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Integrated apple pest management in New York State using predatory mites and selective pesticides

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Abstract

A 3-year demonstration study was conducted in four western New York apple orchards to evaluate current approaches of sustainable pest management in representative commercial orchards. Pests that could be tolerated were regulated by natural antagonists, including predatory mites that were introduced to supplement endemic populations, while those with lower tolerance levels were managed with a schedule of selective pesticides, e.g., insect growth regulators and horticultural mineral oil. Pesticide application decisions (timing and materials) were made on the basis of current state extension guidelines, which involved a combination of protectant and threshold-based sprays determined through timely scouting and sampling procedures. Only non-toxic or minimally toxic pesticides to the principal mite and aphid predators were applied in the orchards. By the third season, effective conservation biological control of European red mite was achieved in all orchards, and fruit quality at harvest was equal or superior to that in comparison blocks managed using the growers' conventional practices.

Keywords: Integrated pest management; Biological control; Selective pesticides; Predator mites; Apple

1. Introduction

Studies conducted in New York State and elsewhere have shown that although biological control of many foliar feeding arthropod pests of apple (*Malus domestica* Borkhausen) is technically feasible, the pesticides used to manage direct fruit feeders are applied too frequently to permit sustained biological mite control in most commercial orchards (Hardman et al., 1991; Walde et al., 1992; Blommers, 1994; Prokopy et al., 1997). With the recent development of more selective management tools such as biologically based pesticides, insect growth regulators, and synthetic sex pheromones, there now exists an opportunity for commercial apple growers to forge a management strategy that allows effective control of arthropod pests without using conventional broad-spectrum toxicants that disrupt populations of natural enemies and pose unacceptable environmental and human safety risks in the long term.

In recent years, the determinant foliar pest in New York apple orchards has been European red mite (*Panonychus ulmi* [Koch]). Although efficacious acaricides continue to be developed and made available, the costs of control using these materials are escalating during a period when many orchardists are attempting to remain economically viable by minimising expenses. Also, aside from the possible

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environmental harm deriving from chemically based mite control programmes, the potential development of resistance to acaricides by the pest mites is a concern (Pree, 1987; Martinson et al., 1991). Biological control of mites is an economically and technologically attainable alternative to pesticides. Two species of predaceous mites predominate in commercial New York orchards, *Amblyseius fallacis* (Garman) and *Typhlodromus pyri* (Scheuten). Although similar in appearance, they differ significantly in their biologies, and *T. pyri* is the more effective biological control agent (Walde et al., 1992; Nyrop et al., 1997). When *T. pyri* is conserved in commercial apple orchards, it can eliminate the need for acaricides (Hardman et al., 1991; Walde et al., 1992; Blommers, 1994).

Mite control in New York orchards has been complicated in recent years by a number of circumstances: the development of resistance to some of the most commonly used materials, dicofol and cyhexatin (Welty et al., 1987, 1989; Dennehy et al., 1988); the unavailability or withdrawal of compounds because of regulatory decisions; and delays in the registration of new acaricides. Mite populations continually require suppression because growers are relying on insecticides that are toxic to mite predators. This constant depletion of natural control agents allows potentially damaging mite populations to build up each season even if satisfactory chemical control was achieved the previous year. Long-term field trials in research orchards have established that, without the repeated negative effects of these destructive pesticides, most endemic *P. ulmi* populations could be kept to non-economic levels by naturally occurring predators in New York orchards, such as *T. pyri*, *A. fallacis*, or *T. occidentalis* Nesbitt (Hardman et al., 1991; Prokopy et al., 1997, 1999).

Alternatives to the pyrethroids and carbamates are needed to control certain key fruit and foliar pests present in most New York apple plantings (Blommers, 1994). The most important and problematic of these species is obliquebanded leafroller (*Choristoneura rosaceana* [Harris]). This tortricid has been the most serious pest in New York apple orchards since it became resistant to commonly used orchard insecticides in the 1970s (Reissig, 1978; Reissig et al., 1986). Spring and summer generation larvae attack both foliar shoots and developing fruits. Growers experienced increased difficulty in controlling this pest using recommended materials during the 1990s and, despite multiple insecticide applications, problem orchards usually showed 3–4% damaged fruit at harvest. The insect's resistance to various insecticides caused growers to resort at times to imprudent pesticide use patterns in an effort to find an application schedule or product mixture that would provide some degree of satisfactory control. The current availability of crop protectants such as *Bacillus thuringiensis* (Bt), the insect growth regulators fenoxycarb and tebufenozide, and synthetic sex pheromones, has offered growers sustainable alternatives, including the possibility of relying on biological control of mites.

Integrated pest management programmes have been conducted in New York apple orchards since the early 1970s, when an extension pilot programme was established to demonstrate existing sampling and monitoring technology (Tette et al., 1979). More recently, a simplified management programme was developed (Agnello et al., 1994a) that relied on simplified sampling techniques and decision rules. Although pesticide usage was often reduced in orchards managed with this simplified programme, a management programme specifically incorporating biological and selective pesticide control of apple pests was desired.

T. pyri is endemic in much of western New York, but is generally undetected because of the pesticide regimen employed against other pests. Moving *T. pyri* from blocks where they are abundant to sites where more predators are desired can aid in its establishment (Nyrop et al., 1995). Affixing branches from trees harbouring *T. pyri* into trees in a recipient orchard increases phytoseiid densities in the target trees (Prokopy et al., 1997, 1999). Predator mite "nurseries" for use as a source of mites to be transferred can also be established in small portions of commercial blocks where the disruptive pesticides can be avoided (Breth, 1995). The results of a 3-year trial are reported, aimed at biologically controlling European red mite in four commercial orchards using selective pesticides to manage insect and disease pests while the predatory mites established.

