Predators associated with the twospotted spider mite, *Tetranychus urticae*, on strawberry at Abbotsford, B.C., and development of non-chemical mite control

D.A. RAWORTH
AGRICULTURE CANADA RESEARCH STATION
6660 N.W. MARINE DRIVE
VANCOUVER, B.C. CANADA V6T 1X2

ABSTRACT

Populations of the twospotted spider mite, *Tetranychus urticae* Koch on strawberry were sampled from 1983-86. The predaceous mite, *Amblyseius fallacis* (Garman), was predominant. Active adults were observed in February and November, earlier in the spring and later in the autumn than any other predator. *Amblyseius fallacis*, cecidomyiid flies of *Aphidoletes* sp. and the ladybird beetle, *Stethorus punctum picipes* Csy., all responded numerically to introductions of the twospotted mite but *A. fallacis* responded to the greatest degree. The rate of increase of *A. fallacis* on a $\log_e$ scale was 1.0335 ± 0.0621 per 100 degree-days above 4C (DD_4) in the spring and summer, and 0.5481 ± 0.0845 per 100 DD_4 in late summer, about 2.1× and 1.6× per week on an arithmetic scale. Slide dip tests showed that populations of *A. fallacis* in the Lower Fraser Valley were resistant to the chemical compounds cyhexatin, endosulfan and malathion, partially resistant to diazinon and very susceptible to carbofuran, demeton, dicofol and dimethoate. Biocontrol of *T. urticae* is discussed in the context of integration with the chemical control of aphids, and predator release rates.

INTRODUCTION

The twospotted spider mite, *Tetranychus urticae* Koch, has long been a sporadic problem on cultivated strawberry, *Fragaria* x *ananassa* Duch., in the Lower Fraser Valley. Although miticides have been used to regulate this pest, researchers and extension workers have thought for some time that alternative methods of mite control should be developed. Work was initiated in 1983 to determine an economic threshold for *T. urticae* on strawberry (Raworth 1986a), to develop simple sampling methods that can be used by pest managers (Raworth and Merkens 1987), and to develop a management plan for the pest (Raworth and Strong 1990). To date, however, there has been no satisfactory alternative method for regulating twospotted mites on strawberry. This paper presents data about natural predators that have been found on strawberry during the previous studies and discusses biocontrol strategies.

MATERIALS AND METHODS

Twospotted Mite Introductions and Field Samples.

A 0.54 ha field of 'Totem' strawberries was planted at Abbotsford 3-6 May, 1983. The crowns were 60 cm apart within rows and 120 cm between rows. Runners were allowed to propagate, forming a 'matted row.' The field was sprayed once with diazinon every April for aphid control and with simazine (Simadex 500 F) each autumn for weed control. No other pesticides were applied. *Tetranychus urticae* was mass-reared in the laboratory for field introductions by splitting one mite-infested leaflet between every eight leaflets of potted strawberry plants and allowing the populations to increase for 10–14 days at 22°C. On 19 May, 1983 every second plant in the field was infested with twospotted mites. Samples of 900 leaflets were collected every 2 weeks and processed with a mite brushing machine. Unknown mites and insects were saved in 90% EtOH and sent to the Biosystematics Research Centre for identification. In 1984 the field was divided into 16 plots, each consisting of seven 7-m matted rows. Plots were separated from each other by 10 m of untreated field. Twospotted mites were introduced into the plots at different rates during 1984–86 (Table 1). Accurate counts of the twospotted mite and its associated predators in each plot were made by collecting mature leaflets at random, holding them at 4°C, and examining them later with a 12× stereomicroscope. The average number of

Table 1

Introduction levels of the twospotted spider mite, *Tetranychus urticae*, and the predatory mite, *Phytoseiulus persimilis*, replication, experimental design, and sample sizes per replicate on each sampling date

