Effects of Low Rates of Esfenvalerate on Pest and Beneficial Species of Apple in Comparison with a Standard Program

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ABSTRACT. A low rate (11.2 g·ha^{-1} a.i.) of esfenvalerate was tested as a single application in a seasonal program of pest control in apple orchards in comparison with the current standard program based on azinphosmethyl. The standard program provided good control of codling moth (<0.5% fruit injury) and leafrollers. Integrated control of tetranychid mites was consistent throughout the 3 years of the test. Esfenvalerate at the pink stage of apple bud development was tested to provide a rotational material for chlorpyrifos for control of leafrollers. This treatment provided suppression of leafrollers in the first year of the test and, in combination with the summer codling moth controls, maintained them at very low levels throughout the 3 years of the test. This treatment failed to provide suppression of *Campylomma verbasci* when substituted for chlorpyrifos in the prebloom period. Some suppression of first generation white apple leafhopper nymphs was achieved, and there was minimal impact on integrated mite control. Esfenvalerate at first codling moth cover was tested as a rotational material for azinphosmethyl for codling moth control. This treatment provided control of codling moth and leafrollers that was equivalent to the standard program. However, it tended to suppress parasitism of white apple leafhopper by a mymarid egg parasitoid, *Anagrus* sp. In addition, there was a serious perturbation of integrated mite control in this treatment during 1994, resulting in high mite populations (> 50 per leaf). Of the

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two timings of esfenvalerate tested, the pink timing appeared to minimize the detrimental impact of this material and may be of use in orchards with leafroller problems.

KEYWORDS. Integrated pest management, biological control, azinphosmethyl

The tree fruit industry is faced with a diminishing supply of agrichemicals for insect control. Materials have been lost either through the re-registration process or through resistance development on the part of pests. In addition, the high costs and strict regulations associated with the development of new products have severely restricted the appearance of new products on the market.

Codling moth, *Cydia pomonella* (L.), is the key pest of Washington apples. This pest has developed resistance to many of the insecticides used against it, including lead arsenate (Hough, 1928) and DDT (Barnes and Moffitt, 1963). More recently, organophosphate (OP)-resistant populations of codling moth have been reported from North Carolina (Bush et al., 1993), the Sacramento Delta region of California (Varela et al., 1993), and the Yakima Valley of Washington and Utah (Knight et al., 1994). Corroborative evidence for OP resistance comes from insecticide-use patterns. Throughout the 1980s, an average of two applications of OPs was needed to control codling moth. The number of azinphosmethyl applications (the primary material used for codling moth in Washington) has increased over time, with an average of 2.8, 3.3, and 3.3 applications per year in 1991, 1993, and 1995, respectively. In addition, the average rate per application went from 0.99 to 1.11 $kg \cdot ha^{-1}$ a.i. in 1991 and 1995 (Washington Agricultural Statistics Service, 1992; 1994; 1996). Codling moth is capable of destroying 70% of the crop in a single year, thus without controls marketable fruit could not be produced in our region. Although new classes of compounds such as the insect growth regulators (IGRs) have been shown to be effective against codling moth, it is difficult to predict when or if these products may be registered. Mating disruption also is a very promising tactic for codling moth control, but it usually is more expensive than conventional control (Williamson et al., 1992) and may not be feasible in all situations (Howell et al., 1992; Gut and Brunner, 1996).

In addition, relatively new pests, such as leafrollers [*Pandemis pyrusana* Kearfott and *Choristoneura rosaceana* (Harris)] and *Campylomma verbasci* (Meyer), have become significant problems in many orchards. Both cause direct fruit damage and have proven difficult to control. There is increasing evidence that leafrollers are resistant to some degree to the current selection of OP insecticides (J. F. Brunner, unpublished). Several studies which have examined a codling moth mating disruption system have noted a moderate to severe outbreak of leafrollers (Knight, 1995; Gut and Brunner, 1994). Faced with this scenario, research was begun on alternative programs with materials which have registrations on apples.