2. Methods and materials

Plots of 1.0–1.5 ha were studied from 1996 to 1998 in commercial fresh market apple orchards at four sites in western New York State (Wayne and Ontario counties) in which biological mite control never occurred because of a lack of sufficient predatory mites. Varieties represented included 'Red Delicious', 'Rome', 'Jerseymac', 'Empire', and 'Cortland'. To control the major pests, a programme was selected that avoided pyrethroids and most carbamates to minimise the harmful effects on beneficial species (Table 1). Cooperating growers applied all sprays in their respective blocks using ground airblast sprayers, and although they were provided recommendations on materials, rates and timings to use for specific pests, all spray decisions were ultimately up to each grower. Comparison blocks were set up at each site with at least one variety in common with the IPM block and comparable characteristics (tree size, age, planting density and style), but under the growers' standard pesticide programmes. Infestation and damage by major pests was assessed throughout the season by fruit and foliar inspections, described in the subsequent pest sections, and by evaluating fruit quality at harvest (Agnello et al., 1994a, 1999). Occurrence and abundance of beneficial species was monitored by counting predatory mites in weekly leaf samples, recording beneficial insect numbers in regular foliar terminal inspections, dissection of leafminer mines for evidence of parasitism, and through foliar beating samples for generalist predators during the summer.

2.1. European red mite

Annual pre-season assessments were made of endemic predatory phytoseiid mite populations in each IPM and comparison block. During March and April, before the mites began to come out of diapause, 30 cm clippings of 1- and 2-year-old wood were collected from 20 to 24 random trees in each orchard and divided into sufficient lots to fill 12 Berlese extraction funnels in the laboratory (Nyrop et al., 1994). Overwintering specimens obtained from the clippings after 48–72 h in these funnels were mounted on a microscope slide and identified to species.

Predatory mites (*T. pyri*) resistant to organophosphates and carbamates were distributed throughout the IPM plots at bloom during the 1996 and 1997 seasons (Nyrop et al., 1995) by transferring blossom clusters collected from a research orchard in which *T. pyri* was established. Five 50 cm shoots containing flower clusters were attached in the canopy of each of 10–12 recipient trees per IPM block. In 1996, to maintain *P. ulmi* populations at acceptable levels while the predators were stabilising at an effective density, a horticultural mineral oil was used, starting with one application during the tight cluster bud stage, and one approximately at fruit set, plus two more at a 10–14-day interval (Agnello et al., 1994b). In 1997, either clofentezine or hexythiazox was applied prebloom instead of oil to keep mites below economic thresholds while the predators established themselves. During the 1998 season because of the steadily increasing *T. pyri* populations no prebloom acaricide was applied.

Mite threshold densities, as recommended by New York State extension guidelines (Nyrop et al., 1989; Agnello et al., 2001) increase each month according to the trees' greater tolerance to feeding injury as the season progresses: June, 2.5; July, 5.0; and August 1–15, 7.5 motile forms/leaf. Monitoring for mites is not advised after August 15 if populations have been kept at or below threshold to this date. These guidelines derive from studies on the cumulative effect on apple trees and fruit of European red mite foliar feeding over time, where population densities are expressed as cumulative mite-days per leaf (Beers et al., 1990; Hull and Beers, 1990; Francesconi et al., 1996). Mite-days are accumulated at each sampling date as:

$$\text{mite-days} = [0.5(\text{mpl}_\text{p} + \text{mpl}_\text{c})]d_{\text{c--p}}$$

where mpl_p is the number of mites per leaf at the prior sampling date, mpl_c the current number of mites per leaf and $d_{\text{c--p}}$ the interval of days between the samples (Beers et al., 1990). Seasonal accumulations of less than 750 mite-days have been found to produce no measurable effect on yield or fruit quality during the year the damage occurred or during the following year (Nyrop and Reissig, 1988; Hull and Beers, 1990). Current state guidelines advise control measures when 500 mite-days have accumulated (Lakso et al., 1996; Agnello et al., 2001).

Weekly foliar samples were taken for mite counting throughout each summer to determine numbers of both phytophagous and predatory mites. Samples of 25 intermediate age leaves were taken from each of the four trees per plot, brushed in the laboratory with a mite-brushing machine (Leedom Engineering, Mi-Wuk Village, CA) and counted under a microscope (3.0–7.0× magnification) to determine the average number of mite immatures and adults per leaf.

Table 1
Total[a] acaricides, fungicides and insecticides applied each year in IPM and comparison (comp) blocks in four apple orchards in New York State, 1996–1998

