

Effects of Two Sterol-Inhibiting Fungicides on Populations of Pest and Beneficial Arthropods on Apple

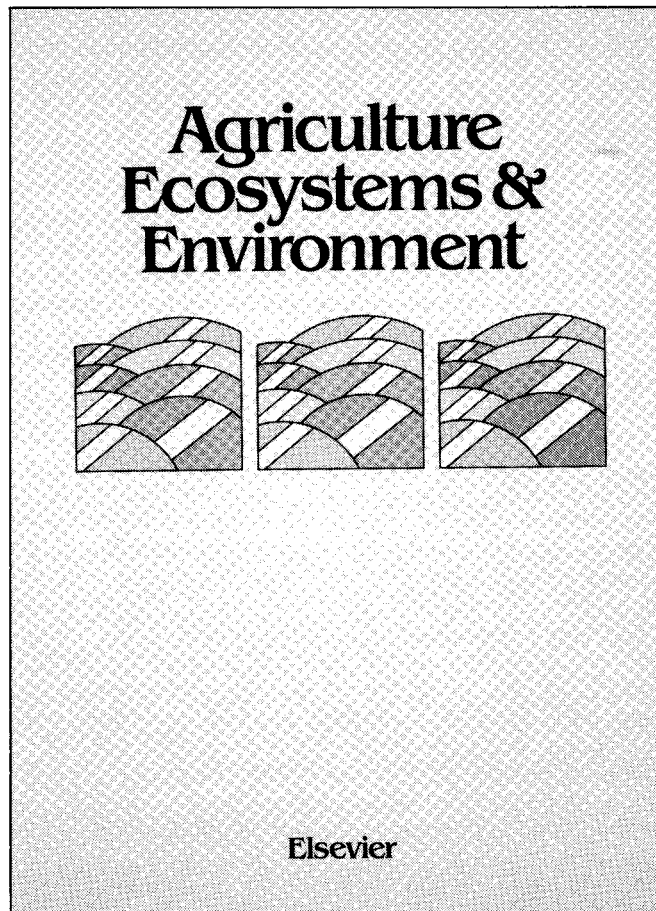
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(Accepted for publication 10 December 1987)

ABSTRACT

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This research demonstrated that sterol-inhibiting fungicides alter the population structure of some pest and beneficial arthropods in apple orchards. Orchard populations of European red mite, *Panonychus ulmi* (Koch) (Acarina: Tetranychidae); the predacious mite, *Typhlodromus caudiglans* Schuster (Acarina: Phytoseiidae); the spotted tentiform leafminer, *Phyllonorycter blancardella* Fabr. (Lepidoptera: Gracillariidae); the leafminer parasite *Pholetesor ornigis* Weed (Hymenoptera: Braconidae); the green apple aphid, *Aphis pomi* DeGeer (Homoptera: Aphididae); white apple leafhopper, *Typhlocyba pomaria* McAtee (Homoptera: Cicadellidae); *Campylomma verbasci* Meyer (Hemiptera: Miridae); chalcids, primarily *Sympiesis sericeicornis* Nees (Hymenoptera: Chalcididae), were monitored for two growing seasons in a McIntosh apple orchard that had received applications, at 2-week intervals, of two sterol-inhibiting fungicides, bitertanol and flusilazole. High rates of flusilazole were associated with increased numbers of European red mite and decreased numbers of predacious mite species, particularly *T. caudiglans*. Trees receiving a high rate of bitertanol had fewer European red mites and predacious mite species. Fungicides did not influence spotted tentiform leafminer oviposition or the number of leafminer larvae in May and June 1985. However, in September 1985 there were fewer leafminer pupae in plots treated with the two lower rates of flusilazole and more larvae in plots treated with the high rate of bitertanol, relative to trees sprayed with captan. In 1986, there were more leafminer eggs in plots treated with the low rate of bitertanol compared with captan and non-sprayed trees. However, by 24 June, all treatments showed similar levels of leafminer larvae and pupae. Populations of *P. ornigis* were generally higher in trees treated with flusilazole in both years. Numbers of aphids and mullein bug were higher in trees treated with flusilazole relative to non-sprayed and captan-treated trees. Chalcid populations were higher in bitertanol-treated trees. Fungicides had no apparent effect on populations of white apple leafhopper.

