Integration of Biological and Chemical Control Tactics for Apple Pests Through Selective Timing and Choice of Synthetic Pyrethroid Insecticides[1]

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ABSTRACT A two-part study was conducted to assess the potential use of synthetic pyrethroid (SP) insecticides in an integrated pest management (IPM) program for apple orchards. The first test evaluated the effects of application timing of fenvalerate (112 g [AI]/ha) on the control of the tufted apple budmoth (TABM), *Platynota idaeusalis* (Walker), and the impact of these applications on the predator–prey interaction between *Stethorus punctum* (LeConte) and the European red mite (ERM), *Panonychus ulmi* (Koch). Two to three applications of fenvalerate were effective for TABM control, but these applications decimated *S. punctum* populations and resulted in higher ERM populations. The second test evaluated the differential activity of six SP's for pest control and predator–prey disruption. All SP's controlled TABM and various other apple pests as well as or better than did the standard organophosphorus insecticide azinphosmethyl. Only the SP permethrin allowed substantial survival of *S. punctum* when applied for control of TABM Broods I and II.

INTEGRATION OF biological and chemical control tactics is the only logical recourse in a multiple-pest agroecosystem, such as apple orchards, where at least one pest is a candidate for biological control. If efforts to preserve natural enemies do not also accommodate the necessity to control pests, the system is unusable. There is a growing, if reluctant, consensus that broad-spectrum insecticides are now and will be in the foreseeable future, an integral part of many integrated pest management (IPM) programs (Hull and Beers 1985). Use of integrated control in an agroecosystem presupposes detailed knowledge of the effect of chemical components on biological components, and there is a considerable body of information available for organophosphorous (OP) and carbamate compounds registered for use on deciduous tree fruits. Toxicities of many insecticides and acaricides to pests and natural enemies have been compiled from extensive laboratory and field research (Croft and Brown 1975, Anon. 1984). This information has been used as a framework to build successful IPM programs (Croft and Bode 1983). Croft and Hoyt (1978) noted that these programs are based in part on resistance acquired by pests and natural enemies as a result of heavy pesticide use over the past 20 years. The introduction of synthetic pyrethroid (SP) insecticides could upset this workable system. The potential for SP's to disrupt predator–prey interactions must therefore be weighed against their effectiveness as insecticides at low dosage levels and with relatively low mammalian hazard.

The most serious direct pest of apples in Pennsylvania is the tufted apple budmoth (TABM), *Platynota idaeusalis* (Walker) (Hull et al. 1983). TABM is bivoltine, and control measures may be necessary during one or both broods. The most insecticide-susceptible stages are the adults, eggs, and early instar larvae (Travis et al. 1981, Rock and Shaltout 1983). These occur in June (Brood I) and again in August (Brood II) in Pennsylvania (Bode 1975). The most serious indirect pest of apples is the European red mite (ERM), *Panonychus ulmi* (Koch). It is active from April to September, but is usually controlled in July and August. The coccinellid predator, *Stethorus punctum* (LeConte), will effectively control ERM with the aid of one or two selective acaricide applications if not eliminated by highly toxic, routine insecticide applications (Hull and Starner 1983). *S. punctum* has become relatively resistant to standard orchard OP insecticides, but is highly susceptible to SP's (Hull and Starner 1983). Other pests usually requiring control during the summer months are the white apple leafhopper (WALH), *Typhlocyba pomaria* McAtee, and the apple aphid (AA), *Aphis pomi* De Geer, both of which are indirect pests.

The objective of our study was to determine if or how the SP's could be successfully integrated into Pennsylvania's working IPM system (Asquith and Hull 1979). Two key factors were examined: timing of SP's for optimal control of TABM, and differential activity of various SP's against direct and indirect pest species. In both studies, the impact of the SP's on the predator–prey interaction

[1] This paper reports the results of research only. Mention of a proprietary product or pesticide does not constitute an endorsement or a recommendation for its use by USDA, nor does it imply registration under FIFRA, as amended.

