

Predation, Reproduction, and Impact of Phytoseiid Mites (Acari: Phytoseiidae) on Cyclamen Mite (Acari: Tarsonemidae) on Strawberry

B. A. CROFT, P. D. PRATT, G. KOSKELA,¹ AND D. KAUFMAN¹

Department of Entomology, Oregon State University, Corvallis, OR 97331

J. Econ. Entomol. 91(6): 1307-1314 (1998)

ABSTRACT Abilities of phytoseiid mites to attack, reproduce, and control cyclamen mite, *Phytonemus pallidus* (Banks), on strawberry were assessed. In laboratory feeding tests, *Typhlodromus pyri* Scheuten, *Neoseiulus fallacis* (Garman), and *N. californicus* (Chant) attacked *P. pallidus* most often; *Amblyseius andersoni* Chant fed on the cyclamen mite most successfully, and *Galendromus occidentalis* (Nesbitt) had difficulty piercing the hardened body of adults. Net predation was *T. pyri* > *N. fallacis* > *N. californicus* > *A. andersoni* > *G. occidentalis*. Although several species fed on cyclamen mites, some are more common on strawberry or are more proven as effective predators of *P. pallidus* and thus later reproduction and pest control tests were conducted with only 2 species. When held with excess cyclamen mites, survival and immature production of *N. fallacis* were ≈50% of when feeding on a more preferred prey, *Tetranychus urticae* Koch and like levels for *N. cucumeris* (Oudemans), a proven effective predator of *P. pallidus*. When releases of *N. fallacis* or *N. cucumeris* were made to plants with moderate densities of cyclamen mites and *T. urticae*, pests were controlled sooner and damage to plants was less with *N. fallacis* than *N. cucumeris*. Releases of both phytoseiids to plants infested with high densities of only cyclamen mites produced fewer of either *N. fallacis* or *N. cucumeris* than when both pests were present, but there was better pest control (less plant damage) and again, *N. fallacis* gave slightly better control than *N. cucumeris*. Although *N. fallacis* gave more rapid control of both pests, *N. cucumeris* may give longer-term regulation at lower densities. Differences in life histories may dictate that unique methods of release are needed for *N. fallacis* versus *N. cucumeris* and mixed releases of both may be effective.

KEY WORDS *Neoseiulus fallacis*, *Neoseiulus cucumeris*, biological control, inoculative release

CYCLAMEN MITE, *Phytonemus pallidus* (Banks), and the common twospotted spider mite, *Tetranychus urticae* Koch, are both pests of many cultivars of strawberry in coastal-inland regions of western North America (Coop and Croft 1995, 1998; Kaufman et al. 1995) and other temperate areas (Jeppson et al. 1975, Cooley et al. 1993). They differ in their ecologies and the damage they cause. *T. urticae* lives on mature leaves where it removes chlorophyll and dense populations destroy leaves and reduce plant and fruit production. *P. pallidus* lives in buds and on new leaves where it causes wrinkling, folding, and blistering. Plants with dense populations of *P. pallidus* are small because petioles fail to elongate, leaves become dwarfed, and leaflets do not unfold and become brown or brittle. Fruits on plants with high densities of cyclamen mites are small and often not harvested (Coop et al. 1997).

We have been developing biological control programs for both twospotted spider mites and cyclamen mites on strawberry using the predaceous mite *Neoseiulus fallacis* (Garman) (Coop and Croft 1995, 1998). This phytoseiid mite can give complete control of *T.*

urticae if selective pesticides that are not destructive to predaceous mites are used to control other pests (Croft 1990, Coop et al. 1997). A tactic of *N. fallacis* use may include minimal releases into new fields where predators can increase and disperse widely and where more pest damage can be tolerated because fruit usually is not harvested. Control by predators also is easier to achieve in 1st-yr fields because pesticide use is less. In more established fields, inoculation of more predators in more dispersed ways may be used if pest mites are not common. Selective acaricides such as fenbutatin oxide and propargite can be applied to reduce pests and not affect predators that then can increase and disperse thereafter. Even more widespread, high-density releases of *N. fallacis* may be needed in established fields if pest mites are dense and rapid control is needed; these releases can be expensive and as expensive as chemical controls (Coop et al. 1997).

Possibilities for biological control of cyclamen mites are not well understood in western Oregon, and this is a major constraint to better control of pests on strawberry. Pesticides such as dicofol and endosulfan are used at rates to control cyclamen mites that disrupt *N. fallacis* and related biological control of *T. urticae*. Also, chemical control of cyclamen mite is difficult

¹ Oregon State University, N. Willamette Research and Extension Center, Aurora, OR 97002.

because of limited coverage of pesticides in buds and evolved resistance to pesticides (Kaufman et al. 1995). There are incentives to develop alternative controls for both pest mites, and some phytoseiids [*N. cucumeris*, *Amblyseius rhenanus* (Oudemans), and *A. reductus* (Wainstein)], are known to control both mites in other regions (Huffaker and Kennett 1956, Malov and Tokunova 1990, Tuovinen 1995). Except for *N. cucumeris*, neither of the *Amblyseius* species or close relatives occur in western Oregon, but *N. fallacis* is common on strawberry and many other crops in the region and several other phytoseiids are found on this fruit crop at lower densities than *N. fallacis* (Hadam et al. 1986). The degree to which any native phytoseiid in western Oregon can control both of these mite pests was the focus of this research.