Trial	Treatment	Rate (Mite infested leaflets per plot)[1]	Reps	Design[2]	Introduction Date (D/M/Y)	*Sample sizes per rep* Mite sample No. leaflets	Plant sample No. quadrats
1.	*T. urticae*	0:42:126:378	4	RCB	26/4/84	35	7
2.	*T. urticae*	140	16		26/4/85		
	P. persimilis	0:28:84:168	4	RCB	2/5/85	35	7
3.	*T. urticae*	0:294	4	R	7/5/86	70	7
4.	*T. urticae*	0:450	2	R	2/7/86	70	7

1. These rates apply only to *T. urticae*. Rates for *P. persimilis* are the number of adult predators on *P. persimilis*-infested leaflets, per plot. *Phytoseiulus persimilis* eggs and immatures were also introduced on the leaflets.
2. RCB—Randomized complete block; R—Completely randomized.

mature leaves in 30 cm of row was also determined for each plot by using quadrats (Table 1). Densities of mites and insects were expressed as numbers per row-meter. The sample data were transformed using natural logarithms and analyzed by ANOVA, setting sample-day as a split-plot. Standard errors were calculated from the residual variation used to test treatment differences. Data were analyzed only for species that consistently appeared in the samples. An index of total numbers for each species during the season, "*T. urticae*-days" and "predator-days," was derived by interpolating the geometric mean number of each species for each day between samples, and summing the estimates for the whole sample period.

Resistance of the predatory mite, *Amblyseius fallacis* (Garman) to Pesticides. During 1986, 10 commercial fields were sampled for twospotted mites. *Amblyseius fallacis* was found in five of the fields between Langley and Agassiz. Collections from four of these locations were maintained in isolated cultures and tested for resistance to field rates of eight pesticides (Table 2) that were commonly used to control pests of strawberry. The slide-dip methodology followed Anonymous (1968) and the modification of Croft et al. (1976), but with 10 *A. fallacis* females per slide rather than 50. The proportion of females alive 48 h after exposure to a pesticide was transformed by arc-sine square-root and analyzed by ANOVA. Duncan's New Multiple Range Test was used to separate means.

Table 2

Proportion of adult female *Amblyseius fallacis* surviving, 48 h after exposure to a pesticide mixed at a concentration equivalent to the maximum recommended field rate (Anonymous 1986). Each replicate 'n' tested survivorship of 10 females

Pesticide	Class[1]	Concentration (ppm)	Proportion alive[2]	n	S.E.[3]	Proportion alive[4]
demeton (Systox SC; 240 g/L)	OP	500	0.0 a	12	4.193	0.0
dimethoate (Cygon 480 E)	OP	1600	0.0 a	8	5.135	0.0
carbofuran (Furadan 480 F)	C	1100	2.30a	8	5.135	0.0016
dicofol (Kelthane EC; 18.5%e.c.)	OC	400	13.5 a	8	5.135	0.054
diazinon (Diazinon 50 EC)	OP	900	48.4 b	16	3.631	0.56
endosulfan (Thiodan 4 E)	OC	800	66.3 c	16	3.631	0.84
cyhexatin (Plictran 50 W)	OT	600	69.3 c	16	3.631	0.88
malathion (Malathion 50 EC)	OP	1200	69.9 c	16	3.631	0.88
distilled water			78.3 c	28	2.745	0.96

1. C—carbamate; OC—organochlorine; OP—organophosphate; OT—organotin
2. Data transformed by arc-sine square-root. Means followed by different letters are significantly different ($p < 0.01$) according to Duncan's New Multiple Range Test.
3. Standard errors given in transformed scale
4. Means back-transformed to original scale

Table 3
Natural predators collected from 'Totem' strawberry leaflets that were infested with the twospotted spider mite, *Tetranychus urticae*, at Abbotsford, British Columbia

