

AN ABSTRACT OF THE DISSERTATION OF

Paul D. Pratt for the degree of Doctor of Philosophy in Entomology presented on
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Neoseiulus fallacis (Acari: Phytoseiidae) in Ornamental Nursery Systems.

Abstract approval

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Brian A. Croft

We identified and evaluated a phytoseiid predator as a biological control agent of multiple spider mites pests that occur in ornamental nurseries. When comparing species, *Neoseiulus fallacis* (Garman) had a wider prey range than *Galendromus occidentalis* (Nesbitt), a higher probability of overwintering than *Neoseiulus californicus* McGregor and was equally or more effective at suppressing spider mites than either of the other 2 phytoseiids in 4 field tests. To further evaluate *N. fallacis* we 1) measured prey range when held with 29 ornamental pests or alternative foods under laboratory conditions, 2) tested biological control of spider mites on representative plant species at both small and large spatial scales, 3) developed release and conservation strategies of the predator, and 4) examined the efficacy of the predator in controlling recently introduced pests. *Neoseiulus fallacis* had greatest survival and reproduction when feeding on spider mites but eriophyid mites, other mites and pollen enhanced survivorship and, in some cases, reproduction. When inoculated into ornamental plants, spider mite suppression was

“acceptable” in 81% of small scale tests and in all large scale tests. Limitations in control occurred in tall, vertical growing plants with little foliar canopy. Inoculation of *N. fallacis* at low prey densities into apple rootstocks was successful at suppressing *Tetranychus urticae* Koch and similar to control achieved at moderate prey densities. In small scale banker plant studies, high densities of adult and immature mites of *N. fallacis* were produced and moved downwind to receiver plants. In field tests with receiver plants placed at greater distances, only *N. fallacis* adult females readily dispersed to 30 m or more. When comparing overwintering survival of adult females among plant types, *N. fallacis* survived most on conifers, intermediate on evergreen shrubs and least on herbaceous perennials, deciduous shrubs and shade trees. Covering plants with protective plastic reduced overwintering survival of the predator. *Neoseiulus fallacis* successfully suppressed the newly introduced pests *Panonychus citri* (McGregor) and *Schizotetranychus celarius* (Banks) on *Skimmia japonica* Thunberg and *Sasaella hidaensis* (Makino and Uchida), respectively. Initial studies suggest that *N. fallacis* can be an effective biological control agent of multiple spider mites in low-growing and selected higher-growing ornamental plants.

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Biological Control of Spider Mites by the Predatory Mite *Neoseiulus fallacis* (Acari:
Phytoseiidae) in Ornamental Nursery Systems.

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- Pratt, P. D., P. Schausberger, and B. A. Croft. 1999.** Prey-food types of *Neoseiulus fallacis* and literature versus experimentally-derived prey-food estimates for five phytoseiid species. *Exp. Appl. Acarol.* 23(7):551-565.
- Pratt, P. D. and B. A. Croft. 1999.** Expanded distribution of the bamboo spider mite, *Schizotetranychus celarius*, and predation by *Neoseiulus fallacis*. *Acarologia*. In Press.

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Biological Control of Spider Mites by the Predatory Mite *Neoseiulus fallacis*
(Acari: Phytoseiidae) in Ornamental Nursery Systems.

1. INTRODUCTION

The United States (USA) is both the largest producer and market for ornamental plants worldwide (Johnson 1998). In the USA, ornamental nurseries are the fastest growing agricultural commodity and in 1996 it was ranked the 7th most important (Johnson 1998). This industry ranks in the top 5 commodity groups in 27 states; the largest producers being California, Florida, North Carolina, Texas and Oregon (Johnson 1998; Fig. 1). Although all states have commercial ornamental nurseries, much of the industry is in the south and west, where growing conditions are ideal for mass production of ornamentals and development of pests (Mizell and Short 1992; Fig. 1).

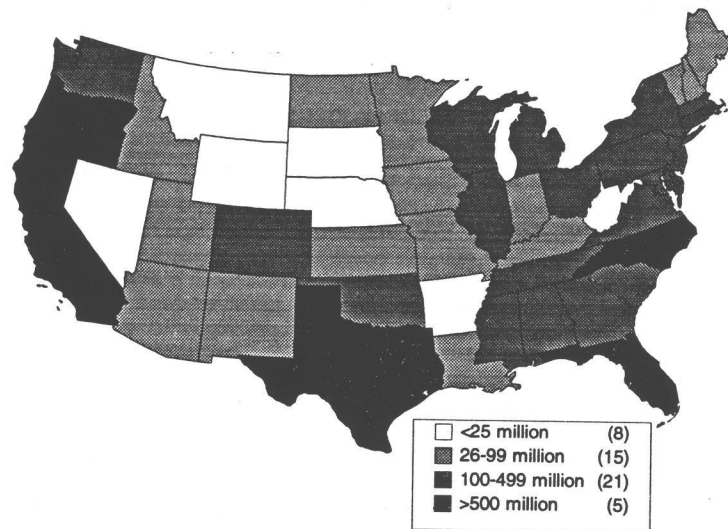


Figure 1. Grower cash receipts for ornamental nursery production in the United States. (Modified from Johnson 1998).

Spider mites (Tetranychidae) are major pests of commercial ornamentals. Tetranychids, specifically *Tetranychus urticae* (Koch), are among the most injurious pests in the USA and are ubiquitous in nurseries worldwide (Brushwein 1991, Mizell and Short 1992, Hamlen and Lindquist 1981). This pest status is due to foliar damage caused by feeding, that can result in abnormal growth, chlorosis, reduction in photosynthesis and defoliation (Tomczyk and Kropczynska 1985, Jeppson et al. 1975). Spider mite damage also can render plants unsightly and unmarketable. Because of their high reproductive potential and short generation time, spider mites can rapidly increase to damaging levels on susceptible plants (Helle and Sabelis 1985). These characteristics, combined with the aesthetic demands of consumers, have led to ultra-low tolerances for pest mites in ornamentals (Schiffauer and Mizell 1988, Smitley and Peterson 1991, Sandof and Alexander 1993).

Historically, ornamental producers have relied on chemical pesticides to suppress spider mites in such highly valued plants (Brushwein 1991, van de Vrie 1985, Weidhaas 1979). These pesticides are often only marginally effective against mites but may decimate sensitive natural enemies (Sclar et al. 1998, Campos et al. 1995, Croft 1990). Similarly, broad-spectrum insecticides directed at other pests (i.e. aphid, root weevil, etc.) may negatively affect spider mite natural enemies and result in secondary or induced outbreaks (Sclar et al. 1998, Croft 1990). Resistance to pesticides also is common among pest mites and few pesticides for ornamental production are registered each year (Croft 1990, Cashion et al 1994, Campos et al. 1995). Restricting availability of chemical products may increase the incidence of resistance among pest mites (Raupp et al. 1992).

An alternative to the use of pesticides for spider mite control is the inoculative release of predatory mites in the family Phytoseiidae. These predators are among the most widely studied biological control agents of spider mites and are considered essential components of some pest control programs (McMurtry and Croft 1997, Helle and Sabelis 1985). During the last 40 years research has focused on specialist phytoseiids in agroecosystems, in contrast to generalist species.

Recently, McMurtry and Croft (1997) classified these specialist and generalist phytoseiid life styles into 4 types according to life history and morphological traits: Type I phytoseiids are specialized predators of *Tetranychus* species, Type II includes selective predators of tetranychid mites and are most frequently associated with spider mites that produce copious webbing, Type III phytoseiids are generalist predators and Type IV species are specialists on pollen but may also feed on mites. This classification of predation types among the Phytoseiidae is consistent with more quantitative estimates of feeding specialization based on literature citations (Croft et al. 1998, Pratt et al. 1999).

As with many other agricultural systems, selection of phytoseiids in high value greenhouse or outdoor ornamental nursery crops has focused on Type I specialist predators (i.e. *Phytoseiulus persimilis* Athias-Henriot) (van de Vrie 1985, McMurtry 1982). For instance, recent studies evaluated *P. persimilis* for suppression of *T. urticae* in outdoor ornamentals grown in semi-tropical regions of the USA (Cashion et al. 1994, Brushwein 1991). Results suggest that *P. persimilis* can reduce *T. urticae* on ornamentals, with the potential of eliminating acaricide applications. Unfortunately, Type I phytoseiids are not ideal biological control candidate for all ornamental growing regions of the USA (i.e. Pacific Northwest). For instance, *P. persimilis* does not enter diapause and the probability of successful overwintering in temperate ornamental growing regions is minimal (Overmeer 1985). Also, Type I specialist predators have narrow prey ranges and are unable to provide adequate control of many important mite pests of ornamentals such as the southern red mite (*Oligonychus illicis* McGregor), the spruce spider mite (*Oligonychus ununguis* Jacobi), the citrus red mite (*Panonychus citri* McGregor), the bamboo mite (*Schizotetranychus celarius* Banks) and various tarsonemid, and eriophyid mites (Weidhaas 1979, Mizell and Short 1992, Horten 1995). Due in part to their specialization on *Tetranychus* mites and lack of feeding on other types of food, Type I species may overexploit their prey and starve or disperse from the crop of interest as prey levels decrease (McMurtry 1992, Walzer and Schausberger 1999).

Although their populations do not numerically increase in response to *Tetranychus* prey as rapidly as Type I species (numerical response), Type II phytoseiids may be more effective at controlling multiple spider mites species found on ornamentals grown in more temperate regions. For instance, numerous Type II species are indigenous to northern climates, they feed on a wide range of prey and are important biological control agents of pest mites in many agricultural systems (McMurtry and Croft 1997). Therefore, the goal of this dissertation was to identify and evaluate a Type II phytoseiid biological control agent that could ultimately be incorporated into an integrated pest management (IPM) program for spider mites on ornamental nurseries of the Pacific Northwest, USA. We wished to provide producers with a control program that would benefit their immediate needs. To accomplish this goal we had the following objectives: 1) identify a suitable phytoseiid species for biological control of multiple spider mite pests in ornamental nurseries, 2) test the reproduction and survival of the predator on nursery pests and alternative food sources available within nursery systems, 3) test biological control of spider mites on representative plant species at both small and large spatial scales, 4) develop release and conservation strategies for the predator in ornamental nurseries and 5) examine efficacy of the phytoseiid predator in controlling new exotic pests. Figure 2 describes how these objectives relate to identification, evaluation, and eventual incorporation into an IPM program.

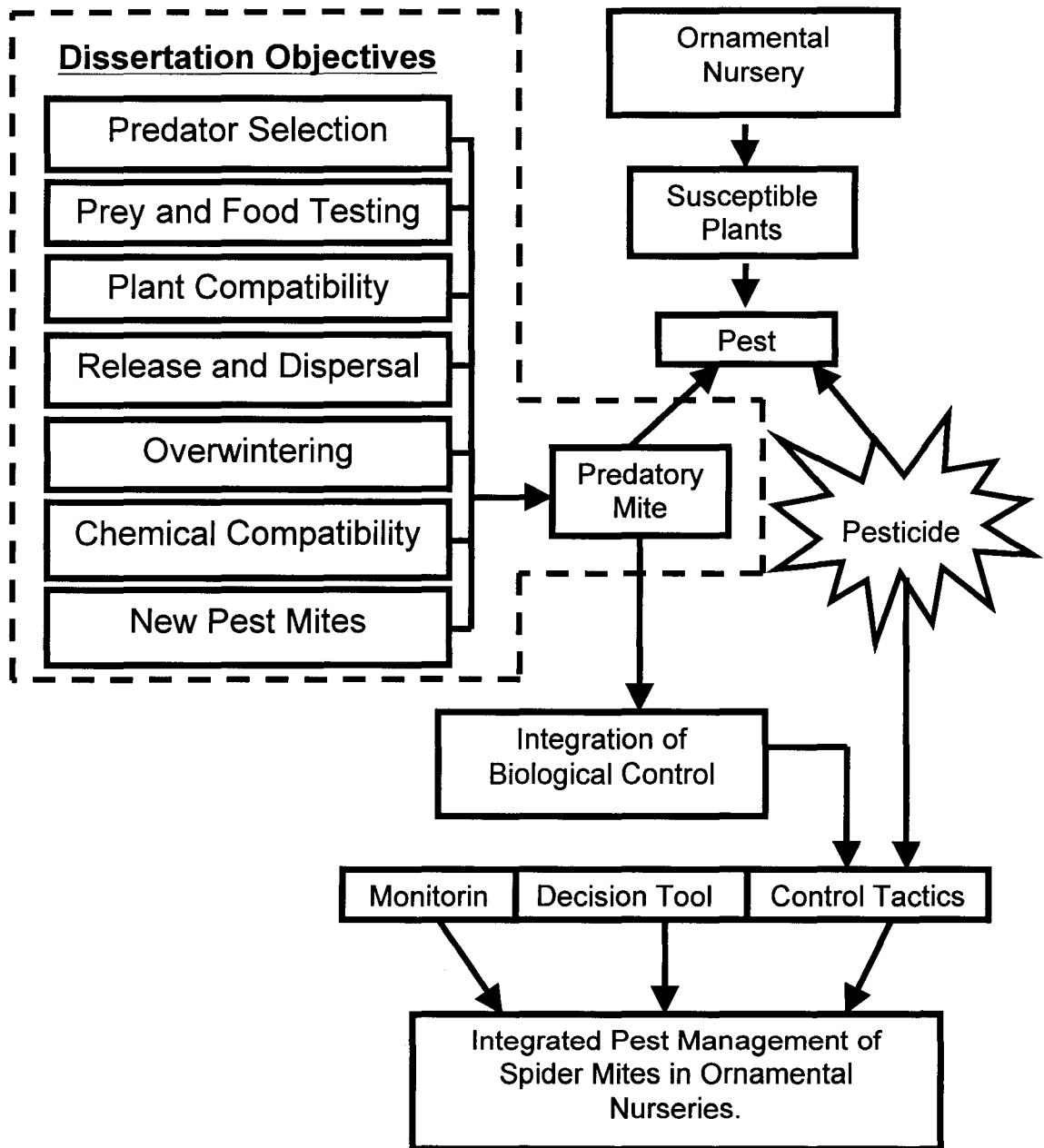


Figure 2. Conceptual description of the objectives of this dissertation and their integration into a biological control tactic of an integrated pest management system for ornamentals.

2. SCREENING OF PREDATORY MITES AS POTENTIAL BIOLOGICAL CONTROL AGENTS OF PEST MITES IN ORNAMENTAL NURSERIES

2.1. Introduction

Spider mites of the Tetranychidae are major pests of ornamental nursery plants worldwide. Foliar damage caused by spider mite feeding renders plants unsightly and unmarketable (Mizell and Short 1992, Hamlen and Lindquist 1981). To protect these high value plants from spider mite damage, ornamental producers have traditionally relied on synthetic pesticides to suppress population outbreaks (Brushwein 1991, van de Vrie 1985, Weidhaas 1979). However, due to resistance of spider mites to pesticides, negative effects of pesticides on natural enemies, and environmental concerns, other control tactics besides pesticides are needed to suppress spider mite pests in ornamental nursery systems (Raupp et al. 1992).

An alternative to the use of pesticides for suppression of spider mites is the inoculative release of predatory mites in the family Phytoseiidae. Predatory mites are important biological control agents of spider mites in many agricultural systems (McMurtry and Croft 1997, Helle and Sabelis 1985). Phytoseiids have been shown to be effective at suppressing pests in ornamental plants grown in greenhouse systems (van der Vrie 1985, van Houten et al. 1995), but few studies have tested their ability to suppress pest mites in ornamentals grown outdoors.

