative strategies for *T. urticae* suppression.

Initially, a classical biological control approach was tried. *Phytoseiulus persimilis* Athias-Henriot was imported from both Chile and Italy and introduced on strawberry in California in the 1960s (McMurtry et al. 1978). Although the predaceous mites became established, an economic level of control was not achieved. Researchers then attempted inundative release programs (Oatman et al. 1968, 1977). These releases provided increased yields through substantial suppression of *T. urticae*, but the cost of releasing over 553,500 predaceous mites per hectare was not economically feasible. In Florida, release of a related phytoseiid, *P. macropilus* Banks, for every 16 *T. urticae* was suggested as an optimal control strategy in strawberries (Poe et al. 1979). However, lack of comparative yield data from treatments makes conclusions regarding the economic viability of that program impossible.

Attempts to integrate chemicals and predaceous mites have met with mixed success in strawberries. Oatman et al. (1967) found that late-season treatments of phorate for *T. urticae* could be replaced by mass releases of *P. persimilis* in midseason; this treatment provided enough control to allow a nearly 18% increase in yield. Unfortunately, the required release rates of >948,000 *P. persimilis* per hectare were apparently too costly for growers, and the approach was not widely adopted.

This latter study, like the research on the potential for the use of *P. persimilis* alone, relied on large releases of predaceous mites only after *T. urticae* populations had built to threshold or near threshold levels. One objective of our research was to examine the economic potential for earlier and smaller inoculative releases using partial-budget analyses. Our second objective was to examine the compatibility of the miticides fenbutatin-oxide, abamectin, and hexythiazox with *P. persimilis* in the strawberry agroecosystem. These compounds were chosen because of their possible compatibility with predaceous mites in other crops (Hoy 1985, Hoy & Ouyang 1986).

Materials and Methods

Horticultural Information. In 1988, 'Selva' strawberry plants (*Fragaria ananassa* L.) were transplanted onto two-row raised beds on 1-m centers in early November into research plots at the University of California's South Coast Field Station in Santa Ana, CA. Beds were mulched with clear plastic ≈1 wk after transplanting. Drip irrigation was used to deliver both water and nutrients at levels consistent with local commercial practices. The field was divided into a randomized complete-block design, with each treatment replicated four times. Blocks consisted of multiple 6.1 by 2 m plots with two beds containing ≈45 plants each. The plots were separated by at least 1 m of rye grass (minimum height 0.33 m), which minimized movement of mites between plots; throughout the study, predaceous mites were observed only in plots where they were released. Treatments included an untreated control, *P. persimilis* releases only, fenbutatin-oxide only (Vendex 50% wettable powder, E. I. du Pont de Nemours, Wilmington, DE) applied at 1.12 kg (AI)/ha, abamectin only (Agri-Mek 0.15 emulsifiable concentrate, Merck, Three Bridges, NJ) applied at 0.011 kg (AI)/ha, hexythiazox only (Savey 25 flowable, E. I. du Pont de Nemours) applied at 293 ml/ha, fenbutatin-oxide plus *P. persimilis*, abamectin plus *P. persimilis*, and hexythiazox plus *P. persimilis*. All pesticides were applied in water at 1,870 liters/ha and 7 kg/cm^2 with a six-nozzle wand attached to a tractor-mounted spray rig.

P. persimilis was released in appropriate treatments at the rate of 4,050/ha on three dates in the 1988–1989 season. The predaceous mites provided by a commercial source (Biotactics, Riverside, CA) were separated from the vermiculite carrier, counted, sealed in plastic straws, and transported to the field for release. An early release before the development of an economically important population of *T. urticae* was made on 11 January in appropriate plots. Additional releases were made on 22 February and again on 4 April, for a total of 12,150/ha. Five plants in each plot were monitored weekly from 6 March to 4 June to determine when most treatments had reached the economic threshold level of five individuals of any active stage of *T. urticae* per leaflet (65% of plants infested on the highest trifoliate before pesticide application, or 85% of the plants infested after the first application [Trumble 1985]). On 1 and 21 April, the threshold level was reached in all treatments and pesticides were applied. Because this study was intended to compare the compatibility of predaceous mites and chemicals, and not necessarily validate an integrated pest management (IPM) program, all chemicals were sprayed on each of the application dates to allow comparative analyses. The only other pest species observed in any plots were aphids, and these did not reach published economic injury levels (Trumble et al. 1983a,b). Total fruit weight from all plants in each plot for each treatment was collected on the same dates as the mites were surveyed. Fruit were weighed to the nearest 0.1 g.