	Forml[b]	Orchard A						Orchard B						Orchards C and D					
		1996		1997		1998		1996		1997		1998		1996		1997		1998	
		IPM	Comp	IPM	Comp	IPM	Comp	IPM	Comp	IPM	Comp	IPM	Comp	IPM	Comp	IPM	Comp	IPM	Comp
Acaricides																			
Abamectin	0.15EC	–	–	–	0.44	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Clofentezine	4SC	–	–	–	–	–	–	–	–	–	1.07	–	–	–	–	–	–	–	–
Formetanate	92SP	–	–	–	–	–	–	–	1.25	–	–	–	–	–	–	–	–	–	–
Hexythiazox	50WP	–	0.66	0.34	–	–	–	–	–	1.00	–	–	–	–	–	1.00	1.00	–	–
Petroleum oil	98.8L	3.59	0.67	–	0.04	–	–	3.75	1.00	–	–	–	–	0.81	0.70	–	–	–	–
Pyridaben	60WS	–	–	–	–	–	0.61	–	–	–	–	–	0.67	–	–	–	–	–	–
Total		3.59	1.33	0.34	0.48	0.00	0.61	3.75	2.25	1.00	1.07	0.00	0.67	0.81	0.70	1.00	1.00	0.00	0.00
Fungicides																			
Benomyl	50WP	0.62	0.39	–	–	1.41	1.80	–	–	–	–	–	–	0.60	0.60	2.22	2.70	3.15	2.52
Captan	50WP, 80WP	0.25	1.05	1.62	0.58	3.69	3.02	0.40	1.20	5.92	0.39	1.58	3.95	0.80	1.20	5.66	2.63	8.28	3.94
Fenarimol	1EC	–	–	–	–	–	–	2.64	–	1.52	–	2.01	0.67	2.56	1.60	–	–	–	2.68
Mancozeb	75DF, 80WP	2.24	2.33	–	1.43	1.44	1.44	2.45	4.69	–	4.69	0.56	1.34	2.78	1.44	0.89	2.45	–	2.34
Myclobutanil	40WP	1.25	1.25	1.26	1.68	–	–	–	–	–	–	–	–	–	–	2.30	0.82	–	–
Phosetyl–al	80WDG	1.36	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Streptomycin	17WP	0.57	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sulphur	95WP	–	–	–	–	–	–	1.00	6.00	–	5.00	–	3.00	–	–	–	–	–	–
Thiophanate–methyl	70WP	0.70	0.62	1.17	1.20	0.47	–	0.78	2.34	–	–	–	–	1.20	1.60	–	–	–	–
Triadimefon	50WP	–	–	–	–	–	–	–	–	–	0.63	–	–	–	–	–	–	–	–
Triflumizole	50WS	–	–	–	–	1.41	1.51	–	–	–	–	–	–	–	–	–	–	2.67	–
Ziram	76WDG	–	–	–	–	–	–	–	–	–	1.00	–	–	1.60	1.60	–	2.00	–	–
Total		6.99	5.64	4.05	4.89	8.42	7.77	7.27	14.23	7.44	11.71	4.15	8.96	9.54	8.04	11.07	10.60	14.10	11.48
Insecticides																			
Azinphosmethyl	50WP	1.00	1.00	0.50	0.50	–	0.67	3.00	2.00	3.33	2.00	2.01	2.00	0.80	1.47	2.47	2.47	0.83	0.83
Bacillus thuringiensis	6.4WP, 10.3DF	–	–	–	–	–	–	1.00	–	–	–	–	1.00	–	–	–	–	–	–
Carbaryl	50WP, 4EC	0.33	0.33	–	0.93	0.21	0.50	0.50	–	0.67	1.33	1.00	1.00	–	–	–	–	–	–
Chlorpyrifos	50WP, 4EC	–	0.98	–	0.33	–	1.09	–	3.47	–	2.17	–	0.87	–	0.35	–	1.52	–	1.30
Dimethoate	4EC	–	–	–	–	–	–	–	–	–	0.67	–	–	–	–	–	–	–	–
Endosulfan	50WP, 3EC	0.75	0.75	0.50	0.84	0.50	–	–	0.67	–	–	–	–	–	0.53	0.50	1.84	0.67	1.17
Esfenvalerate	0.66EC	–	–	–	0.37	–	1.25	–	5.00	–	1.31	–	3.00	–	–	–	–	–	–
Imidacloprid	1.6F	0.33	0.33	0.42	–	0.49	–	–	–	1.00	–	1.00	–	1.12	0.53	0.50	–	–	–
Methomyl	90SP	–	–	–	–	–	0.29	–	–	–	–	–	0.43	–	–	–	–	–	–
Methyl parathion	2FM	–	0.33	–	0.77	–	0.44	–	–	–	0.89	–	–	–	1.24	–	0.89	–	–
Oxamyl	2L	–	–	–	–	–	–	–	–	–	1.00	–	–	–	–	–	–	–	–
Phosmet	70WP	0.83	–	0.50	–	0.92	–	–	–	–	–	–	–	–	–	–	–	–	–
Tebufenozide	2F	2.50	–	3.00	–	3.00	–	4.50	–	3.00	–	4.00	–	2.40	–	2.00	–	3.00	–
Subtotal		5.74	3.72	4.92	3.74	5.12	4.24	9.00	11.14	8.00	9.37	8.01	8.30	4.32	4.12	5.47	6.72	4.50	3.30
Total		16.32	10.69	9.31	9.11	13.54	12.62	20.02	27.62	16.44	22.15	12.16	17.93	14.67	12.86	17.54	18.32	18.60	14.78

[a] Rate of product applied divided by the recommended rate (Agnello et al., 2001).

[b] Forml, formulation; EC, emulsifiable concentrate; SC, sprayable concentrate; SP, soluble powder; WP, wettable powder; L, liquid; WS, water soluble packets; DF, dry flowable; WDG, water dispersible granules; F, flowable; FM, flowable microencapsulated.

Phytoseiid mites found in the samples were mounted on microscope slides for identification to species.

2.2. Spotted tentiform leafminer

At the petal fall stage, fruit clusters were sampled for first generation leafminer sapfeeding mines (Nyrop et al., 1989, 1990). This procedure used sequential sampling of three leaves on each of three fruit clusters from a maximum of seven trees per orchard. Pheromone traps were hung to determine the timing of the second generation flight, and terminal leaves were sampled in early July for sapfeeding mines at approximately 380 degree days (DDs, base 6 °C) after the first male moth catch (Schmaedick and Nyrop, 1993); leaves were sampled again in early August for mines of the third generation. An application of imidacloprid was recommended for any above-threshold infestations (1 mine/leaf for the first generation, 2 mines/leaf for the second and third). A sample of up to 100 leaves with mines was collected from each orchard for the first and second generation each year, and mines were dissected to determine parasitism rates by hymenopterous parasitoids.

2.3. Obliquebanded leafroller

To monitor larval populations during the season, 10 fruit clusters (during the petal fall period) or foliar terminals (in July) per tree on 10 trees per orchard were inspected for infestation by larvae of the overwintered and first summer generation, respectively, using sequential sampling and a 3% infestation threshold (Agnello et al., 1994a, 1999, 2001). Foliar terminals were sampled in 1996 for larval infestations on 10 July and repeated weekly for the remainder of the month. Sampling in 1997 was conducted twice at the end of July, and in 1998, once on 13 July. The insect growth regulator tebufenozide was used each year. For all three seasons, beginning in mid- to late-June, three sprays were recommended on a 14-day schedule against the first summer generation. This timing corresponded with the anticipated first hatch date of eggs according to the pheromone trap catches of leafroller adults in the orchards, starting at approximately 165 DD (base 6 °C) after the first sustained flight (Onstad et al., 1985), with the subsequent sprays intended for 275–330 and 440–500 DD. In 1998 only (owing to a change in its regulatory status), one application was recommended additionally at petal fall against the overwintering generation.