Pyrethroids, although registered, have not been used on Washington apples (Beers and Brunner, 1991; Washington Agricultural Statistics Service, 1992; 1994; 1996). When they originally appeared, their toxicity to predatory mites, especially *Typhlodromus occidentalis* (Nesbitt), made them less desirable candidates for control of direct pests. Applications of pyrethroids produced a flareup of phytophagous mites (Hoyt et al., 1978). At the time, tests both for efficacy and for natural enemy toxicity were done with full rates of the compounds available. In the intervening 15 years, pyrethroids have been used extensively on pears for control of pear psylla, thus exposing *T. occidentalis* populations in pear blocks. It is likely that some level of tolerance to these compounds has developed during that time. The close proximity of apple and pear orchards in the central growing regions of Washington provides a mechanism (gene flow) for higher levels of pyrethroid tolerance by *T. occidentalis* in apple blocks as well. Although bioassays indicated that fenvalerate, the predecessor of esfenvalerate, is still quite toxic to *T. occidentalis* (Babcock and Tanigoshi, 1988), recent field experience indicates that mite flareups do not occur with either the frequency or intensity following pyrethroid applications (E. H. Beers, unpublished).

Currently, faced with the choice between control of a key direct pest and incurring resurgence of secondary pests such as mites, pyrethroid use was re-explored. Low rates and specific timings were used in order to mitigate unwanted side effects. The specific objective of this study was to investigate the potential use of a registered pyrethroid, esfenvalerate (Asana XL 0.66 emulsifiable concentrate, DuPont, Wilmington, DE, USA), at low rates to control either leafrollers or codling

moth, and to determine the effects on secondary pests and natural enemies.

MATERIALS AND METHODS

Three treatment programs were: (1) a standard pest management program but without chlorpyrifos in the delayed-dormant period (oil only) but with esfenvalerate substituted at the pink stage of apple bud development; (2) a standard pest management program with esfenvalerate used at first codling moth cover (250 degree days after biofix); and (3) a standard pest management program where chlorpyrifos (Lorsban 4E, DowElanco, Indianapolis, IN, USA) plus horticultural mineral oil was used in the delayed-dormant period primarily for leafroller control, and azinphosmethyl (Guthion 50WP, Bayer, Kansas City, MO, USA) was used in the summer for codling moth control (Table 1).

The rationale behind the esfenvalerate/pink treatment was to minimize contact with predatory mites and provide leafroller control of the overwintering generation. Chlorpyrifos is currently the predominant conventional insecticide that is used pre-bloom for leafroller control. It also was assumed that some degree of control of *C. verbasci* and white apple leafhopper would be achieved at this timing. Post-bloom codling moth control was achieved with the current industry standard OP, azinphosmethyl, at a rate of 1.12 $kg \cdot ha^{-1}$ a.i. In this program, no chlorpyrifos was included in the delayed-dormant treatment. The esfenvalerate/first-cover treatment was designed to provide an in-season rotation of alternative chemistry for codling moth control; the remaining two or three cover sprays were azinphosmethyl. The first cover timing occurs toward the end of the first generation of white apple leafhopper and could suppress nymphal populations. The azinphosmethyl/standard treatment was horticultural mineral oil plus chlorpyrifos at delayed dormant and three applications of azinphosmethyl at first, second, and third cover (1C, 2C, and 3C, respectively). In 1995, a fourth cover spray was applied to all treatments.

The experiment was conducted in a 2.4-ha block of 16-year-old 'Oregon Spur Delicious' and 'Redspur Delicious' with 'Golden Delicious' pollenizers at the WSU Columbia View orchard near Orondo, WA. Trees were planted at a spacing of 3 m × 5.5 m, were 2.5-3 m in height and irrigated with impact sprinklers. In 1993, irrigation was

TABLE 1. Seasonal programs for major pests of apples, 1993-95.

Treatment	Schedule	Rationale
Esfenvalerate/ pink[z]	DD: Horticultural mineral oil (1.5% vol:vol) Pink: esfenvalerate XL 11.2 g·ha^{-1} a.i. 1C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i. 2C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i. 3C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i.	Oil for European red mite eggs and scale; esfenvalerate at pink for leafrollers, *Campylomma verbasci*, leafhoppers: minimize effects of esfenvalerate on predatory mites; standard three covers for codling moth.
Esfenvalerate/1st cover[z]	DD: Horticultural mineral oil (1.5% vol:vol) + chlorpyrifos 4E 2.2 kg·ha^{-1} a.i. Pink: (nothing) 1C: esfenvalerate XL 11.2 g·ha^{-1} a.i. 2C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i. 3C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i.	Oil plus chlorpyrifos for mites, aphids, scale, leafrollers, *C. verbasci*; 1C esfenvalerate for codling moth, 2C, 3C for codling moth.
Azinphosmethyl/ standard[z]	DD: Horticultural mineral oil (1.5% vol:vol) + chlorpyrifos 4E 2.2 kg·ha^{-1} a.i. Pink: (nothing) 1C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i. 2C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i. 3C: azinphosmethyl 50W 1.12 kg·ha^{-1} a.i.	Oil plus chlorpyrifos for mites, aphids, scale, leafrollers, *C. verbasci*; 1C, 2C, 3C for codling moth.