Predator name		Date
ACARI: MESOSTIGMATA		
Phytoseiidae	*Amblyseius andersoni* (Chant)	2 Aug. 1983
	A. fallacis (Garman)	30 Aug. 1983
	A. isuki Chant & Hansell	2 Aug. 1983
	A. okanagensis (Chant)	31 May 1985
	Typhlodromus pyri Scheuten	2 Aug. 1983
ACARI: PROSTIGMATA		
Anystidae	*Anystis* sp.	20 June 1985
Bdellidae	*Thoribdella* nr. *simplex*	4 July 1984
COLEOPTERA:		
Coccinellidae	*Stethorus punctum picipes* Csy.	19 July 1984
DIPTERA:		
Cecidomyiidae	*Aphidoletes* sp.	4 July 1984

RESULTS

Twospotted Mite Introductions and Field Samples.

Seven species of predaceous mites and two of predaceous insects were found to occur naturally (Table 3). The introduction levels of twospotted mites in 1984 resulted in significantly different population levels of the pest ($p < 0.01$, Fig.1), the predatory mite, *A. fallacis* ($p < 0.01$, Fig.2), a cecidomyiid fly of *Aphidoletes* sp. ($p < 0.05$, Fig.3) and a ladybird beetle, *Stethorus punctum picipes* Csy. ($p < 0.05$, Fig.4). No twospotted mites or predators were seen in three samples of 60 leaflets collected from the field prior to the experiment (27 March, 10 and 24 April). *Amblyseius fallacis* and larvae of *Aphidoletes* sp. appeared simultaneously in the mid-June sample. The beetle larvae appeared in the next sample, but the eggs had been seen in the mid-June sample, indicating predation on

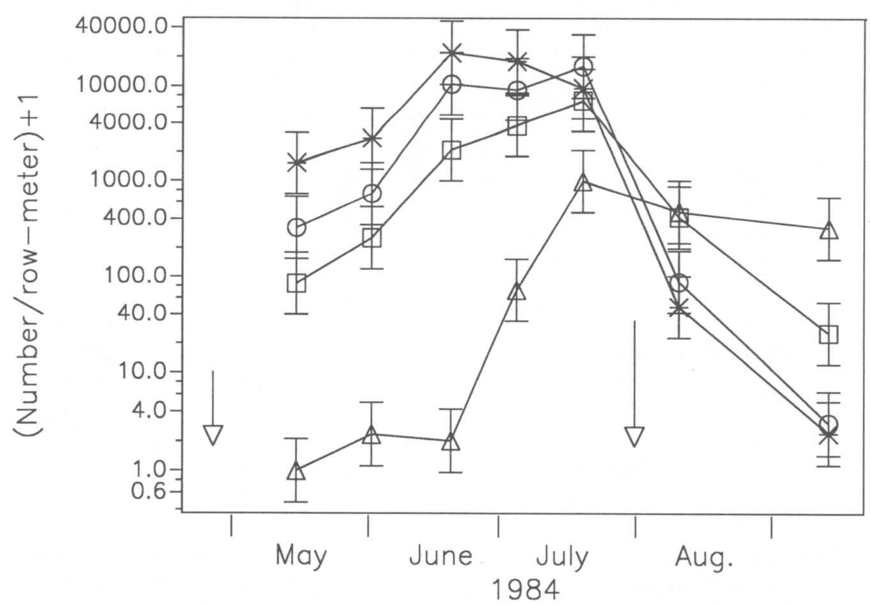

Fig 1. Population trends of *Tetranychus urticae* in 1984 at four introduction levels (high—asterisk; medium—circle; low—square; control—triangle. See Table 1). Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

