Impact of Selective Use of the Synthetic Pyrethroid Fenvalerate on Apple Pests and Natural Enemies in Large-orchard Trials

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ABSTRACT The synthetic pyrethroid, fenvalerate, when used throughout the season (112 g [AI]/ha) in a commercial apple orchard, provided excellent pest control compared to a standard insecticide schedule, but caused outbreaks of the European red mite, *Panonychus ulmi* (Koch). Populations of the mite predator, *Stethorus punctum* (LeConte), never became established in the fenvalerate block, but were numerous and effectively controlled mites in the standard block. Insecticide and acaricide costs were higher for the fenvalerate program, but the reduction in damage due to the tufted apple budmoth, *Platynota idaeusalis* (Walker), over the standard program resulted in a substantial net gain of ca. $395/ha under heavy pest pressure. Late-season sprays of fenvalerate at reduced dosages (56 and 28 g [AI]/ha) also caused a resurgence of mites, higher mite populations occurring in the block sprayed with the higher dosage. Established predator populations were decimated subsequent to the fenvalerate sprays at either dosage. The total costs of the pesticide programs were about equal, but the slightly better control with the fenvalerate program resulted in a net gain of ca. $32/ha. Short- and long-term ramifications of fenvalerate use in an integrated pest management framework are discussed.

THE SYNTHETIC pyrethroids (SP's) are currently being registered for use on apples, and their high activity at extremely low doses makes them very attractive alternatives for control of key pests. There have been predictions (Croft and Hoyt 1978) and incidences in experimental work (Hoyt et al. 1978, Zwick and Fields 1978, Hall 1979, Hoy et al. 1979, AliNiazee and Cranham 1980, Bower and Kaldor 1980, Hull et al. 1982, Hull and Starner 1983) where use of SP's against a key pest species has caused outbreaks of phytophagous mites, apparently through destruction of natural enemies or sublethal effects on behavior. This research has motivated some fruit entomologists to tailor their pest management recommendations to avoid disruption of predator/prey relationships where they play an important role in an integrated pest management (IPM) system (Hull et al. 1982, Anonymous 1983).

The potential for resistance development also has figured prominently in the deliberations on pyrethroid use (Croft and Hoyt 1978). Not only may injudicious use result in loss of effectiveness against key pests, but control directed at resulting mite outbreaks may hasten the development of resistance to acaricides. The ability to control mites is historically a precarious one, as mites have a history of developing resistance to newly introduced compounds that were initially acaricidal (Croft and Bode 1983). To initiate acceptable usage patterns of the SP's in the agricultural community, it is necessary to demonstrate the short-term hazards, e.g., mite outbreaks and attendant increases in acaricide costs; and point out possible long-term costs, especially those cases where loss of effectiveness of an acaricide could make future mite outbreaks more expensive, or even unamenable to chemical control.

Laboratory assays and small replicated field plots are useful indicators of effectiveness, selectivity, and disruption potential of SP's, but are not always directly applicable to commercial situations. In deciduous tree fruit research, the difference in application method (dilute sprays applied with a handgun to all sides of the trees versus concentrated airblast alternate-row middle applications) can make a substantial difference in spray coverage and apparent effectiveness of a chemical (Hull and Beers, in press). Alternate-row middle applications may leave refuges which allow substantial survival of natural enemies (Asquith and Hull 1979). Concentrate sprays reduce run-off of chemicals to the ground cover where some natural enemies hibernate (Croft 1975). Pest populations in research plots may be deliberately cultivated to provide reliable test conditions every year, and chemicals and doses that appear marginal under these conditions may give adequate protection in commercial orchards (Bower and Kaldor 1980).

This study was initiated to demonstrate the impact of season-long and late-season use of a synthetic pyrethroid (fenvalerate) on pests and natural enemies in a commercial Pennsylvania apple orchard where IPM is normally practiced, and to evaluate short-term costs involved in these strategies.

Materials and Methods

The experiments were conducted in two adjacent blocks of a commercial apple orchard near Arendtsville, Pa. Each block was ca. 5.2 ha and they were 190 m apart. Both blocks contained the cultivars Golden Delicious and York Imperial; Block 2 also contained two rows of Jonathan. Each block was bordered by woods on three sides. The trees were all pruned to a height of ca. 4.6 m.