2.4. Other insects

Samples of 10 fruit clusters on each of 10 trees were taken at the pink bud stage each year for rosy apple aphid (*Dysaphis plantaginea* [Passerini]), using a 1% infestation threshold. At petal fall (approximately mid-May each year), phosmet or azinphosmethyl was recommended as a preventive measure to control plum curculio (*Conotrachelus nenuphar* [Herbst]) and codling moth (*Cydia pomonella* [L.]). At fruit set, 1–2 weeks later, fruit was thinned using a spray that included carbaryl, which additionally controls first generation white apple leafhopper (*Typhlocyba pomaria* McAtee) nymphs.

In mid-June, sticky red spheres baited with butyl hexanoate lures were hung in the trees at a rate of 3/block, to monitor ovipositing apple maggot (*Rhagoletis pomonella* [Walsh]) females. Traps were checked twice weekly through August, and an application of phosmet or azinphosmethyl was recommended when the mean catch/trap surpassed 5 flies (Agnello et al., 1990).

Beginning in mid-June each year, fruit and foliar clusters were examined on a 7–10-day basis by sampling 10 clusters in each of 10 trees per block to determine the presence of apple aphid (*Aphis pomi* De Geer) and spirea aphid (*Aphis spiraecola* Patch) colonies and any predaceous insects associated with them. Additionally, on several dates between mid-May and mid-August, foliar beating was conducted in each orchard by striking two branches on each of 10 trees per block over a frame. All insects dislodged were collected, preserved in 70% ethanol, and brought to the laboratory for identification to family to assess the presence of generalist predators in the different blocks.

2.5. Apple scab and summer diseases

A schedule of sterol inhibitor fungicides such as myclobutanil, triflumizole or fenarimol was used to control apple scab (*Venturia inaequalis* [Cooke] Wint.), with applications recommended at the tight cluster bud, pink bud, petal fall and first cover spray timings (Wilcox et al., 1992). A captan protectant was included in some or all of the sprays when high inoculum or other infections occurred. Although an ethylene bis-dithiocarbamate (EBDC) fungicide (mancozeb) was used once in Orchard A and twice in Orchard B during the latter part of the 1996 season, this class of fungicide was minimised and limited to the prebloom period during the final two seasons because of concern over possible detrimental effects on the predator mites (Baynon and Penman, 1987; Frisch, 1988). For summer diseases, applications of benomyl, thiophanate-methyl, or ziram were recommended in late June to mid-August for control of sooty blotch (*Gloeodes pomigena* [Schwein.] Colby) and flyspeck (*Schizothyrium pomi* [Mont. & Fr.] Arx) as necessitated by summer weather patterns and microclimatic conditions.

2.6. Statistical analysis

Cumulative densities of European red mite and phytoseiids were analysed using repeated measures analysis of variance to determine whether there were differences among IPM and comparison blocks, across time, and due to the interaction between time and the two management programmes (Stata Press, 1999). Mean leafminer mine parasitism rates, percent aphid infestation and predator incidence, and percent fruit damage at harvest were transformed using arcsine square root and compared using an analysis of variance and Fisher's Protected LSD test (Abacus Concepts, 1991).

3. Results and discussion

3.1. European red mites and phytoseiids

Because of high tree variability in the distribution of overwintering phytoseiid mites (Nyrop et al., 1994), the pre-season Berlese samples were used to assess species incidence rather than differences in mean densities among the orchards. Very few phytoseiids were obtained from the samples taken in 1996 (Table 2); these results were not unexpected, as previous studies had established that predatory mite levels are characteristically low in commercial New York orchards (Weires and Smith, 1979; Nyrop et al., 1994). A total of 32 specimens were recovered from all the orchards, of which 23 were *A. fallacis*, five were *T. pyri*, and four were either unidentifiable or another *Typhlodromus* species. *A. fallacis* traditionally is not as prevalent as *T. pyri* in western New York. Predator mite surveys in this part of the state identify *T. pyri* as being the more predominant species, with *A. fallacis* occupying a secondary position in importance, owing to the ability of *T. pyri* to survive on alternate food sources such as pollen and fungal conidia, and its higher overwintering survival (Walde et al., 1992; Nyrop et al., 1994, 1997). Predator mites were absent at four of the sites, including both the IPM and comparison blocks of Orchard B.

The pre-season twig and spur samples collected in 1997 and 1998 indicated the presence of *T. pyri* in every block (both IPM and comparison), and constituting a greater percentage of total phytoseiid numbers those years than at the beginning of the study. These results are consistent with a *T. pyri* population that had been relatively stable at the end of the previous growing season and then passed the winter with nominal mortality. Because *A. fallacis* was also present in two of the blocks in 1998, it is possible that a relatively greater proportion of the *A. fallacis* populations left the trees during the 1997 growing season because of a lack of the phytophagous prey mites that constitute the main source of food for this species.

European red mite summer populations were relatively low in 1996, owing to wet and cold early season weather that prevented numbers from building up until late in the season. All the participating growers were able to apply the summer oil sprays as advised, and *P. ulmi* densities remained below the seasonally adjusted thresholds in all IPM orchards except for Orchard A, where an extra summer oil spray was applied on 2 August after the 7.5/leaf threshold was surpassed (Fig. 1a). Mite numbers also surpassed the (5.0/leaf) threshold in the Orchard B comparison block on 16 July, but the grower elected not to apply an acaricide (Fig. 1b). Not all predator mite specimens found were identifiable to species, but from those that could be determined, *T. pyri* was present in at least some summer samples from all IPM blocks in 1996 except Orchard B (Table 2).