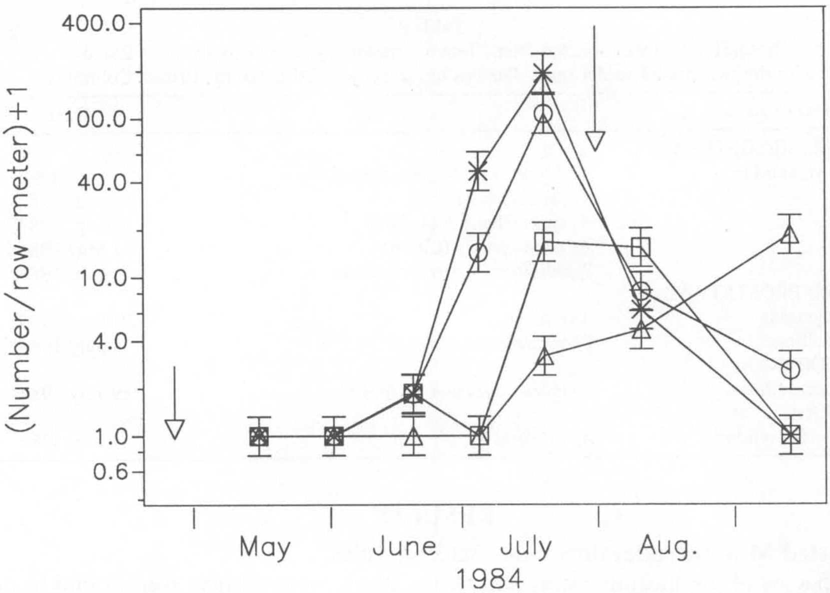

Fig. 2. Population trends of *Amblyseius fallacis* in 1984 at four introduction levels of twospotted mites (high—asterisk; medium—circle; low—square; control—triangle. See Table 1). Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

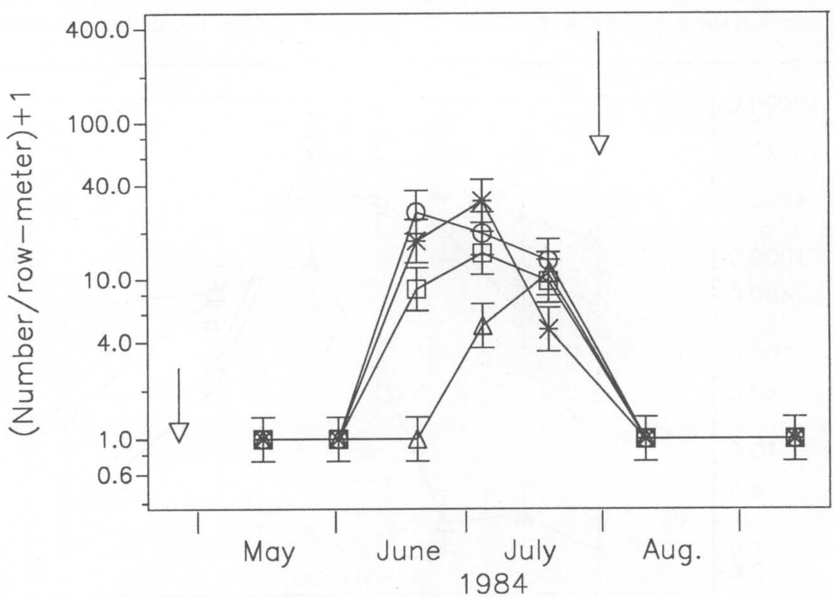

Fig. 3. Population trends of *Aphidoletes* sp. larvae in 1984 at four introduction levels of twospotted mites (high—asterisk; medium—circle; low—square; control—triangle. See Table 1). Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

