

Neoseiulus fallacis: dispersal and biological control of *Tetranychus urticae* following minimal inoculations into a strawberry field

L.B. Coop* and B.A. Croft

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

ABSTRACT

In three separate tests, 100 adult female *Neoseiulus fallacis* (Garman) (plus immatures) were released at five point locations across 1.6-m rows of strawberries to control twospotted spider mites, *Tetranychus urticae* Koch. Beginning in April, during 6–12 weeks, predators controlled pests locally and dispersed downwind by 20–30 m. Up to 100 m² around each release point was colonized, and the entire 2.5 ha field was covered by predators by September. Distances dispersed by *N. fallacis* were similar within and across rows, suggesting that dispersal was primarily by aerial rather than by ambulatory means. Factors that affected dispersal were temperature, wind direction, density of spider mites, and mowing and flailing of foliage. An exponential model of dispersal was fitted to the data. On average, the area dispersed by *N. fallacis* doubled every 70 degree-days. From these results, a strategy of minimum release is suggested. To establish *N. fallacis* over a field in a single season, ca. 100 adult females per 1–2 m of row can be released before 1 July, after *T. urticae* have achieved 2–5 female adults per leaf. Releases should be 50 m apart and to the upwind side of the field. Selective sprays may be needed to suppress spider mites until predators gain control and disperse over the field.

Key words: Phytoseiidae, Oregon, *Tetranychus urticae*.

INTRODUCTION

Neoseiulus fallacis (Garman) is a common phytoseiid mite associated with twospotted spider mites (*Tetranychus urticae* Koch) in western regions of Oregon and other humid areas of North America (Croft *et al.*, 1993; Cooley *et al.*, 1993). In Oregon, this mite is useful in giving biological control of twospotted spider mites on crops such as hop, peppermint, strawberry and corn (Hadam *et al.*, 1986; Strong and Croft, 1993, 1995). On strawberry, *N. fallacis* can provide sufficient control so that acaricides are unnecessary or their use becomes greatly curtailed. This has been shown both where *N. fallacis* is native (Raworth, 1990; Cooley *et al.*, 1993) and where it has been introduced as an exotic control agent (Butcher and Penman 1983; Lee and Lo 1990).

*To whom correspondence should be addressed.

In western Oregon, a practice recommended to enhance control of spider mites is to apply only pesticides that are non-toxic to *N. fallacis*, such as propargite (J. Todd, unpublished data). Selective pesticide use sometimes allows for colonization or recolonization by naturally occurring *N. fallacis* from surrounding host plants, and thus biological control can be successful until the crop is taken out of production several years later. One problem is that immigration of *N. fallacis* is variable and depends on the population dynamics of pest and predatory mites on plants surrounding strawberry fields. If a strawberry site is surrounded by commercial crops that commonly harbour *N. fallacis* such as corn, peppermint or hop, then movement into strawberry may be rapid once spider mites have been suppressed on nearby vegetation. If the field is surrounded by plants that harbour few *N. fallacis*, such as most native plants, grasses or conifers, then immigration and colonization of the strawberry field may be much slower or may never occur.

Because of this variation in colonization, we sought a minimum release strategy that would result in complete colonization of the field within a single year. We inoculated a limited number of *N. fallacis* into a second-year strawberry field from which predaceous mites previously had been eradicated. We assessed the influence of wind, temperature, timing of release, prey density, and mowing and flailing of foliage, on the dispersal and biological control of this phytoseiid mite.

METHODS

Releases of *N. fallacis* were made three times between 8 April and 21 May, 1993 into a 2.5 ha strawberry field of the Totem cultivar in the Willamette Valley, near Rickreall, Oregon. This field had been sprayed in 1992 with carbofuran to control weevil pests. As a result, the native phytoseiids which are very susceptible to this carbamate insecticide (Croft, 1990) had been eliminated from the field. This was verified by extensive early-season samples taken by the methods described below. At the time of the first release of predators in April, there were 15–25 adult female spider mites per leaf, and propargite was applied on 12 and 25 May to suppress spider mites before *N. fallacis* had dispersed significantly.