INTRODUCTION

Fungicides are used in apple orchards primarily for control of apple scab and powdery mildew. Researchers and growers have long recognized the potential

of some fungicides to provide control of arthropod pests, particularly phytophagous mites (Acarina: Tetranychidae). The fungicides sulfur, benlate and dinocap are known to suppress phytophagous mites (Lord, 1949; Morgan et al., 1958; Childers and Enns, 1975). The use of such fungicides was thought to offer a method of reducing the costs of orchard spray programs (Morgan et al., 1958). In addition to their direct or indirect effects on phytophagous arthropods, some fungicides have been shown to be detrimental to beneficial species (Pickett et al., 1946; Pickett, 1949; Ripper, 1956; Nakashima and Croft, 1974; Childers and Enns, 1975). For example, use of sulfur as a fungicide led to increases in populations of phytophagous mites because of specific suppression of the predacious mite species normally found in orchards and vineyards (Pickett et al., 1946; Pickett, 1949). It is for this reason that sulfur is not recommended for use in Ontario pome and stone-fruit IPM programs. In areas where fungicides have been a major portion of the orchard spray program, selecting fungicides that were harmless to predatory species alleviated problems in controlling some phytophagous species (Lord, 1949).

The impact on arthropods of the introduction of sterol-inhibiting (SI) fungicides into established apple pest-management programs is unknown, although the literature suggests some beneficial effects. For example, triforine was reported to suppress European red mite (ERM) (*Panonychus ulmi* (Koch)), (Gilpatrick et al., 1972) and was considered to have no effect on the predacious mite *Amblyseius fallacis* (Garman) (Acarina: Phytoseiidae) (Jones and Croft, 1974). Spotts and Hall (1979) also reported that bitertanol appeared to suppress ERM populations, although other reports have not confirmed this observation (Rosenberger et al., 1982).

Very few investigations into the effects of fungicides on orchard arthropods have been verified statistically. Of over 60 reports published in "Fungicide and Nematicide Tests" pertaining to the effects of fungicides on mites, only 6 reports in the past 23 years were accompanied by statistical analyses.

Knowledge of the effects of fungicides on orchard arthropods is essential to the development and maintenance of effective apple IPM programs. The objective of this study was to monitor beneficial and deleterious insect and mite populations in field plots treated regularly with two SI fungicides.

MATERIALS AND METHODS

The fungicides used in both 1985 and 1986 were bitertanol (Baycor 50 WP, Chemagro Ltd., Mississauga, Ont.) at 16.8 and 8.4 g active ingredient (a.i.) per 100 l of water, flusilazole (NuStar 400 EC (1985) and 20 F (1986) (formerly DPX H 6573), DuPont Canada Inc., Mississauga, Ont.) at 1.4, 2.7 and 5.4 g a.i. per 100 l of water, and captan (Captan 50 WP, Stauffer Chemical Co., Stoney Creek, Ont.) at 70 g a.i. per 100 l of water.

Experiments were conducted in an orchard of semi-dwarf McIntosh trees on

TABLE I

Influence of fungicides on numbers of *P. ulmi* and *T. caudiglans* on foliage of McIntosh apple trees in 1986