[z]In 1995, a 4th cover (4C) of azinphosmethyl 50W 1.12 kg·ha^{-1} a.i. was applied.

with overtree sprinklers, and in 1994-95, with undertree sprinklers. Experimental plots (replicates) in the block ranged from 12-19 trees by 9-10 rows, or 0.2-0.3 ha. The tagged trees were in the interior of the plot spaced over 5 rows, with 3-6 trees between the outermost sample tree and the plot border. Treatments were applied with an airblast sprayer calibrated to deliver 3741 L·ha^{-1}.

Five trees were selected and tagged in each plot (same trees each year), and samples were taken from these trees unless specified otherwise. White apple leafhopper (*Typhlocyba pomaria* McAtee) overwin-

tering eggs were sampled for density and parasitism by a mymarid wasp, *Anagrus* sp., by carefully removing the bark which covered the egg bump with a scalpel. The developing wasp was clearly visible inside the egg by the tight-cluster stage of bud development, whereas normal eggs were opaque white leafhopper embryos (Beers and Elsner, 1988). Ten 10-cm shoot sections per sample tree were examined, and all eggs encountered were classed as parasitized, live, dead (for reasons other than parasitism), or unknown. White apple leafhopper nymphs were assessed three times during the first generation and twice during the second generation by counting all pre-adult stages on 20 leaves per tree. Motile stages of tetranychid mites, eggs and motile stages of predatory mites, and motile stages of eriophyid mites were assessed at intervals throughout the season. Twenty leaves were taken from each sample tree, and the composite sample of 100 leaves was brushed and counted under a stereoscopic microscope. First-generation eggs of the western tentiform leafminer (*Phyllonorycter elmaella* Doganlar & Mutuura) were sampled by examining the lower surface of 10 leaves per sample tree in early April. The 100 leaves per replicate gathered for the mite sample were examined for western tentiform leafminer mines. Counts were made *in situ*. *C. verbasci* nymphs and adult populations were assessed during the first generation by tapping one branch on each of 10 randomly selected trees throughout the plot. Fruit damage assessments were made in June (after June drop) and before harvest by inspecting 40 fruit per tree, 10 trees per replicate. Aphid populations were assessed by counting the number of infested leaves on 10 terminals per sample tree (50 per replicate). All aphid natural enemies on the terminal were recorded during these counts, including lady beetle adults and larvae (Coleoptera: Coccinellidae); *C. verbasci* nymphs and adults; eggs, larvae and adult of lacewings (Neuroptera: Chrysopidae); *Deraeocoris brevis piceatus* (Knight) nymphs (Hemiptera: Miridae); parasitized aphid mummies (probably *Aphidius* spp., Hymenoptera: Aphidiidae); syrphid eggs and larvae (Diptera: Syrphidae); and cecidomyiid larvae (Diptera: Cecidomyiidae). Fruit damage by aphids was assessed by picking a 20-kg sample per tagged tree just before harvest. The fruit were passed over an Aweta grading line, which washed and brushed the fruits. Fruit damage (honeydew and sooty mold) was assessed by visual inspection. Codling moth fruit injury was sampled at the end of the first (late June to early July) and second (mid-September) generation by examining 50 half-fruit per

tree from 20 trees per replicate (1500 fruit per treatment). Adult males were trapped using Pherocon 1CP traps (Trécé, Salinas, CA, USA) (one trap per plot). Lures were changed every 3 weeks during the first generation and every 2 weeks during the second generation. Leafroller larval densities were determined by samples of fruit buds (pre-bloom period) or terminals (post-bloom period). In the first year, fruit buds (10 buds on 15 trees per replicate) were sampled at the half-inch-green (HIG) stage and at the pink stage (10 buds on 15 trees per replicate) of fruit bud development. Buds collected at HIG were returned to the laboratory and examined under magnification for the presence of larvae. At pink, buds were examined in the field without magnification and the presence of live larvae recorded. Following the first year, only the pink sample was made. The post-bloom larval sample was made following petal fall and again in mid-summer by visual examination of terminals (10 terminals on 20 trees per replicate) for the presence of live larvae.