Materials and Methods

Predation on Cyclamen Mites. Several phytoseiids that occur on strawberry (Hadam et al. 1986, Cooley et al. 1993) were reared on standard 12-cm² pan units with waterproofed paper substrates (Strong and Croft 1995): *Amblyseius andersoni* Chant, *Galendromus occidentalis* (Nesbitt), *Neoseiulus californicus* (Chant), *Neoseiulus fallacis* (Garman), and *Typhlodromus pyri* Scheuten. To evaluate each for their abilities to feed on cyclamen mites, observations of direct predator-prey encounters were evaluated with single adult *P. pallidus*. Densities of phytoseiids per unit were 400–600 adult females and associated males and immatures (similar proportions among species). Holding predators with no food for 48 h standardized hunger, after which time cyclamen mites were placed on rearing units. As predators approached a cyclamen mite, contacts by predator appendages with cyclamen mite bodies, feeding attempts, feeding successes, and the predator life stage that exhibited the behavior were scored in 4 replicated, 10-min observation times per species. The efficiency of predation based on comparisons between the actual number of contacts or predation attempts that resulted in death of the cyclamen mite and food uptake by the predator adult female were also calculated. Death was determined by the absence of movement when cyclamen mite was prodded with a brush. Food uptake by the predator was estimated by watching fluids of the pest pass through the body of the predaceous mite. Tests were run at 25 ± 1°C and 80 ± 5% RH. Species responses were compared by analysis of variance (ANOVA) and Fisher least significant difference (LSD) tests (Petersen 1985).

Survival and Reproduction on Cyclamen Mites and Other Foods. Although several phytoseiid species can feed on cyclamen mites, certain ones are more common in the field, whereas others have proven to be more effective predators of this pest in the past. Because *N. fallacis* showed such high levels of predation (above), in later tests, only this mite and the proven effective *N. cucumeris* were studied further. Adult female *N. fallacis* (and *N. cucumeris* with cyclamen mites) of variable age were provisioned with all stages

of cyclamen mites, *T. urticae*, pollen, or no food. Before adding foods, predators were held 24 h singly without food on 2.5-cm² arenas ringed by adhesive (Tangle-foot, Grand Rapids, MI). Treatments were tested simultaneously at 25 ± 1°C and 80% ± 5 RH. Cyclamen mites were added by transferring excised buds to test arenas. For *N. fallacis*, mixed stages of *T. urticae*, corn pollen, or no foods were evaluated separately. Amounts of food added daily were in excess of maximum consumption rates for either predator species: *P. pallidus* = 50–100 mixed life stages; *T. urticae* = 25–50 mixed life stages; pollen = 200–500 grains. Three adult female predators were placed on each arena (8 replicates per species per food type). Adult female survival (%), level of mite activity (walking during 1 min), cumulative eggs per female adult, and cumulative motile stages of immatures per female adult were counted daily for 8 d, which time precluded new adults developing on arenas. A survival index for predators was calculated by dividing the cumulative number of eggs per female by the cumulative number of motile immature life stages present per female, 2 d after eggs were counted. Survival of immature life stages for each egg that was laid also was calculated from the 2 previous data types. Responses of each species, behavior, and food were compared by single-factor ANOVA and Fisher LSD test.

Single Plant Tests of Predation and Biological Control. Strawberry plants (Totem cultivar) were placed individually in 0.5-liter containers. Three or 4 treatments, each with 5 single plant replicates, were evaluated in 2 sets of experiments. Plants were inoculated either with cyclamen at 10–20 per bud + *T. urticae* at 5–10 adult females per leaf or cyclamen mites only at 100–150 per bud. In both tests, 5 adult female predators were added per plant 1 wk after prey mites were added. Predator treatments were *N. fallacis* releases, *N. cucumeris* releases, and 2 controls, 1 with prey + no predators, and 1 with no prey + no predators. Every 2 wk, for 4–8 wk, all life stages of *T. urticae* and phytoseiids were counted on 3 leaflets (1 leaf) of 3 stalks per plant. Cyclamen mites were counted by dissection of budlets after peak densities of predators occurred (1–2 wk after peak densities of *T. urticae*). Before destructive sampling of buds, plant stalks with live or dead leaves, vegetative runners, and live or damaged (wrinkled) buds were counted. All life stages of cyclamen mites, predaceous mites, and plant counts (see above) were analyzed by single-factor (1 date) or repeated-measures (all dates) ANOVAs (von Ende 1993) and Fisher LSD tests (Petersen 1985).