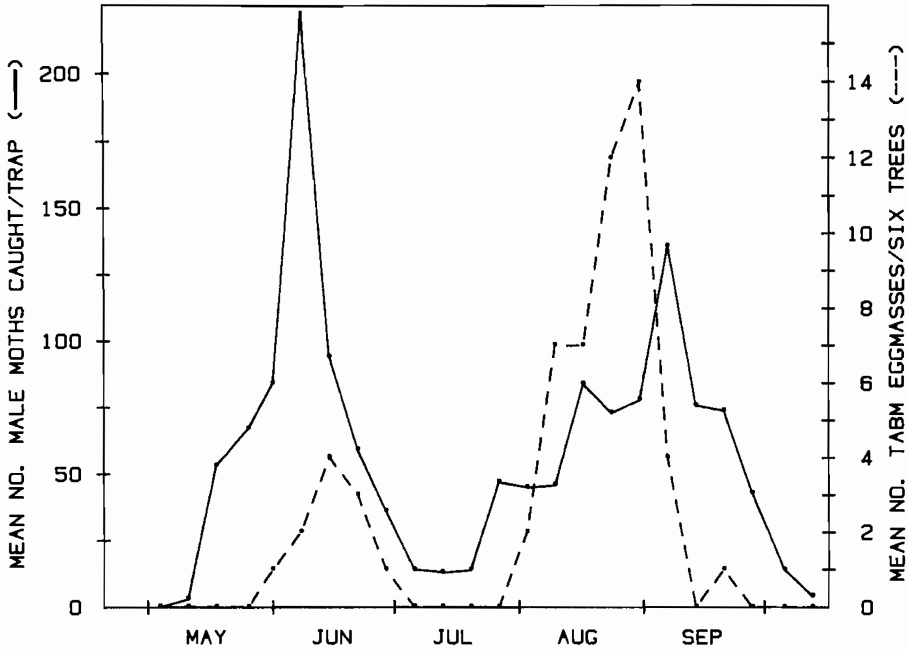

Fig. 1. Seasonal abundance of TABM adult males (——) and egg masses (- - -) on unsprayed apple trees (Arendtsville, Pa., 1981).

of ERM and *S. punctum*, a criterion for usability, was evaluated.

Materials and Methods

Test 1. The experiment was conducted in a 27-year-old apple orchard (0.7 ha) in Arendtsville, Pa., in 1981. The block contained four-tree plots of the cvs. Delicious, Golden Delicious, Stayman, and Rome Beauty. Tree size was maintained at a height of ca. 3.4 m. A standard orchard fungicide program was maintained throughout the season. Insecticide treatments consisted of one to three applications of fenvalerate at 112 g (AI)/ha, with timing based on biological reference points (biofix points) in the seasonal development of TABM—i.e., peak moth flight (PMF) of Brood I (11 June) and Brood II (10 September), and appearance of the first egg mass of Brood II (30 July) (Table 1). Treatments were applied with an airblast sprayer calibrated to deliver 468 liters/ha driven at 3.2 km/h. Both sides of the tree were treated at time of application. Each of the nine treatments, designated as T1 to T9, was applied to three replicates of each four-tree plot in a randomized complete block design.

Seasonal abundance of adult male TABM and egg masses was monitored during 1981 (Fig. 1). Male flight was monitored with Pherocon 1C traps (Zoecon Corp., Palo Alto, Calif.) baited with rubber septa containing TABM pheromone. Moths were counted and removed twice weekly. Trap bottoms and rubber septa were replaced every 3 weeks. Oviposition data were collected in six 'Stayman' trees, which had not received any insecticide sprays, and were distributed regularly across the block from north to south. Foliage on the upper and lower halves of each tree was examined twice weekly for a 10-min period to detect new TABM egg masses. Each egg mass was tagged with a plastic ribbon bearing the date. At harvest, 100 apples per tree (1,200 per treatment) were visually rated for Brood I and Brood II TABM damage.