Sprays were applied using the alternate-row middle technique (Lewis and Hickey 1964) with a Myers airblast sprayer calibrated to deliver 468 liters/ha at 4 km/h. In 1980 both blocks were identically treated with pesticides until petal fall. At this point, Block 1 was treated with fenvalerate at 112 g (AI)/ha at 7 to 12-day intervals (Fig. 1). Block 2 (standard block) was treated with commonly recommended insecticides (azinphosmethyl, methomyl, microencapsulated methyl parathion, dimethoate, and phosphamidon) in various combinations (Pennsylvania State University 1984). Choice of insecticides for Block 2 was based on presence of pests at various times of the season, and was made by a private consultant. Both blocks always were treated on the same day. Acaricide applications were made when conditions warranted, with the number of mites per leaf, predator/prey ratio, and amount of bronzing (leaf damage) taken into consideration.

Treatment effects on pests and natural enemies were evaluated on the cv. York Imperial. The apple aphid (AA), *Aphis pomi* DeGeer, was sampled by counting the number of infested (one or more live aphids) leaves on 20 randomly selected shoots around the periphery of eight trees per block. Populations of the white apple leafhopper (WALH), *Typhlocyba pomaria* McAtee, were determined by counting the number of nymphs per 25 leaves per tree. Populations of the European red mite (ERM), *Panonychus ulmi* (Koch), were sampled at 1- to 2-week intervals by randomly selecting 20 leaves per tree at heights of 1.5 to 2.0 m around the inner periphery of each tree and counting the mites. Mites were removed from the leaves with a mite-brushing machine in the laboratory and counted with a stereoscopic microscope. *Stethorus punctum* (LeConte) adults and larvae were counted by making a 3-min observation while walking slowly around the periphery of each tree, a modification of the method described by Colburn and Asquith (1971). Immediately before harvest, 100 apples were picked from each of 10 trees per block and rated for damage caused by all fruit-feeding insects. However, damage caused by the tufted apple budmoth (TABM), *Platynota idaeusalis* (Walker), was essentially the only type found, so results for other insects are not presented. After harvest, counts of overwintering ERM eggs were made in each block. Eight small twigs were randomly collected from each of eight trees per block. The total number of eggs 12.7 mm on each side of a node, and the corresponding surface area, were estimated.

In 1981, no fenvalerate treatments were applied until the end of July, and both blocks were identically treated with standard insecticides and fungicides before this date. The fenvalerate block received two alternate-row middle acaricide sprays in early July because of more severe mite pressure. In late July, Block 1 was divided into two 2.6-ha sections. Sections 1 and 2 were treated with reduced doses of fenvalerate (28 and 56 g [AI]/ha, respectively) in four alternate-row middle applications made from late July to late August. Block 2 was treated with standard organophosphorus and carbamate insecticides all season as described for 1980. Acaricide applications also were based on the same criteria as in 1980.

Sampling methods for pests, *S. punctum*, and overwintering ERM egg populations were the same as described for 1980, except only four trees each in Sections 1 and 2 (Block 1) were monitored compared to eight trees in Block 2. WALH and AA were not evaluated. Also, 105 apples per tree on eight trees per section and block were evaluated for fruit injury, and injury was ascribed to first- and second-brood TABM.

Results

Fenvalerate (112 g [AI]/ha) applied season-long gave equivalent or better control of the two homopteran pests than did the standard spray program in 1980 (Table 1). TABM control was better in the fenvalerate block, ca. 1% injured apples versus 13.3% in the standard. In 1981, both fenvalerate plots had less total TABM damage than did the standard block. However, only comparisons for Brood II were valid in 1981 since this was the brood primarily affected by the late-season fenvalerate applications, and TABM damage was similar to the standard spray program for this brood. Since control measures for Brood I were identical, the greater damage in the standard block could be due to the relatively poor control provided by the standard chemicals the previous season. Pest pressure was lower overall in 1981, and more injury could be attributed to the first brood of TABM.

Season-long use of fenvalerate in 1980 completely suppressed *S. punctum* populations (Fig. 1A), and allowed mite populations to cause moderate foliar damage (ca. 754 mite-days, where one mite-day is defined as one mite feeding for 1 day). Six alternate-row middle applications of an acaricide were necessary to contain the mites, and two of these were applied late in the season (late Aug. and early Sept.). Late-season resurgences of mite populations have become relatively rare in Pennsylvania, because of the efficiency of *S. punctum* and the low toxicity of acaricides to this natural enemy. A typical predator/prey relationship occurred in the standard block, with mite buildup

Table 1. Pest numbers, TABM apple injury, and ERM overwintering eggs in seasonal programs of either fenvalerate or standard organophosphorus and carbamate insecticides