Treatment and rate (g a.i. per 100 l)	<i>P. ulmi</i> ¹			<i>T. caudiglans</i>		
	9 May '86	26 May '86	7 July '86	9 May '86	26 May '86	7 July '86
Non-sprayed	10.9 ^{de2}	0.8 ^b	0.0 ^c	1.0	0.1	0.2 ^b
Captan (70)	44.7 ^b	7.4 ^a	0.2 ^{ab}	0.9	0.0	0.3 ^a
Bitertanol (8.4)	38.3 ^{bc}	7.0 ^a	0.2 ^{bc}	0.6	0.0	0.4 ^a
Bitertanol (16.8)	7.2 ^e	1.6 ^b	0.1 ^{bc}	1.9	0.1	0.1 ^{bc}
Flusilazole (1.4)	26.3 ^{cd}	6.8 ^a	0.2 ^b	0.8	0.1	0.2 ^b
Flusilazole (2.7)	26.7 ^{cd}	2.2 ^b	0.1 ^{bc}	1.6	0.1	0.0 ^{cd}
Flusilazole (5.4)	63.8 ^a	5.5 ^a	0.4 ^a	0.6	0.0	0.0 ^d

¹For 9 May 1986, number of mites per clusters from 10 clusters per tree, 5 trees per treatment per block. For 26 May 1986, number of mites per leaf from 5 leaves per tree, 5 trees per treatment per block. For 7 July 1986, number of mites per leaf from 10 leaves per tree, 5 trees per treatment per block.

²Means with different letters in columns denote significant differences according to Duncan's multiple range test ($P=0.05$). Columns without superscripts indicate a nonsignificant F -test ($P=0.05$).

M. 26 rootstock planted in 1976 and spaced at 2.4 × 4.9 m. Seven 5-tree plots were arranged in four blocks using a randomized complete block design. Guard trees were positioned between treated trees and between blocks (rows) to reduce spray drift. Fungicides were sprayed until runoff (c. 8.0 l per tree) with a handgun attached to a John Bean plot sprayer operating at 2760 kPa.

In 1985, fungicides were applied on 7 and 21 May, 3 and 19 June, 11 and 30 July and 10 August. In addition, flusilazole was applied on 3 September. Azinphosmethyl (Guthion 50 WP, 0.15 kg per 100 l) and phosmet (Imidan 50 WP, 0.31 kg per 100 l) were applied to the entire orchard for control of the codling moth, *Cydia pomonella* (L.), and the plum curculio, *Conotrachelus nenuphar* W., on 4 June and 17 July, respectively. In 1986, trees were sprayed with the same fungicides at the same rates as in 1985 except that captan was excluded from the former bitertanol plus captan treatment thus providing two rates of bitertanol alone. Fungicides were applied at approximately 14-day intervals on 13 and 27 May, 11 and 25 June, 9 and 23 July and 6 and 20 August. No insecticides were applied during this period.

Apple scab incidence was determined monthly, in both years, by examining 10 terminals per tree in each treatment for the presence of lesions on any terminal leaves. Spearman's rank correlation procedure (Steel and Torrie, 1980) was used to examine the statistical relationship between disease incidence and insect populations at each sampling time (Tables I–VIII). The test was conducted by correlating the ranks of the fungicide treatments according to

TABLE II

Influence of fungicides on oviposition and numbers of larvae and pupae of *P. blancarcella* on foliage of McIntosh apple trees in 1985

Treatment and rate (g a.i. per 100 l)	Eggs ¹	Larvae ²		Pupae ²
	10 May	11 June	30 Sept	30 Sept
Non-sprayed	0.2	0.3	4.2 ^{c3}	18.2 ^{abc}
Captan (70)	0.4	0.4	6.4 ^b	22.4 ^a
Bitertanol (8.4) + captan (70)	0.2	0.3	6.6 ^b	20.0 ^{ab}
Bitertanol (16.8)	0.2	0.3	8.8 ^a	18.8 ^{abc}
Flusilazole (1.4)	0.3	0.2	5.4 ^{bc}	16.9 ^{bc}
Flusilazole (2.7)	0.4	0.2	6.9 ^b	14.2 ^c
Flusilazole (5.4)	0.3	0.3	5.8 ^{bc}	19.4 ^{ab}

¹Mean number of eggs per cluster, data collected from 10 clusters per treatment per block.