Populations of ERM were sampled by randomly selecting and removing 20 leaves per tree from the periphery of the canopy at a height of ca. 1.5 to 2.0 m. Mites were brushed from the leaves with a mite brushing machine and counted with the aid of a stereoscopic microscope. Overwintering ERM eggs were counted on eight small twigs collected from each tree. Eggs on both sides of a central node were counted, up to a distance of 12.7 mm from the node. Twig surface area was estimated by considering it to be a cylinder 25.4 mm in length, and using the circumference at the node. *S. punctum* were counted using a modification of the method described by Colburn and Asquith (1971). Observers recorded numbers of adults and larvae during a 3-min period while walking slowly around the periphery of the tree. Populations of ERM and *S. punctum* were sampled on cv. Delicious only. Data from this test were subjected to

Table 1. Apple injury by TABM in treatments of one to three applications of fenvalerate (112 g [AI]/ha) timed to correspond to TABM development (Arendtsville, Pa., 1981)

Treatment no. & TABM biofix point[a]		Application date	Brood controlled	TABM injuries/100 apples[b]		
				Brood I	Brood II	Total
T1	Brood I: PMF	11-VI	I	3.3bc	2.9b	6.2d
T2	Brood I: PMF Brood I: PMF +11	11-VI 22-VI	I	1.8ab	1.2ab	2.9b
T3	Brood I: PMF Brood II: PMF	11-VI 10-IX	I & II	2.0ab	1.2ab	3.2bc
T4	Brood I: PMF Brood II: FO +7 Brood II: FO +21	11-VI 6-VIII 20-VIII	I & II	1.0a	0.2a	1.2a
T5	Brood II: FO +7 Brood II: FO +21	6-VIII 20-VIII	II	4.3cd	0.9ab	5.2cd
T6	Brood II: FO +21	20-VIII	II	5.4d	2.1b	7.5d
T7	Brood II: FO +21 Brood II: PMF	20-VIII 10-IX	II	5.7d	2.1b	7.8d
T8	Brood II: PMF	10-IX	II	11.3e	5.3c	16.5e
T9	Control	—	—	11.6e	6.9c	18.5e

[a] PMF, Peak moth flight; FO, first oviposition. Numbers preceded by '+' indicate the number of days after the biofix point.

[b] Means within columns followed by the same letter are not significantly different ($P = 0.05$; Waller-Duncan K-ratio t test [Goodnight et al. 1982]).

analysis of variance, and treatment means were separated by the Waller-Duncan K-ratio t test (Goodnight et al. 1982). The amount of fruit injury was also tested by grouping treatments according to the brood controlled (I, I and II, II) (Table 1) and these groups were compared using linear contrasts (Neter and Wasserman 1974).

Test 2. This experiment was conducted in a 33-year-old apple orchard near Biglerville, Pa., in 1982. The orchard, equipment, and method of application were described in Hull and Starner (1983). Treatments consisted of the SP's permethrin (3.2EC and 2E), cypermethrin, and flucythrinate applied during the peak oviposition period for both broods of TABM. Applications for Brood I were 8 and 22 June, and those for Brood II were 4 and 18 August. These periods were chosen to maximize TABM control while minimizing impact on ERM and *S. punctum*. A standard insecticide (azinphosmethyl, 15 g/100 liters) was used on 25 May, 6 and 21 July, and 1 September. The SP's fenpropathrin and FMC-54800 [1,1′-biphenyl-3ylmethyl-*cis*-3-(2-chloro-3,3,3-trifluoropropenyl)-2,2-dimethylcyclopropanecarboxylate], which have significant acaricidal activity, were applied on all eight dates. Sampling methods for ERM and *S. punctum* were the same as those described in Test 1. WALH populations were determined by counting the number of nymphs on 25 leaves per tree. AA was sampled by counting the number of aphids on the most infested leaf per terminal on 10 terminals per tree (Hull and Grimm 1983). All fruit that dropped after 1 July, and two bushels of apples per replicate at harvest, were visually examined for TABM injury. Data from this test were subjected to analysis of variance, and treatment means were separated by the Waller-Duncan K-ratio t test (Goodnight et al. 1982). Data were transformed to square roots (WALH) or logarithms (TABM) before analysis.