The experimental design was randomized complete block with three replications. The experimental unit was a composite count from all sample trees within a plot, with means reported per tree, terminal, bud, leaf, or cm of shoot, or percentage fruit injury. Cumulative mite days (CMDs) were calculated as:

$$CMD = \Sigma 0.5(P_a + P_b)D_{a\text{-}b}$$

where P_a is the population density (mean mites/leaf at time a), P_b is the population density at time b, and $D_{a\text{-}b}$ is the number of days between time a and time b. Data were analyzed using analysis of variance (PROC GLM, Statistical Analysis System Software, SAS Institute, Cary, NC, USA). Population data were tested for unequal variances using Levene's test. Data with unequal variances were transformed [$\log(y + 0.5)$] for analysis. Means were separated using either the Waller-Duncan k-ratio t-test or Fisher's protected LSD.

RESULTS AND DISCUSSION

Codling moth. Carryover pressure from 1992 was very high, resulting in relatively high levels of damage in 1993 (Table 2). The first cover was accidentally omitted from the azinphosmethyl/standard and esfenvalerate/pink treatments in 1993, which was assumed to be the

TABLE 2. Codling moth injury over 3 years in esfenvalerate vs. azinphosmethyl treatments, Orondo, WA.[z]

Year	Treatment	First generation	Harvest
1993	esfenvalerate/pink	2.2 b	2.1 a
	esfenvalerate/1st cover	0.2 c	1.1 b
	azinphosmethyl/standard	5.0 a	4.1 a
1994	esfenvalerate/pink	0.0 a	0.0 a
	esfenvaierate/1st cover	0.0 a	0.1 a
	azinphosmethyl/standard	0.0 a	0.1 a
1995	esfenvalerate/pink	0.1 a	0.1 a
	esfenvalerate/1st cover	0.3 a	0.0 a
	azinphosmethyl/standard	0.1 a	0.0 a

[z]Mean separation within column and year by Fisher's Protected LSD ($P = 0.05$).

cause for this high level of damage. Damage was significantly lower in the esfenvalerate/first-cover treatment, the only treatment which received any insecticide at first cover in this season, confirming previous trials showing low rates of esfenvalerate to be effective against codling moth (Brunner and Smith, 1993c). Damage was negligible in 1994 and 1995 in all treatments.

Mites. Tetranychid mite populations were low during 1993, with peak populations of < 1 mite/leaf (Table 3). There was suppression of predatory mites [*T. occidentalis* and *Zetzellia mali* (Ewing)] in the esfenvalerate/first-cover treatment, but the esfenvalerate/pink population mean was not different from the azinphosmethyl/standard treatment. Populations of *Z. mali* were unusually high in 1993, with ca. 69% (seasonal average) of the predatory mite population composed of this species. There was a outbreak of tetranychid mites (primarily twospotted spider mites) in the esfenvalerate/first-cover treatment in 1994, with a peak population of more than 50 mites per leaf. Tetranychid mites did not exceed three mites per leaf in the esfenvalerate/pink treatment and did not exceed 0.3 per leaf in the azinphosmethyl/standard treatment. Predatory mites, especially *T. occidentalis* (86% of the predatory mite population in 1994), built up in all plots in response to

TABLE 3. Phytophagous and predatory mite populations over 3 years in esfenvalerate vs. azinphosmethyl treatments, Orondo, WA.[z]

		Peak mites/leaf		Seasonal cumulative mite days	
Year	Treatment	Tetranychids[y]	Predators[x]	Tetranychids	Predators
1993	esfenvalerate/pink	0.0 a	0.6 ab	1.8 a	24.1 ab
	esfenvalerate/1st cover	0.6 a	0.4 b	7.1 a	8.2 b
	azinphosmethyl/standard	0.0 a	1.1 a	0.4 a	56.4 a
1994	esfenvalerate/pink	3.0 b	0.9 a	72.1 b	27.5 a
	esfenvalerate/1st cover	53.7 a	1.9 a	1504.5 a	24.1 a
	azinphosmethyl/standard	0.2 b	0.5 a	7.0 b	36.0 a
1995	esfenvalerate/pink	0.4 b	0.7 ab	34.9 a	11.5 b
	esfenvalerate/1st cover	1.8 a	0.3 b	38.6 a	7.6 b
	azinphosmethyl/standard	0.0 b	0.9 a	1.8 b	35.0 a