Program	Dose[a] total kg (AI)/ha (g [AI]/ha per application)	WALH per 25 leaves	No. AA-infested leaves per terminal	TABM injuries per 100 apples			ERM eggs per cm^2
				Brood I	Brood II	Brood I + II	
			1980				
Standard	4.17	3.2	1.6	—	—	13.3	0.3
Fenvalerate 2.4EC	0.73 (112)	1.3	0.2	—	—	1.0	4.4
			1981				
Standard	1.80	—	—	3.4	0.8	4.2	2.9
Fenvalerate 2.4EC	0.13 (56)	—	—	0.4	0.3	0.7	26.4
Fenvalerate 2.4EC	0.06 (28)	—	—	0.7	0.1	0.8	13.0

[a] Grams of active ingredient per ha per application and total kg of active ingredient per ha during the periods of 16 May to 28 Aug. in 1980 (13 applications) and 27 July to 4 Sept. in 1981 (4 applications). See text for insecticides in standard block.

closely followed by a rise in *S. punctum* populations (Fig. 1B). Only two alternate-row middle applications of acaricide were necessary to manage mites at about the same number of mite-days (719), and once under control, no resurgence occurred. This is typical of the management needed in orchards where IMP is practiced (Hull et al. 1983).

Predator populations in 1981 were similar in Sections 1 and 2 of the fenvalerate block, so only the combined results are shown (Fig. 1C). Late-season use of fenvalerate in 1981 allowed substantial numbers of *S. punctum* to survive in the early and middle parts of the season, and in conjunction with two alternate-row middle applications of acaricide, the predators were controlling the mite populations. The first application of fenvalerate on 27 July reduced *S. punctum* populations from ca. 90 per 3-min count to 0. Mite populations rebounded subsequent to this spray, requiring a further complete (both sides) acaricide application late in the season. Mite populations subsequent to the 27 July application were higher in the section where the higher dose of fenvalerate was used (860 and 674 mite-days in the high and low sections, respectively). In the standard block, the predator/prey interaction and necessity for acaricidal treatment were similar to that for 1980 (Fig. 1D). Total mite-days accumulated for the season were ca. 441.

Overwintering ERM eggs in 1980 and 1981 were more numerous in the fenvalerate than in the standard block (Table 1). However, there was a 6-fold increase in number of eggs deposited in the fall of 1981 in all blocks compared to 1980. Where two doses of fenvalerate were used (1981), egg counts were higher in the section receiving the higher insecticide dose (56 g [AI]/ha). The difference in numbers of overwintering eggs laid in the fall of 1980 was probably responsible for the differential mite pressure in the early and middle parts of the 1981 season.

Where fenvalerate was used at 112 g (AI)/ha in a seasonal program (13 alternate-row middle applications, 1980) the total cost of pesticides was ca. 1.8-fold higher, reflecting an increase in the cost of both insecticides (1.5-fold) and acaricide (3.9-fold) over the standard program. Due to severe TABM pressure in 1980, and superior pest control, the savings in terms of damaged fruit was $485.58/ha, and the net gain to the grower for fenvalerate use was $395.14/ha (Table 2).

Use of fenvalerate in a late-season schedule (four alternate-row middle applications, 1981) reduced insecticide costs ca. 2.5- and 5-fold for the high and low doses, respectively, although this reduction was partly due to a shift to more expensive chemicals in the 1981 standard program. Acaricides in the fenvalerate schedule, however, were 4-fold more expensive, which on the average made the programs nearly equal in cost. Only the acaricide sprays that were applied during the period of fenvalerate use (27 July on) were included (i.e., one alternate-row middle spray at one-fourth the full dose in the standard block, plus one complete spray at the full dose in the fenvalerate block) to equalize the effect of earlier and more severe mite buildup in the fenvalerate block, due to the effects of the previous season's sprays. TABM pressure was much lower in 1981, resulting in a net gain of only $32.18/ha for fenvalerate use when Brood II alone was considered. However, if Brood II damage had been 2.9% (a more representative figure under Pennsylvania conditions) (Hull et al. 1983), the net gain would have been $151.28/ha. Brood II normally causes much more damage than does Brood I (unpublished data).