Results

Predation on Cyclamen Mites. When adult *P. pallidus* were introduced into colonies of mixed stages of predators, predation attempts and actual predation values varied among the 5 species (Table 1). Predation attempts were highest for *T. pyri*, *N. fallacis*, and *N. californicus* and were least for *A. andersoni* and *G. occidentalis*. Actual feeding was *T. pyri* = *N. fallacis* > *N. californicus* = *A. andersoni* > *G. occidentalis*. The

Table 1. Predation attempts and successful feeding on cyclamen mites (*P. pallidus*) by adult females and other life stages of phytoseiid mites of 5 species

Phytoseiid species	Attempt predation ^a	Actual predation ^b	Effective predation ^c	Net predation ^d	Predation by non-adult female stages ^e
<i>Amblyseius andersoni</i>	0.318a	0.273b	85.7	27.3	36.4 (M,D,P)
<i>Calendromus occidentalis</i>	0.318a	0.045a	14.3	4.5	00.0
<i>Neoseiulus californicus</i>	0.523b	0.341b	65.2	34.1	61.5 (D,P)
<i>Neoseiulus fallacis</i>	0.659bc	0.455c	69.0	45.5	26.3 (M,D,P)
<i>Typhlodromus pyri</i>	0.727c	0.523c	71.9	52.3	54.5 (M,D,P)

Means in column followed by the same letter are not statistically different ($P = 0.05$).

^a Frequency per contact. Mean of 4 replicates/spp. ($n = 44$); $F = 12.8$, $df = 4, 15$, $P = 0.0001$.

^b Frequency per contact. Mean of 4 replicates/spp. ($n = 44$); $F = 18.9$, $df = 4, 15$, $P < 0.0000$.

^c Predation attempts/actual predation (percentage); no statistical comparison made.

^d Contacts (n)/actual predation (percentage); no statistical comparison made.

^e Predator life stage observed feeding: M, male adult; D, deutonymph; P, protonymph.

degree of successful predation per attempt (effective predation) was highest for the largest phytoseiid, *A. andersoni*, near equal for *T. pyri* and either *Neoseiulus* spp. and least for *G. occidentalis* (statistics not calculated for these derived measures, see statistical comparisons for values used in calculations). Net predation or percent of contacts that resulted in death of prey was $T. pyri > N. fallacis > N. californicus > A. andersoni > G. occidentalis$. Predation by stages other than adult females was highest for *N. californicus* and *T. pyri*. For all species but *G. occidentalis*, active immature stages were able to feed on adult cyclamen mites. Although *T. pyri* showed high levels of predation on cyclamen mites, this predator does not widely occur on strawberry in the region (Hadam et al. 1986), so further testing was not done with this mite.

Survival and Reproduction on Cyclamen Mites and Other Prey. When held with excess *P. pallidus*, activity was less and survival more for *N. fallacis* than *N. cucumeris* (Table 2). Cyclamen mites seemed to be suitable prey for either phytoseiid. However, knowledge of their life history traits caused us to qualify our conclusions: *N. fallacis* is a more specialized predator of spider mites that aggregates more in response to *T. urticae* than does *N. cucumeris* (Croft et al. 1998a). Thus, greater activity (or less aggregation) may have caused *N. cucumeris* to get into sticky borders more and be lost from tests more often. Studies with other confinement techniques are needed to see if either phytoseiid survives better on cyclamen mites. *N. fallacis* had fewer cumulative eggs per female per day

than *N. cucumeris* but cumulative immatures per day per female were similar (Table 2). Again, greater movement of immature *N. cucumeris* could have influenced results.

In comparing foods for *N. fallacis*, it is important to establish the relative value of different food types to which *P. pallidus* can be compared. In this regard, activity was least and survival most when held with *T. urticae* (Table 2). Less activity or arrestment usually indicates a favorable food source (Croft et al. 1998a). For pollen and no food, *N. fallacis* activity was higher than with either of the prey mites. Less movement in the last few days just before death lowered the mean activity value for the no food treatment and made it similar to pollen. Maize pollen probably is not a preferred food in that *N. fallacis* continues to search for other foods even when pollen is abundant. When with *P. pallidus* as food, activity for *N. fallacis* was lower than with all other foods, except *T. urticae*. Activity data may indicate that cyclamen mite is a more preferred food than pollen for *N. fallacis*. Survival either on cyclamen mite, *T. urticae*, or corn pollen was high (>90%). Egg and immature production for *N. fallacis* when with cyclamen mites were as high as with pollen, but lower than with *T. urticae* (Table 2). With cyclamen mite or pollen, immature survival was near 60% for *N. fallacis* (versus 100% with *T. urticae*) and much higher than with no food. When compared with *N. cucumeris* when held with *P. pallidus*, *N. fallacis* had lower activity, higher survival, lower egg production, similar immature production, and similar immature

Table 2. Activity, survival and reproduction of 2 *Neoseiulus* species of phytoseiid mites when provisioned with excess *P. pallidus* or other foods on small arenas