N. fallacis that had been reared continuously for 3 years, originally came from insecticide resistant mites collected from apple in Michigan and hops and strawberry in western Oregon (BAC, unpublished data). Predators were reared in a greenhouse on lima bean infested with *T. urticae* (Strong and Croft, 1995). Just before release, predators had eliminated almost all spider mites on the lima beans. Pre-counts of adult female predators were made just before bean plants were taken to the field. For each point of release, 100 ± 20 adult female predators on 15–30 bean plants were placed onto strawberry foliage covering a $1.6 \text{ m} \times 0.3 \text{ m}$ row. Release dates were 8 April, 28 April, and 20 May. On each release date, releases were replicated at five new points in the field, with at least 30 m separating all points. There were a total of 15 different release points arranged around the field.

After release, it was found that two points had been made along the east edge of the field in which a non-susceptible variety, Hood, was grown. These points were not included in the data analyses.

Presumably, some immature *N. fallacis* survived and moved from bean to strawberry foliage, but this was assumed to have negligible impact, and was similar across all the timing tests. Before releases were made, counts of spider mites were taken from 20 trifoliolate leaves per release point. At three week intervals, counts of adult *N. fallacis* and *T. urticae* were taken in transects reaching in cardinal directions at 1, 3, 5, etc. metres from release points, until *N. fallacis* were not found. At each distance/directional point, 10 leaves were examined with a hand lens or optical visor at 10× magnification. The smaller sample numbers at the radiating points were taken because we were establishing distance travelled and not mite densities at these points.

After harvest, a horticultural procedure that is widely used is to mow and flail strawberry foliage. With this process, virtually all but a few leaves are removed from plants. Clippings are left near where they are cut, but in some instances small amounts are transported some distance by equipment, blowing wind, etc. Since spider mites and predators must move to the remaining old leaves or new leaves which emerge within a few days after this occurs, considerable mortality of both mites can occur. This field was mowed and flailed on the 3rd of July. Thus, monitoring of mites was carried out several days before and 26 days after mowing and flailing. In the last sample on 28 July, a 30 m × 30 m grid sample was taken to assess overall population densities of predators and prey mites across the field. The sample at each point was the number of adult female spider mites and adult female *N. fallacis* on 20 strawberry leaves (55 total samples) taken the same as at individual points (above). Inverse-distance squared interpolation of grid data (GRASS 4.1, USACERL, 1993), was used to estimate the extent of the field coverage by predators.

To establish climatic trends during the study, daily maximum and mean temperatures were collected from a nearby weather station and data were compared to 13-year averages for the area. Daily average wind directions were computed from samples taken at 15 minute intervals from an Oregon State University Station at Hyslop Farm between Corvallis and Albany, Oregon. This site was 25 km from the field where predator releases were made. Drapek (1993) demonstrated high correlation of data between this station and that in corn 1–2 km from our strawberry site.

Means and confidence intervals of mite counts were plotted for 3–6 sample dates from April to late July for the three predator release dates. Treatments were compared by overlap of confidence intervals (Jones, 1984). Equity of dispersal by predators in cardinal directions was tested by analysis of variance and the protected least significant difference procedure (Petersen, 1985). Least squares multiple regression models were built to describe distance dispersed as a function of

temperature summarized as degree-days (10 °C threshold) and initial level of prey mites present (Neter *et al.*, 1989).

RESULTS AND DISCUSSION

Weather

Temperature and wind are two variables that affect dispersal of predaceous mites (Helle and Sabelis, 1985). Figure 1 summarizes data for 8 April to 30 July 1993 along with average max-mins for the past 13 years (1980-92). Daily max-mins in 1993 were near the 13 year averages except for cooler than average max values in early April and a warmer than usual period of about eight days in mid-May. Also in June and July, maxs were lower than normal (Fig. 1) These trends were reflected as well in accumulated heat units above 10 °C (a common threshold for *T. urticae* and *N. fallacis*; Dover *et al.*, 1979). Degree-days for intervals between samples were 31 (8 April–28 April; 21 days), 99 (29 April–20 May; 23 days), 121