Results

Test 1. More fruit injury was caused by Brood I than by Brood II TABM larvae in this test (Table 1). Treatments aimed solely at Brood I (T1 and T2) had fewer injured apples than treatments aimed solely at Brood II (T5–T8) ($P = 0.05$). Control measures aimed at both broods (T3 and T4) did not produce significantly fewer injured apples than control measures aimed at only Brood I, but these treatments resulted in fewer injured apples than those aimed only at Brood II ($P = 0.05$).

Within the group of treatments where Brood I and II were controlled, three sprays (T4) gave significantly better seasonal control did than two (T3) (Table 1). In treatments where only one spray was applied, the best control was in T1 aimed at Brood I PMF or T6 aimed at Brood II. Where two sprays were applied, the best control occurred where timing was for Brood I alone, or one application during each brood (T2 and T3). Where control was aimed solely at Brood II (T5–T8), only the single PMF application (T8) gave significantly poorer control than did the other treatments. The addition of a PMF application (T7) to an oviposition biofix-timed spray (T5 and T6) did not improve control. One application at 21 days after first oviposition of Brood II moths (T6) provided control similar to two applications at +7 and +21 days (T5).

Table 2. *S. punctum* adult (A) and larval (L) and ERM (motile and egg) populations in treatments of one to three applications of fenvalerate (112 g [AI]/ha) timed to correspond to TABM development (Arendtsville, Pa., 1981)

Treatment no. & TABM biofix point[a]		Application date	Brood con-trolled	ERM/leaf 31-VII	S. punctum/3-min search[b]										ERM/leaf 25-VIII	ERM[b] eggs/cm^2
					31-VII		5-VIII		10-VIII		19-VIII		24-VIII			
					A	L	A	L	A	L	A	L	A	L		
T1	Brood I: PMF	11-VI	I	71a	1e	0b	11ab	0b	10cd	0c	22a	1de	7abc	0a	83b	27.4ab
T2	Brood I: PMF Brood I: PMF +11	11-VI 22-VI	I	102a	2de	0b	12ab	1b	11cd	0c	32a	2de	11abc	0a	79b	32.0ab
T3	Brood I: PMF Brood II: PMF	11-VI 10-IX	I & II	99a	4cde	0b	30ab	0b	15c	0c	41a	9cd	23ab	1a	93b	21.5ab
T4	Brood I: PMF Brood II: FO +7 Brood II: FO+21	11-VI 6-VIII 20-VIII	I & II	108a	4cde	0b	6b	0b	1e	0c	13a	1d	1cd	0a	40ab	26.3ab
T5	Brood II: FO +7 Brood II: FO +21	6-VIII 20-VIII	II	114a	12a–d	4ab	35ab	43a	3de	1c	17a	0e	0d	0a	15a	30.8ab
T6	Brood II: FO +21	20-VIII	II	72a	18a	5ab	43ab	50a	29ab	62a	37a	71ab	9abc	1a	7a	26.8ab
T7	Brood II: FO +21 Brood II: PMF	20-VIII 10-IX	II	86a	17ab	1ab	35ab	15a	30ab	10b	43a	86a	5bcd	0a	12a	33.5b
T8	Brood II: PMF	10-IX	II	42a	17ab	5ab	45a	53a	20bc	40a	28a	72ab	80a	6a	2a	7.3a
T9	Control	—	—	94a	28a	10a	43a	92a	39a	50a	27a	34cd	2cd	0a	12a	8.0a

[a] PMF, Peak moth flight; FO, first oviposition. Numbers preceded by '+' indicate number of days after the biofix point.
[b] Means within columns followed by the same letter are not significantly different ($P = 0.05$; Waller-Duncan K-ratio t test [Goodnight et al. 1982]).