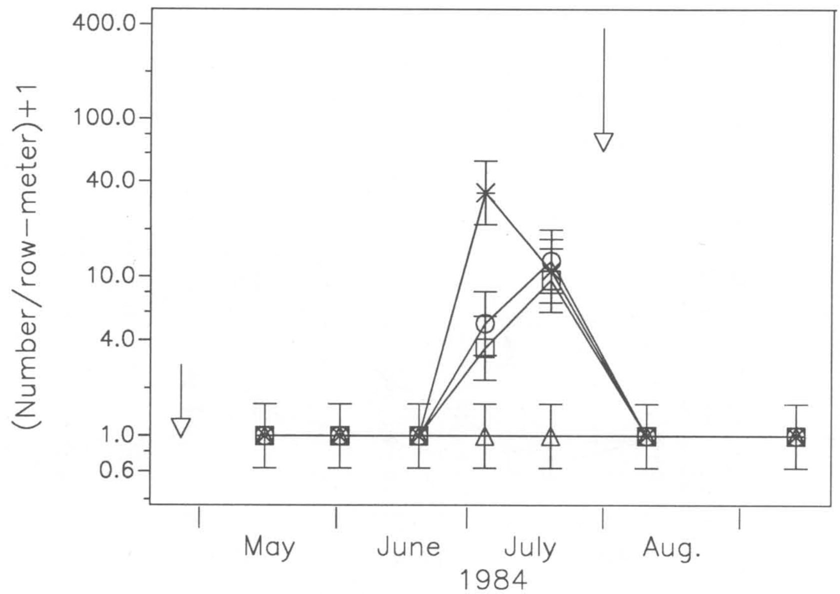

Fig. 4. Population trends of larvae of *Stethorus punctum picipes* in 1984 at four introduction levels of twospotted mites (high—asterisk; medium—circle; low—square; control—triangle. (See Table 1.) Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

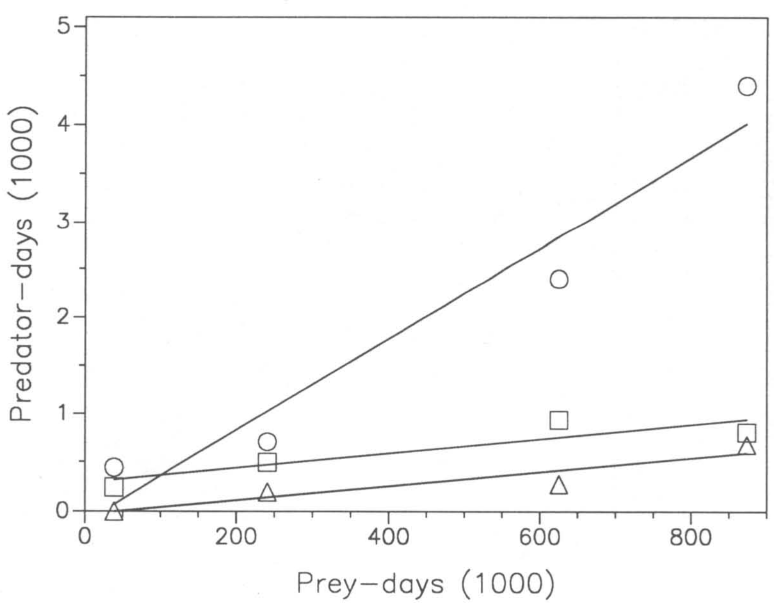

Fig. 5. The number of predator-days (*Amblyseius fallacis*—circle; *Aphidoletes* sp. larvae—square; and *Stethorus punctum picipes* larvae—triangle) as a function of twospotted-mite-days. The overall within-species regression was statistically significant ($p<0.01$ $r=0.714$ 8df), and the slopes of the individual regressions were significantly different ($p<0.01$; *A. fallacis* 0.0047; *Aphidoletes* sp. 0.00075; and *S. punctum picipes* 0.00071 where ±1 SE =0.0005009).