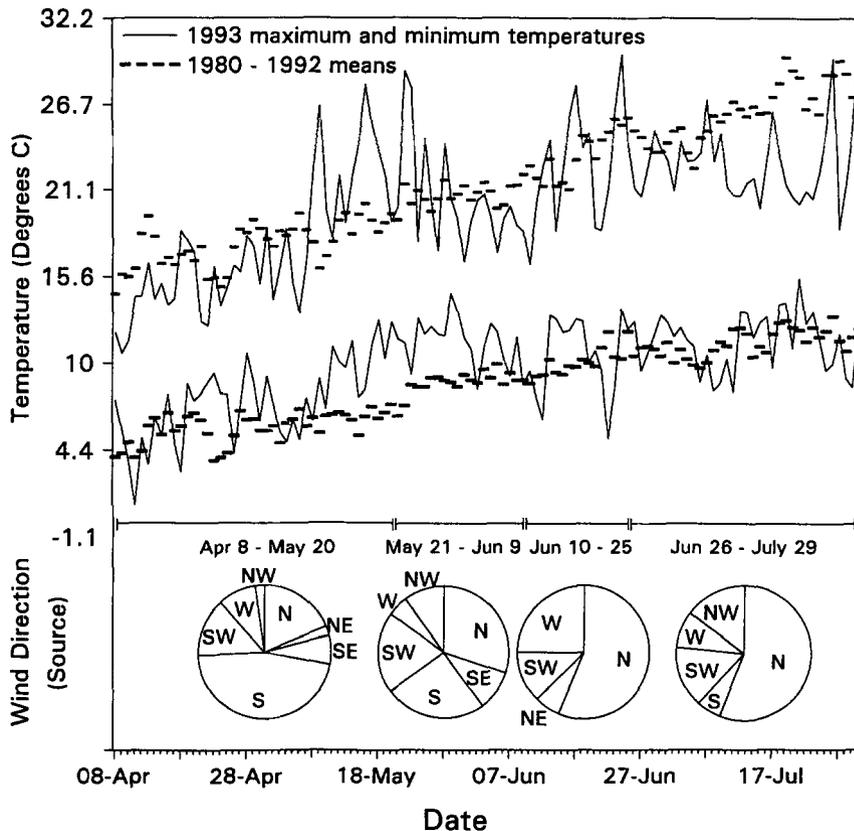


Fig. 1. Temperature and daily resultant wind direction (expressed as percent) for intervals relevant to sampling of adult female *N. fallacis* in strawberry near Corvallis, Oregon, 1993.