Recent studies evaluated the use of *Phytoseiulus persimilis* Athias-Henriot for the suppression of *Tetranychus urticae* Koch in ornamental plants grown in semi-tropical regions of the USA (Cashion et al. 1994, Brushwein 1991). Results suggest that *P. persimilis* can reduce *T. urticae* populations on ornamental nursery plants below economic levels. However, this predator is not an ideal biological control agent for all ornamental growing regions. For instance, *P. persimilis* does not enter diapause and the probability of successful overwintering in important temperate growing regions of the USA (e.g. the Pacific Northwest) are minimal (Overmeer

1985). In addition, *P. persimilis* is a specialist of *Tetranychus* species and will not control other pests in the spider mite complex (Walzer and Schausberger 1999, Johnson and Lyon 1991).

Phytoseiid mites that feed on a wide range of tetranychid prey yet rapidly respond to suppress them were classified by McMurtry and Croft (1997) as selective Type II predators. The objective of this study was to identify a phytoseiid mite from among the Type II predator classification for biological control of multiple spider mites in outdoor ornamental nurseries of the Pacific Northwest. We first compared the life history traits of several species that appeared to be suitable candidates based on literature reports. From among the candidates that possessed the most promising characteristics, we performed field tests to compare their effectiveness when released into ornamental plants of 4 representative types.

2.2. Background of Predator Selection

Three Type II selective predators of tetranychids that are indigenous to the western USA are *Galendromus occidentalis* Nesbitt, *Nesoeiulus californicus* (McGregor) and *Neoseiulus fallacis* Garman (Hadam et al. 1986, McMurtry and Croft 1997). For these species, we compared intrinsic rate of increase, number of prey killed per day, ability to overwinter in the Pacific Northwest, humidity tolerance and commercial availability (DeBach 1964, Gilstrap and Fries 1985, McMurtry and Croft 1997). Although *Tetranychus* species, and especially *T. urticae*, are major pests in ornamental nurseries, we were also interested in comparing the prey range of selected phytoseiids for non-*Tetranychus* diets (i.e. *Oligonychus*, *Schizotetranychus*, *Panonychus*, pollen etc.). Unfortunately, experimental data for prey range among phytoseiids is limited (Croft et al 1998a, b). Recently, feeding specialization of selected phytoseiids on a range of prey or food types was estimated by Croft et al. (1998a). This estimate was obtained by counting each literature citation of a phytoseiid feeding on 6 prey or food types: *Tetranychus* spider mites, other spider

mites, eriophyid mites, other mites than those previously mentioned, insects or pollen. The proportion of citations for each prey or food type to the total number of citations for a selected phytoseiid was calculated. Therefore, we estimated the prey range of *G. occidentalis*, *N. californicus* and *N. fallacis* by calculating the sum of non-*Tetranychus* proportions from the literature citation index (LCI) of Croft et al. (1998). Our assumption that the LCI adequately describes the prey range of Type II phytoseiids is based on recent comparisons among LCI and actual prey range tests for a limited number of species (Pratt et al. 1999, Ch. 3).

When comparing life history data from the literature (Table 1), values of intrinsic rate of increase were similar among *N. fallacis* and *N. californicus* when feeding on *Tetranychus* prey, but lower for *G. occidentalis* (Croft and Zhang 1999, Sabelis and Janssen 1994, Ma and Laing 1973). In contrast, Fries and Gilstrap (1982) found the number of *Tetranychus* prey killed per day was higher for *G. occidentalis* than *N. californicus*. In an unrelated study, prey killed per day by *N. fallacis* appears intermediate to that of the other phytoseiids (Ball 1980). With respect to overwintering, *N. fallacis* and *G. occidentalis* are indigenous to the Pacific Northwest and are expected to persist assuming adequate hibernation sites are present (Hadam et al. 1986, Croft et al. 1998b, Overmeer 1985). While *N. californicus* occurs in California, it has not been collected in the Pacific Northwest and overwintering in this region is unlikely (Hadam et al. 1986). Assuming the LCI adequately describes prey range, *N. californicus* appears to feed on the widest range of prey, *G. occidentalis* the narrowest, with *N. fallacis* intermediate (Croft et al. 1998a,b). While commercial availability from producers is similar among all 3 species, their humidity tolerances are quite different. *Galendromus occidentalis* eggs are tolerant of much lower humidity ranges than either of the *Neoseiulus* species (Croft et al. 1993, Castagnoli and Simoni 1994).

2.3. Materials and Methods

Laboratory cultures of the phytoseiids used in this study were originally collected from agricultural crops in the Willamette Valley, OR, USA (Hadam et al. 1986). These cultures have been maintained for 3-6 years with regular additions from field-collected mites. Cultures were held at 25 ± 5 °C, 16:8 light:dark L:D, and $80 \pm 10\%$ relative humidity (RH), and mites were fed mixed life stages of *T. urticae* 3 times per wk. Source populations of predators for inoculative releases in field tests came from a mass rearing facility at Oregon State University: phytoseiids were produced on lima beans (*Phaseolus lunatus* L.) infested with *T. urticae* under greenhouse conditions of 26:21 (± 5)° C day:night (D:N), 75% (± 10) RH and a photoperiod of 16:8 L:D h (Strong and Croft 1995).

To compare the 3 candidate phytoseiid species, we performed field tests of 2 or more of these species in 4 spider mite infested ornamental nursery crops that are produced in the Willamette Valley, OR, USA. These crops were selected because they represent a range of plant architectural types and harbor a diversity of mite pest species.

2.3.1. *Malus* Rootstock.

The study site was located near Gervais, OR, USA (45.1N lat. and 122.8W long.). *Malus* rootstocks (MM.106 EMLA) were cultivated in a 7.3 ha stoolbed field with 400 (± 22) plants per m² and 1 m between each row. Rootstock stoolbeds were rows of established root systems with sawdust drawn up along each row to cover roots and encourage growth of new branches (Hartmann and Kester 1983, Vasek and Howard 1984). Plants emerged from perennial roots in early spring and by May a continuous dense canopy of leaves was created within rows and nearly between rows. Rootstocks were sprinkler irrigated as need according to soil moisture sensors. In

Table 1. Characteristics of potential biological control agents of spider mites in ornamental nursery systems.

Phytoseiid Predator	Predator type	Intrinsic Rate of Increase	Prey Killed/ Female/d	Over-wintering ⁱ	Prey range ^k	Commercially Available	Humidity Tolerance (RH ₅₀ of eggs)	Humidity Tolerance Reference
<i>Galendromus occidentalis</i>	II ^a	0.228 ^b	14.39 ^g	Yes	0.373	Yes	28.41	Croft et al. 1993
<i>Neoseiulus californicus</i>	II	0.287 ^c	10.05 ^g	Unknown	0.564	Yes	73.73	Castagnoli and Simoni 1994
<i>Neoseiulus fallacis</i>	II	0.298 ^d	11.40 ^h	Yes	0.419	Yes	69.65	Croft et al. 1993

^a Type II selective predator of tetranychid spider mites (McMurtry and Croft 1997).

^b Average r_m calculated from 6 estimates as reported in Sabelis and Janssen (1994).

^c Ma and Laing 1973.

^d Croft and Zhang 1999.

^g Fed excess eggs of *T. cinabarinus*.

^h Fed excess eggs of *T. urticae*.

ⁱ Winter survival in Pacific Northwest.

^k Prey range estimated as a summation of the literature citation index of non-*Tetranychus* diets from Croft et al. (1998a).

fall, apple rootstocks were harvested, sawdust replaced and no plant material remained above ground during winter.

In 1995 we tested the ability of *G. occidentalis* and *N. fallacis* to control *T. urticae* in small plots. Fifteen 1000 m² plots were randomly assigned one of three treatments: release of 210 (± 8) adult females of either *N. fallacis*, *G. occidentalis* or no release of predators (control). We monitored mite populations in each replicate plot by removing 50 leaves in an “X” type pattern every 14 days. On 27 June, spider mite populations had increased to 0.60 (± 0.12) per apple leaf and predatory mites were released into plots by placing a bean leaf containing 3 adult females every 6 m along each of 12 rows per replicate. Leaf samples were placed in an ice cooler, transported to the laboratory and a 40X microscope was used to count the pest and predator populations. All predators found on sampled leaves were mounted on glass slides and identified by morphological characteristics (Schuster and Prichard 1963). To normalize data of density estimates, we performed a $\log(x+1)$ transformation prior to analysis. To adjust for sampling the same populations over time we compared treatments with repeated measures analysis of variance (ANOVA) (von Ende 1993).

2.3.2. *Acer x freemanii* ‘Jeffersred’

After initial success of the predatory mites in the *Malus* rootstock system, in 1996 we compared the ability of *G. occidentalis*, *N. californicus*, and *N. fallacis* to suppress populations of *T. urticae* on deciduous shade trees. The study site was located near Dayton, OR, USA (45.2 N lat. and 123.1W long.) and consisted of 2 ha field of 1 yr old (since budding) *Acer x freemanii* ‘Jeffersred’ saplings. Trees were planted in rows spaced approximately 1 m apart and 0.76 m within the row. *Acer* trees were irrigated via overhead sprinklers as needed and measured approximately 0.9 (± 0.3) m in height with 10 (± 4) leaves per tree at the initiation of the experiment. Due to the sparse canopy we questioned if the more humid-adapted *Neoseiulus* species would be as effective at suppressing spider mites as the arid-tolerant *G. occidentalis*.

A single, randomly selected row from the 2 ha *A. x freemanii* planting was used for this test. One hundred and fifty trees were randomly assigned 1 of 4 treatments: release of *G. occidentalis*, *N. californicus*, *N. fallacis* or no release (control). Three trees within the row were used as a border between each of the replicates. On 2 July, *T. urticae* populations reached 1.1 (± 0.2) per leaf and 2 adult females of a single species were added to a basal leaf of each of the trees within the release blocks. Estimates of mite populations were made by scanning 3 randomly selected leaves from basal, intermediate and apical portions of each tree with an optical visor at 10X magnification. Predator and pest mites per leaf were averaged within trees and replicates. Predator identification and data analysis were performed as described above.

In the proceeding tests, *N. fallacis* was equally or more effective than *G. occidentalis*. Therefore, we proceeded with only *N. fallacis* and *N. californicus* in the final 2 plant assessments.

2.3.3. *Spiraea bumalda* 'Crispa'

The test site was also located near Dayton, OR (see above) and consisted of 0.3 ha plot of 2 year old *Spiraea bumalda* 'Crispa' plants that were planted in rows spaced 0.76 m apart. The plants were contiguous within the row and irrigated with overhead sprinklers as needed. Again, a single row, measuring approximately 35 m, was randomly selected for this test. Four 1 m replicated blocks per treatment were randomly assigned along the row with a 0.5 m border between each replicate. Borders did not receive release of predaceous mites but were sampled to indicate the degree of predator movement between plots. Treatments were release of *N. fallacis*, *N. californicus* or no release (control). On 2 July, 1996 *T. urticae* populations reached 1.9 (± 0.3) per leaf and 5 adult female predators were released into the center of the canopy of each release block. Samples of the borders and replicates were taken every wk to estimate spider mite and predator mite populations. Samples consisted of 10

randomly selected leaves removed from each replicate and border. Processing of samples, predator identification and data analysis were performed as described above.

2.3.4. *Rhododendron* ‘Hotie’

As mentioned above, we questioned if the predatory mites would also suppress other, non-*Tetranychus* spider mites found in the ornamental system. *Oligonychus illicis* (McGregor) is a major pest of rhododendrons in the USA (Johnson and Lyon 1991). In addition, leaves of some rhododendrons are smooth and lack morphological characteristics known to affect phytoseiid behavior (such as pronounced domatia or indumentum, Walter and O’Dowd 1992). Therefore, we compared the ability of *N. fallacis* and *N. californicus* to suppress *O. illicis* on rhododendron plants possessing smooth leaves.

The study site was located near Corvallis, OR, USA (44.5 N lat. and 123.3W long.). Four yr old *Rhododendron* ‘Hotie’ plants were grown in a 5 X 10 m plot with plants spaced approximately 0.5 m apart. Fifteen replicate plants were randomly assigned one of three treatments: release of either *N. californicus*, *N. fallacis* or no release. Predatory mites were inoculated into release plants on 17 June. At least a one plant-border surrounded each replicate. Irrigation, sampling, identification of predators and data analysis were exactly like previous studies except only 5 leaves were sampled per replicate.

2.4. Results

2.4.1. *Malus* Rootstock

Introduction of the predators *G. occidentalis* and *N. fallacis* into *Malus* rootstock plants significantly reduced populations of *T. urticae* when compared to the control plot ($P < 0.001$; Fig. 3). No significant differences were found among populations of spider mites in either of the 2 predator release treatments ($P > 0.05$).

Release of either *G. occidentalis* or *N. fallacis* resulted in a reduction of *T. urticae* populations as much as 95% when compared to the control plots (Fig. 3). For instance, in *N. fallacis* release plots spider mite population levels peaked in early August at 1.34 (± 0.32) per leaf with predator populations peaking at 0.48 (± 0.10) per leaf 16 days later. *Tetranychus urticae* population levels in control plots reached 6.45 (± 0.35) per leaf in early September.

2.4.2. *Acer x freemanii* 'Jeffersred'

Release of the predatory mites significantly reduced the populations of *T. urticae* when compared to control treatments ($P < 0.001$; Fig. 3). Although not significantly different ($P\text{-value} > 0.05$) spider mite populations were slightly higher in *G. occidentalis* treatments than the *Neoseiulus* species. While some dispersal of predatory mites did occur from release treatments into the control late in the experiment, biological control was not realized in the control treatments.

2.4.3. *Spiraea bumalda* 'Crispa'

When compared to the control treatment, the predatory mites *N. fallacis* and *N. californicus* significantly reduced populations of *T. urticae* in the ornamental shrub *S. bumalda* 'Crispa' ($P < 0.001$). Although not significantly different at all dates, spider mite densities were often lower in release plots of *N. fallacis* as compared to those of *N. californicus* (Fig. 3). In contrast, *N. californicus* dispersed from release locations to border plants earlier than did *N. fallacis* ($P < 0.05$).

2.4.4. *Rhododendron* 'Hotie'

The introduction of the predatory mite *N. fallacis* significantly reduced populations of *O. illicis* when compared to either the control or release of *N. californicus* ($P < 0.001$; Fig. 3). Two wks after the release date no individuals of *N.*

californicus were recovered. No differences were found among *O. illicis* densities in control or release of *N. californicus* treatments ($P > 0.05$). On 15 May *N. fallacis* was collected from control and *N. californicus* treatments. The decrease in pest densities in the control and *N. californicus* treatments on the last sampling date may have been due to the arrival of *N. fallacis* or declining host suitability (Fig. 3).

2.5. Discussion

Based on literature data, we summarized information of 3 Type II selective phytoseiids that could be used for release as biological control agents of spider mites on outdoor ornamentals of the Pacific Northwest. When comparing traits among species, selection of a single phytoseiid for this system was difficult. For instance, *G. occidentalis* has the lowest intrinsic rate of increase yet kills more prey items per day (Table 1). Similarly, *N. californicus* appears to feed on a wider range of ornamental pests but its potential to overwinter in the region is unlikely (Table 1). In addition, sparsely canopied ornamental plants (shade tree saplings) that grow several meters above ground may have humidities below the tolerances of humid adapted *Neoseiulus* species. These findings suggest that each species has one or more traits that may be limiting and that selection based on literature data alone is difficult (DeBach 1974). Results from our field studies demonstrated that *N. fallacis* was equally effective as *G. occidentalis* at suppressing spider mites in either *Malus* rootstock or *Acer* shade trees. Further comparisons among *N. fallacis* and *N. californicus* in *Spiraea* and *Rhododendron* suggested that *N. fallacis* is equally or more effective at suppressing pest mites (Fig. 3). The reason for the disappearance of *N. californicus* from *Rhododendron* plants was unclear. Possible explanations include incompatibility with the host plant or the prey, *O. illicis*. Therefore, when considering that 1) *N. fallacis* will numerically respond to a wider range of pest mites than *G. occidentalis* and 2) *N. fallacis* was equally or more effective than the other 2 candidates in field tests, we suggest that *N. fallacis* is the best candidate for biological control of multiple spider mite pests infesting ornamentals in the region.