²Mean larvae or pupae per leaf, data collected from 20 leaves per tree per treatment per block.

³Means followed by different superscripts in columns are significantly different according to Duncan's multiple range test ($P=0.05$). Columns without superscripts indicate a non-significant F -test ($P=0.05$).

TABLE III

Influence of fungicides on oviposition, and numbers of larvae and pupae of *P. blancarcella* on foliage of McIntosh apple trees in 1986

Treatment and rate (g a.i. per 100 l)	Eggs ¹	Larvae ²		Pupae ²	
	9 May	24 June	29 July	24 June	29 July
Non-sprayed	1.8 ^{b3}	4.4	3.4 ^d	3.9	2.8 ^b
Captan (70)	2.6 ^b	4.3	5.9 ^c	4.7	5.2 ^a
Bitertanol (8.4)	5.6 ^a	3.6	7.9 ^{ab}	5.2	5.2 ^a
Bitertanol (16.8)	3.4 ^{ab}	4.4	9.3 ^a	4.5	4.4 ^a
Flusilazole (1.4)	2.0 ^b	5.3	7.0 ^{bc}	3.8	4.7 ^a
Flusilazole (2.7)	2.8 ^b	5.8	9.4 ^a	3.5	5.1 ^a
Flusilazole (5.4)	3.8 ^{ab}	4.8	8.2 ^{ab}	3.9	4.7 ^a

¹For oviposition, number of eggs on 2 clusters per tree, 5 trees per treatment per block.

²For 24 June, number of larvae or pupae per leaf from 10 leaves per tree, 5 trees per treatment per block. For 29 July, number of larvae or pupae per leaf from 5 leaves per tree, 5 trees per treatment per block.

³Means with different superscripts in columns are significantly different according to Duncan's multiple range test ($P=0.05$). Columns without superscripts indicate a non-significant F -test ($P=0.05$).

TABLE IV

Influence of fungicides on percentage of larvae of *P. blancarcella* parasitized by *P. ornigis* on foliage of McIntosh apple trees in 1985 and 1986

Treatment and rate (g a.i. per 100 l)	<i>P. ornigis</i> ¹			
	12 June '85	30 Sept '85	24 June '86	29 July '86
Non-sprayed	43.1	7.6 ^{b2}	26.8 ^b	13.6 ^{ab}
Captan (70)	21.5	6.2 ^b	20.5 ^c	10.4 ^b
Bitertanol ³ (8.4) + captan (70)	34.2	8.4 ^b	20.7 ^c	13.8 ^{ab}
Bitertanol (16.8)	32.0	7.4 ^b	24.9 ^{bc}	11.4 ^{ab}
Flusilazole (1.4)	38.9	6.8 ^b	33.4 ^a	10.9 ^{ab}
Flusilazole (2.7)	46.6	13.6 ^a	36.5 ^a	15.1 ^a
Flusilazole (5.4)	33.2	6.2 ^b	36.3 ^a	18.4 ^a

¹For 24 June 1986 larvae or pupae parasitized by percentage of *P. ornigis*, data collected from 10 leaves per tree, 5 trees per treatment per block; for 30 Sept 1985 and 29 July 1986, data collected from 5 leaves per tree, 5 trees per treatment per block.

²Means with different superscripts in columns are significantly different according to Duncan's multiple range test ($P=0.05$). Columns without superscripts indicate a non-significant F -test ($P=0.05$).

³The lower rate of bitertanol was used alone in 1986.