Phytoseiid	Food/prey	Females tested	Activity frequency	Survival (8 d)	Cumulative eggs/female/d	Cumulative immatures/female/d	Immatures/egg
<i>N. fallacis</i>	<i>T. urticae</i>	24	0.17a	1.00d	2.85d	2.87c	1.04c
	Maize pollen	24	0.69e	0.93cd	1.83bc	1.32b	0.62b
	no food	24	0.57d	0.36a	0.07a	0.00a	0.00a
	<i>P. pallidus</i>	24	0.32b	0.91c	1.63b	1.15b	0.65b
<i>N. cucumeris</i>	<i>P. pallidus</i>	24	0.45c	0.77b	2.19c	1.10b	0.64b
	ANOVA F value ^a		27.54	97.50	46.10	59.43	26.37
Significance of P =			<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means in columns followed by the same letter are not significantly different at $P > 0.05$.

^a $df = 4, 35$ for each ANOVA test.

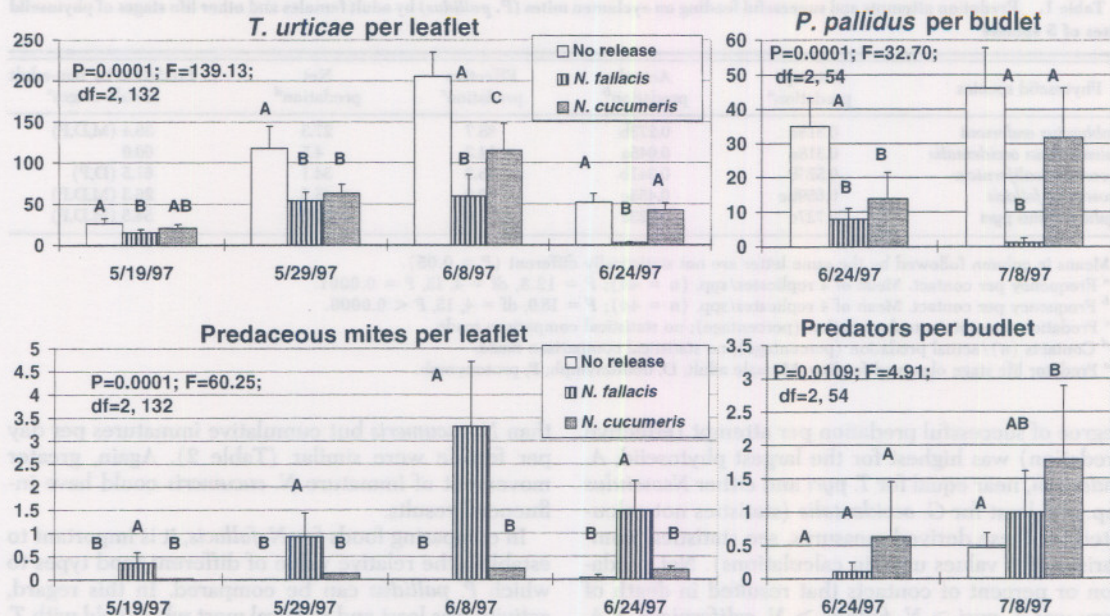


Fig. 1. Population trends of *N. fallacis*, *N. cucumeris*, and pest mites *P. pallidus* and *T. urticae* in strawberry plots after inoculations with spider mites, cyclamen mites, and predator mites.

survival per egg laid. The difference in egg production was considered a minor difference in light of immature production being so similar. A difference in activity with pollen versus mite prey is less likely for a generalist like *N. cucumeris* that feeds readily on pollen (McMurtry and Croft 1997). Overall, from these data we concluded that cyclamen mite is a moderately suitable prey for *N. fallacis*, but, wondered if *N. fallacis* would remain in a bud when only cyclamen mites were present?

Single Plant Tests with *T. urticae* (Moderate Density) Plus Cyclamen Mites. When *N. fallacis* or *N. cucumeris* were added to plants infested with *T. urticae* and *S. pallidus*, predator densities and plant damage differed (Fig. 1). *N. fallacis* increased rapidly by feeding on *T. urticae*. By 8 June when spider mites densities peaked, *T. urticae* was less on plants with *N. fallacis* versus *N. cucumeris* and even more in controls than plants inoculated with either predator by ≈ 2 - to 4-fold, respectively (Fig. 1, upper left). *N. fallacis* was 14 times more common than *N. cucumeris* by 8 June and almost no predators were in controls (Fig. 1, lower right). Cyclamen mites could only be counted near test end because of destructive bud sampling, but by 24 June some reduction of this pest in buds was seen even though *T. urticae* were still appreciable (Fig. 1, upper right). By 8 July, impact on cyclamen mite in buds was more by *N. fallacis* than by *N. cucumeris*; but in budlets, *N. cucumeris* was more common (Fig. 1, lower right). Because the number of buds per plant were much less than the number of leaves per plant, the actual densities of *N. fallacis* were much greater than those for *N. cucumeris* on a whole plant basis. The occurrence of more *N. cucumeris* in buds versus leaves

may indicate it is adapted to feed on cyclamen mites or prefers the humid habitat of the bud.