Table 3. Pest populations and TABM damage to apple after treatments with various pyrethroids (Biglerville, Pa., 1982)

Treatment[a]	Rate (g [AI]/100 liters)	% Reduction AA/most infested leaf/terminal[b]	WALH/25 leaves[c]	TABM injuries/100 apples[c]
Fenpropathrin	9.0	52.0ab	0.0a	0.98a
FMC-54800	1.8	94.8a	0.3a	2.99a
Permethrin 3.2EC	3.0	80.1a	6.8b	3.19a
Cypermethrin 2.5EC	3.0	90.6a	1.0a	1.22a
Flucythrinate 2.5EC	4.8	91.2a	1.5a	0.66a
Permethrin 2E	6.0	77.7a	1.8a	2.51a
Azinphosmethyl 50WP	15.0	42.6ab	18.8c	2.63a
Control	—	18.4c	14.3c	9.53b

[a] Treatments of permethrin (3.2EC and 2E), cypermethrin, and flucythrinate received azinphosmethyl 50 WP 15.0 g (AI)/100 liters on 25 May, 6 July, 21 July, and 1 September. Synthetic pyrethroids were sprayed on 8 and 22 June, and 4 and 18 August.

[b] Prespray and postspray counts were 7 and 11 June, respectively. Means within columns followed by the same letter are not significantly different ($P = 0.05$; Duncan's multiple range test [Goodnight et al. 1982]).

[c] Analyses were on square root (WALH) and logarithms (TABM) of data. Means within columns followed by the same letter are not significantly different ($P = 0.05$; Waller-Duncan K-ratio t test [Goodnight et al. 1982]).

Mite populations were high (42–114 mites per leaf) in all treatments on 31 July regardless of numbers of sprays applied up to that date (Table 2). In all treatments where control for Brood I was included (T1–T4), *S. punctum* larvae averaged less than one per 3-min count during late July and August, despite the lapse of 40–70 days after the applications. Adult *S. punctum* populations were also greatly reduced, although moderate recolonization took place where no sprays were applied in August (T1–T3). In both cases, predator populations were not sufficient to bring ERM under control, and the number of mites per leaf ranged from 40 to 93 on 25 August (Table 2).

In treatments which included Brood II control only (T5–T8), *S. punctum* adults and larvae continued to increase throughout July and early August, until numbers declined from lack of prey, or because an application of fenvalerate was made (T5). ERM numbers were low (2–15 mites per leaf) by 25 August in this group of treatments and in the control, indicating that substantial biological control had occurred. The spray application on 6 August (T4 and T5) decimated larval *S. punctum* populations and reduced adult populations (Table 2), but partial biological control of ERM occurred. ERM populations were lowest in treatments where no spray was applied until 20 August or later, and the spray application on 10 September had no apparent effect on ERM or *S. punctum*.

Large, late-season mite populations, or any treatment including an application for Brood II, produced a large number of overwintering mite eggs (Table 2), although, with the exception of T7, these were not significantly different from the check (Table 2). There was, however, a distinct drop in the number of overwintering eggs (T8 and T9) where either treatment was delayed until 10 September, or no SP's were applied (control).

Test 2. Control of AA was better with all of the SP's than in the control (Table 3). All SP's except permethrin 3.2EC provided commercially acceptable control of WALH when compared with OP and the control treatments. All insecticide treatments resulted in fewer TABM injuries at harvest than the control, although none of the SP's were significantly better than the OP insecticide.

The SP's fenpropathrin and FMC-54800 suppressed *S. punctum* populations throughout their normal period of activity in July and August (Fig. 2). Because of the acaricidal activity, however, an increase in mite populations did not occur in the absence of *S. punctum*. The two June applications of cypermethrin and permethrin 2E caused the mite population to increase earlier (ca. 30–50 mites per leaf on 20 July) than did the other treatments (<20 mites per leaf on 20 July). Cypermethrin and flucythrinate applications on 4 August drastically reduced rising *S. punctum* populations, which subsequently remained low for the remainder of the season. Both formulations of permethrin, while slowing *S. punctum* population increase, allowed these predators to increase to a level at which biological control of ERM occurred. The more severe reduction in predator populations after the 18 August application was due in part to the normal decrease following decreasing prey populations. The predator population in the control and the standard OP treatment show trends typical of this predator–prey relationship in Pennsylvania (Hull and Starner 1983).