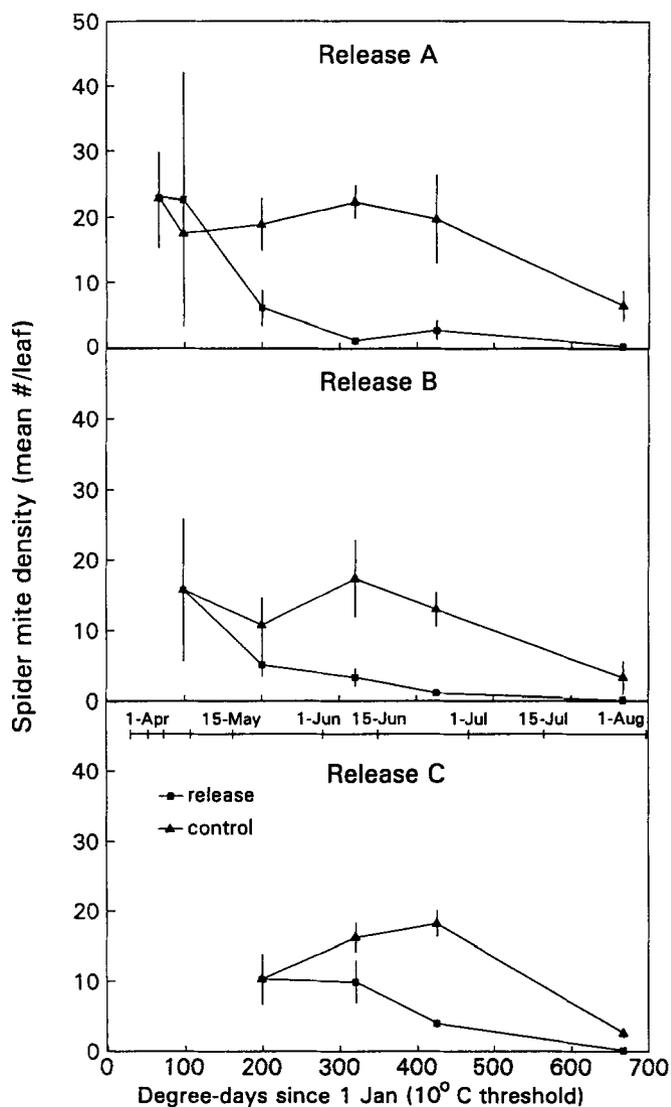


Fig. 2. Density of adult female *T. urticae* on strawberry after release of *N. fallacis*. Controls are means of sample points taken 1 m beyond *N. fallacis* colonization area.

(21 May–9 June; 19 days), 105 (June 10–June 25; 15 days), and 241 (June 26–July 29; 34 days), compared to 13 year norms of 44, 72, 99, 102, and 289 degree-days, respectively.

During April 8–May 20, the prevailing wind (using daily wind direction) was from the S + SW (59.5%), while N + NE made up only 20.9% of all days (Fig. 1). From May 21 to June 9, the S + SW was 45.0% and N + NE was only 30.0%.

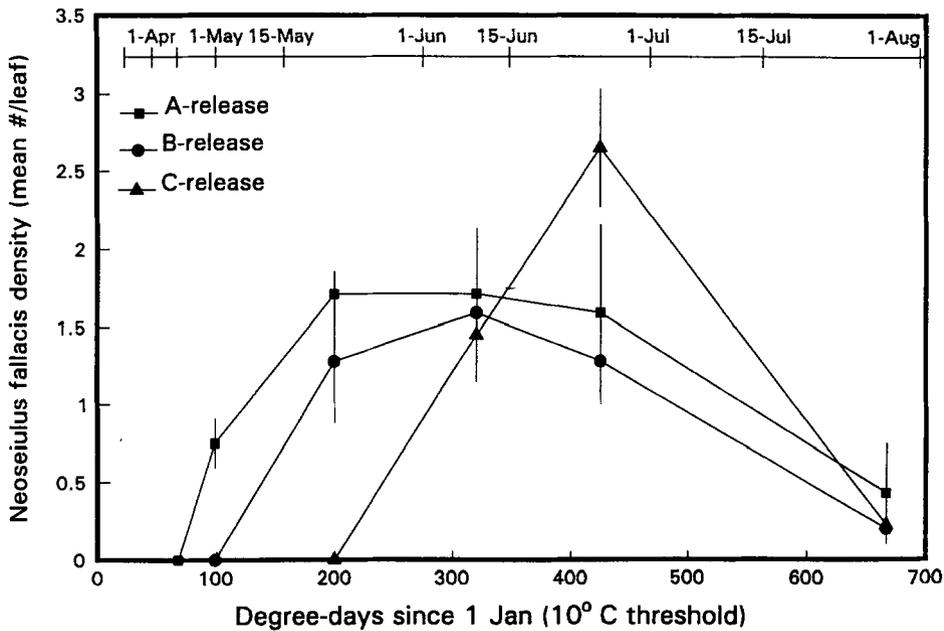


Fig. 3. Mean density of adult female *N. fallacis* in three timed release plots in strawberry.

During the last two samples in June and July, patterns switched to 20.6 and 12.5% for S + SW, and to 56.3 and 55.9% for N + NE. In general, winds in spring were from the SW and in summer from the N. The rows in our field were aligned closely with these cardinal coordinates, being longest in N–S. Because of the field layout and predominant SW wind in spring, inferences could be made about within- and cross-row dispersal of *N. fallacis* (see below).

Control of pest mites

Figure 2 shows mean levels (and 95% confidence intervals) of *T. urticae* in releases A–C and controls from March–late July, 1993. Data for controls are mean spider mites at one metre beyond the perimeter of predator dispersal in each cardinal direction. Means for treatments are at the centre of release plots beginning on 8 April (A), 28 April (B) and 20 May (C), 1993.