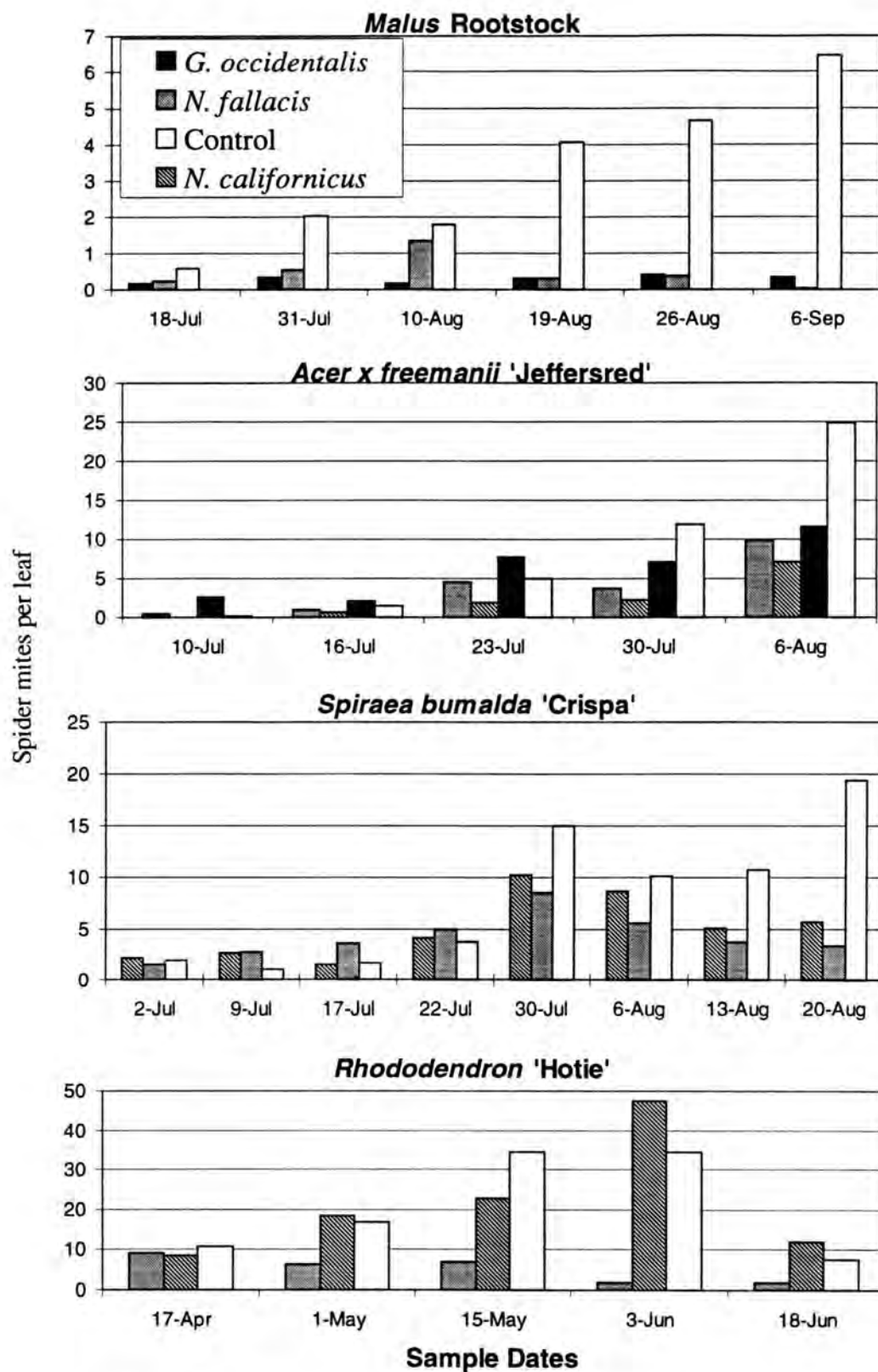


Figure 3. Biological control of spider mite pests by different combinations of 3 phytoseiid predators in ornamental nursery systems.

As described by Raupp et al. (1992), laboratory and field studies are needed to provide acceptable alternatives to the use of pesticides for control of pests of outdoor landscape and nursery plants. This is the first report of the use of a phytoseiid for control of multiple mite pests in outdoor ornamentals. As shown in these studies, inoculative releases of *N. fallacis* into *Malus*, *Rhododendron* and *Spiraea* plants provided suppression of spider mite populations below damaging levels, resulting in marketable plants without the use of pesticides.

Unlike most agricultural systems, outdoor ornamental nurseries are complex polycultures with many pests. When developing biological control in such systems, one must identify the range of pests to be controlled. We sought a Type II selective predator that would suppress many, if not all, pest mites in the system. Our findings suggested that *N. fallacis* would numerically respond to *T. urticae* and *O. illicis* (Fig. 3). Similarly, Boyne and Hain (1983) determined that *N. fallacis* was an effective predator of *Oligonychus ununguis* (Jacobi) in conifers. *Neoseiulus fallacis* will control *Phytonemus pallidus* (Banks) and *Panonychus ulmi* Koch in strawberry and apple, respectively (Croft et al. 1998c, Croft and McGroarty 1977). Studies are needed to describe the full prey range of *N. fallacis* on pests of ornamentals as well as alternative foods, such as pollen, that may enhance predator conservation (McMurtry 1992).

Compatibility with plant microhabitats also may be equally relevant to biological control success as the ability to feed and reproduce on the pest (DeBach 1974). For instance, morphological differences in pea plants affected the ability of *Coccinella septempunctata* to suppress aphids (Kareiva and Sahakian 1990). Similarly, plant-pest-natural enemy (tritrophic level) relationships have been described among phytoseiid mites and leaves possessing acarodomatia and nectaries (Dicke and Sabelis 1988, Walter and O'Dowd 1992, O'Dowd and Pemberton 1998). In this study, *N. fallacis* was less effective in shade trees than lower profile plants (rootstocks and shrubs). One explanation may be the low relative humidity in the sparsely canopied shade trees (Croft et al. 1993, Strong 1995). Although *N. fallacis* has been inoculated

into many crops with diverse external morphologies in the past, its compatibility with the range of plants in outdoor ornamental nurseries is unknown.

Our data also have relevance to dispersal of *N. californicus* and *N. fallacis*. When comparing within-plant movement in the presence of excess prey, Pratt et al. (1998) demonstrated that *N. californicus* disperses over a greater distance than *N. fallacis*. In this study, *N. californicus* dispersed into contiguous *Spiraea* border plants earlier than *N. fallacis*, suggesting that *N. californicus* dispersed more throughout the plots compared to *N. fallacis*, which remained more in the area of release. With respect to *N. californicus*, biological control was realized over a larger area but suppression of pest mites was slower than for *N. fallacis* (Fig. 3). Dispersal of biological control agents influences rate of pest control, area of pest control and sampling (Kareiva 1986, Pratt et al. 1998, Croft et al. 1998b).

Our results and decision to focus on the use of *N. fallacis* are consistent with other studies that sought a predator of spider mites in agricultural systems of the more humid inland valley regions of the Pacific Northwest: Strong (1995) selected *N. fallacis* over *G. occidentalis* for control of *T. urticae* in hops in areas of western Oregon and Washington states, for similar reasons as was seen in our studies on ornamentals. Similarly, introductions of *N. fallacis* into strawberry fields resulted in marked reductions of *T. urticae* and the cyclamen mite *P. pallidus* in this humid region (Croft and Coop 1998, Croft and Pratt 1997). Morris (1998) also selected *N. fallacis* for biological control of *T. urticae* in peppermint systems in both humid and arid regions of the western USA.

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3. NURSERY-RELATED PREY-FOOD TYPES OF *NEOSEIULUS FALLACIS* AND LITERATURE- VERSUS EXPERIMENTALLY- DERIVED PREY-FOOD ESTIMATES FOR FIVE PHYTOSEIID SPECIES

3.1. Introduction

Phytoseiid mites are effective biological control agents of pest mites in many plant systems (Helle and Sabelis, 1985). For instance, *Neoseiulus fallacis* (Garman) has been shown to suppress spider mites on apple, hops, peppermint, strawberry (Strong and Croft, 1995; Morris et al., 1996; Croft and Coop, 1998), and more recently ornamental nursery crops (Pratt and Croft, 1998, Ch. 2). Although typically released to control *Tetranychus urticae* Koch, recent studies have shown that *N. fallacis* can suppress other, non-*Tetranychus* mite species such as *Panonychus citri* (McGregor) (Pratt and Croft, 1998), *Oligonychus ununguis* (Jacobi) (Boyne and Hain, 1983) and *Phytonemus pallidus* (Banks) (Croft and Pratt, 1998). These studies suggest that *N. fallacis* may numerically respond to multiple mite pests on many different plant types. These attributes may be advantageous when multiple pests occur within a highly diverse multi-cropping system as is found in commercial ornamental nurseries.

Unfortunately, little is known about the prey or food range of *N. fallacis*. To our knowledge, no studies have measured feeding and development on a wide range of prey-food types using standard methods. McMurtry and Croft (1997) used qualitative methods to classify *N. fallacis* as a type II selective predator of tetranychid species that produce dense webbing. Their analysis was based on provisional food preference values. The classification of type II is consistent with the more quantitative model derived from the literature citation analysis of food types performed by Croft et al.(1998b). Croft et al.(1998b) suggested that a more accurate estimate of the feeding preference could be obtained through comprehensive studies on the effect of various diets on reproduction. Thus, objectives of this study were to: 1) measure ability of *N. fallacis* to survive, feed and reproduce on a range of prey-food types using standard methods, 2) compare results of (1) to data from literature citation index model of Croft

et al. (1998b) and 3) to compare similarly derived data for other selected species that represent a full range of life style types (Croft et al., 1998a, McMurtry and Croft, 1997).

3.2. Materials and Methods

3.2.1. *Neoseiulus fallacis* cultures

Laboratory cultures of *N. fallacis* were originally collected from agricultural crops in the Willamette Valley, OR, USA (Hadam et al., 1986). These cultures have been maintained for 6 years with yearly additions from field-collected mites. Cultures were held at 25 ± 5 °C, 16:8 L:D, and $80 \pm 10\%$ RH, and mites were fed mixed life stages of *T. urticae* three times per wk. Randomly selected gravid females were used in this study. Prior to tests, adult female mites were held without food for 24 h to produce similar levels of hunger.

3.2.2. Feeding tests

The 27 prey-food types presented to *N. fallacis* were collected from ornamental nursery plants or neighboring agricultural fields from March-June 1997. Pollen grains were collected by aspirating anthers from respective host plants (Table 2). Mites and insects were collected from ornamental nursery plants except for *Tetranychus lintearius* Dufour, which was collected from gorse plants (*Ulex europaeus* L.) near Clackamas OR, USA. When held with insects, *N. fallacis* was always provisioned separately with 1st instar thrips, scale, whitefly or 1st and 2nd nymphal instars of psocids. Honeydew droplets were collected from the aphid *Illinoia lambersi* MacGillivray that had been feeding on rhododendron ('Anah Kruschke'). A mixture of honey water was created from equal parts of *Apis mellifera* L. honey and distilled water.

Except for two diets (see below), all feeding tests were conducted on 2.5 X 2.5 cm arenas constructed of waterproof paper and ringed with a sticky material (Tanglefoot®, The Tanglefoot Co., Grand Rapids MI 49504) to prevent escape. When *N. fallacis* was provisioned with *Panonychus ulmi* Koch or *Aculus schlechtendali* (Nalepa), a 2.5 cm² apple leaf arena (containing midrib) ringed with water soaked cotton tissue was used. All feeding arenas were replicated eight times per prey-food type and placed on a piece of water-saturated foam rubber contained in a tray of water (Croft et al., 1998a). Three *N. fallacis* adult females of similar age were transferred to each arena with a camel's hair brush. Excess amounts of each prey-food were provisioned every 24 hours and arenas were placed in a 1 X 2 m environmental chamber at 25±1°C, 80±10% RH, and 16:8 L:D for 7 days. *N. fallacis* was also held without food on each of the feeding test substrates (paper or apple leaf). Survivorship, activity (percent of time spent in ambulation per minute in the arena), oviposition per female per day, and the number of immatures (larva, protonymph, deutonymph) present per female per day were assessed every 24 hours. Eggs and immatures were not removed from the arenas but eggs and immatures per female per day were derived by comparing stage composition changes between days. Cannibalism was also assessed daily by reviewing each arena for dead or shriveled corpses. Means of each measured attribute were analyzed by analysis of variance (ANOVA) and Tukeys HSD.

3.2.3. Literature-based versus oviposition-based feeding preference models

To compare our findings with a proposed literature citation index (LCI) model (Croft et al., 1998b) we categorized diets into six groups: *Tetranychus* spider mites (TSM), other spider mites (OSM), eriophyid mites (EM), other mites then those previously mentioned (OM), insects (INS) and pollen (POL). Assuming that ovipositional rates reflect feeding specialization (Dicke et al., 1990), feeding acceptance and recognition (preference) indices (FPI) were calculated by averaging the ovipositional rates of *N. fallacis* within each of the six prey-food types in Table 2 and then determining the proportion associated with each prey-food type mean to the sum

of the six means of each type (see Appendix I). Because proportion data have unknown underlying distributions we used randomization tests, which are more powerful than other non-parametric tests, to compare the LCI with the FPI (Manly, 1991). Our null hypothesis was that the squared difference of the LCI model and the FPI equaled 0, whereas the alternative hypothesis was that the squared difference was greater than 0. We randomly reordered the FPI 1000 times, found the difference between the LCI and the FPI and calculated the sums of squares for each randomization. We then identified the sums of squares greater than the observed sums of squares and divided by 1000 to compute the empirical probability (proportion) of accepting the null hypothesis (Manly, 1991).

We also sought to compare results of the LCI of Croft et al. (1998b) with an FPI calculated from oviposition rates from previous studies of *Phytoseiulus persimilis* A.H., *N. fallacis*, *Typhlodromus pyri* Scheuten, *Euseius finlandicus* (Oudemans) and *Euseius hibisci* (Chant). The criteria for selecting these species was that they have been the most commonly studied ones relative to prey types, they spanned the range of life style types I-IV and, for *N. fallacis*, we could determine the effect of the data reported herein on the FPI (McMurtry and Croft, 1997). The criteria for selecting the specific feeding test data consisted of tests with: 1) excess prey-food provided, 2) conditions of 22-27°C and RH of 60-90% and 3) the duration of the test must be ≥ 7 days. Again, proportions for each species were derived and randomization tests were performed as before (see Appendix I).

3.3. Results

3.3.1. Feeding tests

Survivorship of *N. fallacis* was significantly different among prey-food treatments ($F=10.71$, d.f.=28,203, $P<0.0001$). *N. fallacis* had highest survival when feeding on tetranychid species and reached maximum survival when feeding on *T.*

urticae (Table 2). When compared to *T. urticae*, survival significantly decreased when held with OSM and OM ($P<0.05$), except *P. ulmi* or the tarsonemid *P. pallidus*, respectively. *N. fallacis* survived equally as well when held with *T. urticae* or the eriophyid *A. schlechtendali*. Whiteflies, psocids and thrips provided similar survival for *N. fallacis* as *T. urticae*, and insects in general improved survival as compared to starvation conditions. Pollen increased survival when compared to starvation and approximately 73% of the pollen types provided similar survival as *T. urticae*. When fed honey water, survival was similar to that when held with *T. urticae* but aphid honey dew was not different from starvation. In contrast, *N. fallacis* held without foods survived at lower levels, but longer on apple leaves than on water-proof paper arenas.