In 1990, the horticultural practices and experimental design were similar except that releases of *P. persimilis* (4,050/ha per release) were made in appropriate plots on 16 January, 20 February, 12 March, and 16 April for a total of 16,200/ha. All plots were monitored weekly from 26 February to 28 May to determine if the economic treatment levels had been reached (same as in 1988–1989 planting). On 4 and 28 March, pesticide treatments were applied as described previously. Total weight of marketable fruit from all plants in each plot were collected weekly from 26 February to 28 May. As in the previous year, the only other pest species observed in any plots were aphids, and these were present only at very low levels.

Partial-Budget Economic Analyses. A partial-budget economic analysis of these data required weekly harvest values for the season because the price for strawberries varies on a weekly basis. To conduct the economic analyses, we needed the FOB ("Free on Board") value for each harvest date for both years. These data were compiled from the Federal-State Market News Reports by the California Strawberry Research Advisory Board. The harvest data were then compiled by week over the season to calculate total crop value.

The costs of the various control measures were also calculated. Inputs for ground applications of pesticides were standardized to 1990 dollars (at 4% inflation per year) and estimated at $50.68/ha per application (Welch et al. 1985). Commercial costs of pesticides were provided by the California Strawberry Advisory Board. Costs included fenbutatin oxide at 1.12 kg (AI)/ha = $113.82 per application; abamectin at 0.011 kg (AI)/ha = $128.32. Hexythiazox was withdrawn by du Pont before registration in the United States and costs are unknown. For example, abamectin costs $195/liter. One liter will treat 1.62 ha at 0.011 kg (AI)/ha, for a cost of $128.32/ha for pesticide. Pesticide plus application equals $179 per application. *P. persimilis* cost $10 per 1,000 or $741 for 74,100/ha in 1988–1989 and $988 for 98,800/ha in 1990–1991. The cost of releasing the mites is estimated to range between $12 and $15/ha per release (C. Hoffman, Driscoll Strawberry Associates, personal communication). The higher value

Table 1. Seasonal trends (1988–1989) in percentage strawberry plants infested with twospotted spider mites

Treatment	% infestation during week[a]											
	1	2	3	4	5	6	7	8	9	10	11	12
Control	15	35	45	**70**	**100**	**100**	**100**	**100**	**100**	80	55	15
Abamectin	30	45	55	**75**	5	40	95	45	40	45	25	15
Hexythiazox	15	30	35	**80**	**85**	75	**90**	65	45	40	25	15
Fenbutatin-oxide	5	30	35	**80**	**85**	75	**90**	65	45	40	25	15
P. persimilis only	15	15	20	**80**	**85**	75	**100**	**100**	**100**	80	55	5
Abamectin + *P. persimilis*	25	25	35	**65**	30	25	80	25	45	25	10	5
Hexythiazox + *P. persimilis*	10	20	35	**85**	65	70	**95**	55	50	20	10	5
Fenbutatin-oxide + *P. persimilis*	15	20	30	**85**	55	75	**85**	**95**	70	55	30	15

[a] Mites discovered in early March; first sample on 6 March. Means based on five plants per replicate; **boldface** text indicates populations exceeded published treatment thresholds; pesticides were applied between weeks 4 and 5, and between weeks 7 and 8.

was conservatively chosen for incorporation into our analyses.

The net benefit of each treatment was calculated by subtracting the harvest value of the fruit from the untreated control from the total value of the harvest of fruit from each pesticide treatment (minus application costs). All returns were standardized on a per-hectare basis by scaling up yields from the research plots. Net benefit of the use of predaceous mites alone, or in combination with pesticides, was calculated in the same fashion.

Results and Discussion

Horticultural Information. In both seasons, the percentage of plants infested with *T. urticae* increased rapidly in the treatments without pesticides, so that ≈80% infestation or higher was maintained for at least half of the sample dates (Tables 1 and 2). The general decline observed in the late season in all treatments during both years is typical in Southern California and reflects a decline in the suitability of the strawberry plants (Oatman et al. 1982, Trumble 1985).