Discussion

SP's effectively control several indirect and direct apple pests at rates ca. 1.7- to 8.3-fold less AI than the standard OP insecticide. One or two sprays for each brood of TABM will be necessary, depending on insect pressure and the intended market for the fruit. Brood II pressure is normally greater than Brood I in Pennsylvania (unpublished data), so August will usually be the critical period for control.

Use of SP's against Brood I TABM causes mite populations to escalate, necessitating additional acaricide applications to avoid ERM damage. If SP's are used again later in the season, mite populations that would normally decline because of predation can rebuild, sometimes requiring control in September (Hull et al. 1985). When mite populations are high in early fall, large numbers of overwintering eggs are deposited, which leads to a substantial increase in ERM populations the following spring. Excessive use of acaricides to control mites may hasten the development of resistant strains (Croft and Hoyt 1978). Because of the paucity of effective acaricides and the impedi-

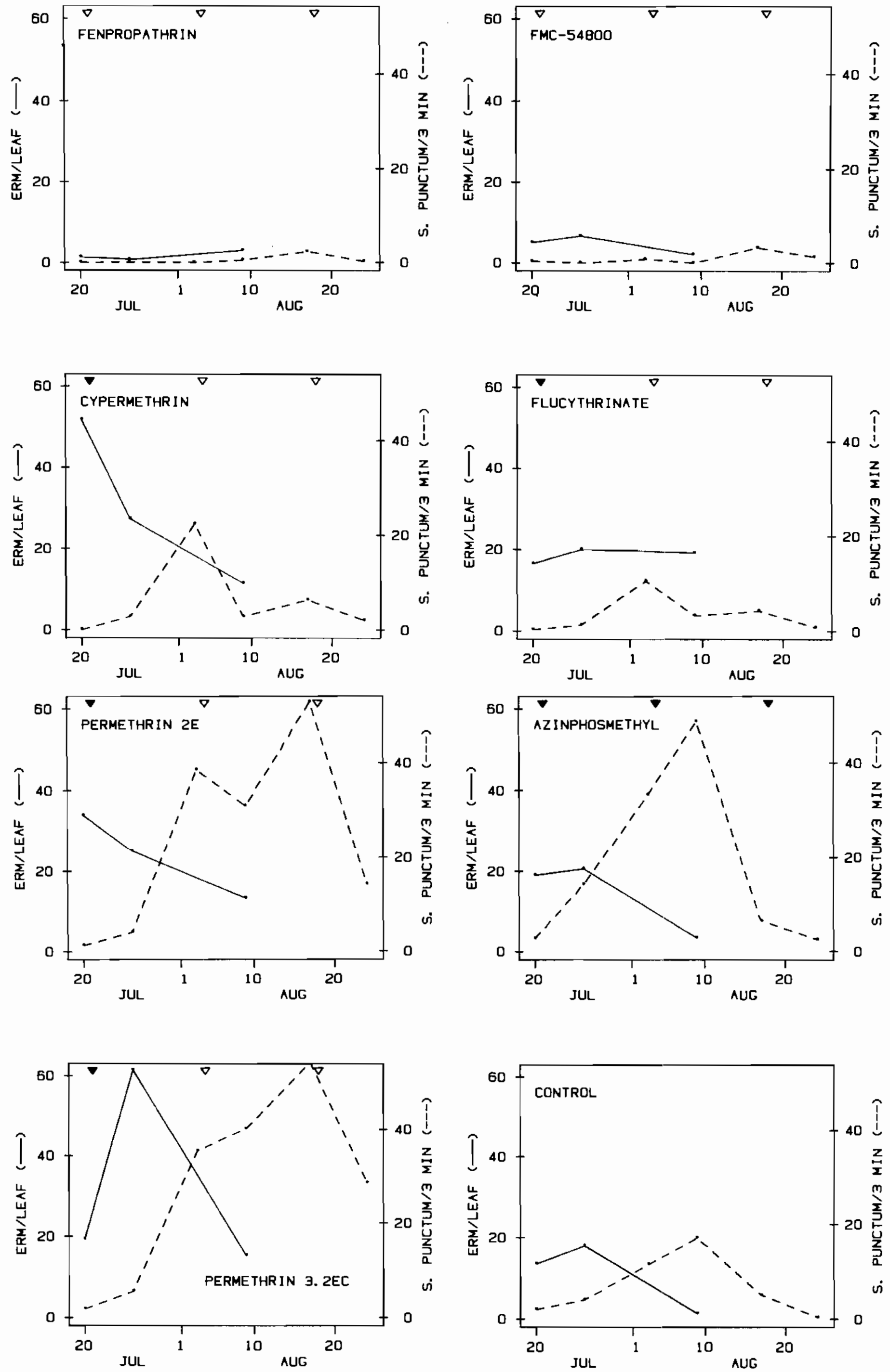

Fig. 2. Population trends in ERM (——) and *S. punctum* (- - -) in treatments of synthetic pyrethroids (▽) and a standard insecticide (▼).

ments in development and registration of new materials, every effort should be made to avoid resistance development.

The following strategy may be effective in the Pennsylvania apple IPM system to delay the onset of resistance to acaricides and maintain adequate natural enemy populations. Petal fall coincides with the completion of overwintering ERM egg hatch, and the key period for control of WALH. However, use of SP's at this time may stimulate mite dispersal, and lead to a subsequent explosion in population (Hall 1979, Iftner and Hall 1983). Control of Brood I TABM in June should be accomplished only with OP insecticides which will allow *S. punctum* to increase in response to mite populations. SP use also should be avoided in July, when the susceptible stages of TABM are not present (Fig. 1). Although AA may require control in July, this period usually coincides with the peak movement of predators into the orchard. An SP application would again disrupt the ERM–*S. punctum* relationship. Selectively-timed applications of SP's should only be used to Brood II TABM control.