[z]Mean separation within column and year by Waller-Duncan *k*-ratio *t*-test, *k*-ratio = 100.
[y]Peak tetranychid mites/leaf: 2 Sept. 1993; 2 Aug. 1994; 8 Sept. 1995.
[x]Peak predatory mites/leaf: 2 Sept. 1993, 9 Aug. 1994; 8 Sept. 1995.

the mite populations. This buildup occurred by 7 July in the azinphosmethyl/standard treatment but was delayed until mid-August in the esfenvalerate/first-cover treatment (data not shown), after substantial foliar damage had occurred. There was a substantial level of predators by late July in the esfenvalerate/pink treatment, which prevented mite populations from attaining damaging levels. However, there were no significant differences in predatory mite populations among treatments either in terms of peak populations or cumulative mite days. A late-season *Stethorus picipes* Casey population also aided biological mite control in both pest management programs that included esfenvalerate treatments (data not shown). Mite populations in 1995 were relatively low, although the peak mite population in the esfenvalerate/first-cover treatment was significantly higher than the other two treatments, and the seasonal cumulative mite days for both of the treatments containing esfenvalerate were higher than the azinphosmethyl

standard. In general, predatory mites (67% *T. occidentalis* in 1995) effected biological control in time to prevent damage. Cumulative mite days for predatory mites were significantly lower in the two esfenvalerate treatments than in the azinphosmethyl/standard treatment.

C. verbasci. Populations were low to moderate throughout the study, but nymph populations were significantly higher in the esfenvalerate/pink treatment in comparison to the azinphosmethyl/standard treatment (Table 4). The esfenvalerate/pink treatment is the only one in which chlorpyrifos was omitted in the delayed-dormant application. Esfenvalerate has not proven effective against *C. verbasci* in other trials (Reding and Beers, 1993; 1994; 1995), whereas chlorpyrifos has shown excellent activity in several tests (Reding and Beers, 1995). It is probable that the delayed dormant application of oil plus chlorpyrifos was responsible for *C. verbasci* suppression in the other treatments. Fruit damage was negligible in all 3 years of the test.

Pandemis leafroller. The only leafroller species identified from the test orchard was *P. pyrusana.* Leafroller populations were initially

TABLE 4. *Campylomma verbasci* nymphal populations and resulting fruit injury over 3 years in esfenvalerate vs. azinphosmethyl treatments, Orondo, WA.[z]

Year	Treatment	Peak numbers of nymphs/tap[y]	Fruit injury (%)
1993	esfenvalerate/pink	0.4 a	0.0 a
	esfenvalerate/1st cover	0.0 ab	0.0 a
	azinphosmethyl/standard	0.0 b	0.0 a
1994	esfenvalerate/pink	5.1 a	0.0 a
	esfenvalerate/1st cover	0.0 b	0.0 a
	azinphosmethyl/standard	0.0 b	0.0 a
1995	esfenvalerate/pink	3.4 a	0.0 a
	esfenvalerate/1st cover	0.0 b	0.0 a
	azinphosmethyl/standard	0.1 b	0.0 a

[z]Mean separation within column and year by Waller-Duncan *k*-ratio *t*-test, *k*-ratio = 100.
[y]Peak counts occurred on 20 May 1993, 21 Apr. 1994, and 18 May 1995, respectively.

high, a carryover from the previous studies in the test orchard, i.e., codling moth mating disruption tests. There were no differences in plots assigned treatments prior to any insecticide applications (Table 5). Following the HIG chlorpyrifos plus oil application, leafroller densities were lower in the azinphosmethyl/standard and esfenvalerate/first-cover treatments. The oil applied in the esfenvalerate/pink treatment had no effect on leafroller densities. Following the esfenvalerate application at pink leafroller densities were the same in all treatments (Table 5). In 1994 and 1995, leafroller densities were very low and there were no differences among treatments. The results from 1993 confirm results from other trials showing low rates of esfenvalerate being an effective control of pandemis leafroller (Brunner and Smith, 1993a; 1993b). Once the initial high population of leafrollers was reduced, all treatment programs provided adequate suppression of this pest.