All chemicals or combinations of chemicals plus predaceous mites reduced *T. urticae* infestations as compared with untreated control plots or plots where *P. persimilis* was used alone (Tables 1 and 2). At the time of the first pesticide application in either season, we detected no significant difference in the percentage of plants infested with *T. urticae* (1988–1989: $F = 1.7$; df = 7; $P = 0.158$; 1990–1991: $F = 2.3$; df = 7; $P = 0.062$). Abamectin was superior at reducing the numbers of plants infested with *T. urticae* compared with other chemical treatments. In the 2 wk after the first application in 1988–1989, abamectin and abamectin plus *P. persimilis* had plant infestation levels averaging 23–27%, whereas infestations averaged 20–35% in the 5 wk after the second application. In contrast, infestations with fenbutatin-oxide and fenbutatin-oxide plus *P. persimilis* averaged 62–74% after the first application and 54–61% after the second application. Although hexythiazox and hexythiazox plus *P. persimilis* provided poor suppression after the first application (78–80% infested plants), the percentage of infested plants declined to 28–40% after the second application. The control treatment and the *P. persimilis*-only treatment averaged 100 and 80% infestation after the first application and 69 and 71% after the subsequent application, respectively.

Although the percentage of plants infested with *T. urticae* was higher in 1990–1991 than in the previous season, similar trends were observed. In the 3 wk after the first application, abamectin and abamectin plus *P. persimilis* had plant infestation levels averaging 53–65%, whereas the percentage plants infested averaged 9–22% for the 7 wk after the second application. All other treatments had 81–98% infested plants after the first application, with the same rank order as in 1988–1989. In the 7 wk after the second application, hexythiazox and hexythiazox plus *P. persimilis* both averaged ≈40% infested plants; fenbutatin oxide (64%) and fenbutatin oxide plus *P. persimilis* (44%) had somewhat higher percentages of plants infested. The control treatment and the *P. persimilis*-only treat-

Table 2. Seasonal trends (1990–1991) in percentage strawberry plants infested with twospotted spider mites

Treatment	% infestation during week[a]													
	1	2	3	4	5	6	7	8	9	10	11	12	13	1[illegible]
Control	**85**	**95**	**100**	**100**	**100**	**65**	**100**	**100**	**75**	**65**	60	60	10	[illegible]
Abamectin	**100**	30	60	55	70	0	10	15	30	35	25	40	0	[illegible]
Hexythiazox	**95**	**95**	**85**	65	**85**	25	35	50	45	55	50	20	20	1[illegible]
Fenbutatin-oxide	**100**	75	**100**	85	**95**	75	75	70	75	60	60	35	20	1[illegible]
P. persimilis only	**90**	**100**	**100**	85	**90**	**90**	**90**	**100**	40	45	60	50	10	
Abamectin + *P. persimilis*	**80**	65	75	60	55	0	5	0	30	10	10	10	0	
Hexythiazox + *P. persimilis*	**100**	**95**	**100**	75	**95**	35	**30**	45	20	55	50	35	10	1[illegible]
Fenbutatin-oxide + *P. persimilis*	**100**	**90**	**100**	70	**90**	35	55	50	70	50	50	15	15	

[a] Mites discovered in early March; first sample on 6 March. Means based on five plants per replicate; boldface text indicate populations exceeded published treatment thresholds; pesticide treatments were made between weeks 1 and 2, and betwee weeks 5 and 6.

ment averaged 75 and 70% of the plants infested, respectively, during this latter period.

Mean weekly weights of fruit were variable between years (Fig. 1). A brief period of cold weather resulted in blossom drop during the early 1990–1991 season, resulting in a substantial reduction in early season yield. However, the plants recovered to produce at higher levels during the second half of the season than were seen in 1988–1989. In general, treatment effects on yield were not evident during the first half of the season. During the last 4 to 7 wk, yields from the control and *P. persimilis*-only treatments were depressed compared with all other treatments (Fig. 1). This effect was particularly noticeable in 1990–1991, when late-season yields were higher and *T. urticae* populations developed sooner than in 1988–1989. The treatments of abamectin alone, abamectin plus *P. persimilis*, hexythiazox plus *P. persimilis*, and fenbutatin-oxide plus *P. persimilis* provided consistently high productivity.

Partial-Budget Economic Analyses. Although the late-season yields were higher in the 1990–1991 season, early fruit commanded higher prices and the total seasonal value of the fruit was greater in 1988–1989 (Table 3). In 1988–1989, the value of the fruit from the control treatment was over twice that in 1990–1991 (56.1% higher), caused, in part, by the early season cold period that caused blossom drop in 1990–1991. However, because the 1988–1989 harvest values from effective miticide treatments such as abamectin and abamectin plus *P. persimilis* were only 21% better than in 1990–1991 (rather than the 56.1% in the controls), *T. urticae* populations also contributed substantially to yield losses in 1990–1991. The possibility that increased yields might be partly because of physiological enhancement of strawberry productivity by abamectin application was eliminated by previous research (Trumble et al. 1988).