In 1997, after a cold and rainy spring, weather conditions during the summer were eventually favourable for the development of populations of both pest and predatory mites. All the blocks, both IPM and comparison, attained season-long mite control with

Table 2
Presence[a] (1996) or numbers of phytoseiid mites collected (1997–1998) in four apple orchards in New York State

Orchard	Apple twigs (pre-season samples)						Apple leaves (summer samples)					
	1996		1997		1998		1996		1997		1998	
	A.f.[b]	T.p.[c]	A.f.	T.p.	A.f.	T.p.	A.f.	T.p.	A.f.	T.p.	A.f.	T.p.
A-IPM	4	0	1	2	0	102	+	+	1	113	0	28
A-comp[d]	19	1	3	52	0	13	+	−	0	2	4	3
B-IPM	0	0	7	12	9	123	−	−	6	25	0	44
B-comp	0	0	9	4	8	23	+	−	0	3	1	18
C-IPM	0	0	1	3	0	33	−	+	0	64	0	42
C-comp	0	3	2	77	0	3	+	+	0	35	0	49
D-IPM	0	1	0	54	0	122	−	+	0	55	0	64
D-comp	0	0	5	67	0	113	+	+	0	43	0	51

[a] +, present; −, absent.
[b] *Amblyseius fallacis*.
[c] *Typhlodromus pyri*.
[d] Comparison.

no above-threshold counts recorded (Fig. 1c and d). In the case of the IPM blocks, this resulted from the combination of the prebloom ovicide application and the resident predator mites, which reached maximum densities in individual orchards ranging from 0.8 to 3.3 motiles per leaf (Fig. 1c); nearly all of these specimens proved to be *T. pyri* (Table 2).

A very early and warm spring in 1998 provided weather conditions conducive to the development of populations of both pest and predatory mites. All the IPM blocks again achieved acceptable season-long mite control with no above-threshold counts recorded, except for one localised edge section of Red Delicious trees adjacent to a wooded area in the Orchard A IPM block. Because some of the foliar samples taken on 14 August were collected from these trees, the mean mite density on this date did exceed the threshold of 7.5/leaf (Fig. 1e); however, because this was the final mite sampling date, and European red mite densities in the remainder of the orchard remained very low, no acaricide treatment was recommended. The Orchard B comparison block also showed over-threshold mite numbers at the end of the sampling period (Fig. 1f), despite the fact that an acaricide had been applied earlier in the season.

European red mites in the IPM blocks during 1998 were controlled exclusively by the resident predatory mites, which reached maximum densities ranging from 0.6 to 1.3 motiles per leaf in individual orchards (Fig. 1e). A resampling of the three edge rows of Red Delicious in Orchard A showed a mean density of 1.8 *T. pyri* motiles per leaf at the time, which was unfortunately not sufficient to prevent some foliar bronzing in these trees.

There were no differences in European red mite densities between the management programmes, among years, or due to an interaction between programmes and years. The similarity in cumulative densities is shown in Fig. 2a. In all the blocks, mite densities remained well below the recommended tolerable level of 500 mite-days (Lakso et al., 1996; Agnello et al., 2001). In contrast to European red mite numbers, cumulative densities of phytoseiids were higher in the IPM blocks ($F = 6.48$, d.f. $= 1.6$, $P = 0.004$) and varied among years ($F = 8.11$, d.f. $= 2.12$, $P < 0.01$ [Huynh-Feldt epsilon $= 1.0$]). There was no significant interaction between management programmes and time, although a plot of the data (Fig. 2b) suggests that there were no differences among the two management programmes during the first year. This would be a sensible pattern, as it usually requires more than one year to realise a change in *T. pyri* numbers following adoption of a conservation strategy.

Even though predatory mites were seeded in the IPM blocks for two consecutive years (1996 and 1997), it cannot be assumed that all of the *T. pyri* found in these orchards were necessarily a result of population growth of the released mites, as only a small proportion of trees were actually seeded, and the dispersal of this species has been shown to be a gradual process