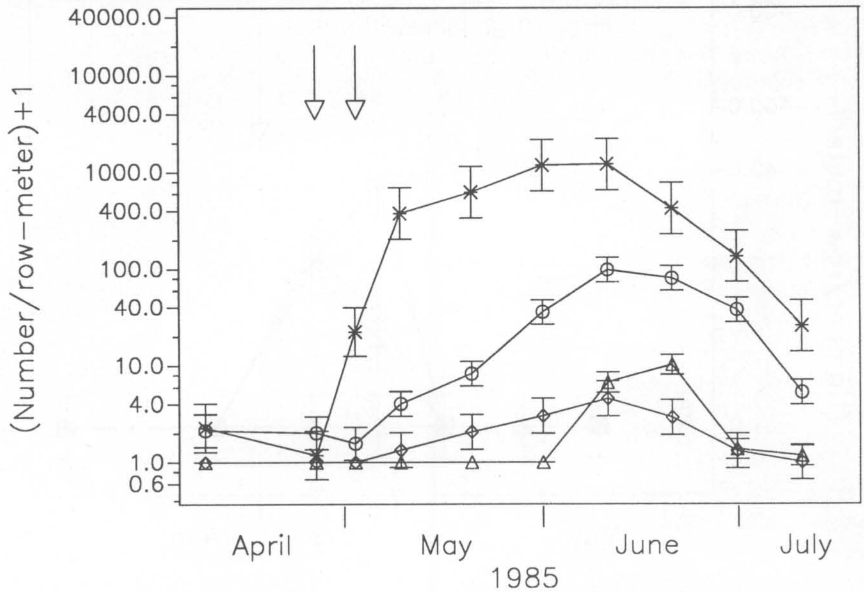

Fig. 6. Population trends of: *Tetranychus urticae*—asterisk; *Amblyseius fallacis*—circle; *Phytoseiulus persimilis*—diamond; and *Stethorus punctum picipes* larvae—triangle, in 1985. Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the introduction of *P. persimilis.*

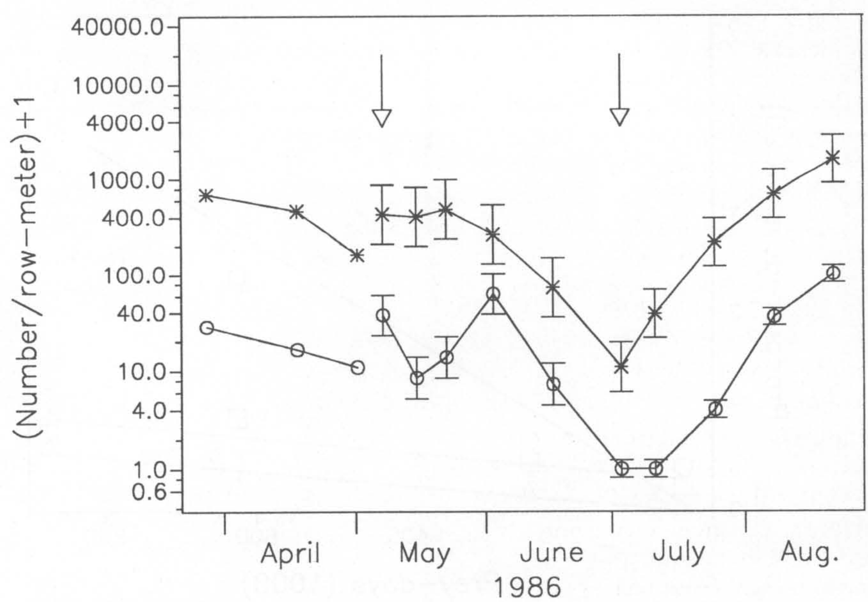

Fig. 7. Population trends of: *Tetranychus urticae*—asterisk; and *Amblyseius fallacis*—circle, in 1986. Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the first introduction of twospotted mites and the right arrow, the second introduction.