Relegating SP use to mid-August and September may allow the interaction between *S. punctum* and ERM to occur naturally, and at the same time provide excellent control of TABM. Because of the long residual of the SP's (versus the shorter residual of OP and carbamate insecticides), and the fact that most growers cease spraying insecticides in the latter part of August (Hull et al. 1983), use of SP's during this period would give better control of the susceptible TABM stages, which are present until mid-September. However, the size of the mite population during August applications of SP's is extremely important for minimizing the deposition of overwintering ERM eggs (unpublished data).

The variability of SP activity toward ERM and *S. punctum* may also provide an opportunity for their selective use. Cypermethrin and flucythrinate completely suppressed *S. punctum*, whereas permethrin (both formulations) allowed substantial survival of the predators. Hoyt et al. (1978) noted the differential activity of permethrin and fenvalerate, emphasizing the difficulty in making generalizations about this class of compounds. The combined acaricidal–insecticidal activity of fenpropathrin and FMC-54800 may encourage some workers to consider the use of these materials in a seasonal program. Past experience, however, has demonstrated that acaricidal activity is lost more quickly than insecticidal activity, and it is likely that mites would become resistant in a matter of a few years, while predators remain susceptible (Croft and Bode 1983).

Integrated control of multiple pests is possible if pesticide evaluations are fitted into a framework that includes the preservation of natural enemies while maintaining adequate pest control. Knowledge and selection of pesticides, combined with selective timing to avoid contact with susceptible stages of natural enemies are essential features. Introducing new insecticides into a viable system requires careful forethought and research in order to avoid a continuous cycle of resistance acquisition in pest species.

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