While *T. urticae* adult females exceeded 20 per leaf in late April after release A was made, they were suppressed by predators quickly to less than five per leaf (provisional action threshold used by field consultants) in 100 to 150 degree-days (four to six weeks). In A controls, *T. urticae* remained at 17–23 per leaf from late April through to late June and only declined in July after berries were harvested and foliage was mowed and flailed. Almost the same level of control in A was seen in B, although releases were made three weeks later (Fig. 2). Because April was cool, it appeared there was little benefit to releasing before late April, but this

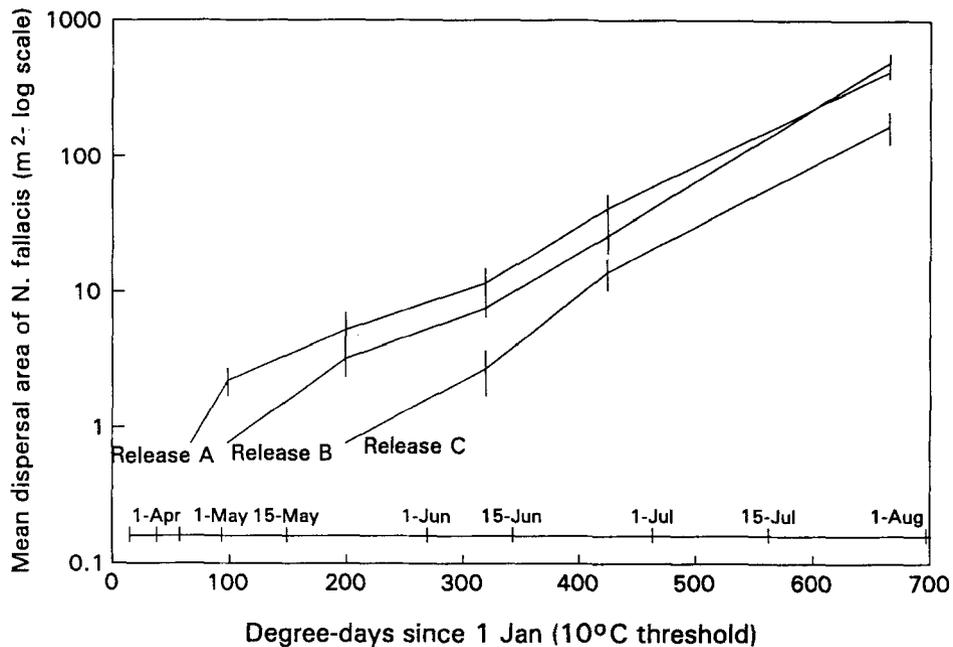


Fig. 4. Dispersal area of adult female *N. fallacis* in three timed release tests in strawberry.

conclusion may not be true in a warm spring. Although no non-spray controls were set up, propargite appeared to suppress spider mites partially without noticeable harm to predators as they continue to cover the field. Pest mites in controls for B were from 10 to 18 per leaf from late April to mid-June. In late season, pest mites in controls for A and B showed a similar decline after plants were mowed and flailed. In the C release plots (Fig. 2), prey levels and biological control followed similar patterns as with A and B releases. Predators gave effective control in C by late June (about 150 degree-days after release) and levels in July did not differ from those in A and B. Spider mites in the C release were also apparently impacted by mowing and flailing.

Predaceous mite levels

Densities of *N. fallacis* at the centre of release plots for releases A–C are shown in Fig. 3. For plots in all three releases, predators built up in 100 degree-days to 1.25–1.75 adult females per leaf. Trends in A and B were similar, and by about mid-May there were no differences between tests. *N. fallacis* in C reached 2.5 per leaf (Fig. 3) after 226 degree-days. After mowing and flailing, predator densities averaged less than 0.5 per leaf in all plots.