Activity of *N. fallacis* was also significantly different among prey-food treatments ($F=12.27$, d.f.=28,203, $P<0.0001$). *N. fallacis* tended to be arrested most when held with *T. urticae*. None of the other treatments differed from the starvation treatments.

Egg production by *N. fallacis* was significantly different among prey-food treatments ($F=52.26$, d.f.=28,203, $P<0.0001$). When held with TSM, *N. fallacis* produced nearly twice as many eggs as compared to all other treatments (Table 2). OSM provided a lower oviposition rate but was significantly greater than starvation treatments. Among OM, only *P. pallidus* provided egg production above that of the starvation level. When *N. fallacis* was held with *A. schlechtendali*, egg production was higher than all other treatments except for TSM. *N. fallacis* produced more eggs on whiteflies than when starved but mean values for other insects were not significantly different. Among several pollens, honey water and honeydew, corn pollen was the only source that provided for greater egg production than starvation. Egg production did not differ between starvation treatments.

Immature production by *N. fallacis* was significantly different among prey-food treatments ($F=29.9$, d.f.=28,203, $P<0.0001$). When *N. fallacis* was held with TSM more immatures were produced per female per day than other prey food treatments ($P<0.05$). Among OSM, *Oligonychus illicis* (McGregor), *O. ununguis*

Table 2. Adult female survival, activity, oviposition and immature development of *N. fallacis* when held with excess amounts prey-food types over 7 days.

PREY-FOOD	SURVIVORSHIP ^a	ACTIVITY ^b	EGG/FEM/D ^c	IMM./FEM/D ^d
TETRANYCHUS SPIDER MITES (TSM)				
<i>Tetranychus urticae</i>	1.00a ^f	0.17h	1.78a	1.15a
<i>Tetranychus lintearius</i>	0.94a-d	0.22g-h	2.00a	1.27a
OTHER SPIDER MITES (OSM)				
<i>Oligonychus ununguis</i>	0.68e-h	0.72a-e	0.75b-d	0.37b-g
<i>Oligonychus illicis</i>	0.63f-h	0.67a-e	0.54c-f	0.43b-d
<i>Panonychus citri</i>	0.73b-g	0.52d-g	0.83b-c	0.41b-f
<i>Panonychus ulmi</i>	0.99a	0.77a-e	0.51c-g	0.27d-h
OTHER MITES (OM)				
<i>Orthotydeus</i> spp.	0.68e-h	0.59b-f	0.12j-k	0.10g-h
<i>Phytonemus pallidus</i>	0.91a-e	0.32f-h	0.73b-d	0.42b-e
<i>Tyrophagus putrescentiae</i>	0.45h-i	0.95a	0.13l-k	0.00h
ERIOPHYID MITES (EM)				
<i>Aculus schlechtendali</i>	0.87a-f	0.94a	0.96b	0.60b
INSECTS (INS)				
<i>Trialeurodes vaporariorum</i>	0.92a-e	0.69a-e	0.54c-e	0.44b-e
<i>Psocidae</i>	0.92a-e	0.54c-g	0.24e-k	0.17e-h
<i>Frankliniella occidentalis</i>	0.79a-g	0.67a-e	0.08k	0.02h
<i>Quadraspidotus perniciosus</i>	0.70c-g	0.47e-h	0.22e-k	0.15e-h
POLLEN (POL)				
<i>Zea mays</i>	0.93a-e	0.69a-e	0.77b-d	0.56b-c
<i>Hypericum frondosum</i>	0.94a-c	0.78a-e	0.47d-i	0.36b-g
<i>Tilia cordata</i>	0.93a-e	0.74a-e	0.51c-g	0.38b-g
<i>Rubus discolor</i>	0.95a-c	0.72a-e	0.48e-h	0.39b-f
<i>Trifolium pratense</i>	0.95a-c	0.80a-d	0.44de-j	0.29c-h
<i>Nandina domestica</i>	0.64f-h	0.93a	0.19f-k	0.06h
<i>Cucurbita pepo</i>	0.96a-b	0.74a-e	0.15h-k	0.09g-h
<i>Weigela florida</i> 'Red Java'	0.76a-g	0.84a-c	0.18g-k	0.15e-h
<i>Catalpa speciosa</i>	0.68d-g	0.83a-d	0.12j-k	0.09g-h
<i>Spiraea x bumalda</i> 'Gold Flame'	0.70c-g	0.86a-b	0.15h-k	0.13f-h
<i>Fuchsia hybrida</i>	0.78a-g	0.91a	0.21e-k	0.19d-h
OTHERS				
Honey water	0.83a-g	0.52d-g	0.34e-k	0.28c-h
Honeydew	0.58g-i	0.33f-h	0.18g-k	0.18d-h
Starvation (arena)	0.36h	0.57b-f	0.04k	0.00h
Starvation (apple leaf)	0.64f-g	0.71a-e	0.21e-k	0.16e-h
P-value ^e	<0.0001	<0.0001	<0.0001	<0.0001

^a Percent female survival after 7 days in arenas.

^b Percent female activity (ambulation) within arena per 1 min observation per day.

^c Number of eggs produced per female per day.

^d Number of immatures produced per female per day.

^e Means of all tests were analyzed simultaneously by ANOVA, d.f.=28, 203.

^f Means followed by different letters are significant at $\alpha=0.05$ (Tukeys HSD).

(Jacobi), and *P. citri* provided for more production than starvation treatments. *N. fallacis* produced more immatures on *P. pallidus*, *A. schlechtendali* and whitefly crawlers than when starved, although prey food types OM, EM and INS were not significantly different. Only *Zea mays* L., *Hypericum frondosum* Michaux, *Tilia cordata* Miller and *Rubus discolor* Weihe & Nees pollens allowed for more immature production than starvation treatments. Neither honeydew nor honey water influenced immature production as compared to starvation treatments.

3.3.2. Literature-based versus oviposition-based feeding preference models

The literature-based model accurately predicted feeding specialization of the type II *N. fallacis* as measured by reproduction and preexisting literature (Table 3, Fig. 4b). Only 10 of 1000 random sums of squares tests had a better fit of the model than values determined from our reproduction tests. When comparing the FPI generated from literature only, 32 of 1000 random sums of squares had a better fit to the data. Similarly, feeding specialization was predicted well for the Type I *P. persimilis* (Table 3, Fig. 4a), with only 1 of 1000 randomizations greater than actual reproduction data from various studies. In contrast, the model output for Type III *T. pyri* was only

Table 3. Randomization test comparing literature citation indices (LCI) versus feeding preference indices (FPI) for five phytoseiid mites (Manly 1991).

	Life Style Type ^a	No. of Models with Better Fit ^b	Empirical Proportion ^c	Goodness of Fit Rank ^d
<i>P. persimilis</i>	I	1	<0.99	1
<i>N. fallacis</i> (Table 1)	II	10	<0.99	2
<i>N. fallacis</i> (Literature)	II	32	0.96	3
<i>T. pyri</i>	III	136	0.86	4
<i>E. finlandicus</i>	IV	370	0.63	5
<i>E. hibisci</i>	IV	431	0.57	6

^a Based on assignments made by McMurtry and Croft (1997).

^b Number of sums of square values less than the observed sums of squares.

^c Proportion of extreme values in randomization test.

^d Ranking of goodness of fit between literature citation model and reproductive values.

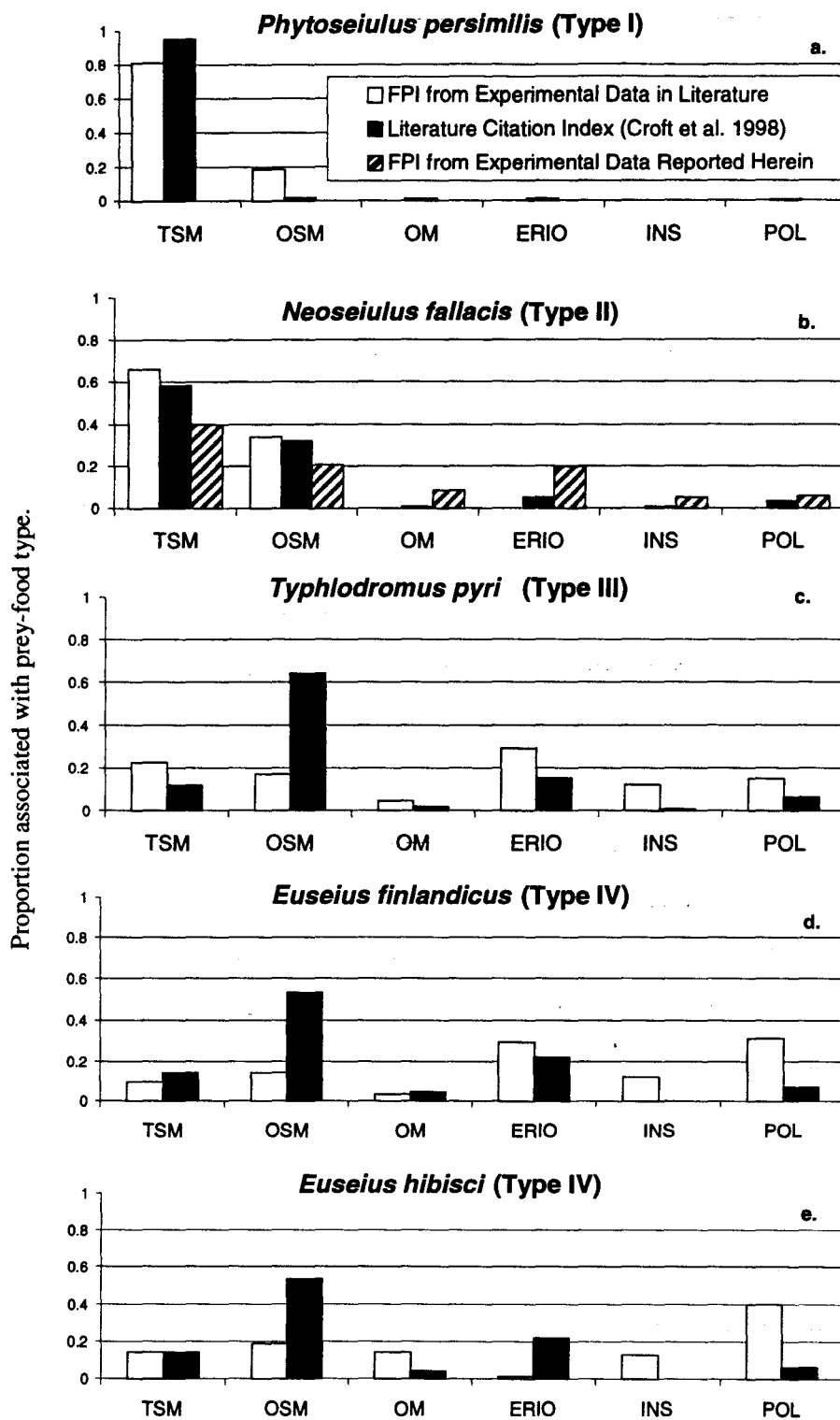


Figure 4. Graphic comparison of feeding preference as described by literature citation index (LCI) and reproductive based feeding preference index (FPI).

moderately similar to reproductive data from the literature and the Type IVs, *E. finlandicus* and *E. hibisci*, had even more disparity between literature and measured reproductive values (see Appendix I, Fig. 4c-d).

3.4. Discussion

Type II selective predators of tetranychid mites are described as having a broad range of prey within the Tetranychidae and limited reproduction on other mite groups, insects and pollen (McMurtry and Croft, 1997; Croft et al., 1998a). Our experimental data suggest that *N. fallacis* has a prey range similar to species that are classified as Type II selective predators of tetranychid mites. Survival, reproduction and development were consistently highest, and activity lowest, when held with *Tetranychus* species. Reproduction was limited when with non-tetranychid species although representatives from nearly all prey-food types provided for reproduction that was higher than at starvation conditions.

One possible explanation for the better performance of *N. fallacis* when feeding among *Tetranychus* species would be the preconditioning of metabolic functions or experience gained from having been reared on *T. urticae*. Would a strain of *N. fallacis* reared strictly on pollen behave differently than the one tested herein? Such strain tests have yet to be conducted, but they would be useful in estimating how adaptive phytoseiids might be in adjusting to predominant food sources. While our findings were not adjusted for previous food sources, *Tetranychus* species may be typical prey items of Type II predators and any preconditioning experienced in these studies may be similar to those prey conditions found in nature (McMurtry and Croft, 1997).

Our data have relevance to use of *N. fallacis* as a biological control agent of pest mites and even to a broader range of species that occur in a diversified cropping system like ornamental nurseries (Pratt and Croft, 1998). McMurtry (1992) proposed that species with broad prey ranges may remain longer on plants and regulate pest mite outbreaks effectively. Such species also may readily disperse between plant systems

where they can prey on different prey types and supplemental foods (Pratt et al., 1998). Ahlstrom and Rock (1973) suggested that pollen might enhance stability of the predator populations during periods of low spider mite populations. We showed that *N. fallacis* will feed and reproduce on various pests, and that other less-injurious mites, insects, or pollen may enhance survival when pest mites are scarce. As predators leave hibernacula in spring, alternative prey may have importance while tetranychid mites are still in diapause (Overmeer, 1985). Also, alternate prey or foods may aid in establishment of predators released to control low densities of primary target pests (Ramakers and Voet, 1995).

Our data give perspective to the literature-based model of Croft et al. (1998b). Based on our limited analyses, this model predicts prey-food suitability of Type I and II predators of spider mites quite well (Fig. 4a-b) when compared to experimental data for oviposition, but predictions for generalist Type III and Type IV species are less accurate (Fig. 4c-e). One explanation for high predictability of the Type I predators may be due to lack of reproductive values for *P. persimilis* on non-tetranychid food (see Appendix I). These missing parameters may be a function of the lack of reporting due to unsuccessful results, them not being found in our literature search or they have simply not been studied. Another explanation is there has been greater emphasis on testing reproductive performance on pests of economic importance in the past rather than on alternate prey or supplemental foods (Sabelis and Janssen, 1994; Croft et al., 1998b). Literature-based values consistently underestimate reproductive success among the rarely tested groups of OM, INS and POL (Fig. 4c-e). Type III and Type IV readily feed upon these foods. Expanding tests to include a fuller range of these prey-foods will likely improve estimates of prey acceptance and recognition for all life style types.

Finally, we note that Dicke et al. (1990) found that prey-food preference was usually correlated with reproductive values, but there may be exceptions where a high prey-food preference does not indicate a source upon which a natural enemy will show its greatest survival, development and reproduction. For example, they found that *T. pyri* preferred feeding on the spider mite, *P. ulmi*, but had higher rates of population

increase (r'_m) when feeding on the eriophyid mite, *A. schlechtendali*. In our study, we assumed that prey preference would be closely correlated to reproductive success but we propose that a better estimate of prey-food preference may be derived from multiple food tests with differing amounts of each presented simultaneously, and that several different parameters of survival and reproduction should be included. Such tests are difficult and expensive too carry out, but they would better represent the feeding preference of phytoseiid predators in natural systems.