twospotted mites by adults. Only *A. fallacis* was observed in the autumn samples. The response of *A. fallacis* in terms of accumulated predator-days at different levels of twospotted mites was significantly greater than that of the other two species (Fig.5). Twospotted mites overwintered in the field in 1985, and *A. fallacis* appeared in the samples before any other predator (Fig. 6). Analysis of the sample data prior to the introduction of the pest indicated that there was no carry-over effect of the 1984 treatments with respect to the prey or predator ($p > 0.05$). Analysis of the sample data after the introduction of the predator mite, *Phytoseiulus persimilis* Athias-Henriot, suggested that there were no detectable effects from its various introduction levels ($p > 0.05$). The numbers of twospotted mites and associated predators in the 16 plots were therefore pooled. Population levels of *A. fallacis* were much higher than those of *P. persimilis* and *S. punctum picipes* (Fig.6). Only one *Aphidoletes* sp. larva was seen on 560 leaflets on 10 June, and three on 30 June. The presence of eggs of the ladybird beetle indicated predation on twospotted mites by adult beetles from 20 May to 30 June. Active *A. fallacis* were collected in field samples as late as 15 November. *Phytoseiulus persimilis,* a tropical species, did not overwinter successfully to the spring of 1986.

In 1986, *A. fallacis* was collected in a field sample on 16 February. The average number per row-m in March-April, 17.2 (+5.56, −4.21) (Fig. 7), was higher than the number observed in April 1985 (Fig. 6). Introductions of twospotted mites in May and July failed to produce significantly different population trends relative to control plots ($p>0.05$), despite the fact that the release rates were equivalent to those of the medium-to-high density treatments of 1984 (Table 1). The data for the treatments and controls were therefore pooled (Fig. 7). Only four *S. punctum picipes* larvae were observed on 560 leaflets on 2 June, and three were observed on 16 June. However, the presence of eggs of the ladybird beetle indicated adult predation on the twospotted mites from 22 May to 7 August. One *Aphidoletes* sp. larva was observed on 16 June. The *A. fallacis* population trend followed that of the twospotted mites from April through August.

Amblyseius fallacis was the predominant predator of *T. urticae* over the 3 years. The rate of increase of *A. fallacis* in each treatment in 1984, and in each experiment in 1985–86 was determined as the slope of the regression of ln(mean number per row-m) against degree-days above 4°C (DD_4) (Table 4). Although there was a statistically significant relationship between the rate of increase of *A. fallacis* and the average density of twospotted mites during the time when *A. fallacis* was increasing in 1984, the data for 1985–86 did not support the relationship. The two lowest rates of increase were observed during August and September and these were significantly different from the rates observed during May, June and July ($p<0.05$). Based on an overall regression, the average rate of increase of *A. fallacis* per 100 DD_4 during spring and early summer was 1.0335 ±0.0621, while that during late summer and early autumn was 0.5481 ±0.0845. These rates were equivalent to a population increase of 2.1× and 1.6× per week [$e^{(b \times time/100)}$]: where 'b' is the slope of the regression line and 'time' is DD_4 per week (about 70 DD_4 per week from May to July and 85 from August to mid-September).

Resistance of the predatory mite, *A. fallacis* to Pesticides.

There were no differences in pesticide resistance with respect to the origin of *A. fallacis* ($p > 0.05$), but there were differences in resistance to the different pesticides (Table 2). Carbofuran, demeton, dicofol and dimethoate were very toxic, whereas cyhexatin, endosulfan, and malathion had little effect. Diazinon was intermediate. There did not appear to be any cross-resistance between pesticides within similar chemical groups.

Table 4

Rates of increase of *Amblyseius fallacis*, calculated as the slope of the regression of ln(mean per row-m) against degree-days above 4C (DD_4). The geometric mean density of twospotted mites during the period of *A. fallacis* increase was also determined

Year	Months	Treatment	Rate per 100 DD_4	(± SE)	Density of twospotted mites per row-m
1984	July - Sept.	Control	0.5299	0.1104	535
	June - July	Low	0.7822	0.2175	3861
	June - July	Medium	1.1128	0.2175	11555
	June - July	High	1.2597	0.2175	15589
1985	May - June	Pooled	1.0012	0.1967	376
1986	May	Pooled	0.9897	0.3780	373
	July - Aug.	Pooled	0.6048	0.1952	625