Discussion

Large-orchard trials of fenvalerate under commercial conditions support field and laboratory evidence that the SP's will give excellent pest control, but will cause outbreaks of phytophagous mites. Side-by-side comparisons and previous experience (Hull and Starner 1983) indicate that this phenomenon is due primarily, but not exclusively, to the destruction of a normally very effective predator, *S. punctum*. Unlike the increase in wooly apple aphids following SP use (Penman and

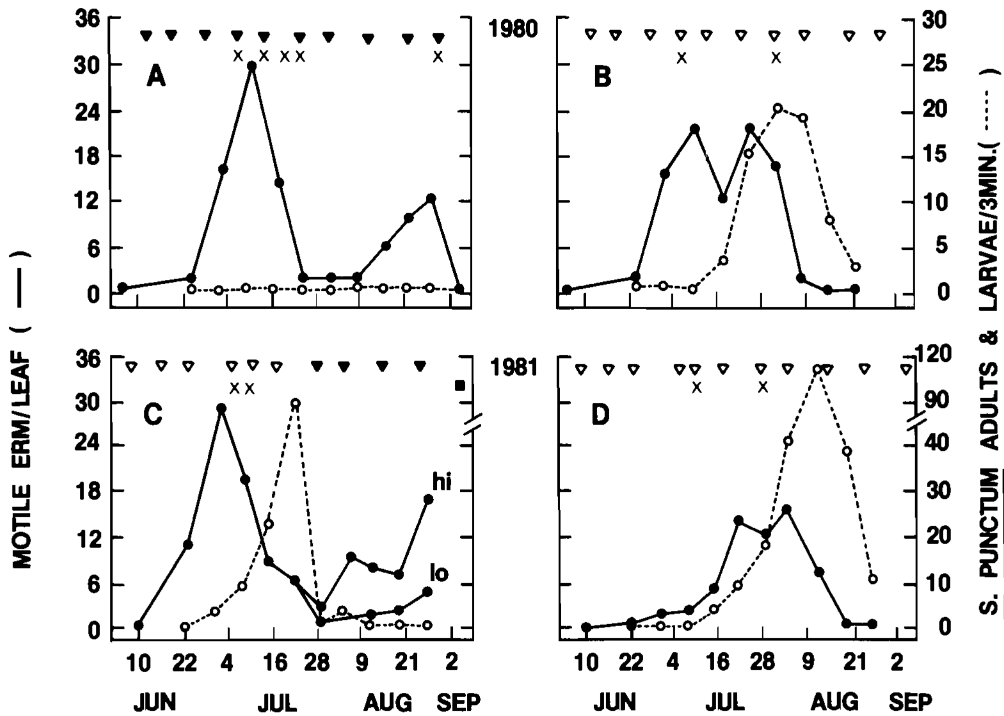

Fig. 1. Population trends of *P. ulmi* and *S. punctum* in fenvalerate (A, C) and standard (B, D) plots, Arendtsville, Pa., 1980–1981. Symbols represent spray applications of: standard insecticides ▽; fenvalerate ▼; acaricide (alternate-row middle) ×; acaricide (both sides) ■. Three early-season fenvalerate sprays are not shown.

Chapman 1980), standard insecticides have no significant mite-suppressant activity. More acaricidal sprays were required to reduce mite populations to noninjurious levels, with a concurrent 4-fold increase in acaricide costs. When only short-term costs are considered, the high degree of pest control provided by fenvalerate could result in a substantial net gain to the grower if the potential for TABM damage is high, even given the increases in the costs of both insecticides and acaricides.

It is not our intention to provide a sophisticated analysis of the economics of SP use at this point. We realized at the outset that the calculations made are rudimentary in nature, and are based on assumptions that may or may not be tenable in a given situation. It is important to realize, though, that these are the types of calculations most accessible to growers, and hence the most likely to figure in their decision-making process. They do, however, serve to point out some of the factors that will need to be considered in implementing realistic economic thresholds. These include: (1) Multiple season effects. Populations of both ERM and TABM appear to have been influenced by the previous season's program; in the fenvalerate block, the explosive ERM population (1981) must be weighed against the apparent reduction in TABM potential. (2) Damage due to mites. No attempt was made in this analysis to include differences in damage due to mite feeding. There is contradictory evidence concerning mean apple size and yield reduction (Chapman et al. 1952, Zwick et al. 1976, Hoyt et al. 1979), but we (unpublished data) found statistically significant ($P < 0.05$) reductions in these parameters under varying conditions of rainfall, crop load, cultivar, and mite damage. (3) Conditions under which SP's cause mite outbreaks. There appears to be a number of factors which influence the occurrence of mite outbreaks, including the time of season, the mite population, its distribution, direction of the population trend, the condition of the foliage (especially previous mite damage), and the presence, effectiveness, and pyrethroid susceptibility of the natural enemy complex (Hoyt et al. 1978, Hall 1979, Rock 1979, Iftner and Hall 1983, Riedl and Hoying 1983). These conditions may be more specific than is currently understood, and are now being studied in Pennsylvania. (4) Dose and activity effects. There have been numerous indications that both the relative activity of a given pyrethroid (physiological selectivity) and the dose at which it is applied (eco-