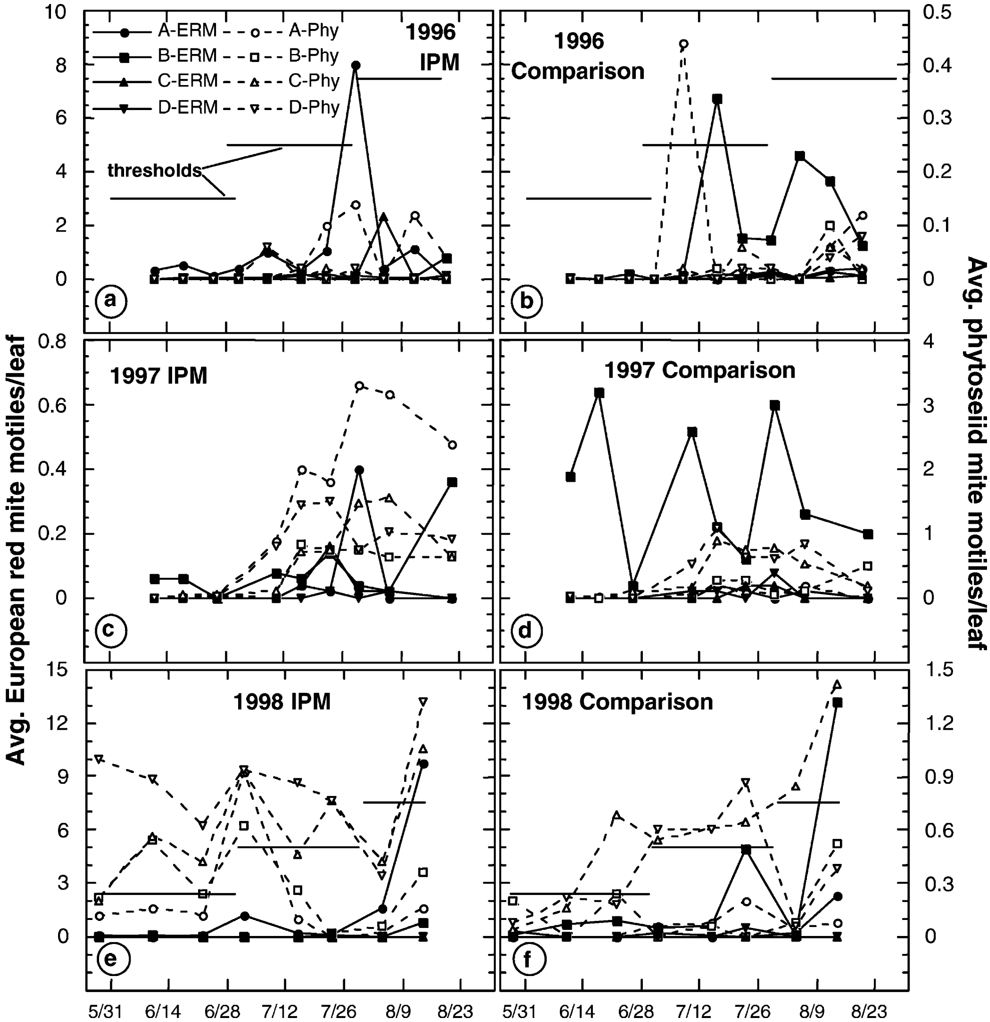

Fig. 1. European red mite (ERM) and predatory phytoseiid (Phy) mite densities in foliar samples during the summer in IPM and comparison blocks in four apple orchards in New York State, 1996–1998.

(Prokopy et al., 1997). However, the high predator counts during the 1998 season do support the observations of others (Nyrop, 1991; Blommers, 1994) that a stable phytoseiid population is attainable if it is not disrupted by use of pesticides detrimental to these species.

3.2. Spotted tentiform leafminer

Spotted tentiform leafminer populations were relatively light in these orchards for the duration of this study, and no above-threshold infestations were ever detected in any block. However, number of mines from the first and second generations were sufficient to collect samples each year for dissection to determine the percent parasitism by braconid and eulophid wasps. Very few first generation mines could be found the first 2 years of this study, except for Orchard A in 1996 and Orchard B in 1997, and parasitism levels in individual blocks never exceeded 30% for the first generation and about 50% for the second. No statistical differences in mean parasitisation levels between IPM and comparison blocks were found any year for either generation.

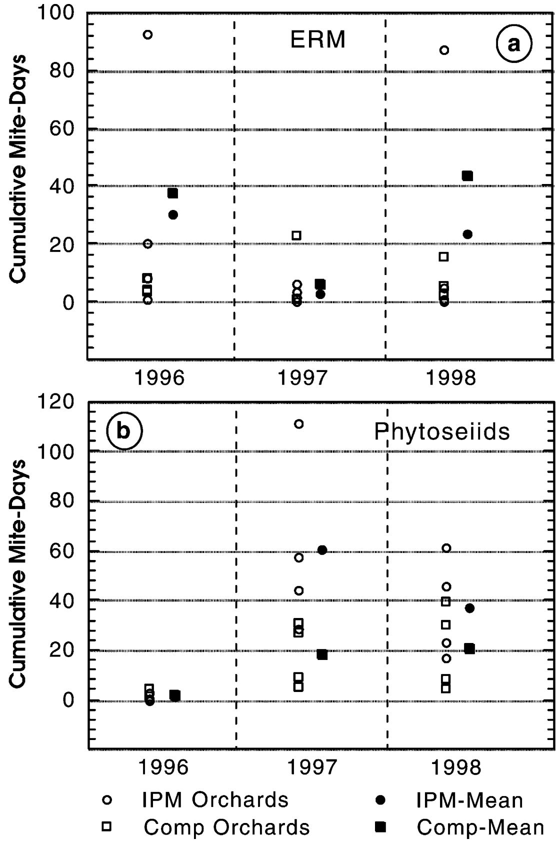

Fig. 2. Cumulative mite-days of European red mites (ERM) and predatory phytoseiid mites from foliar samples collected during the summer in IPM and comparison blocks in four apple orchards in New York State, 1996–1998.

3.3. Aphids

Green aphid populations in 1996 were highest during June and August in all orchards, but rescue sprays (applied in all blocks except Orchard B IPM) and predator populations provided effective control. Infestations, ranging from 9 to 13%, and predator numbers (present on less than 1% of terminals) were statistically equivalent in the two treatments. In 1997, aphid populations were highest beginning the second week of July in all orchards, and although infestation levels, averaging approximately 15%, and predator incidence, on 4–7% of terminals, were similar in all blocks, the Orchard A IPM block had a larger number of predator species than the comparison. Only syrphids (hover flies) were found in the comparison block, and usually only the egg stage, but by mid-July the predators in the Orchard A IPM block samples comprised syrphids plus cecidomyiids (midges), coccinellids (lady beetles), chrysopids (lacewings) and spiders, including nymphal and adult forms of all insect families.

The highest populations of aphids in 1998 occurred either in mid-June or at the end of July. There was again no difference in percent infested terminals (15–20%) or predator incidence (rarely present on >1% of terminals) between IPM blocks and their respective comparisons, but the number of predator species in the IPM blocks was higher than in the comparison blocks in Orchard A (cecidomyiids, syrphids, coccinellids and chrysopids as opposed to only syrphids), Orchard B (cecidomyiids and coccinellids, versus none), and Orchard C (coccinellids and chrysopids, compared with coccinellids only).