The impact of *N. cucumeris* on cyclamen mites (Hufaker and Kennett 1956) and its limited response to *T. urticae* have been noted before (Croft et al. 1998b). Evidence for its greater adaptation to *P. pallidus* was seen in egg production (Table 2); *N. cucumeris* had a value 130% of the value for *N. fallacis*. But in budlets, cyclamen mites levels differed giving with *N. fallacis* giving $\approx 75\%$ reduction on 24 June and 98% by 8 July (Table 3) compared with 53 and 32% by *N. cucumeris*. Considering the short time span of these tests, the results were attributed more to differences in rates of increase between the 2 predators rather than their adaptations to the pest. If studies had been carried out longer, then regulation of cyclamen mites might have been better by *N. cucumeris* than *N. fallacis*. This is often the case, when one looks at the relative efficiency of control versus regulation by a specialist versus a generalist predator of mites (McMurtry and Croft 1997).

Differences among treatments in pest damage were less discriminating than mite levels, partly because of smaller sample sizes for leaflets versus budlets (15 versus 5 per plant) and partly because of difficulty in estimating when symptoms were maximally expressed. On 24 June (when cumulative pest effects might be most), damaged bud levels were statistically different, and dead leaves were nearly different ($P = 0.089$; Table 3). Although data for other damages did not differ on the last date, some did over all dates: Total stems per plant did differ and they were most common in plots with *N. fallacis* (repeated measures ANOVA $F = 5.94$; $df = 2, 12$; $P = 0.016$). Runners did not differ

Table 3. Plant parts and pest damage caused by moderate densities of *P. pallidus* and *T. urticae* after releases of *N. fallacis* or *N. cucumeris* on strawberry plants

Date: 24 June Treatment ^a	n ^b	Plant parts per plant			Plant damage units per plant	
		Stems	Runners	Buds	Dead leaves	Dead buds
Means Attributes						
<i>N.f.</i> release	5	6.2	2.2	1.8	2.0	0.8a
<i>N.c.</i> release	5	5.4	1.8	2.0	2.8	2.0b
Control (nr)	5	3.6	2.2	2.4	4.2	2.2b
ANOVA F ^c		2.25	0.31	0.52	2.98	6.14
Significance of P =		0.148	0.741	0.608	0.089	0.015

Means in column followed by the same letter are not significantly different at $P > 0.05$.

^a See treatment densities of spider mite, cyclamen mite and predator mites in Fig. 1.

^b Number of plants sampled.

^c $df = 2, 14$ for ANOVA test.

across all dates ($F = 0.25$; $df = 2, 12$; $P = 0.783$) nor did bud levels ($F = 0.85$; $df = 2, 12$; $P = 0.452$). Dead leaves were the more common in the controls over all dates ($F = 10.89$; $df = 2, 12$; $P = 0.002$) and were always associated with highest spider mite densities. While damaged bud levels differed on the last date (Table 3), they did not differ for all dates ($F = 1.72$; $df = 2, 12$; $P = 0.221$). Thus, bud damage was expressed more slowly than leaf damage and clearly, there were differences in timing of plant responses to spider mites versus cyclamen mites feeding.

Overall, numbers of live stems and dead leaves were inversely related; this likely reflected spider mite density differences. Stems were the more common and dead leaves less common in the *N. fallacis* plots (Table 3) that had the fewest spider mites. Runners did not differ in treatments in single and multivariate analyses. New buds were correlated to damage levels, with more on more damaged plants. Combined damage from spider mites and cyclamen mites may have caused plants to have more damaged buds and dead leaves, but fewer new stalks and more new buds. Although spider mites and cyclamen mites were fewer with *N. fallacis* (Fig. 1), some damage occurred in *N. fallacis* release plots (Table 3). This was because releases were made after pest mites had been present for some time.

Plots with Cyclamen Mites Only. Once it was clear that *N. fallacis* could suppress cyclamen mites when spider mites were present, tests with cyclamen mite alone were attempted. Although some *T. urticae* appeared in plots, densities were similar and never >2 per leaf in plots for all life stages. Four weeks after predators were introduced, cyclamen mites in budlets showed differences among treatments (Fig. 2, upper left). Levels were highest (>68 mites per budlet) in controls with cyclamen mites added but no predators, intermediate (>17 per budlet) in controls without added cyclamen mites, and low (<1 per budlet) in either predator release plot. Predator densities in budlets were variable and low (Fig. 2, lower left), but again (Fig. 1), *N. cucumeris* was more than *N. fallacis*.