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4. BIOLOGICAL CONTROL OF SPIDER MITES ON A RANGE OF ORNAMENTAL PLANT TYPES

4.1. Introduction

Predatory mites in the family Phytoseiidae are important biological control agents of pest mites, particularly those in the Tetranychidae (Helle and Sabelis 1985, McMurtry and Croft 1997). Inoculative releases of these predatory mites into many agricultural crops have resulted in suppression of spider mite populations and a decreased reliance on miticides (Croft 1990). For instance, *Neoseiulus fallacis* (Garman) suppress spider mites on crops such as apple, hops, peppermint and strawberry (Strong and Croft 1995, Morris et al. 1996, Croft and Coop 1998). Recently, *N. fallacis* was also selected for evaluation as a biological control agent of spider mites in the diverse cropping system of outdoor-grown ornamental nursery plants (Ch. 2, Pratt and Croft 1997).

Unfortunately little is known about the compatibility of *N. fallacis* with the range of plants grown in ornamental systems. Studies have demonstrated that phytoseiids are sensitive to plant architecture. Plant morphology such as trichomes, acarodomatia and nectaries may directly affect leaf residency time and ultimately biological control success (Pemberton 1993, Walter and O'Dowd 1992, English-Loeb et al. 1999). In addition, phytoseiids are vulnerable to low humidity, which may occur in plants with little foliage in the canopy (Croft et al. 1993). McMurtry and Croft (1997) classified *N. fallacis* as a Type II selective predator of tetranychids and suggested that these predators may be more affected by plant morphology than other more specialized predators of spider mites. Negative responses to external plant morphology may include dispersal from the plant, thereby releasing spider mite populations from natural control and resulting in excessive plant damage (Grevstad and Klepetka 1992, Karieva and Sahakian 1990). Understanding compatibility of *N. fallacis* with the plant types of ornamental nurseries is important to development of biological control tactics for these commodities (DeBach 1976, Stilings 1993).

The objective of this study was to test the ability of *N. fallacis* to suppress spider mites on a range of plants produced in outdoor ornamental nurseries. To do this, we first identified plants susceptible to spider mites from among the major morphological types grown in the Pacific Northwest. Initially, we inoculated *N. fallacis* into selected spider mite infested plants and measured the level of pest suppression. We then selected a subset and performed large scale releases of predators into entire fields.

4.2. Materials and Methods

4.2.1. Predator Source

Laboratory cultures of *N. fallacis* were initially collected from agricultural crops in the Willamette Valley, Oregon (Hadam et al. 1986). These cultures have been maintained for 6 years with periodic additions from field-collected mites. In all experiments, source populations of predators came from a mass rearing facility at Oregon State University: *N. fallacis* were produced on lima beans (*Phaseolus lunatus* L.) infested with *T. urticae* under greenhouse conditions of 26:21 (± 5)°C day:night (D:N), 75% (± 10) relative humidity (R.H.) and a photoperiod of 16:8 light:dark (L:D) h (Strong and Croft 1995). Prior to release of predators, spider mites had nearly been eliminated on the lima beans. Release of predators was performed by placing bean leaves containing known quantities of *N. fallacis* individuals directly into the canopy of selected plants that were infested with spider mites.

4.2.2. Small Scale Tests

We selected 30 ornamentals that represented conifers, shade trees, evergreen shrubs, deciduous shrubs, and herbaceous perennials to determine if *N. fallacis* would suppress spider mites on them (Table 4). All tests were conducted in northern

Willamette Valley ornamental production facilities under typical cultural practices. In all tests, spider mite infested plants were randomly assigned 1 of 2 treatments: release of *N. fallacis*, as described above, or no release (control). A minimum of 4 replicates per treatment were used for each test.

To estimate mite densities, randomly selected leaves or branches (Table 4) were removed, without replacement, from each replicate for several wks after the introduction of predators. Samples were placed in a cooler chest, transported to the laboratory and mite densities were recorded under a 40X microscope within 24 h. All predators found on sampled branches were mounted on glass slides in Hoyer's medium, heated for 1 wk on a slide-warmer at 40°C and identified by morphological characteristics as described by Schuster and Prichard (1963) using a 200X phase-contrast microscope.

Control of spider mites by *N. fallacis* was categorized into 3 levels in small scale tests based on visual inspection of plants and spider mite densities at the end of each test: 1= unacceptable levels of spider mite control resulting in unmarketable plants (>3 spider mites per leaf); 2= acceptable spider mite control resulting in marketable plants (<3/leaf); 3= same as 2 and reduction of spider mite to levels that were undetectable by our sampling method. In addition, we classified the foliar density of each plant into 1 of 3 categories based on visual inspection: 1= dense, 2=moderate or 3= sparse. For detailed descriptions of the methods for each test refer to Table 2 and Appendix II. We report only the summaries of individual tests in this chapter of the dissertation.

4.2.3. Large Scale Demonstration Plots

Neoseiulus fallacis was effective at suppressing spider mites on most plant tested in small scale experiments (Section 4.2.2.). Therefore, in 1998 we performed large scale inoculative releases of *N. fallacis* into entire plantings of *Abies procera*,

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Table 4. Biological control of spider mite pests by the predaceous mite *Neoseiulus fallacis* in ornamental nursery plants that represent a range of ornamental plant types.

Ornamental Plant	Type ^a	Age ^b	Size ^c	Substrate ^d	Canopy Density ^e	Release rate ^f	Release Date	Spider Mite	Pest Density ^g	Control ^h	Comments
<i>Abies procera</i> ¹	C	8	2.0 m	F	2	10	June 13	<i>O. ununguis</i>	3/B ^j	2	Reduced pest to sufficient levels.
<i>Acer x freemanii</i> 'Jeffersred' ²	ST	1	1.0 m	F	1	3	July 10	<i>T. urticae</i>	1/L	1	Predators rarely sampled in upper leaves
<i>Astilbe simplicifolia</i> 'Sprite' ³	HP	1	3.8 L	C	3	3	June 20	<i>T. urticae</i>	0.9L	3	
<i>Azalea</i> 'Vuyks Scarlet' ⁴	ES	1	3.8 L	C	3	0.25	July 17	<i>T. urticae</i>	4/L	2	Predators readily dispersed to borders between replicates
<i>Buddleia davidii</i> 'White Bouquet' ⁵	DS	1	3.8 L	C	1	2	July 10	<i>T. urticae</i>	5/L	2	Pest suppression best on lower leaves.
<i>Euonymus alatus</i> 'Compacta' ⁶	DS	2	11.3 L	C	2	2	July 18	<i>T. urticae</i>	5/L	3	
<i>Geranium cinereum</i> 'Ballerina' ⁷	HP	1	3.8 L	C	3	2	June 20	<i>T. urticae</i>	10/L	2	
<i>Geum chiloense</i> 'Georgenberg' ⁸	HP	1	3.8 L	C	1	5	June 30	<i>T. urticae</i>	1/L	2	
<i>Hemerocalis</i> 'Happy Returns' ⁹	HP	1	3.8 L	C	1	2	June 30	<i>T. urticae</i>	2/L	2	
<i>Ilex crenata</i> 'Convexa' ¹⁰	DS	1	3.8 L	C	2	5	June 25	<i>T. urticae</i>	3/L	3	Suppressed pest at high densities.

Table 4 (Continued)

<i>Magnolia stelleta</i> 'Royal Star' ¹¹	DS	2	0.8 m	F	1	1	July 8	<i>T. urticae</i>	2/L	1	Required miticide application
<i>Malus</i> 'EMLA 106' ¹²	R	1	0.6 m	F	3	4000/ha	June 27	<i>T. urticae</i>	0.6/L	3	
<i>Picea glauca</i> 'Conica' ¹³	C	1	3.8 L	C	3	5	June 30	<i>O. ununguis</i>	4/B	2	
<i>Potentilla fruticosa</i> 'Gold Finger' ¹⁴	DS	1	3.8 L	C	2	5	June 25	<i>T. urticae</i>	4/L	3	Poorer control as compared to smaller plants.
<i>Potentilla fruticosa</i> 'Gold Finger' ¹⁵	DS	2	11.3 L	C	3	2	July 18	<i>T. urticae</i>	2/L	2	
<i>Rhododendron</i> 'Ana Kruschke' ¹⁶	ES	4	0.6 m	F	2	2	June 17	<i>O. illicis</i>	1/L	2	Fed on spider mites on adaxial and abaxial sides of the leaf.
<i>Rhododendron</i> 'Hotie' ¹⁷	ES	4	0.6 m	F	2	2	June 17	<i>O. illicis</i>	5/L	2	
<i>Salvia superba</i> 'East Friesland' ¹⁸	HP	1	3.8 L	C	3	3	June 30	<i>T. urticae</i>	0.9/L	2	
<i>Sasaella hidaensis</i> 'Murai' ¹⁹	ES	2	3.8 L	C	2	3	June 11	<i>S. celarius</i>	2/L	3	Predator readily entered webbed colonies.
<i>Skimmia japonica</i> 'Female' ²⁰	ES	2	7.6 L	C	2	10	June 25	<i>P. citri</i>	12/L	2	Adequate control at high pest densities
<i>Skimmia japonica</i> 'Female' ²¹	ES	2	7.6 L	C	2	0.5	July 2	<i>T. urticae</i>	1/L	2	
<i>Spiraea bumalda</i> 'Crispa' ²²	DS	2	0.6 m	F	3	5	July 2	<i>T. urticae</i>	2/L	2	Predators readily dispersed to border plants.

Table 4 (Continued)

<i>Spiraea bumalda</i> 'Gold Mound' ²³	ES	2	3.8 L	C	3	2	July 5	<i>T. urticae</i>	1/L	2	
<i>Thuja occidentalis</i> 'Little Giant' ²⁴	C	2	3.8 L	C	3	3	April 14	<i>O. ununguis</i>	2/B ⁱ	2	Early season release resulted in adequate control
<i>Thuja occidentalis</i> 'Little Giant' ²⁵	C	2	3.8 L	C	3	3	June 15	<i>O. ununguis</i>	10/B ⁱ	2	
<i>Tilia cordata</i> 'Greenspire' ²⁶	ST	1	0.9m	F	1	2	July 2	<i>T. urticae</i>	2/L	1	Predators confined to lower leaves only
<i>Viburnum opulus</i> 'Sterile' ²⁷	DS	1	3.8 L	C	2	2	July 2	<i>T. urticae</i>	3/L	1	
<i>Viburnum plicatum</i> 'Newport' ²⁸	DS	2	0.25 m	F	3	3	June 15	<i>T. urticae</i>	5/L	2	
<i>Weigela florida</i> 'Red Java' ²⁹	DS	1	3.8 L	C	2	2	June 26	<i>T. urticae</i>	4/L	2	
<i>Weigela florida</i> 'Verigata' ³⁰	DS	1	3.8 L	C	2	5	July 2	<i>T. urticae</i>	8/L	2	

^a C = conifer; ES = evergreen shrub; DS = deciduous shrub; ST = shade tree; HP = herbaceous perennial

^b Age of plants in years.

^c Plant size described as height (m) or container size (L).

^d F = field planted ; C = plastic container

^e Categories of foliar density in plant canopy: 1=dense, 2=moderate, 3=sparse.

^f Number of predators released per plant or per ha

^g Number of spider mites per leaf (L) or branch (B) at date of release.

Table 4 (Continued)

^h 1= Unacceptable levels of spider mite control resulting in unmarketable plants; 2= Acceptable spider mite control resulting in marketable plants; 3= Same as 2 and reduction of spider mite to undetectable levels.

ⁱ Sample consists of a randomly selected, 4 cm branch.

^j Samples consist of 3 randomly selected, 10 cm terminal branches that were removed at 0.5, 1, 1.5 m above the soil surface

1= Pinaceae, 2= Aceraceae, 3= Saxifragaceae, 4= Ericaceae, 5= Buddlejaceae, 6= Celastraceae, 7= Geranuaceae, 8= Rosaceae, 9=

Hemerocallidaceae, 10= Aquifoliaceae, 11= Magnoliaceae, 12= Rosaceae, 13= Pinaceae, 14= Rosaceae, 15= Rosaceae, 16= Ericaceae, 17=

Ericaceae, 18= Labiatae, 19= Gramineae, 20= Rutaceae, 21= Rutaceae, 22= Rosaceae, 23= Rosaceae, 24= Cupressaceae, 25= Cupressaceae, 26=

Tiliaceae, 27= Caprifoliaceae, 28= Caprifoliaceae, 29= Caprifoliaceae, 30= Caprifoliaceae

Thuja occidentalis 'Emerald', *Malus* MM.106 EMLA rootstock and, *Viburnum plicatum* 'Newport'.

1. *Abies procera*. The study site was a 0.5 ha planting of 2 m tall (8 yr old) *A. procera* trees located near Independence, Oregon (44.86 N lat. and 123.2 W long.). Trees were planted on a 4% NW slope and spaced ca. 2 m apart. During the experiment, populations of the spruce spider mite, *Oligonychus ununguis* (Jacobi), were monitored weekly by sampling branches from 40 randomly selected trees within the study site. Samples consisted of 3 randomly selected 10 cm terminal branches that were removed from each tree at 0.5, 1 and 1.5 m above the soil surface. Samples were placed in an ice cooler, transported to the laboratory and a 40X stereomicroscope was used to count the mites present. On 8 May spider mite densities reached 2.75 (± 1.02) mites per branch and 8,000 adult female *N. fallacis* were evenly distributed on plants within the study site. All predators found in samples were mounted on glass slides and identified as described earlier.

2. *Thuja occidentalis* 'Emerald'. The study site was near Woodburn, Oregon (45.14 N lat. and 122.5W long.) and consisted of 500 field-planted *T. occidentalis* 'Emerald' trees. Plants were 1.25 (± 0.11) m tall, spaced ca. 1 m apart and irrigated with overhead sprinklers as needed. Spruce spider mites were monitored on 25 randomly selected trees by removing 2 terminal branches of 4 cm in length located at 0.5 and 1 m above the soil surface. On 12 June spider mite densities reached 1.23 (± 0.64) per branch and 3,000 *N. fallacis* adult females were evenly distributed on plants throughout the study site. Sampling and predator identification was performed as described earlier.

3. *Malus* MM.106 EMLA rootstock. The study site was near Gervais, Oregon (45.6N lat. and 122.5W long.). *Malus* rootstocks (MM.106 EMLA) were cultivated in a 7.3 ha stoolbed field with 400 (± 22) plants per m² and 1 m between each row. Stoolbeds were rows of established root systems with sawdust drawn up along each row to cover roots and encourage growth of new branches (Hartmann and Kester

1983, Vasek and Howard 1984). Plants emerged from perennial roots in early spring and by May a continuous dense canopy of leaves was created within rows and nearly between rows. Rootstocks were sprinkler irrigated as need according to soil moisture sensors. In fall, apple rootstocks were harvested, sawdust replaced and no plant material remained above ground during winter. To sample mites, 400 leaves in an "X" pattern were taken across the field every 14 days. When spider mites reached 0.22 (± 0.05) per leaf, *N. fallacis* was released uniformly at 4000 adult females per ha. Leaves were transported, scanned for mites and predators were identified as described earlier.

4. *Viburnum plicatum* 'Newport'. The study site was a 0.5 ha field of 2-yr-old *V. plicatum* 'Newport' shrubs near Dayton, Oregon (45.2 N lat. and 123.1 W long.). The shrubs were planted in contiguous rows and spaced ca. 0.76 m apart. Mites were monitored by removing a single leaf from each linear m of contiguous foliage. Spider mites reached 1.1 (± 0.58) per leaf on 15 June and 3000 *N. fallacis* adult females were uniformly distributed into the field. Irrigation, estimation of mite densities and identification of predators were performed as described above.