Most of the treatments provided an economically viable return for the costs invested (Table 3). Because spider mite damage is cumulative on strawberry plants (Sances et al. 1981), net benefits of *T. urticae* suppression were higher in 1990–1991 because of the early season buildup and higher population densities of pest mites. Although the release of *P. persimilis* alone provided a substantial net benefit in both years, the use of two applications of either fenbutatin-oxide or abamectin generated substantially higher net benefits for the money invested. Thus, from the grower's point of view, as long as the pesticides remain effective the chemical approach is more profitable than release of *P. persimilis* alone. However, this analysis does not include additional costs associated with the loss of effectiveness if pesticide resistance develops, or any possible increase in market value for pesticide-free fruit.

Use of abamectin was compatible with *P. persimilis*. In both years, the additive net benefits per hectare of abamectin alone and *P. persimilis* alone were essentially equal to the net benefit from the combination. This would be expected if the *T. urticae* suppression of the treatments were additive and not antagonistic or synergistic. The lack of negative interaction between these control strategies may be a result of the activity spectrum of abamectin. This chemical lasts only a short period of time on the leaf surface (Lasota & Dybas 1991), and contact with the active stages of *P. persimilis* would be minimized by releases made 4 d after treatment. In addition, this chemical does not kill the egg stage of *T. urticae* (Lasota & Dybas 1991); thus, an easily handled food source is preserved for the predaceous mites.

Use of fenbutatin-oxide was not consistently compatible with *P. persimilis*. In 1988–1989, the net benefit of the fenbutatin-oxide plus *P. persimilis* treatment was $2,222, >$4,000 less than the net benefits for the fenbutatin-oxide-only treatment added to the net benefits of the *P. persimilis* treatment. Thus, interactions between these control strategies appeared to be antagonistic. We suspect that this antagonistic interaction is caused by the contact toxicity of fenbutatin-oxide to *P. persimilis*. In 1990–1991, the discrepancy was not as dramatic, and the combination treatment produced a net benefit about $1,000 less than the additive net benefits of the individual treatments. However, despite the lack of additive benefits in 1990–1991, the use of the combination still provided an improved economic return over the use of either treatment alone. Additional research is needed to determine why such variability between years occurred for this combination.

Although the potential costs of hexythiazox are not available, the use of a fictitious cost (arbitrarily set between the cost of abamectin and fenbutatin-oxide) allows determination of compatibility with predaceous mites. Assuming the cost of pesticide and application were $350/ha, the following net benefits per hectare would have resulted in 1988–1989 and 1990–1991, respectively: hexythiazox alone = $5,074 and $13,362; hexythiazox plus *P. persimilis* = $6,028 and $12,989. Thus, in 1988–1989, the net benefit of the combination would have been about $1,000 less than the additive benefits of the two treatments separately. In 1990–1991, the net benefit of the combination was nearly $4,600 less than the additive benefits from the two treatments applied separately, and the interaction was strongly antagonistic.

The results of this study should be interpreted with the caveat that changes in the experimental design (e.g., frequency of application, numbers and timing of *P. persimilis* releases) will influence the economic returns for the different treatments. Nonetheless, because the experimental