TABLE V

Influence of fungicides on percentage of parasitism of *P. blancarcella* larvae by chalcidoids, primarily *S. sericeicornis* and *S. marylandensis* on foliage of McIntosh apple trees in 1985 and 1986

Treatment and rate (g a.i. per 100 l)	Chalcidoids ¹		
	30 Sept '85	24 June '86	29 July '86
Non-sprayed	5.3	4.6	5.6 ^{b2}
Captan (70)	9.2	2.1	6.2 ^b
Bitertanol ³ (8.4) + captan (70)	7.8	5.0	12.0 ^a
Bitertanol (16.8)	9.4	1.8	11.8 ^a
Flusilazole (1.4)	8.7	3.7	6.6 ^b
Flusilazole (2.7)	7.9	4.5	7.4 ^b
Flusilazole (5.4)	8.4	3.9	8.2 ^b

¹For 30 Sept 1985 and 29 July 1986 percentage of leaves with chalcids from 5 leaves per tree, 5 trees per treatment per block; for 24 June 1986, percentage of leaves with chalcids from 5 leaves per tree, 5 trees per treatment per block.

²Superscripts in columns denote significant differences according to Duncan's multiple range test ($P=0.05$). Columns without superscripts indicate a non-significant F -test ($P=0.05$).

³The lower rate of bitertanol was used alone in 1986.

TABLE VI

Influence of fungicides on numbers of *C. verbasci* on foliage of McIntosh apple trees in 1986

Treatment and rate (g a.i. per 100 l)	<i>C. verbasci</i> ¹	
	2 June	13 June
Non-sprayed	2.8	1.7 ^{b2}
Captan (70)	3.6	2.1 ^b
Bitertanol (8.4)	3.6	2.3 ^{ab}
Bitertanol (16.8)	2.8	2.9 ^{ab}
Flusilazole (1.4)	2.2	3.2 ^{ab}
Flusilazole (2.7)	3.2	4.0 ^a
Flusilazole (5.4)	3.9	2.6 ^{ab}

¹Number of *C. verbasci* on 5 terminals per tree, 3 trees per treatment per block.²Superscripts in columns denote significant differences according to Duncan's multiple range test ($P=0.05$). Columns without superscripts indicate a non-significant *F*-test ($P=0.05$).

TABLE VII

Influence of fungicides on numbers of *A. pomi* on foliage of McIntosh apple trees in 1985 and 1986

Treatment and rate (g a.i. per 100 l)	1985 ¹					1986 ²			
	11 June	19 June	27 June	9 July	26 July	22 Aug	2 June	13 June	7 July
Non-sprayed	1.1	10.5 ^{ab3}	15.6 ^b	19.6 ^c	0.1	0.5 ^b	4.1	0.1	12.0
Captan (70)	2.6	4.8 ^b	36.1 ^{ab}	19.5 ^c	0.0	0.8 ^b	4.1	1.1	29.9
Bitertanol ⁴ (8.4) + captan (70)	2.2	15.8 ^a	68.3 ^a	76.7 ^{abc}	0.1	0.2 ^b	4.8	1.8	20.2
Bitertanol (16.8)	1.1	9.2 ^{ab}	23.6 ^b	25.9 ^{bc}	16.8	2.6 ^a	2.3	1.2	26.1
Flusilazole (1.4)	1.6	6.1 ^b	30.4 ^{ab}	20.8 ^c	1.2	0.0 ^b	3.1	2.3	20.7
Flusilazole (2.7)	1.0	3.6 ^b	10.3 ^b	86.6 ^{ab}	0.2	0.0 ^b	1.8	0.5	10.2
Flusilazole (5.4)	2.0	8.7 ^{ab}	37.0 ^{ab}	109.1 ^a	0.0	0.8 ^b	2.2	1.3	16.2

¹For 1985, total number of aphids per terminal, from 5 terminals per tree, 3 trees per treatment per block.²For 1986, total number of aphids on 5 terminals per tree, 3 trees per treatment per block.³Superscripts in columns denote significant differences according to Duncan's multiple range test ($P=0.05$). Columns without superscripts indicate a non-significant *F*-test ($P=0.05$).⁴The lower rate of bitertanol was used alone in 1986.

monthly apple-scab incidence and numbers of insects (or percentage parasitism by *P. ornigis* and chalcidoids) at each measurement time.