Aphids. Populations did not build up to any extent in 1993-94; only moderate populations occurred in 1995 (Table 6). Predator popula-

TABLE 5. Leafroller larvae over 3 years in esfenvalerate vs. azinphosmethyl treatments, Orondo, WA.[z,y]

		Larvae/spur		Larvae/shoot	
Year	Treatment	Half-inch green	Pink	Postbloom	Summer
1993	esfenvalerate/pink	0.1 a	0.05 b	0.0 a	0.0 a
	esfenvalerate/1st cover	0.1 a	0.00 a	0.0 a	0.0 a
	azinphosmethyl/standard	0.1 a	0.00 a	0.0 a	0.0 a
1994	esfenvalerate/pink	---	0.00 a	0.0 a	---
	esfenvalerate/1st cover	---	0.00 a	0.0 a	---
	azinphosmethyl/standard	---	0.70 a	0.0 a	---
1995	esfenvalerate/pink	---	0.00 a	0.0 a	0.0 a
	esfenvalerate/1st cover	---	0.00 a	0.0 a	0.0 a
	azinphosmethyl/standard	---	0.00 a	0.0 a	0.0 a

[z]Mean separation within column and year by Fisher's Protected LSD ($P = 0.05$).
[y]Samples dates: 19 Apr. (HIG; half-inch green tip), 5 May (pink), 20 May (postbloom), 5 Aug. (summer) 1993; 29 March (pink) and 10 May (postbloom), 1994; 14 Apr. (pink), 18 May (postbloom), 25 July (summer) 1995.

TABLE 6. Aphid and natural enemy populations over 3 years in esfenvalerate vs. azinphosmethyl treatments, Orondo, WA.[z]

Year	Treatment	Peak number of aphid-infested leaves/shoot[y]	Peak total number of predators/shoot[x]
1993	esfenvalerate/pink	0.5 a	0.3 a
	esfenvalerate/1st cover	0.7 a	0.3 a
	azinphosmethyl/standard	0.7 a	0.1 b
1994	esfenvalerate/pink	1.1 a	0.2 a
	esfenvalerate/1st cover	0.2 a	0.3 a
	azinphosmethyl/standard	1.2 a	0.1 a
1995	esfenvalerate/pink	1.7 a	0.6 a
	esfenvalerate/1st cover	2.1 a	0.7 a
	azinphosmethyl/standard	2.5 a	0.4 a

[z]Mean separation within column and year by Waller-Duncan *k*-ratio *t*-test, *k*-ratio = 100.
[y]Peak aphid count: 12 July 1993; 24 Aug. 1994; 2 Aug. 1995.
[x]Peak predator count: 12 July 1993; 24 Aug. 1994; 26 July 1995.

tions also were low, due at least in part to lack of prey. There were no differences among peak aphid populations in treatments in any of the 3 years of the test. There were fewer predators (peak population) in the azinphosmethyl/standard treatment than either of the two esfenvalerate treatments in 1993, but no differences occurred in 1994 or 1995.

White apple leafhopper. Past tests on first generation white apple leafhopper nymphs have shown that azinphosmethyl has only a moderate level of suppression when applied at the optimum timing (first appearance of the fourth instar nymphs, which occurs shortly after petal fall) (Beers and Elsner, 1987). The esfenvalerate/pink treatment gave some suppression of first generation leafhoppers in comparison to the azinphosmethyl/standard treatment in 1993 and 1995 (Table 7). Because adults are quite mobile, there is likely a considerable amount of mixing between the generations. The second generation of leafhopper nymphs was exposed to the same insecticide program in all treatments. It is difficult, therefore, to explain the significantly higher level of nymphs in the esfenvalerate/pink treatment during 1993 second

TABLE 7. White apple leafhopper overwintering eggs and nymphal populations over 3 years in esfenvalerate vs. azinphosmethyl treatments, Orondo, WA.[z]

		Peak number of nymphs/leaf		Overwintering eggs[y]		
Year	Treatment	First gen.	Second gen.	Total/ 10 cm	Live/ 10 cm	Percent parasitized
1993	esfenvalerate/pink	0.6 b	10.5 a	24.1 a	8.1 a	66.3 a
	esfenvalerate/1st cover	1.5 a	2.9 b	31.1 a	21.8 a	25.6 b
	azinphosmethyl/standard	2.0 a	3.1 b	31.4 a	15.1 a	50.1 ab
1994	esfenvalerate/pink	0.6 a	0.9 ab	9.1 a	7.1 a	12.8 a
	esfenvalerate/1st cover	0.7 a	0.1 b	3.3 a	2.9 a	5.4 a
	azinphosmethyl/standard	0.8 a	1.4 a	6.6 a	5.1 a	15.6 a
1995	esfenvalerate/pink	0.6 b	6.4 a	0.4 a	0.2 a	60.1 a
	esfenvalerate/1st cover	0.2 c	1.9 b	0.9 a	0.4 a	45.5 a
	azinphosmethyl/standard	0.8 a	6.6 a	0.6 a	0.2 a	68.1 a