Table 2. Insecticide and acaricide costs for a standard organophosphorus and carbamate program and one using fenvalerate, Arendtsville, Pa., 1980–1981

Program	Chemical	kg (AI)/ha[a]	Dollar cost per hectare: Pesticide[b]	Change in pesticide cost[c]	TABM damage[d]	Increased cost of TABM damage[e]	Net gain[f]
			1980				
Standard	Insecticides	4.17	71.19	—	—	—	—
	Acaricides	0.31	20.21	—	—	—	—
	Total	—	91.40	—	525.06	485.58	—
Fenvalerate	Insecticides	0.73	104.08	—	—	—	—
	Acaricides	1.23	77.76	—	—	—	—
	Total	—	181.84	90.44	39.48	—	395.14
			1981				
Standard	Insecticides	1.80	39.98	—	—	—	—
	Acaricides	0.11	8.70	—	—	—	—
	Total	—	48.68	—	41.74	31.31	—
Fenvalerate	Insecticides	0.09	13.02	—	—	—	—
	Acaricides	0.44	34.79	—	—	—	—
	Total	—	47.81	−0.87	10.43	—	32.18

[a] Total kg (AI)/ha during the periods of 16 May to 28 Aug. in 1980 (13 applications) and 27 July to 4 Sept. in 1981 (4 applications). See text for insecticides in standard block.

[b] Costs shown cover only the period in which fenvalerate was used (*see* footnote *a*). Pesticide costs were estimates based on prices given by local pesticide distributors.

[c] Per-hectare cost of fenvalerate program minus that of standard; 1981 fenvalerate figures are a mean of the two doses, and damage is that due to Brood II only.

[d] Assumptions: 1,236 bu/ha yield all blocks, both years; TABM damage caused downgrading from fresh ($5.42/bu) to canner ($2.226/bu) in 1980, and from $6.72/bu to $2.499/bu in 1981. (Figures courtesy of the Pennsylvania Crop Reporting Service.)

[e] Cost of TABM damage in standard minus cost in fenvalerate; 1981 fenvalerate figures are a mean of the two doses, and damage is that due to Brood II only.

[f] Net gain = increased cost of TABM injury − increased cost of protection.

logical selectivity) may subtly or drastically alter the outcome where secondary pests and natural enemies are concerned. The mite population in 1981 rebounded more strongly in the section where the higher dose of fenvalerate was used. Hoyt et al. (1978) also noted a direct relationship between dose of another SP, permethrin, and posttreatment *Tetranychus urticae* Koch population density. Fenvalerate appears to be more active than permethrin per unit AI, and this difference is reflected in a 2- to 4-fold increase in survival of *S. punctum* in permethrin plots when the two materials were used at an identical dose (Hull and Starner 1983).

From the research completed at this point, it is possible to give a tentative, but reasonable, projection of what constitutes judicious use of SP's in deciduous fruit trees in Pennsylvania. There appears to be a high probability of mite or other secondary pest outbreak (Penman and Chapman 1980, Weires 1984) if SP's are used throughout the season, so this usage should be discouraged. The potential for resistance in target pests to SP's and the associated resistance problems with outbreaks of secondary pests is further reason to discourage season-long use (Croft and Hoyt 1978). The difficulty in placing a dollar value on complete or partial loss of effectiveness of a material should not be a barrier to its consideration when planning strategies of pesticide use, nor should the short-term advantages be presented without thorough discussion of long-term aspects. Reducing numbers or doses of applications are recognized strategies for slowing resistance development (Tabashnik and Croft 1982), and there are several ways in which these may be implemented. Currently, the SP's are only recommended for use in the preblooming period in Pennsylvania (Pennsylvania State University 1984), which is before mites hatch or predators are active. Applications for Brood II TABM can be expected to effectively control the most damaging stage, and if delayed until ca. 20 August or later, mite and predator populations should not be affected. However, the timing, dose, and application technique of late-season SP applications are still under investigation. More precise delineation of conditions preceding mite resurgence, along with better prediction of the time and occurrence of TABM damage, will help determine cost-effective use of SP's in a pest management program.

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