The arthropods listed below were monitored at irregular intervals during the 1985 and 1986 growing seasons: European red mite; the predacious mite, *Typhlodromus caudiglans* Schuster (Acarina: Phytoseiidae); the spotted tentiform leafminer, (*Phyllonorycter blancardella* Fabr., Lepidoptera: Gracillariidae); the leafminer parasites *Pholetesor ornigis* (Weed), (Hymenoptera:

TABLE VIII

Influence of fungicides on numbers of *T. pomaria* on foliage of McIntosh apple trees in 1985 and 1986

Treatment and rate (g a.i. per 100 l)	<i>T. pomaria</i> ¹			
	12 Aug '85	9 May '86	22 May '86	13 June '86
Non-sprayed	1.9	0.1	1.4	1.0
Captan (70)	1.8	0.1	1.0	0.8
Bitertanol ² (8.4) + captan (70)	2.2	0.1	1.0	1.0
Bitertanol (16.8)	1.6	0.1	0.8	0.6
Flusilazole (1.4)	1.9	0.2	1.3	1.0
Flusilazole (2.7)	2.1	0.2	1.3	0.9
Flusilazole (5.4)	2.2	0.2	1.0	0.4

¹For 12 August 1985, number of WALH per cluster, data collected from 2 clusters per tree, 5 trees per treatment per block. For 9 and 22 May 1985, number of WALH per leaf, data collected from 5 leaves per tree, 5 trees per treatment per block. For 13 June 1986, number of leafhoppers per leaf, data collected from 5 terminals per tree, 5 trees per treatment per block. None of the sampling yielded a significant treatment effect ($P=0.05$).

²The lower rate of bitertanol was used alone in 1986.

Braconidae) and the chalcidoids, primarily *Sympiesis sericeicornis* (Nees) and *S. marylandensis* Girault, (Hymenoptera: Chalcididae); the green apple aphid (*Aphis pomi* DeGeer, Homoptera: Aphididae); white apple leafhopper (*Typhlocyba pomaria* McAtee, Homoptera: Cicadellidae); the mullein bug, *Campylomma verbasci* Meyer (Hemiptera: Miridae). The sampling varied depending on the number of arthropods observed in preliminary samples. The sampling procedures are listed as footnotes in the appropriate tables.

All data were subjected to analysis of variance with means separated using Duncan's multiple range test ($P=0.05$) (Steel and Torrie, 1980). Data for percentage parasitism by *P. ornigis* and the chalcidoids were transformed to arcsin percentage prior to analyses (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Flusilazole was associated with decreased levels of the predacious mite, *T. caudiglans*, on 7 July 1986 (Table I). Trees treated with 2.7 and 5.4 g a.i. per 100 l flusilazole had smaller populations of *T. caudiglans* relative to all other treatments. Reduction in numbers of predacious mites could be a practical concern in orchards where flusilazole is the dominant fungicide. Levels of ERM were highest in trees treated with 5.4 g of flusilazole when examined on 9 May and 7 July 1986. The lowest populations of ERM were associated with non-sprayed trees and trees treated with 16.8 g a.i. per 100 l bitertanol (9 May, 26 May and 7 July 1986). These data suggest that this rate of bitertanol may

suppress ERM. The low rate of bitertanol (8.4 g a.i. per 100 l) and captan did not suppress *T. caudiglans*. Bitertanol has been reported previously to have a suppressive effect on ERM (Spotts and Hall, 1979). Triforine has been shown to suppress ERM on apple foliage (Gilpatrick et al., 1972) without affecting *A. fallacis*.