To see if cyclamen had escaped predation deep in the crown of the plant (and the pest might later reinfest buds), stalk bases were dissected and pest and predator densities were assessed 4 wk after predators

were released (Fig. 2). Bases of 3 stems per plant where stems entered crowns and crevices within sheath areas were examined for cyclamen mites and predators. As in bud counts, *P. pallidus* densities differed among treatments (Fig. 2, upper right); they were most (>243 per stem base) in controls with added cyclamen mite and no *N. fallacis* or *N. cucumeris* were found (Fig. 2). There were fewer *P. pallidus* (21 per leaf base) in plots without releases of this pest. There were a few cyclamen mites with *N. cucumeris* but none with *N. fallacis*. Both of the predator treatments (Fig. 2, lower right) had adult female phytoseiids deep within crown bases and there were more *N. cucumeris* than *N. fallacis*. *N. cucumeris* eggs were in crowns, indicating that it was still responding reproductively to low densities of cyclamen mite or other foods. Single adult *N. fallacis* were in 4 of 5 crowns but no immatures were found, indicating that it had almost eliminated foods. Adult female *N. fallacis* did not appear robust or gravid but all had gut color, indicating that some food was still present.

Again, interpretation of plant damages were limited by smaller sample sizes than mite samples, but some ANOVAs were significant (Table 4). For stems, runners, and dead leaves, no differences were seen but trends were similar to tests with both mite pests (Table 3): Highest densities of plant stems occurred in *N. fallacis* plots, lowest ones in controls with cyclamen mite releases (Tables 3 and 4). Only 1 runner was produced in any plot and no differences in dead leaves occurred because these were caused mostly by spider mite feeding (Table 3). Live buds, damaged buds, and dead buds were different or nearly so among treatments (Table 4). Plots with *N. fallacis* + cyclamen mites and controls without cyclamen mite releases had the most live buds but the least damaged and dead buds. Controls with releases of cyclamen mites had the fewest buds but the most damaged and dead buds. *N. cucumeris* plots were intermediate for new, damaged, and dead buds.

Discussion

Reasons why phytoseiids probe (attempt predation) cyclamen mites but do not feed (actual predation) may be the result of unfavorable tactile stimuli

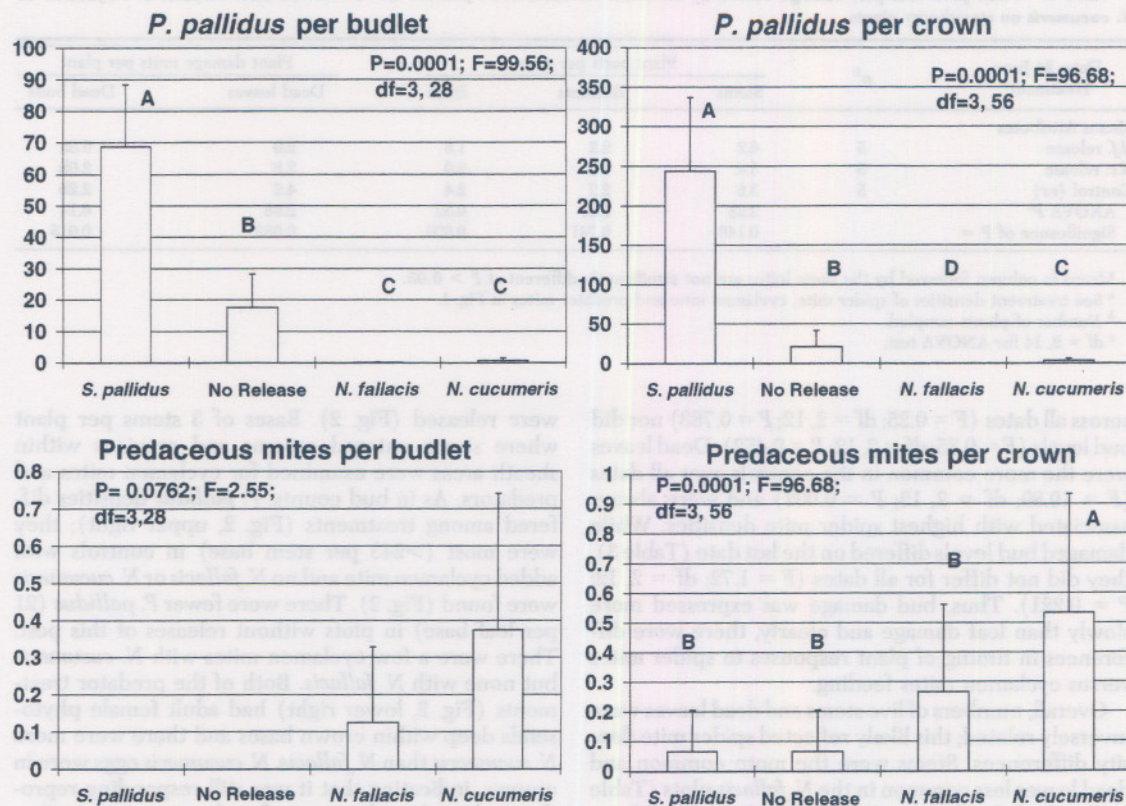


Fig. 2. Population trends of *N. fallacis*, *N. cucumeris*, and pest mites *P. pallidus* and *T. urticae* in strawberry plots after inoculations with both pests and predator mites.