DISCUSSION

Several predator species were associated with twospotted mites on strawberry but one, *A. fallacis*, has a number of qualities that make it potentially useful as a biological control agent: it successfully overwinters; it may be found associated with its prey from early spring until late autumn; it responds numerically to population increases of twospotted mites, with a rate of increase equivalent to that of the prey in commercial fields (Raworth and Strong 1990); it is resistant to a number of pesticides; and it can be reared in the laboratory throughout the year. However, the data presented do not indicate how effective *A. fallacis* was at regulating twospotted mites because there were no controls in which predators were excluded. Experimental releases of mass-reared *A. fallacis* are needed. A basic problem with releasing predaceous mites to control *T. urticae* is that the predators are usually exposed to pesticides applied to control aphids. Aphids vector virus diseases that substantially reduce yields (Mellor and Krczal 1987) and are of great concern to growers. In the past, endosulfan, diazinon and malathion were used to control aphids. *Amblyseius fallacis* has some resistance to these compounds (Table 2), but recently, many growers have preferred to control aphids with a systemic such as demeton, which is highly toxic to *A. fallacis*. Integration of *A. fallacis* releases into the current cultural system may be possible by artificially selecting for resistance to specific pesticides (Hoy 1982). Alternatively, because aphid numbers increase most in the spring (Shanks 1965), systemic sprays could be used before harvest, and a spray-free period could be established after harvest to provide time for increase in the numbers of introduced predators. Given the activity of *A. fallacis* late in the autumn and early in the spring, its introduction would maximize the effective length of the spray-free 'window.' When it is necessary to spray for aphids in the autumn, one of the three pesticides that are not harmful to *A. fallacis* could be used.

Raworth and Strong (1990) developed and tested a management plan for twospotted mites. Sampling is recommended at intervals of 1-3 weeks when mite density is below five per leaflet and, above that level, sprays are recommended depending on the rate of population increase. However, neither the plan nor the binomial sampling methodology that is used to determine mite density is applicable when inundative predator releases are used for pest control. Given the current mass-rearing technology, a grower could afford to introduce 50,000 predators per ha at a cost of about $500 per ha. This release rate is equivalent to six predators per row-m when there are 8300 row-m of strawberries per ha. Although effective predator:prey ratios have not yet been determined, studies conducted with other mite systems (Collyer 1958; Hamai and Huffaker 1978; Waite 1988; and Wilson *et al.* 1984) suggest that a ratio of 1:20 (6:120) is a reasonable estimate. Leaflet densities increase through the season, but 120 twospotted mites per row-m is about 0.4 per leaflet in May (270 leaflets per row-m, 1984 data) and 0.3 per leaflet before mowing in

July (366 leaflets per row-m, 1984 data). As an action threshold, 0.4 pest mites per leaflet is an order of magnitude below the threshold for spray application, therefore the Raworth and Strong (1990) management plan is not valid when predators are released as a control measure. Furthermore, the sampling methodology becomes increasingly unreliable as mite density decreases below one mite per leaflet (Raworth 1986b). Sampling is still useful, however, not to determine if twospotted mite densities are high enough to warrant release of predators, but to determine whether the mite densities are low enough that the predators have a chance of being effective. A density of five pest mites per leaflet, for example, is equivalent to about 1500 per row-m. A release of 50,000 predators per ha at this density would result in a predator:prey ratio of 1:250. Under this circumstance, a grower should probably apply one spray to bring mite numbers down before releasing the predators. Alternatively, if the samples are examined closely for predators, the grower may find that there is little advantage in predator releases because there are substantially more predators in the field than the number being released. A predator density of 0.1 per leaflet is equivalent to about 40 per row-m, 7 × the 50,000 per ha release rate. Time and experience are required to work out the details of an integrated biocontrol plan, but the strategies must be considerably different from those in which pesticides are the only method of control.

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