There are no previous reports on the influence of fungicides on the spotted tentiform leafminer (STLM), and its parasites *P. ornigis*, *S. sericeicornis* and *S. marylandensis* or on mite and aphid predators such as *C. verbasci*. Fungicides did not influence STLM oviposition or numbers of larvae in June 1985 (Table II). However, in September, there were more larvae in trees treated with the high rate of bitertanol compared to all other fungicide treatments and the non-sprayed trees. In addition, there were fewer leafminer pupae in plots treated with the two lower rates of flusilazole, compared with plots treated with captan. In 1986, more STLM eggs were deposited in plots treated with the lower rate of bitertanol relative to captan and non-sprayed trees (Table III) although, on 24 June, all treatments showed similar levels of larvae and pupae. On 29 July, there were more larvae on trees treated with the highest rate of bitertanol and the moderate rate of flusilazole.

Of the 43 rank correlations to examine the possibility of an association between disease incidence and arthropod numbers, the only significant finding occurred for the 29 July 1986 data for numbers of STLM larvae. There was a significant negative correlation between disease severity and number of larvae (Spearman's $r = -0.75$, $t = 2.54$, $P = 0.05$, 5 d.f.). Where the least apple scab infections occurred, more STLM larvae were found. There was no measurable effect of SI fungicides on numbers of STLM pupae in 1986. All fungicide treatments had more pupae in mines relative to non-sprayed trees.

In addition to having an influence on populations of STLM, SI fungicides were also related to variations in the occurrence of STLM parasites and predators. On 30 September 1985, there was greater parasitism by *P. ornigis* in trees treated with the moderate rate of flusilazole, compared with all other treatments and non-sprayed trees (Table IV). In 1986, on 24 June, there was increased parasitism in trees treated with all three rates of flusilazole. This effect continued to 29 July when trees treated with the 2.7 and 5.4 g a.i. per 100 l of flusilazole exhibited increased levels of parasitism relative to captan-treated trees.

There was no apparent effect of fungicides on the percent parasitism of STLM larvae by the chalcidoids *S. sericeicornis* and *S. marylandensis* on 30 September 1985 and 24 June 1986 (Table V). By 29 July 1986, more chalcidoids were observed in both bitertanol treatments compared with all other treatments and non-sprayed trees.

Although *C. verbasci* was monitored in 1986 only, on 13 June the numbers of this insect were greater in trees treated with 2.7 g of flusilazole than on the captan-treated or non-sprayed trees (Table VI).

Flusilazole was associated with increased parasitism of STLM by *P. ornigis* and increased numbers of *C. verbasci*. Flusilazole, at all rates, was generally associated with increased numbers of STLM (Table II, 12 July and Table III, 29 July) and, consequently, increased levels of parasitism by *P. ornigis*, particularly in the first leafminer generation in 1986 (Table IV, 24 June). Bitertanol and captan treatments had little effect on parasitism of STLM by *P. ornigis*; although, the former fungicide was associated with increased levels of parasitism by chalcidoids in July 1986.

In the present study, levels of aphids were increased in plots treated with 2.7 and 5.4 g per 100 l of flusilazole in early July 1985, a year that was extremely favourable for aphid infestations on many crops in Ontario (Table VII). No significant increases in aphid populations were observed in 1986. Increased green aphid levels on potato have been associated with the suppression of fungi pathogenic to aphids by captafol, mancozeb and Bordeaux mixture (Nanne and Radcliff, 1971). However, other studies have shown that fungicides have little effect on field populations of aphids (Wilding, 1982). It is not known whether the increased numbers of aphids observed in the present study were caused by fungicidal effects on aphid pathogens or by a subtle effect on plant metabolism leading to an increased susceptibility to aphids. Some SI fungicides have been shown to have plant growth-regulator activity (Fletcher and Hofstra, 1985).

Populations of *C. verbasci* were also higher in trees treated with 2.7 g per 100 l flusilazole in 1986. Fungicides did not influence numbers of the white apple leafhopper in either year (Table VIII). There were no previous reports of this insect being affected by fungicides.

In summary, this research has demonstrated that SI fungicides alter the population structure of some pest and beneficial arthropods in apple orchards. The introduction of these materials into apple pest-management programs should be preceded by examinations of their effects on local arthropod populations.

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