The total areas over which *N. fallacis* dispersed from release points are shown in Fig. 4. Mites moved from ca. 0.5 m² to 50–120 m² by 30 July. Data indicated that there was no significant difference between the two initial dates of release but

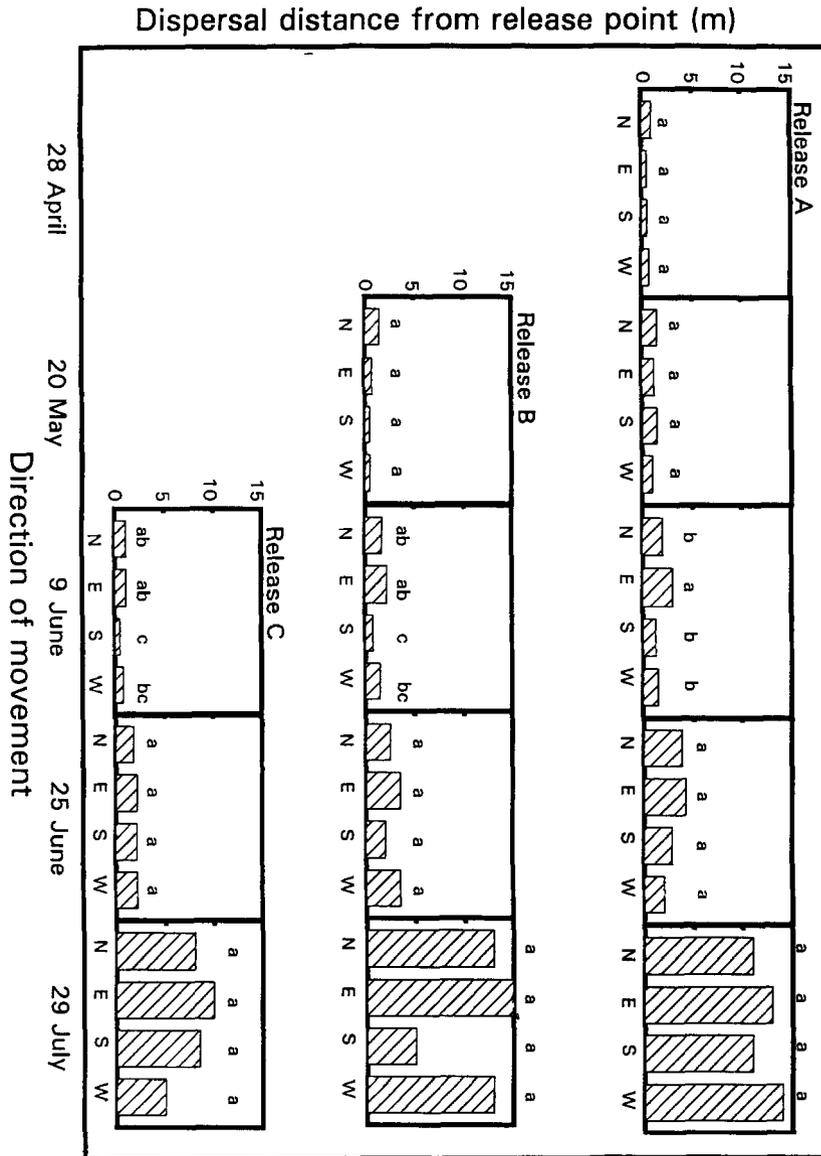


Fig. 5. Dispersal distance of adult female *N. fallacis* from release points within rows (N and S directions) and across rows (E and W directions) in strawberry. Same letters above means for each release and date indicate no significant difference (protected LSD, $p = 0.05$).

there was a lesser area of colonization in C. The rates of increase in dispersal areas were exponentially related to cumulative degree-days (Fig. 4). The average rate of dispersal was also computed.

Factors influencing dispersal

The influence of wind on the direction and distance dispersed by *N. fallacis* is shown for 3–5 dates for A–C in Fig. 5. Dispersal tended to be slightly more to the N and E up to 9 June when winds were mostly out of the S and SW (Fig. 1). Later, winds came more from the N and NE, which tended to even out the direction of predator movement away from release points by 2 August (Fig. 5).

Movement *within* a row of continuous foliage compared with *across* a row of open soil for 3 m was of interest in that it would give information about the mechanisms of dispersal of *N. fallacis*. Preliminary tests had shown that *N. fallacis* suffered high losses trying to ambulate across open soil between plants (unpublished data). Since wind direction was mostly from the SW in early season, samples downwind to the N (along rows) would indicate movement from plant to plant, both by ambulatory and aerial means, whereas those to the E (across rows) would mostly reflect aerial movement. As shown in Fig. 5, there was little difference in dispersal in samples from these two directions, and the same was true for S and W, although counts were slightly lower in S and W than N and E on 9 June.