(e.g., lack of appropriate odors); another explanation may be difficulty in piercing the body. For *G. occidentalis*, piercing the adult integument was difficult but this mite could feed on the softer immature life stages (unpublished data). *N. fallacis* would hold the adult and probe the hardened exterior until it found softer tissues near the leg or mouthpart bases and then it would pierce the body. *A. andersoni*, the largest phytoseiid studied, had little difficulty piercing adult tissues, suggesting that its mouthparts may be more

adapted to hardened exocuticles. In other studies, *A. andersoni* readily fed on adult phytoseiids and insects with hardened cuticles (Croft 1994, Croft and Croft 1996). All 5 phytoseiid species had less difficulty feeding on the immature life stages of cyclamen than on the adult mites (unpublished data).

We assessed whether *N. fallacis* would reproduce on exposed cyclamen mites that left the strawberry buds. Predation data indicated that this tarsonemid was a suitable prey for reproduction of *N. fallacis* and

Table 4. Plant parts and pest damage caused by high densities of *P. pallidus* and low densities of *T. urticae* after release of *N. fallacis* or *N. cucumeris* on strawberry plants

Dates: 4 Aug. Treatment ^a	<i>n</i> ^b	Plant parts per plant			Plant damage units per plant		
		Stems	Runners	Buds	Dead leaves	Damaged buds	Dead buds
Means Attributes							
<i>N.f.</i> release	5	5.2	0.0	1.6a	0.2	0.0a ³	0.0
<i>N.c.</i> release	5	4.0	0.0	0.6b	0.2	0.2ab	0.2
Control -cm	5	4.6	0.0	1.2ab	0.2	0.2ab	0.0
Control +cm	5	3.2	0.2	0.6b	0.2	0.6b	0.6
ANOVA <i>F</i> ^c		1.15	1.00	4.36	0.00	5.81	3.00
Significance of <i>P</i> =		0.359	0.418	0.020	1.000	0.018	0.061

Means in column followed by the same letter are not significantly different at $P > 0.05$.

^a See treatment densities of spider mite, cyclamen mite and predator mites in Fig. 2.

^b Number of plants sampled

^c $df = 3, 16$ for ANOVA test.

implied that some predation probably occurs at high densities when cyclamen mites are exposed more on curled leaves (versus only in buds). Activity data indicated that *P. pallidus* elicited arrestment of *N. fallacis* when compared with the *T. urticae* and no food treatments. These results suggest that if *N. fallacis* would enter leaf buds, they might remain there with cyclamen mites even if other alternate prey or foods were not present. In other studies of cyclamen mite control, the effectiveness of 2 phytoseiids, either *A. rhenanus* or *A. reductus*, was attributed to their persistence in the confined habitat of buds and in folded leaves with cyclamen mites (Tuovinen 1995).

Finally, individual plant studies indicated that biological control of *P. pallidus* was achieved as readily by *N. fallacis* as by *N. cucumeris*, the latter is thought to be a highly effective biological control agent of cyclamen mite (Huffaker and Kennett 1956). However, pest control was only sampled over a short period. *N. fallacis* is a more specialized predator of tetranychid mites than *N. cucumeris*; the latter feeds on a wider range of arthropods and pollens (McMurtry and Croft 1997). It is well-known generally, that generalist phytoseiids are better regulators of pest mites, whereas specialist are better at numerically responding and controlling high density populations of phytophagous mites (McMurtry and Croft 1997). Thus, *N. fallacis* might show a faster numerical response to pest mites than *N. cucumeris*, as was observed in these experiments. With cyclamen mites alone (Table 4), the difference in plant damage that occurred between predator treatments was thought to be because of slower pest control by *N. cucumeris*, even though by the end of the test, pest levels were similar between predator treatments. However, over longer periods, *N. cucumeris* may persist and regulate cyclamen mites better than *N. fallacis* because it feeds on other foods more. *N. fallacis* may stay in plant crowns less when cyclamen mites become scarce. This was indicated when *N. cucumeris* was more common than *N. fallacis* after cyclamen mites had been suppressed at the end of tests.

Relative to both mite pests that occur on many cultivars of strawberry, we expected that cyclamen mite control by *N. fallacis* might be affected more by the overall population dynamics of *T. urticae*. However, suppression of cyclamen mites occurred even when *T. urticae* was dense and *N. fallacis* was present. Furthermore, based on plant damage estimates, we concluded that some suppression of cyclamen mites occurred even before *T. urticae* was fully suppressed to very low densities. Just what preference *N. fallacis* has for *T. urticae* versus *P. pallidus* is not known precisely, but it likely differs from that of *N. cucumeris*. *N. cucumeris* does not prefer *T. urticae* to cyclamen mite, but *N. fallacis* probably does (Croft et al. 1998b).