3.4. Foliar beating samples

Because of variability in specimen numbers between taxonomic groups collected and number of sample sessions each year, results were examined in terms of different taxa represented. Very few specimens were obtained in any of the four foliar beating samples in 1996, and only a small percentage of the taxa found were generalist predators. Those collected included Anthocoridae (minute pirate bugs), Reduviidae (assassin bugs), Chrysopidae (lacewings) and various spiders. Numbers of taxa obtained the next 2 years were generally higher than in the 1996 samples, and the diversity of groups represented across all orchards appears to have increased over the three seasons in all blocks (1996, 21 families in 8 orders; 1997, 29 families in 9 orders; 1998 64 families in 13 orders), including spiders, Coccinellidae (lady beetles), Formicidae (ants), Forficulidae (earwigs), Nabidae (damsel bugs), Carabidae (ground beetles), Cleridae (checkered beetles), and several hymenopterous parasitoids (Braconidae and Chalcididae).

3.5. Obliquebanded leafroller

All orchards in 1996 except the Orchard D comparison block had foliar infestations above the threshold during the summer. Because of tebufenozide's mode of action, larvae that reach the newly expanding

Table 3
Incidence of fruit disease and insect damage at harvest in IPM and comparison (comp) blocks in four apple orchards in New York State, 1996–1998 (% ±SEM[a])

Orchard (variety)	Clean fruit	Apple fruit scab	Obliquebanded leafroller	Tarnished plant bug	Flyspeck
1996					
A-IPM (Red Delicious)	90.3 (1.3) a	0.0 (0.0) a	5.5 (0.3) a	1.0 (0.6) a	1.5 (0.7) a
A-comp (Red Delicious)	90.0 (1.7) a	0.0 (0.0) a	5.5 (1.6) a	2.8 (1.0) a	1.5 (0.7) a
B-IPM (Rome-North)	98.0 (0.4) a	0.0 (0.0) a	0.8 (0.8) a	1.0 (0.4) a	0.0 (0.0) a
B-comp (Rome-North)	90.0 (1.6) b	0.0 (0.0) a	9.5 (1.7) b	0.5 (0.5) ab	0.0 (0.0) a
B-IPM (Rome-South)	98.3 (0.8) a	0.0 (0.0) a	1.0 (0.4) a	0.5 (0.3) ab	0.0 (0.0) a
B-comp (Rome-South)	98.8 (0.9) a	0.0 (0.0) a	1.3 (0.9) a	0.0 (0.0) b	0.0 (0.0) a
C-IPM (Jerseymac)	97.0 (0.4) a	0.0 (0.0) a	1.8 (0.5) a	0.3 (0.3) a	0.0 (0.0) a
C-comp (Jerseymac)	98.3 (0.9) a	1.0 (0.7) a	0.5 (0.3) a	0.0 (0.0) a	0.0 (0.0) a
C-IPM (Empire)	99.3 (0.3) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a
C-comp (Empire)	94.5 (1.3) a	0.0 (0.0) a	0.0 (0.0) a	0.0 (0.0) a	4.3 (1.7) b
D-IPM (Cortland)	87.5 (2.3) a	0.8 (0.5) a	6.3 (1.5) a	0.0 (0.0) a	0.3 (0.3) a
D-comp (Cortland)	66.0 (6.0) b	12.3 (7.1) a	1.8 (0.5) a	0.0 (0.0) a	20.8 (1.1) b
1997					
A-IPM (Red Delicious)	87.5 (1.7) a	0.0 (0.0) a	11.5 (1.3) a	0.3 (0.3) a	0.5 (0.3) a
A-comp (Red Delicious)	89.0 (1.2) a	0.3 (0.3) a	9.8 (1.1) a	0.5 (0.5) a	0.0 (0.0) a
B-IPM (Red Delicious)	96.0 (0.9) a	0.5 (0.3) a	3.3 (0.8) a	0.0 (0.0) a	0.3 (0.3) a
B-comp (Red Delicious)	97.5 (0.9) a	0.0 (0.0) a	2.3 (1.0) a	0.0 (0.0) a	0.3 (0.3) a
C-IPM (Jerseymac)	96.3 (0.9) a	0.3 (0.3) a	3.0 (0.8) a	0.3 (0.3) a	0.0 (0.0) a
C-comp (Jerseymac)	98.8 (0.8) a	0.3 (0.3) a	1.0 (0.6) a	0.0 (0.0) a	0.0 (0.0) a
C-IPM (Empire)	96.5 (1.8) a	0.8 (0.3) a	2.5 (0.9) a	0.0 (0.0) a	0.0 (0.0) a
C-comp (Empire)	97.8 (0.5) a	1.3 (1.3) a	0.8 (0.5) a	0.0 (0.0) a	4.3 (1.7) b
D-IPM (Cortland)	83.3 (3.1) a	0.0 (0.0) a	14.5 (3.0) a	0.0 (0.0) a	1.0 (0.0) a
D-comp (Cortland)	88.0 (1.3) a	1.0 (0.7) a	5.5 (1.3) b	0.0 (0.0) a	6.0 (1.1) b
1998					
A-IPM (Red Delicious)	86.5 (4.4) a	4.5 (2.1) a	4.8 (0.6) a	0.0 (0.0) a	0.0 (0.0) a
A-comp (Red Delicious)	88.5 (1.0) a	3.0 (0.7) a	7.5 (1.7) a	0.0 (0.0) a	0.0 (0.0) a
B-IPM (Red Delicious)	88.8 (1.0) a	0.3 (0.3) a	3.8 (0.9) a	0.0 (0.0) a	0.0 (0.0) a
B-comp (Red Delicious)	75.3 (2.4) b	0.5 (0.3) a	10.0 (3.0) a	0.0 (0.0) a	0.0 (0.0) a
C-IPM (Jerseymac)	81.0 (3.5) a	0.3 (0.3) a	17.5 (3.1) a	0.0 (0.0) a	0.0 (0.0) a
C-comp (Jerseymac)	69.8 (2.6) b	1.0 (0.6) a	29.3 (2.2) b	0.0 (0.0) a	0.0 (0.0) a
C-IPM (Empire)	92.3 (1.7) a	0.0 (0.0) a	5.5 (1.3) a	0.0 (0.0) a	0.0 (0.0) a
C-comp (Empire)	81.3 (3.7) a	0.8 (0.5) a	10.8 (0.5) a	0.0 (0.0) a	0.0 (0.0) a
D-IPM (Cortland)	76.8 (5.1) a	3.3 (0.8) a	17.5 (4.9) a	0.0 (0.0) a	0.0 (0.0) a
D-comp (Cortland)	70.8 (4.1) a	15.5 (4.8) b	14.8 (2.6) a	0.0 (0.0) a	0.0 (0.0) a