4.2.4. Statistical Analysis

Treatments in small scale tests were compared over time with repeated measures analysis of variance (ANOVA) after a $\log(x+1)$ transformation of the data (von Ende 1993). The Huynn-Feldt adjustment was used when the covariance matrix of data did not meet the assumption of sphericity (von Ende 1993, SAS Institute 1990). Due to unknown underlying distributions and unbalanced sample sizes we used the non-parametric Kruskal-Wallis test and Fisher's least significant difference (LSD) when comparing levels of spider mite control among plant types (Ramsey and Schafer 1997). Differences of control levels among field grown versus containerized plants and among spider mite genera were compared with the non-parametric Mann-Whitney test (Statgraphics 1997). Simple linear regression was used to estimate the

relationship between the density of foliage in the plant canopy and spider mite control (Ramsey and Schafer 1997). Caution should be used when drawing inferences from statistical comparisons among plant types, production methods and pest genera because data were not standardized to adjust for differences in plant size, morphology, or other parameters that may influence biological control. For results of large scale tests, statistical procedures could not be used since the maintenance of control plots was not possible. For these tests we only plot spider mite and predator densities over time.

4.3. Results and Discussion

Control levels achieved over all small scale tests ($n=30$) by inoculative releases of *N. fallacis* were rated at 2.06 (± 0.58) on a scale of 1= unacceptable control, 2= acceptable control and 3= highly acceptable control. Among plant types, *N. fallacis* was most effective on shrubs and herbaceous perennials and less so on conifers and shade trees (Table 5). The observed differences in pest control may be related to the density of foliage within plant canopies. For instance, spider mites were controlled to significantly lower levels in plants with dense canopies ($P=0.016$). Also, *N. fallacis* is sensitive to low relative humidities that may occur in sparsely canopied plants (Croft et al. 1993, Nyrop et al. 1998, Ch. 2).

Ornamentals are typically produced in either individual plastic containers (pots) or planted directly into cultivated fields. In our studies, *N. fallacis* was equally effective at controlling spider mites on containerized versus field grown plants ($P=0.09$). In contrast, survival of long-range dispersal may be quite different among propagation substrates. For instance, the base substrate on which containerized plants are typically placed consists of a coarse gravel bed, as compared to soil in field-produced plants. Recent studies have shown that post dispersal survival of *N. fallacis* varies greatly when mites land on substrates other than the host plant (Jung and Croft 1999). For example, Jung and Croft (1999) found that survivorship was lowest when

N. fallacis landed on gravel as compared to soil or grass. In addition, predator conservation may be affected by production method. For instance, in peppermint *N. fallacis* moved to, or only survived in, leaf litter near the soil surface during winter (Morris et al. 1996). Overwintering survival of predators may be quite different among field grown and containerized production nurseries.

Table 5. Biological control of spider mites among different plant types grown in ornamental nurseries.

PLANT TYPE	NUMBER OF TESTS	CONTROL LEVEL ^a : MEAN (\pm SD)
Shade Tree	2	1.00 (0.00)a ^b
Conifer	4	1.50 (0.58)a
Evergreen Shrub	7	2.14 (0.38)b
Deciduous Shrub	12	2.17 (0.72)b
Herbaceous Perennial	5	2.20 (0.45)b
P-value		0.03 ^c

^a Categories of spider mite suppression: 1= Unacceptable levels of spider mite control resulting in unmarketable plants; 2= Acceptable spider mite control resulting in marketable plants; 3= Same as 2 and reduction of spider mite to levels that we were unable to sample pests.

^b Means followed by different letters are significant at $\alpha = 0.05$ (Fisher's LSD).

^c P-value derived from Kruskal-Wallis test, test statistic= 10.89.

Initial criteria for selecting *N. fallacis* as a biological control agent of spider mites included the ability to feed on many different tetranychid pests. In these studies, there was no difference among control levels when comparing control of *Tetranychus* versus non-*Tetranychus* prey ($P=0.35$). These data are consistent with prey range tests that demonstrated *N. fallacis* can readily feed and reproduce on many spider mite genera (Pratt et al. 1999, Ch. 3). Also, these data support the classifications of *N. fallacis* as a selective Type II predator of tetranychid mites; it being a group that shows a greater prey range than species that commonly have been

released in greenhouse and other high value plant systems (e.g. *Phytoseiulus persimilis*; McMurtry and Croft 1997, Croft et al. 1998).

Effective biological control of spider mites occurred in all 4 large scale inoculative releases of *N. fallacis*. In *V. plicatum* shrubs, *T. urticae* peaked at 1.28 (± 0.49) spider mites per leaf and were reduced to 0.35 (± 0.26) six wks later; *N. fallacis* peaked at 0.13 (± 0.06) six wks after release (Fig. 5a). Similarly, spider mites reached 3.83 (± 1.1) per branch in *A. procera* trees but were suppressed below 1 per branch on wk 9 (Fig. 5b). *Neoseiulus fallacis* effectively suppressed *O. ununguis* below 1 mite per branch in *Thuja occidentalis* trees and predator densities peaked at 0.33 (± 0.1) per leaf one month later (Fig. 5c). In apple rootstocks spider mites did not exceed 0.9 (± 0.12) mites per leaf yet *N. fallacis* averaged 1.47 (± 0.10) per leaf at wk 8 (fig 5d). Population levels were sufficiently low in all 4 tests that pest managers did not apply miticides prior to marketing.

4.4. Conclusions

Historically, selection of phytoseiids for suppression of spider mites in high value greenhouse or outdoor ornamental nursery crops has focused on Type I specialist predators of *Tetranychus* species (i.e. *Phytoseiulus persimilis* A. H.) (McMurtry 1982, Brushwien 1991, Cashion et al. 1994). While these biological control agents can rapidly respond numerically to *Tetranychus* species, they tend to disperse rapidly from plants as prey densities decrease and provide only short-term control (Walzer and Schausberger 1999, Helle and Sabelis 1985). For instance, to maintain adequate densities of *P. persimilis* Cashion et al. (1994) made inundative releases at 2 wk intervals for control of *T. urticae* in croton (*Codiaeum variegatum* L.). Type I phytoseiids also have narrow prey ranges and may be ineffective at controlling other important spider mites or other mite pests in these systems (Pratt et al. 1999, McMurtry and Croft 1997, Ch. 3).

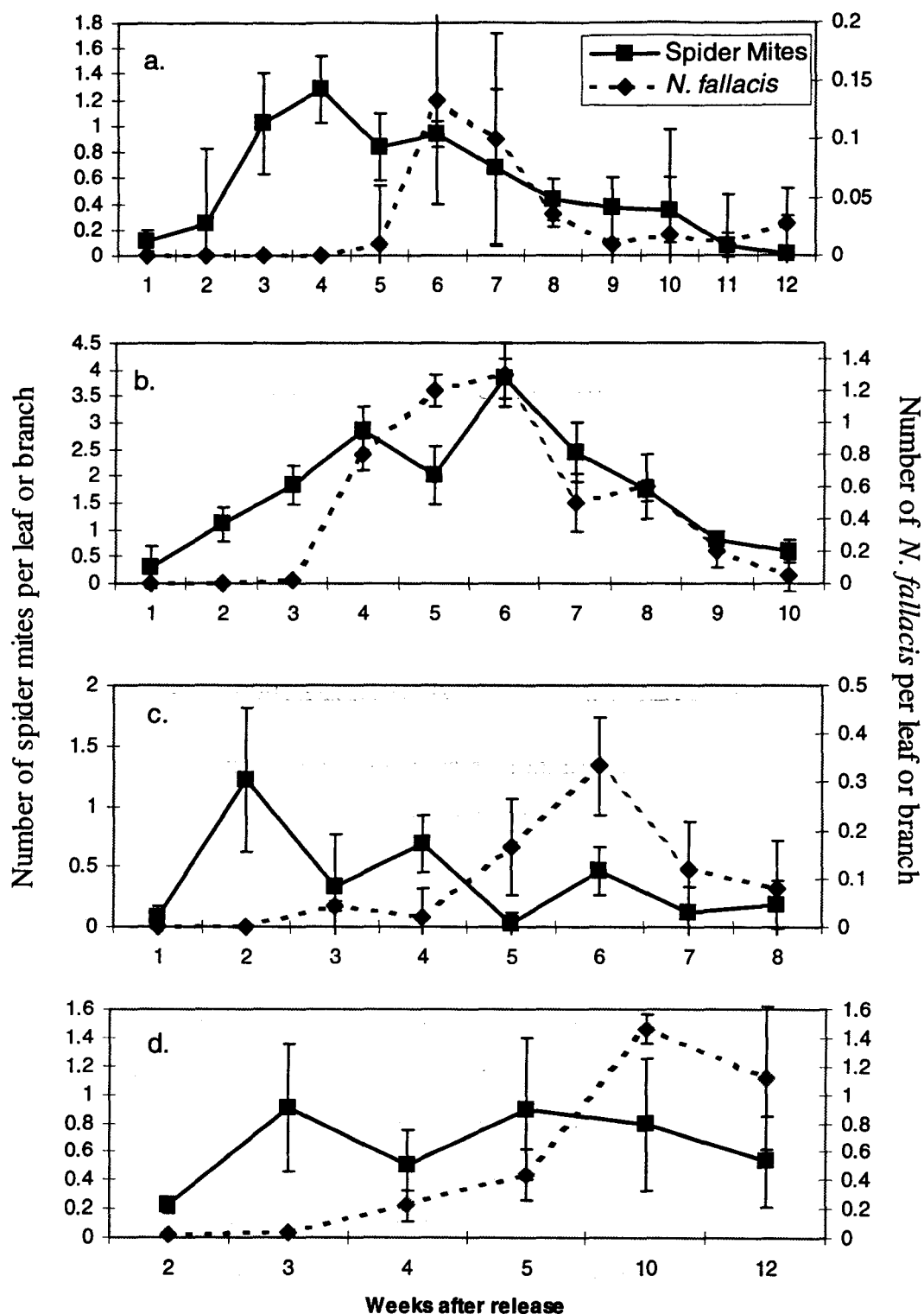


Figure 5. Population trends of the predaceous mite *N. fallacis* and its prey *O. ununguis* (b & c) or *T. urticae* (a & d) in a: *V. plicatum* 'Newport', b: *A. procera*, c: *T. occidentalis* 'Pyramidalis' and d: *Malus* rootstock 'MM.106'

We wished to develop a more sustainable biological control program for multiple spider mite pests for outdoor ornamentals of the Pacific Northwest. We hypothesized that a Type II selective predator would enhance the long-term control of spider mites in these systems. We selected *N. fallacis* because it numerically and functionally responds to many different spider mite pests (Boyne and Hain 1983, Croft et al. 1998, Pratt et al. 1999). While this species does not provide pest control as fast as some Type I phytoseiids, it also feeds on pollen, insects and other alternative diets that may enhance persistence in the crop of interest (McMurtry 1992). In addition, *N. fallacis* is native to the growing region and overwinters within ornamentals (Hadam et al. 1986, Ch. 7). We demonstrate that *N. fallacis* will control spider mites in most ornamental types tested (Table 4). Spider mite suppression was “acceptable” in 81% of the small scale tests (Table 4) and in all 4 large scale field tests (Fig. 5).

Limitations in control of spider mites by *N. fallacis* occurred mostly in tall, vertical growing plants with little foliar canopy. In these circumstances more arid-adapted species may be more effective, although the dry-adapted *Galendromus occidentalis* (Nesbitt) and *Neoseiulus californicus* McGregor were not effective in our shade tree tests (Ch. 2). Release of combinations of phytoseiid species that are adapted to specific plant types may be useful in complex polyculture systems like ornamental nurseries (Croft et al. 1999, Walzer and Schausberger 1999, Yao and Chant 1989).

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5. RELEASES OF *NEOSEIULUS FALLACIS* AT LOW PEST DENSITIES FOR SUPPRESSION OF *TETRANYCHUS URTICAE*

5.1. Introduction

The introduction of biological control agents for suppression of pests is an underlying principle of many integrated pest management (IPM) strategies (Messenger et al. 1976). When releasing natural enemies, IPM practitioners must consider when to release, how many agents to release and where to place them in the commodity of interest. Much research has focused on applying control tactics at the highest pest density before economic damage occurs to the crop (i.e. action thresholds, economic injury level; Horn 1991). Alternatively, less attention has been given to releases of natural enemies at very low pest densities. Introductions at very low prey levels may reduce the number of agents needed and reduce the effort of release by optimizing dispersal of the agent within a crop. In contrast, introductions of natural enemies into cropping systems with levels of prey that are too low has been identified as one reason why many introductions of biological control agents fail (Beirne 1975, Stiling 1993). Considering these contrasting paradigms, we questioned whether the biological control agent *Neoseiulus fallacis* (Garman) would effectively suppress *Tetranychus urticae* Koch when released at very low pest densities within a uniform nursery planting of apple rootstock.

Neoseiulus fallacis is an important biological control agent of spider mites in temperate regions of the USA. A great deal of research with this species has concentrated on suppression of pest mites in apple orchards (reviewed in Croft 1990). In contrast, an apple stoolbed system is quite different than a conventional orchard in that the former is more humid, low growing, and consists of a contiguous series of apple shoots with very little exposed soil (Hartmann and Kester 1983, Vasek and Howard 1984). Its overall growth characteristics are more like those of a dense caneberry (raspberry, blackberry) planting than an orchard production system. These plant characteristics may enhance successful aerial dispersal of mites, as

compared to an orchard, due to increased probability of landing on a favorable plant (Jung and Croft 1999). Little is known about the inoculation of *N. fallacis* at extremely low prey levels and the ensuing dispersal and biological control that would be required in an apple stoolbed system. Therefore, objectives of this study were to determine: 1) if releases of *N. fallacis* would suppress moderate initial population densities of *T. urticae* in a uniform planting of apple rootstock, 2) if releases of *N. fallacis* would effectively disperse and control very low densities of *T. urticae*, 3) if an individual-based simulation model would adequately describe within-field dispersal of *N. fallacis*, and 4) how field dimensions would affect emigration of *N. fallacis* as described by simulation.

5.2. Materials and Methods

5.2.1. Predator Source, Study Site and Weather Conditions

Source populations of *N. fallacis* came from Biocontrol Works of Jefferson Oregon. All *N. fallacis* were produced on lima beans (*Phaseolus lunatus* L.) infested with *T. urticae* under controlled environmental conditions (Strong and Croft 1995). Lima bean plants harboring predators were harvested just prior to release when predators had nearly eliminated all spider mites.

The study site, near Gervais, Oregon (45.6N lat. and 122.5W long.), consisted of apple rootstocks (MM.106 EMLA) cultivated in a 7.3 ha stoolbed field with 400 (± 22) plants per m² and 1 m between each row. Rootstock stoolbeds were rows of established root systems with sawdust drawn up along each row to cover roots and encourage growth of new branches (Hartmann and Kester 1983, Vasek and Howard 1984). Plants emerged from perennial roots in early spring and by May a continuous dense canopy of leaves was created within rows and nearly between rows. Rootstocks were sprinkler irrigated as need according to soil moisture sensors. In

fall, apple rootstocks were harvested, sawdust replaced and no plant material remained above ground during winter.

In 1995-1997, we gathered wind velocity and direction data at 1 h intervals from a weather monitoring station located approximately 15 km from the study site. Wind direction was categorized into 8 cardinal directions (N, NE, E, SE, S, SW, W, NW). Only wind data for the period of these experiments were used for model simulation.