Overall, life history differences between these predators would dictate different release tactics for each. If rapid suppression of both pests were needed, then *N. fallacis* would be best because of its tendencies to feed on both mites and numerically respond to either pest rapidly. If long-term regulation of both pests was

the goal, then releases of *N. cucumeris* at low pest densities might be appropriate. As noted, generalist predators of spider mites are usually better regulators of mite pests than specialists. A mixed release of both may be a useful strategy: *N. fallacis* could reduce dense populations of either pest and *N. cucumeris* could keep them at low levels if selective pesticides were used for control of other pests. Study of key interactions among *N. fallacis*, *N. cucumeris*, and both mite pests are needed to more fully develop a mixed release strategy of both phytoseiids.

Acknowledgments

We thank J. Todd (Willamette Agricultural Consulting) for assistance in collecting cyclamen mites. This research was funded in part by grants to the Northwest Center for Small Fruits and Oregon State University from the USDA-ARS. This is Journal Article 11, 421 of the Oregon Agricultural Experiment Station.

References Cited

- Coop, L. B., and B. A. Croft. 1995. *Neoseiulus fallacis*: dispersal and biological control of *Tetranychus urticae* following minimal inoculations into a strawberry field. *Exp. Appl. Acarol.* 19: 31-43.
- Coop, L. B., R. Rosetta, and B. A. Croft. 1997. Release calculator and guidelines for *Neoseiulus fallacis* to control twospotted spider mites in strawberry. OSU. Version 1.1. [<http://www.orst.edu/Dept/entomology/ipm/mcalc.html>].
- Cooley, D. R., S. G. Schloewmann, and A. F. Tuttle. 1993. Development and implementation of integrated pest management for strawberries in Massachusetts. *Adv. Strwb. Res.* 12: 1-10.
- Croft, B. A. 1990. Arthropod biological control agents and pesticides. Wiley, New York.
1994. Biological control of apple mites by a phytoseiid mite complex and *Zetzellia mali*: long-term effects and impact of azinphosmethyl on colonization by *Amblyseius andersoni*. (Acari: Phytoseiidae). *Environ. Entomol.* 23: 1317-1325.
- Croft, B. A., and M. B. Croft. 1996. Intra- and interspecific predation among adult female *Metaseiulus occidentalis*, *Typhlodromus pyri*, *Neoseiulus fallacis* and *Amblyseius andersoni*. *Environ. Entomol.* 25: 853-858.
- Croft, B. A., and L. B. Coop. 1998. Effects of temperature, release rate, prey density and plant age on dispersal by *Neoseiulus fallacis* (Acari: Phytoseiidae) after inoculation into strawberry. *J. Econ. Entomol.* 91: 94-100.
- Croft, B. A., L. N. Monetti, and P. D. Pratt. 1998a. Comparative life histories and predation types: Are *Neoseiulus californicus* and *N. fallacis* (Acari: Phytoseiidae) similar selective predators of spider mites? *Environ. Entomol.* 27: 531-538.
- Croft, B. A., J. A. McMurtry, and H. Luh. 1998b. Do literature records of predation reflect food specialization among species and predation types of phytoseiid mites (Acari: Phytoseiidae)? *Exp. Appl. Acarol.* 22: 467-480.
- Hadam, J. J., M. T. AliNiasee, and B. A. Croft. 1986. Phytoseiid mites of major crops in Willamette Valley, Oregon, and pesticide resistance in *Typhlodromus pyri* Scheuten. *Environ. Entomol.* 15: 1255-1263.

- Huffaker, C. B., and C. E. Kennett. 1956. Experimental studies on predation: predation and cyclamen-mite populations on strawberry in California. *Hilgardia* 26: 191-222.
- Jeppson, L. R., H. H. Keifer, and E. W. Baker. 1975. Mites injurious to economic plants. University of California Press, Berkeley, CA.
- Kaufman, D., G. Koeskla, R. Rosetta, and R. Collins. 1995. Cyclamen mite control on strawberries. *Proc. Oreg. Hortic. Soc.* 86: 140-142.
- Malov, N. A., and M. V. Tokunova. 1990. Biological control of berry mites in the USSR. *Zachchita Rastenii* 6: 22.
- McMurtry, J. A., and B. A. Croft. 1997. Life styles of phytoseiid mites and their roles as biological control agents. *Annu. Rev. Entomol.* 42: 291-321.
- Petersen, R. G. 1985. Design and analysis of experiments. Marcel Dekker, New York.
- Strong, W. B., and B. A. Croft. 1995. Inoculative release of phytoseiid mites into the rapidly expanding canopy of hop for control of *Tetranychus urticae* Koch. *Environ. Entomol.* 24: 446-453.
- Tuovinen, T. 1995. Phytoseiid mites on cultivated berries in Finland. In: *The Acari. Physiological and ecological aspects of acari-host relationships*: pp. 315-322. D. Kropczynska, J. Boczek and A. Tomczyk [eds.], Oficyna DABOR, Warsaw, Poland.
- von Ende, C. N. 1993. Repeated-measures analysis: growth and other time-dependent measures, pp. 113-137. In: S. M. Scheiner and J. Gurevitch [eds.], *Design and analysis of ecological experiments*. Chapman & Hall, New York.

Received for publication 9 March 1998; accepted 4 August 1998.