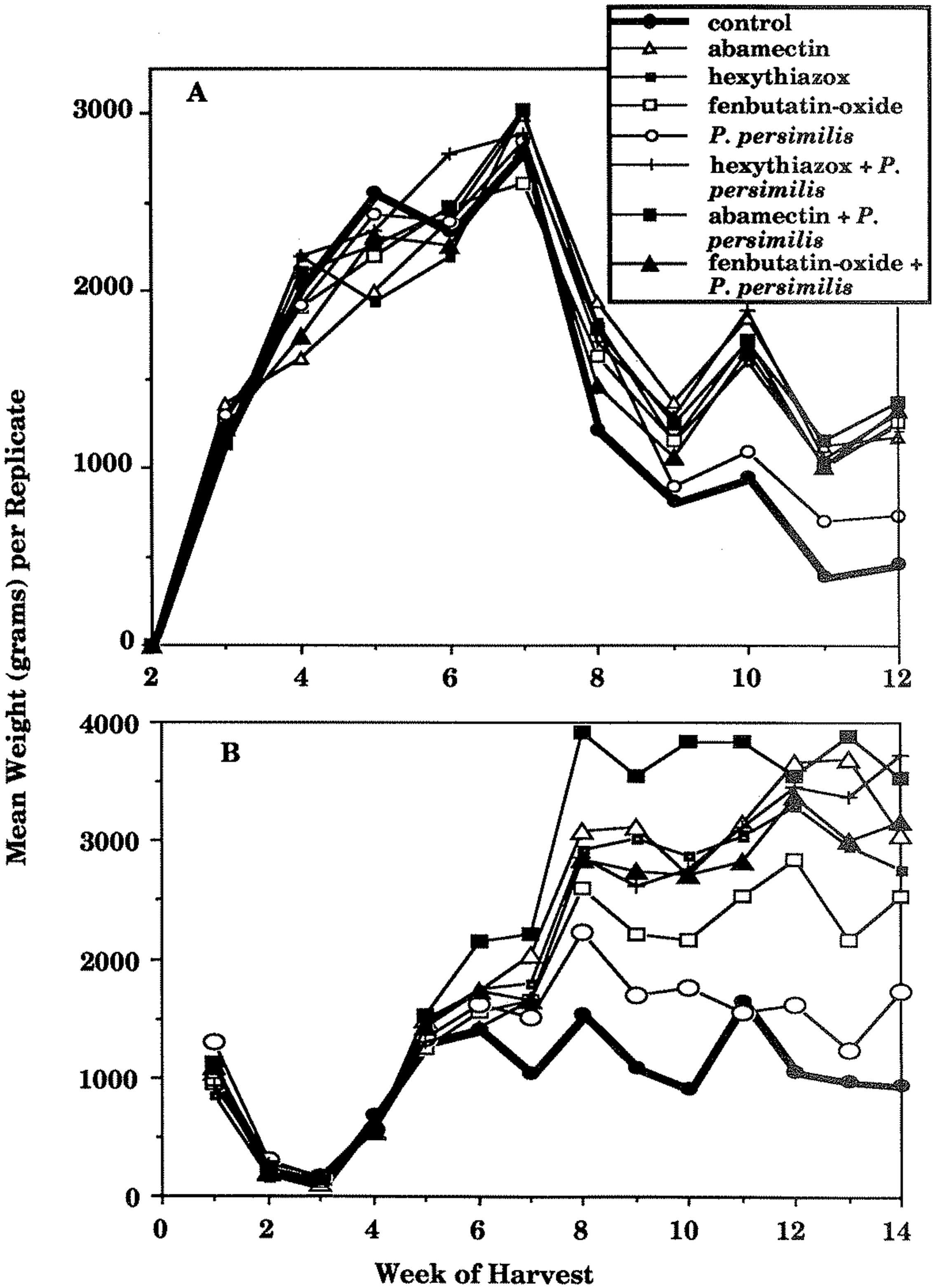

Fig. 1. Average weekly yields from each treatment. Rates and dates of pesticide applications and releases of *P. persimilis* are given in the *Materials and Methods* section. (A) 1988–1989. (B) 1990–1991.

Table 3. Economic analysis of various chemical, biological, and integrated strategies for controlling the twospotted spider mite in strawberries

Treatment	1988–1989			1990–1991		
	Value of harvest[a]	Cost of control[b]	Net benefit of treatment[c]	Value of harvest[a]	Cost of control[b]	Net benefit of treatment[c]
Control	$42,377	0	0	$18,605	0	0
Abamectin	$47,797	$ 358	$ 5,062	$37,755	$ 348	$15,802
Hexythiazox	$47,801	—[d]	$32,317	—[d]		
Fenbutatin-oxide	$47,107	$ 329	$ 4,401	$28,080	$ 329	$ 9,146
Control + *P. persimilis*	$45,333	$ 786	$ 2,170	$23,953	$1,033	$ 4,315
Abamectin + *P. persimilis*	$50,411	$1,144	$ 6,890	$39,692	$1,352	$19,705
Hexythiazox + *P. persimilis*	$49,541	—[d]	$32,975	—[d]		
Fenbutatin-oxide + *P. persimilis*	$45,669	$1,115	$ 2,177	$32,437	$1,362	$12,470

[a] Per hectare, calculated weekly using 1990 and 1991 FOB prices provided by the California Strawberry Research Advisory Board; all values rounded to nearest dollar.
[b] Cost estimates include application and control costs as described in the *Materials and Methods* section.
[c] Net benefit of treatment is (value at harvest − cost of pest control) − harvest value of untreated control.
[d] Pesticide cost data not available.

design generally followed the best available IPM information for Southern California, and the numbers of *P. persimilis* released were the same as recommended by the California Strawberry Research Advisory Board, the economic data provided insight into why most growers currently prefer pesticidal control rather than releases of *P. persimilis*. However, the data presented here indicate that the combination of abamectin and *P. persimilis* will consistently generate a better economic return on investment costs than the use of abamectin alone. Additional research designed to maximize the effectiveness of this strategy in IPM programs for strawberries is warranted.

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