[z]Mean separation within column and year by Waller-Duncan *k*-ratio *t*-test, *k*-ratio = 100.
[y]Overwintering egg assessments were taken the following spring.
[x]Peak 1st generation: 27 May 1993; 10 May 1994; 22 June, 1995.
[w]Peak 2nd generation: 27 Aug. 1993; 15 Aug., 1994; 17 Aug., 1995.

generation. This treatment was not different than the standard program during the second generation during 1994-95. The esfenvalerate/first-cover treatment suppressed first generation nymphs in comparison to the standard program only during 1995. In 1993 and 1995, the peak population occurred after the first cover had been applied and thus could have been affected by it. Suppression by the first cover esfenvalerate carried over to the second generation as a lower density of nymphs in 1995.

A pre-treatment count of overwintering leafhopper eggs and parasitism was taken pre-bloom in 1993 (reflects 1992 conditions). There were no differences among the treatments, and the level of parasitism averaged about 59% (data not shown). The number of eggs per 10 cm-shoot section was high following the 1993 season, apparently due to the high second generation nymph populations the previous fall. Rates of parasitism were also high in comparison to the 1994 season. The esfenvalerate/first-cover treatment suppressed parasitism (in com-

parison to esfenvalerate/pink) in 1993 (Table 7), and while the same trend appeared in 1994 and 1995, there were no significant differences among the treatments.

SUMMARY

The azinphosmethyl/standard program provided good control of codling moth. No problems with this insect had been experienced in the past in this orchard, thus the three-to four-cover program was adequate. Because of the application of chlorpyrifos at delayed dormant, good suppression of *C. verbasci* nymphs was observed. Where population pressure is moderate, no additional treatments for this insect would be needed. Leafroller populations were controlled by the delayed dormant chlorpyrifos treatment in the first year and this, plus suppression by other summer insecticides, maintained leafrollers at very low levels thereafter. Leafrollers in some Washington apple orchards cannot be controlled with this program, and additional controls, e.g., treatments of *Bacillus thuringiensis* or encapsulated methyl parathion, are necessary (Brunner, 1996). While little suppression of white apple leafhopper is provided, a high rate of parasitism can occur given a high host population. The strong point of the standard program is stable integrated mite control. Predatory mite populations generally were highest in this treatment, with correspondingly low populations of phytophagous tetranychid mites. This has been a general observation in Washington apple orchards using this type of program.

The esfenvalerate/pink treatment was shown to work as well as the chlorpyrifos plus oil as a delayed-dormant treatment in the azinphosmethyl/standard for leafroller control. However, several negative side effects also were evaluated. One weakness was the lack of suppression of *C. verbasci.* In orchards where leafrollers are a major problem and *C. verbasci* is at low levels, an application of esfenvalerate at pink may be an acceptable trade-off. This timing of esfenvalerate appeared to minimize the impact on predatory mites, and although a low level of phytophagous mites occurred in 1994-95 (less than four per leaf), there were sufficient numbers of predators to effect biological control. Organophosphate resistance and cross-resistance to other classes of insecticides in leafrollers has not been well documented in Washington, so it is possible that esfenvalerate may be useful in orchards experiencing severe leafroller problems. Because leafroller popula-

tions are intensifying in many areas of Washington state (Brunner, 1996), this strategy may merit further investigation.

Esfenvalerate timed for first cover achieved the desired objective, i.e., control of codling moth. However, there appear to be several drawbacks to the use of esfenvalerate this late in the season. First, esfenvalerate at this timing appeared to give the greatest suppression of parasitism of overwintering white apple leafhopper eggs. More importantly, however, there was a severe perturbation of biological mite control. While this occurred only one year out of three, it would be best to avoid this timing if possible. Since this experiment was begun, a new study (J. E. Dunley and S. C. Welter, unpublished data) showed correlated cross-resistance between azinphosmethyl and esfenvalerate in codling moth. Thus, esfenvalerate or other synthetic pyrethroids might not be suitable candidates for use as rotational products in an azinphosmethyl-resistance management program.

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