5.2.2. Small Scale Releases (1995)

In 1995 we tested the ability of *N. fallacis* to control *T. urticae* in replicated small plots within the downwind edge of an apple rootstock field (Fig. 6). Ten 1000

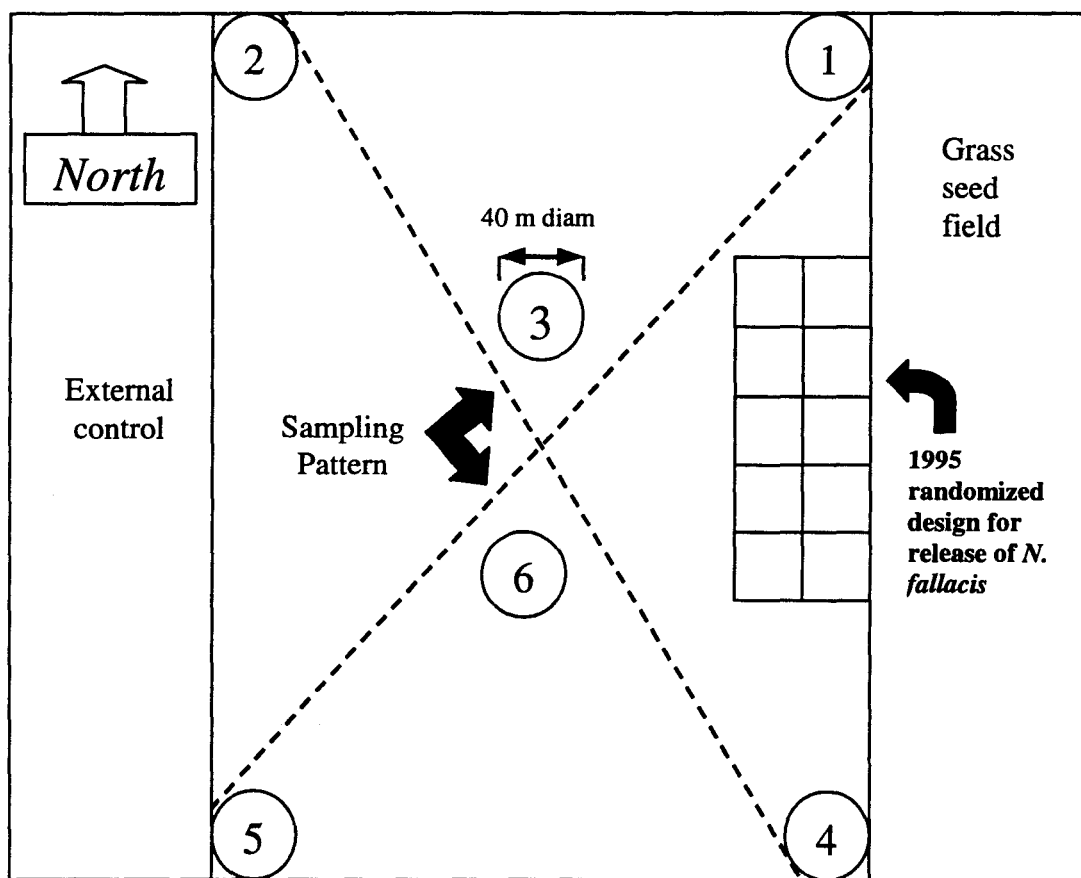


Figure 6. Representation of the 7.3 ha apple rootstock field. Circles 3 and 6: 40 m control sites in 1996; Circles 1-6: 40 m control sites for 1997.

m² plots were randomly assigned one of two treatments: 1) release of 210 (± 8) adult female *N. fallacis* or 2) no release of predators (control). We monitored each replicate by removing 50 leaves in an “X” type pattern across the plot every 14 days. We also monitored a neighboring apple rootstock field that served as an external field control. On 27 June spider mite populations had increased to a moderate density of 0.60 (± 0.12) per apple leaf and *N. fallacis* were released into small plots by placing a bean leaf containing 3 adult females every 6 m along each of 12 rows per replicate (ca. 4000 *N. fallacis* per ha). Leaf samples were placed in an ice cooler, transported to the laboratory and processed within 24 h. A 40X microscope was used to count pest and predator populations. All predators found on sampled leaves were mounted in Hoyer’s solution on glass slides and identified by morphological characteristics (Schuster and Prichard 1963). To normalize population data, we performed a $\log(x+1)$ transformation prior to analysis. To adjust for sampling the same populations of mites over time, we compared treatments with repeated measures analysis of variance (ANOVA) (von Ende 1993).

5.2.3. Release of *N. fallacis* at Low Prey Densities (1996)

In 1996 we measured biological control of spider mites by *N. fallacis* in a whole field when released at very low densities of prey (*T. urticae*). To monitor spider mites within the 7.3 ha field, we removed 400 leaf samples in an “X” sampling pattern every 14 days and processed these samples as described earlier. Areas of no release were created by defining two, 40 m diam circles, each located near the center of the field (Fig. 6). The diameters of the control circles were chosen according to reported dispersal distances of *N. fallacis* in strawberry fields approximately 10 wks after release (Coop and Croft 1995). To monitor spider mites, 100 leaves were removed from the center of each control circle. When spider mites increased to 0.22 (± 0.05) per leaf across the field, *N. fallacis* were released. Release of predators was similar to that made in 1995 with 4000 adult females released per ha in a uniform distribution across the entire field, excluding control circles.

5.2.4. Modeling Dispersal of *N. fallacis* (1997)

In 1996, *N. fallacis* suppressed spider mites in release areas but also rapidly dispersed into and suppressed spider mites in control circles. Eventually, higher levels of *N. fallacis* were sampled within the control circles than in the release areas. We questioned if the surprising rate that *N. fallacis* colonized control circles was related to their locations within the field and the prevailing wind direction. We hypothesized that control circles centrally located in a field would have higher densities of dispersed predators due to winds from any direction. Circles near edges of the field would have lower densities according to the prevailing wind and permeability of the boundaries. For instance, downwind control circles would be recipients of many dispersing mites but also lose many predators as they disperse from the field to locations downwind. In contrast, upwind circles would only be recipients of immigrants when the occasional non-prevailing wind occurred. This rationale suggests that centrally located circles would have the highest densities of predatory mites, whereas upwind circles would have the lowest and downwind circles would be intermediate.

To test this hypothesis, we modeled aerial dispersal of *N. fallacis* in the apple rootstock system using the scientific programming package PV-WAVE® (Visual Numerics, Inc., Houston, Texas). The model has three components. (1) The simulated area of predator and prey mite interaction was a two-dimensional matrix filled with a 195 X 375 array of cells, representing a cropland of 195m X 375m. (2) The model is individual-based. The predator mites foraging and dispersal behaviors are modeled individually across the simulated area. The prey population is modeled independently in each cell, following a logistic function with a carrying capacity that is randomly generated between 1-100 and an intrinsic rate of increase of 0.25 (Sabelis 1985). This allowed the population phenomena to be produced solely by local interactions between predators and prey. Initially, each simulation began with 30,000 uniformly distributed predators, with populations developing by preying upon

spider mites at local sites of release. A predator will sense the amount of prey in the cell it resides and if the number of prey is not enough for the predator mites daily needs, it will disperse. (3) Dispersal is determined by wind, including both direction and velocity. To ensure that wind directions and velocities as represented in the model were ecologically reasonable, probability functions were defined as piece-wise linear functions derived from wind data gathered as described previously. Each simulation consisted of 42 time steps that represented 42 d and simulations were repeated 100 times.

To validate the model in the field, inoculative release of the predator, sampling and control circles were exactly as before except that 4 additional control circles were added in extreme corners of the field (Fig. 6). We sampled each circle after 6 wks and ranked circles according to predatory abundance. We then compared validation ranks with simulation model outputs after 42 times steps (days). To measure model accuracy, we analyzed data at 3 levels of resolution. At a coarse level, we compared only relative abundance of *N. fallacis* in upwind circles (1+2+3) versus downwind (4+5+6). Medium resolution compared densities among upwind (1+2), central (3+6) and downwind (4+5) circles, respectively, and finest resolution compared ranks among all 6 circles. Ranks derived from simulation were considered not different from validation ranks when confidence intervals overlapped.

Assuming that the model accurately predicted dispersal of *N. fallacis*, we also questioned what effect field shape would have on predator emigration. To assess this, we used the same individual-based model but adjusted the length of the upwind border while maintaining the same area. We compared 13 field shapes with upwind borders ranging from 10 to 7312.5 m. Emigration was calculated by subtracting the number of *N. fallacis* present in the field after 42 d from the initial 30,000 predators. Again, overlapping confidence intervals between different lengths of upwind borders were considered not significantly different.

5.3. Results

5.3.1. Small Scale Release (1995)

Introduction of the predator *N. fallacis* into apple rootstock plants significantly reduced populations of *T. urticae* ($P < 0.001$). Pest mites were reduced 95% when compared to control plots (Fig. 7). In release plots, spider mite population levels peaked in early August at $1.34 (\pm 0.32)$ per leaf with predator

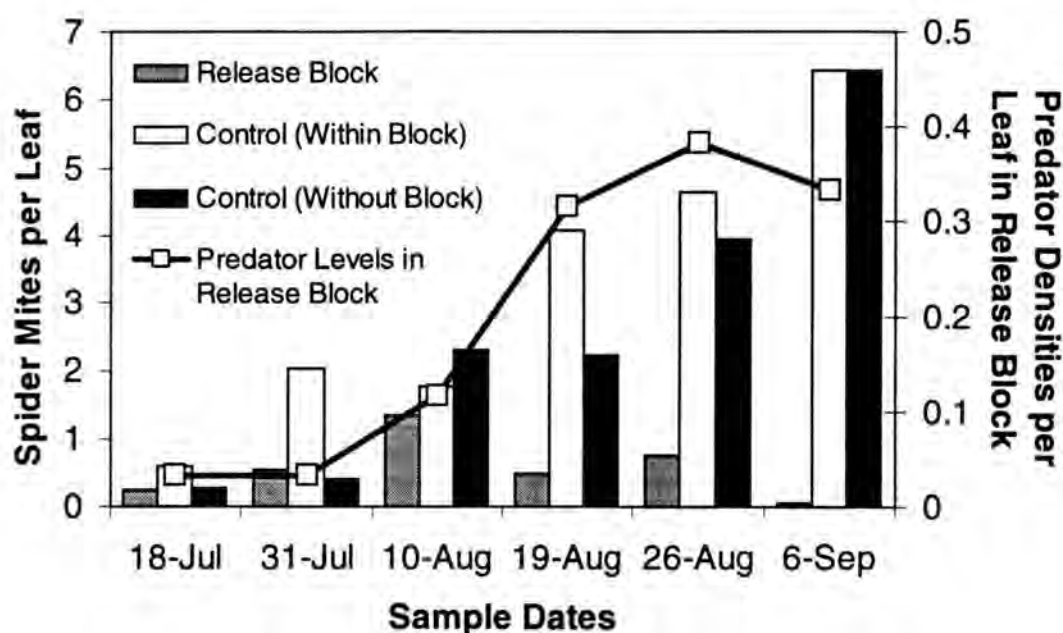


Figure 7. Mite densities after release of *N. fallacis* into apple rootstock.

populations peaking at $0.48 (\pm 0.10)$ per leaf 16 days later. *Tetranychus urticae* levels in control plots reached $6.45 (\pm 0.35)$ per leaf by early September.

5.3.2. Release of *N. fallacis* at Low Prey Densities (1996)

Releases of *N. fallacis* into low prey densities were highly effective at suppressing *T. urticae* (Fig. 8). Spider mites never exceeded $0.90 (\pm 0.12)$ individuals

per leaf in the release treatment as compared to $26 (\pm 4)$ per leaf in a nearby field without releases of *N. fallacis*. Surprisingly, higher population densities of *N. fallacis* were observed in the control circles (within block controls) than other areas of the field that had been inoculated with the predator (Fig. 8b). *N. fallacis* levels peaked at $1.47 (\pm 0.10)$ in the release areas as compared to $2.20 (\pm 0.12)$ in the control circles. As a result of the rapid dispersal of *N. fallacis* into the control circles, *T. urticae* densities were low and similar in control circles versus release sites.

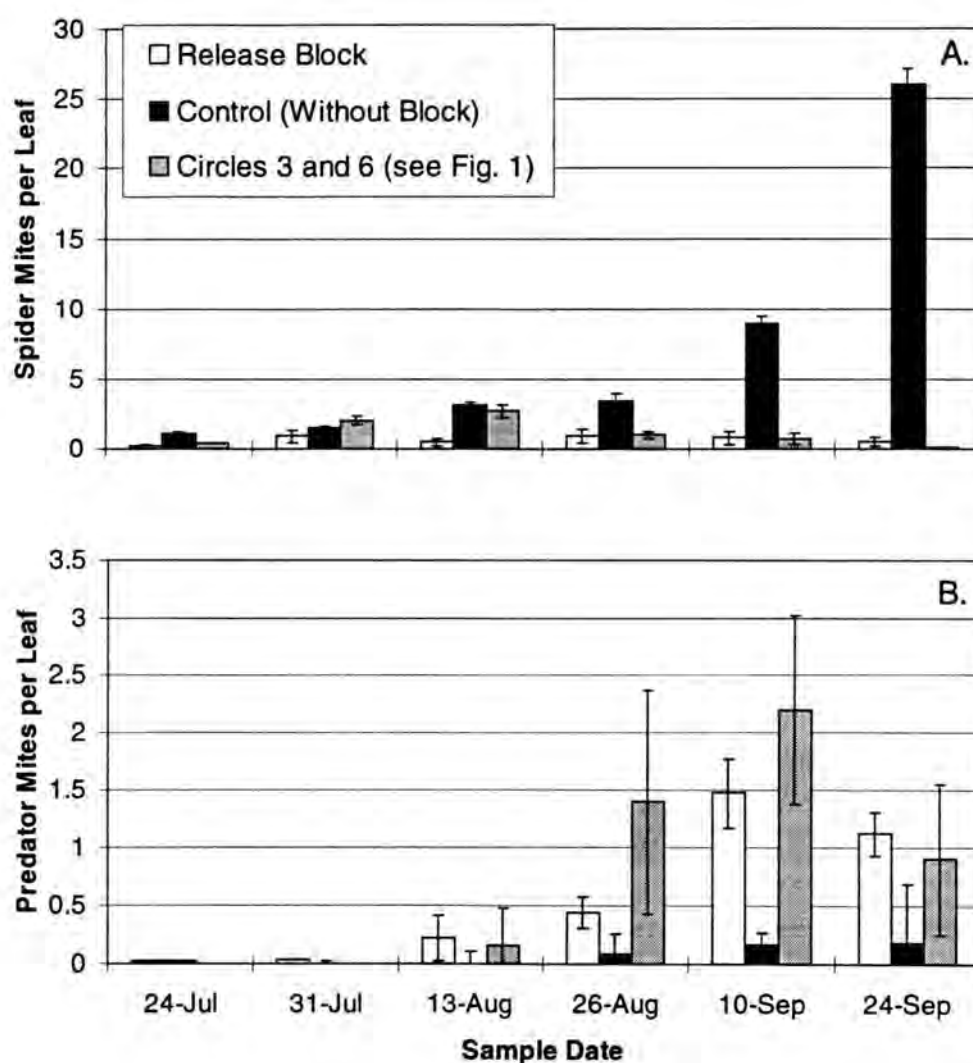


Figure 8. Suppression of *T. urticae* in apple rootstock after releases of *N. fallacis* into low prey densities.

5.3.3. Wind Velocity and Direction for 1995-1997.

Wind direction frequencies during July-September in 1995-1997 were greatest from N, NW, and W, with all other combined wind directions contributing less than 25% of frequencies (Fig. 9). Southerly winds increased in 1997 to 17% of total wind direction as compared to previous years (1995= 9% and 1996= 8%). No easterly winds were observed during the intervals of interest. When pooling wind speeds from 1995-1997, southerly winds had the greatest average velocity, with all others except E and SE being about equal (Fig. 9).