[a] Values are mean % damage in 100 apples from each of four trees per treatment in each plot. ANOVA done individually for each damage type within each plot, with means separation on arcsine square root-transformed values. Within each year, orchard and variety, values followed by same letter are not significantly different ($P < 0.05$; Fisher's protected LSD test).

terminals are not affected by sprays of this material until they get to the fruits. Despite the uniformly high foliar infestations in the IPM blocks, subsequent fruit damage by obliquebanded leafroller at harvest was considerably less than anticipated (Table 3). In Orchard B, which was evaluated in two sections to minimise any differences due to unequal pest pressure in the northern (>30-year-old trees) versus southern (<10-year-old trees) halves, fruit damage was less in the north IPM than its comparison block ($F = 15.43$, d.f. $= 3.9$, $P < 0.001$; Fisher's Protected LSD test). In all other cases, damage levels between management programmes in 1996 were similar.

In 1997, most orchards (except for the Orchard B comparison block) once again exhibited more than the 3% larval infestation threshold on both sampling dates. Fruit damage at harvest was higher in the Orchard D IPM block than in the comparison (Table 3; $F = 8.21$, d.f. $= 1.6$, $P = 0.03$).

All IPM orchards received an application of tebufenozide during the petal fall period (15–18 May) of 1998. Above-threshold terminal infestations occurred in all plots except for the Orchard D comparison block. Fruit damage at harvest in the IPM blocks was lower (Orchard C-Jerseymac; $F = 9.40$, d.f. $= 1.6$, $P = 0.02$) or equal to that in the comparison blocks (Table 3), although all damage levels were higher than acceptable injury (Agnello et al., 1994b).

3.6. Other pests

Adult apple maggot catches never reached the treatment threshold in any of the IPM blocks except for the Orchard A IPM site in 1998 (5.0/trap; 10 August), but preventive sprays of azinphosmethyl and chlorpyrifos were still elected by the growers in most cases, normally during the first half of August, when the peak flight period of this insect occurs (Reissig and Tette, 1979). Similar applications, and often more of them (Table 1), were made in the comparison blocks at these sites. No evidence of fruit damage or infestation by this insect was found in any of the harvest evaluations for the duration of this study.

Samples for rosy apple aphid turned up very low numbers (1997: 1% infestation, Orchard C comparison; 2%, Orchard D IPM; 1998: 1%, Orchard D IPM; zero in all other cases), and a pink treatment for this pest was recommended only in the Orchard D IPM block in 1997 and 1998. No white apple leafhopper infestations warranting treatment were noted in any of the orchards.

Clean fruit ratings at harvest each year tended to reflect the amounts of leafroller and flyspeck damage seen in the respective blocks, as these were generally the categories with the most damage (Table 3). However, clean fruit levels in the IPM blocks were always as high as or higher than those in the comparisons. Non-significant amounts of damage were seen at various times in both treatments from plum curculio, tarnished plant bug, and rosy apple aphid. Apple fruit scab control was generally very good in all IPM blocks during this study, but the standard programme failed to control apple scab in two cases, when >10% damage was seen in the Orchard D comparison in 1996 and 1998 (Table 3).

4. Conclusions

A major objective of this study was to establish a stable population of predatory phytoseiid mites capable of effecting biological control of European red mite in four commercial fresh fruit orchards. This objective was achieved in the generally accepted (Nyrop, 1991; Blommers, 1994; Prokopy et al., 1997) minimum period of three growing seasons.

In 1996, seed populations of *T. pyri* mites were introduced and subsequently detected at low levels in three of the four blocks. Twig and branch samples taken in the spring of 1997 showed *T. pyri* to be present in every block, but there was concern over detrimental effects of the fungicides used during the first season. The disease control strategy was therefore modified to a captan/sterol inhibitor/thiophanate-methyl programme in 1997, and the predators were re-seeded in the programme blocks. Due to the presence of *T. pyri* in all the IPM block Berlese samples in 1998, all early season acaricide applications were suppressed that year.

Orchard B was ideally set up to compare the IPM management programme with a grower standard. The Berlese samples in 1996 turned up no predator mites from either side, and none were detected in the IPM half during the summer foliage samples. Some *T. pyri* were found in the 1997 Berlese samples, but summer foliar populations were negligible until mid-July, when they jumped to 0.8 motiles per leaf, and stayed high for the remainder of the season. Summer levels in 1998 never exceeded 0.6 per leaf, but European red mite numbers remained close to 0 for most of the season; in contrast, the comparison rows immediately adjacent suffered notable bronzing damage from above-threshold infestations, despite the application of a pyridaben rescue treatment in late June. Some *T. pyri* had been in the trees at the start of the season, but they evidently did not survive the non-selective insecticide applications.

Insect pest control in the IPM blocks was comparable to that in the comparison blocks, but usually no better than the growers' standard programmes in managing obliquebanded leafroller. Programmes based on selective pesticides are generally more expensive than conventional approaches. Growers tend to compensate for more expensive materials by applying low rates (e.g., imidacloprid and tebufenozide in Table 1), a practise intended to balance economics and risk that does not always have the desired consequences.

Obliquebanded leafroller remains the most problematic pest in western New York. Tebufenozide used against both generations may occasionally be more effective than alternative programmes, but cross-resistance has already been identified in this and related species (Wearing, 1998; Waldstein et al., 1999). It would be desirable for the growers to maintain the populations of beneficial arthropods in their IPM blocks for an indefinite period and some of the principles used in these four orchards, which are applicable to pest management programmes in commercial orchards.

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