Figure 6 shows predator densities sampled on 29 July as a whole-field grid of 55 sites with interpolation between sites. Predators were widely distributed in some spots of low density, especially towards upwind edges of the field in the W and S. This sample was taken 25 days after the field was mowed and flailed. Compared to the 26 June sample, predator coverage continued to expand exponentially (see Fig. 4). The exact amount added over what would have occurred without these cultural practices could not be assessed precisely because controls without mowing and flailing could not be maintained in the grower field. Later, less extensive samples of mites in September, 1993 and April, 1994 verified that coverage by predators was complete across the field and that biological control was completely successful and the use of acaricides was unnecessary in 1994 (Jim Todd, unpublished data).

Many studies have shown that daily temperatures affect development of phytoseiids and rates of biological control (Helle and Sabelis, 1985). Here, because of the cool spring, differences in biological control and areas over which predators disperse were not as different on a calendar basis as would probably occur under warmer conditions. However, on a degree-day basis, rates of dispersal were similar among the timed release experiments (Figs 3–4). A model of dispersal area versus cumulative degree-days (DD) was highly significant ($r^2 = 0.91$, $p = 0.0000$, $df = 35$):

$$\text{Area dispersed} = 1.196\exp(0.009902 \times \text{DD}) - 1$$

This model estimates that complete predator dispersal could be achieved over 2.5 ha after 731 degree-days with 15 optimally spaced releases of *N. fallacis*. In a study of natural spread of *N. fallacis* in apple, colonization of a tree (*ca.* 10 × 10 × 10 m) required 333 degree-days (base 12.2°C) (Johnson and Croft, 1976; 1979).

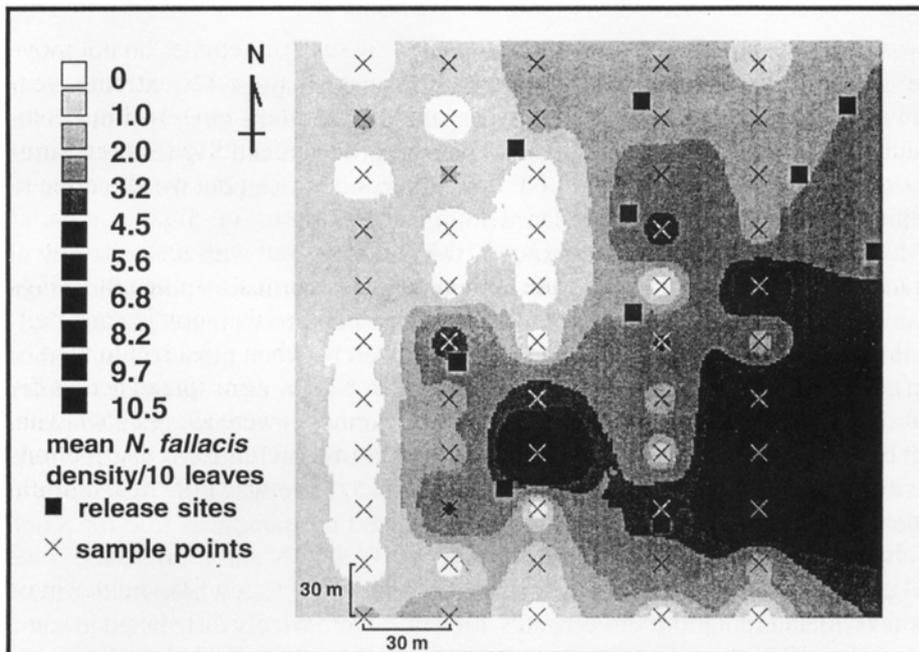


Fig. 6. *N. fallacis* distribution on 28 July after 100 adult females were released at each of 15 release points from 8 April–21 May, 1993.

In a two-dimensional strawberry field, our model predicts a coverage of 31 m² over the same time. The model for strawberry, gives a doubling of area dispersed about every 70 degree-days. These estimates apply only to this study, which included releases of *ca.* 100 adult *N. fallacis* in 15, 0.5-m² plots, and a mean initial density of 14.8 *T. urticae* per leaf. Other rates would result from different predator–prey conditions. Also, the propargite applied during May had some effect in limiting prey that could have affected predator increase and dispersal. The effects of this factor could depend on resistance in spider mites to propargite, on the efficacy of application, etc, and could thus affect prey and levels of predator dispersal.

The affect of density of spider mites at the time of release was incorporated into a multiple regression model ($r^2 = 0.92$, $p = 0.0000$, $df = 35$). In this case, both degree-days and this variable were significant at $p < 0.05$:

Area dispersed =

$$1.60745 \exp(0.009907 \times DD - 0.08481 \times \text{sqrt}(\text{prey density} + 0.5)) - 1$$

For this model, a varying initial prey density did not affect the heat units required for doubling the area of dispersal, which remained at 70 degree-days. The effect of increasing initial prey densities was to increase the time required to cover a given area. To cover a 2.5-ha field for an initial density of 1 mite/leaf, 711 degree-days were required; at 25 mites/leaf, 744 degree-days were required. A high initial

prey density causes a lag in predator dispersal because adult females do not move extensively until prey have been locally suppressed. At the other extreme, very low prey densities do not support adequate predator build up and thus limit colonization potentials. Subsequent prey densities may also affect dispersal in a similar way, but data were not analysed in these studies for later prey density effects.

Spider mite levels in second-year plantings of strawberry normally decline as leaves mature in July and August (BAC, unpublished data), but just what effect this had on the decline in spider mite and predators in our tests is uncertain (Figs 2 and 3). While there were no untreated controls, it appeared that mowing and flailing impacted similarly on pest and predaceous mites. Both species had to recolonize newly developing leaves from dead, drying ones that were spread across the field. While the distributions of spider mites and predators were altered somewhat by these actions, if anything they seemed to result in more uniform distributions of both (Fig. 6). More research is needed to evaluate the impact of these cultural methods on mite dispersal.

It is clear that effective biological control of pest mites can be improved by minimal inoculation of *N. fallacis* in strawberries in western Oregon. Our studies indicate that predators rapidly build up and then disperse across a field as prey mites are reduced. They show that limited releases (*ca.* 100 adult female *N. fallacis* per point, 1500 females per 2.5 ha field) can give a much larger coverage over a growing season. In effect, when releases are made in this manner, each release point becomes a rearing unit in producing predators that then can disperse over a much larger area.

N. fallacis displays a specific dispersal behaviour when food is scarce and wind currents are present by assuming a raised stance on leaf margins (Johnson and Croft, 1976). This leads to downwind dispersal for a distance that depends on the elevation from which they arise (Johnson and Croft, 1979). Therefore, we expect that wind direction would influence the direction of movement, as was seen at least on 9 June in this study. Direction of winds should be considered and release points made upwind accordingly. We found that dispersal across rows was similar to rates along rows of strawberry, suggesting that if all other factors are the same, then aerial dispersal will allow predators to move as easily in patchy strawberry plantings (such as with first year fields) as in older fields with more dense plantings. This idea needs to be tested more fully. Plant density may be important in influencing biological control as are heat units and prey densities.

While our studies were only for a limited scope and duration, it is clear that with more research one could design optimal programs of predator release using data on field size and colonization time. More testing of the number of predators per released point, sites per field and their distribution, impact of prey and foliage density and economic analyses are needed to make precise recommendations. However, some suggestions can be made now. To establish *N. fallacis* in one growing season, releases of 100 adult females per 2 m of row should be made before 1 July,

once *T. urticae* have achieved 2–5 female adults per leaf. Releases should be made at equal distant points, upwind, 50 m apart. Initially, selective acaricides may be needed to suppress spider mites until predators provide biological control and disperse throughout the field.

ACKNOWLEDGEMENTS

We thank J. Todd of Willamette Agricultural Consulting for assistance with this project. Supported by a USDA/CSRS grant to the Pacific Northwest Center for Small Fruits. Ward Strong, Oregon State University, reviewed an earlier draft of this paper. Journal article 10669 of the Oregon Agricultural Experiment Station, Corvallis, OR.

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