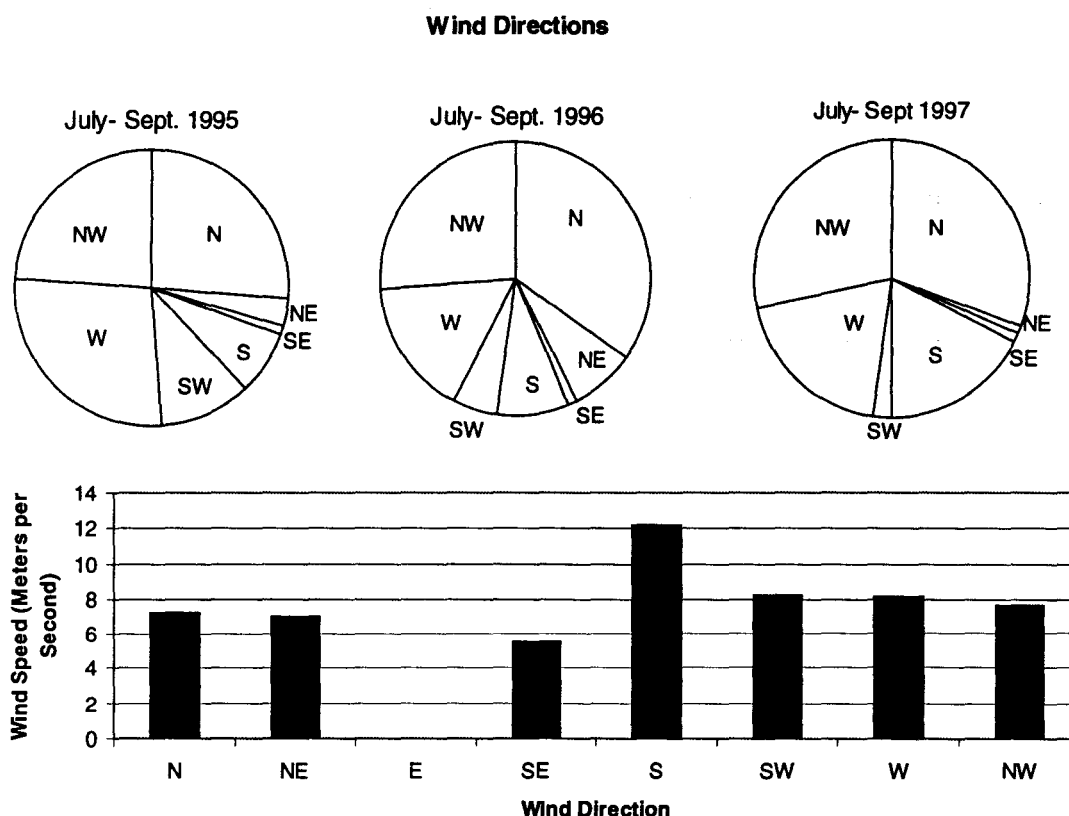


Figure 9. Wind direction and speed for months July-September 1995-1997.

5.3.4. Modeling Dispersal of *N. fallacis*.

The individual-based simulation model accurately predicted the relative density of *N. fallacis* at different locations within a single field at coarse and medium resolutions (Fig. 10). When comparing the coarse resolution data, control circles downwind had higher densities than those upwind. At the medium resolution, upwind control circles also had lower densities, downwind intermediate and centrally located control circles had the highest. In addition, the simulation was accurate at the fine resolution except for circles 3 and 4. The simulation overestimated densities in circle 3 while underestimating those in circle 4.

Adjusting field shape in the simulation model resulted in greatest number of *N. fallacis* emigrating from the field when upwind borders were at maximum or minimum lengths (Fig. 11). Emigration was reduced as field dimensions approached homogeneity. When upwind borders ranged from 150 to 487.5 m more than 84% of the predatory mite population was conserved within the simulated field. At upwind border lengths of 50 or 1462.5 m only ca. 62% of the mites were conserved.

5.4. Discussion

Little attention has been given to release of natural enemies at low pest densities. One explanation for this trend may be that the probability of establishment of a biological control agent is positively correlated to availability of prey (Beirne 1975). In contrast, releasing natural enemies at low prey density may reduce costs associated with purchasing natural enemies. In addition, taking advantage of the maximum searching and dispersal tendencies of the natural enemy may reduce the need for close release points of the biological control agent (Coop and Croft 1995). In this study, the introduction of *N. fallacis* at low prey densities was successful at reducing densities of the pest mite *T. urticae*. Releases of *N. fallacis* into low prey density in 1996 produced similar levels of control as when with moderate prey densities in 1995.

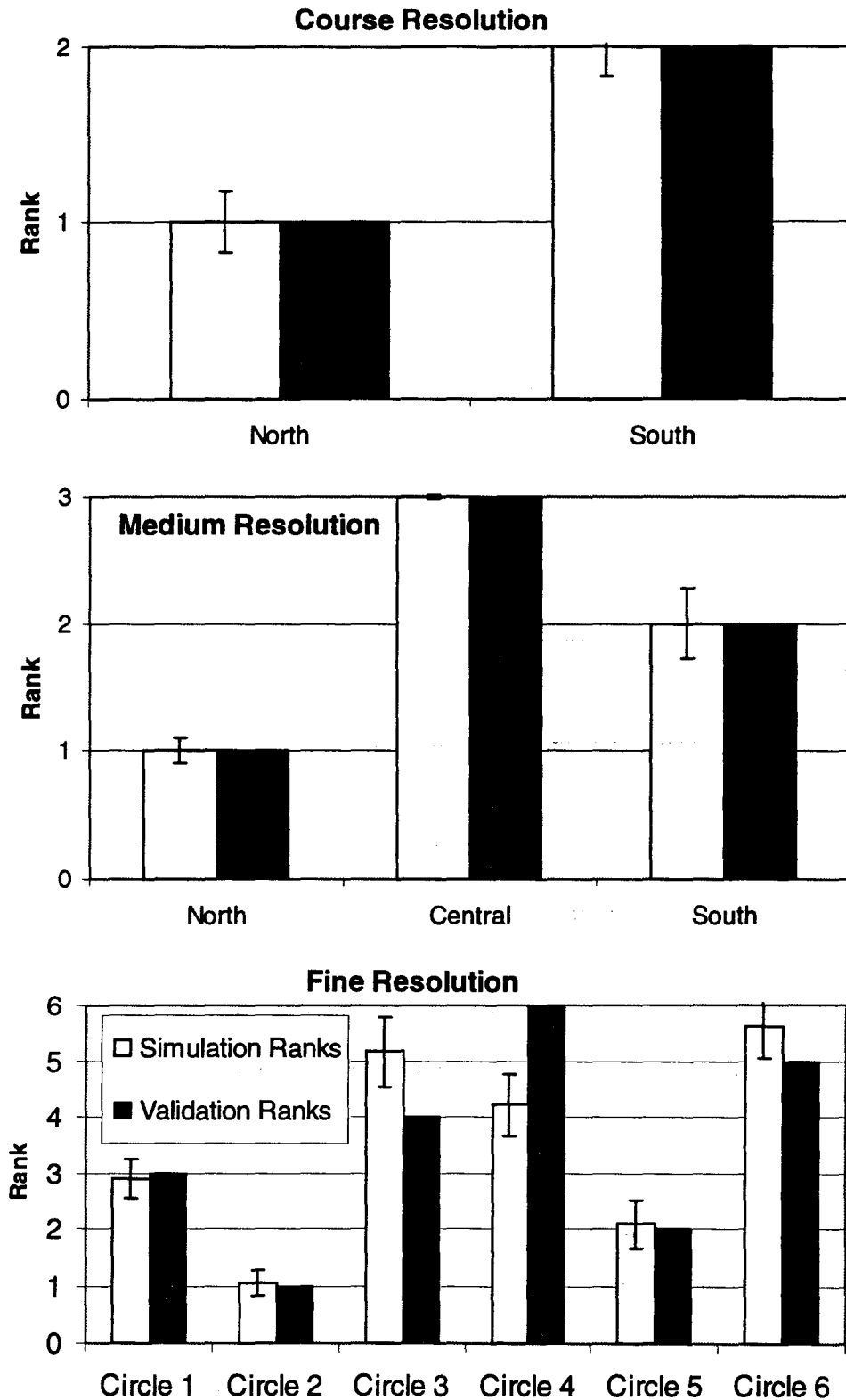


Figure 10. Comparison among validation and simulation data for the dispersal of *N. fallacis* analyzed at 3 levels of resolution.

These data also provide insights into dispersal of phytoseiids. Sabelis and Dicke (1985) demonstrated suppression of long range dispersal of phytoseiids by spider mite products and kairomones, and rapid dispersal when leaves contained no

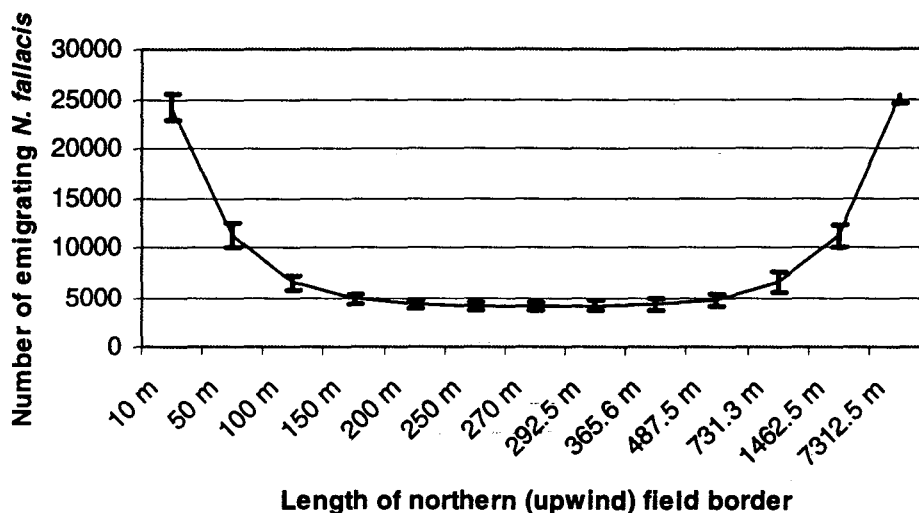


Figure 11. Individual based simulation model output predicting emigration of *N. fallacis* from 13 field shapes, each with a constant area of 7.3 ha (confidence intervals =SD).

prey (Pratt et al. 1998). In this study, phytoseiids appeared to be dispersing at high rates when spider mites densities were low but dispersal was terminated once a spider mite colony was located. In 1996, densities of *N. fallacis* were higher in control circles than areas of release. An explanation for this result may be that emigration from control circles was lower than release areas due to higher initial levels of spider mites (Fig. 8). Thus, reproduction would be higher in control circles, resulting in higher densities of *N. fallacis*. Later, increased predatory mite densities in centrally located control circles resulted in lower spider mite densities near the end of the test (Fig. 8).

The individual-based model accurately described the dispersal of *N. fallacis* in apple rootstock system at the coarse, medium and in most locations at fine resolution (Fig. 10). These finding suggest that wind direction and velocity are

important factors affecting the dispersal of *N. fallacis* in this system (Sabelis and Dicke 1985, Johnson and Croft 1979). Our findings suggest that upwind areas have higher emigration and reduced immigration of *N. fallacis* than downwind areas. Therefore, control of pests by passively dispersed natural enemies would be lowest on upwind field locations. One explanation for the lack of fit among the simulation data and the validation data for control circles 3 and 4 may be that random samples of wind direction and velocity taken at 1 h intervals may not adequately describe actual microenvironmental characteristics of wind movement in the field. Another explanation may be that the predatory mites were able to return to the field after dispersing out of the boundary, which is not incorporated in the current model (Jung and Croft 1999).

Nursery systems represent an extreme in artificial ecosystems. In these systems, spatial and temporal dispersion of plants are highly structured for uniformity and regularly managed for irrigation, fertilization and pesticide applications. In contrast, adjusting field shapes for improved conservation of natural enemies has rarely been evaluated (Herzog and Funderburk 1986). By adjusting field dimensions in our model we demonstrate that *N. fallacis*, and possibly other passively dispersed organisms, readily dispersed from field boundaries when upwind borders were either extremely short or long (Fig. 11). Fields with similar border lengths are predicted to have the highest densities of predatory mites. These findings have relevance to many agricultural systems, including outdoor ornamental nurseries, that utilize long narrow fields. Such field configurations may be detrimental to conservation of passively dispersed natural enemies like *N. fallacis*.

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6. BANKER PLANTS: RELEASE STRATEGIES FOR PREDATORY MITES IN OUTDOOR ORNAMENTAL NURSERY SYSTEMS

6.1. Introduction

Mites in the Tetranychidae, Eriophyidae and Tarsonemidae are major pests of commercial ornamental nurseries. Historically, ornamental producers have relied on chemical applications to suppress pest mites in these high value plants (Brushwein 1991, Mizell and Short 1992). An alternative to chemical control of pest mites is the introduction of predaceous mites (Phytoseiidae) into nursery crops. Recent studies have evaluated the use of *Neoseiulus fallacis* (Garman) to control pest mites on ornamentals and have demonstrated that inoculative releases can reduce populations, to the extent of eliminating miticide applications (Pratt and Croft 1999, Pratt and Croft 1998, Ch. 4).

Unfortunately, only limited attention has been given to identifying methods of releasing predatory mites into nursery systems. Although other methods occasionally have been used (McMullin 1995), introduction of predatory mites usually consists of purchasing predators and distributing them, by hand, into infested foliage (Pratt, personal observation). This procedure can be labor intensive and expensive, especially when multiple releases per season are required (Cashion et al. 1994, Brushwein 1991). In addition, improper timing of releases has been implicated in many biological control failures (Stiling 1993, Beirne 1975). In ornamental systems, releases of predatory mites in the absence of prey may result in starvation of the predator and release of predators in abundance of prey may cause unacceptable damage on the ornamental crop.

Ramakers and Voet (1996) described an alternative method of rearing and dispersing predatory mites from banker plants in greenhouse systems. Banker plants are any plant addition that aids in development and dispersal of predators for control of herbivorous pests. In castor bean banker plants, predatory mites fed on pollen and extra-floral nectaries and dispersed from the host plants to other plants, suppressing

pests such as thrips and spider mites for several months. To our knowledge, banker plants have not been evaluated for production and release of predatory mites in outdoor ornamental plants.

6.2. Banker Plant Concepts

To give perspective to our research, it is important to describe a “banker plant system.” The three basic components are the predatory mite, the banker plant and the prey or alternative food. Each is dependent and influences the others in complex ways (Fig. 12).

6.2.1. The Predator

Does the predator suppress the pest in the nursery crop? The ultimate objective is to control spider mites in ornamental crops. Thus, the initial criteria for selecting a predatory mite must be that it responds and can suppress the spider mite pest in the crop(s) of interest. Initial tests of predator-crop plant interactions must be conducted prior to incorporating a predator into a banker plant system.

Is the predator oligophagous? Preferably, the prey or the alternative food on the banker plant will be different than the mite pest that feeds on the ornamental crop. Thus, phytoseiid predators possessing a wide prey or food range may be more easily integrated into a banker plant system (Pratt et al. 1999, Ch. 3).

Will the predator numerically respond to the prey or alternate food in the banker plant? The banker plant and associated foods can potentially serve as a rearing unit for the predatory mite. Therefore, initial inoculations of the predator into the banker plant system may be quite low if the predator numerically responds greatly to the prey or alternate foods. The extent of onsite rearing of the predatory mite will often reduce the costs of purchasing, transporting and dispersing the predators appreciably.

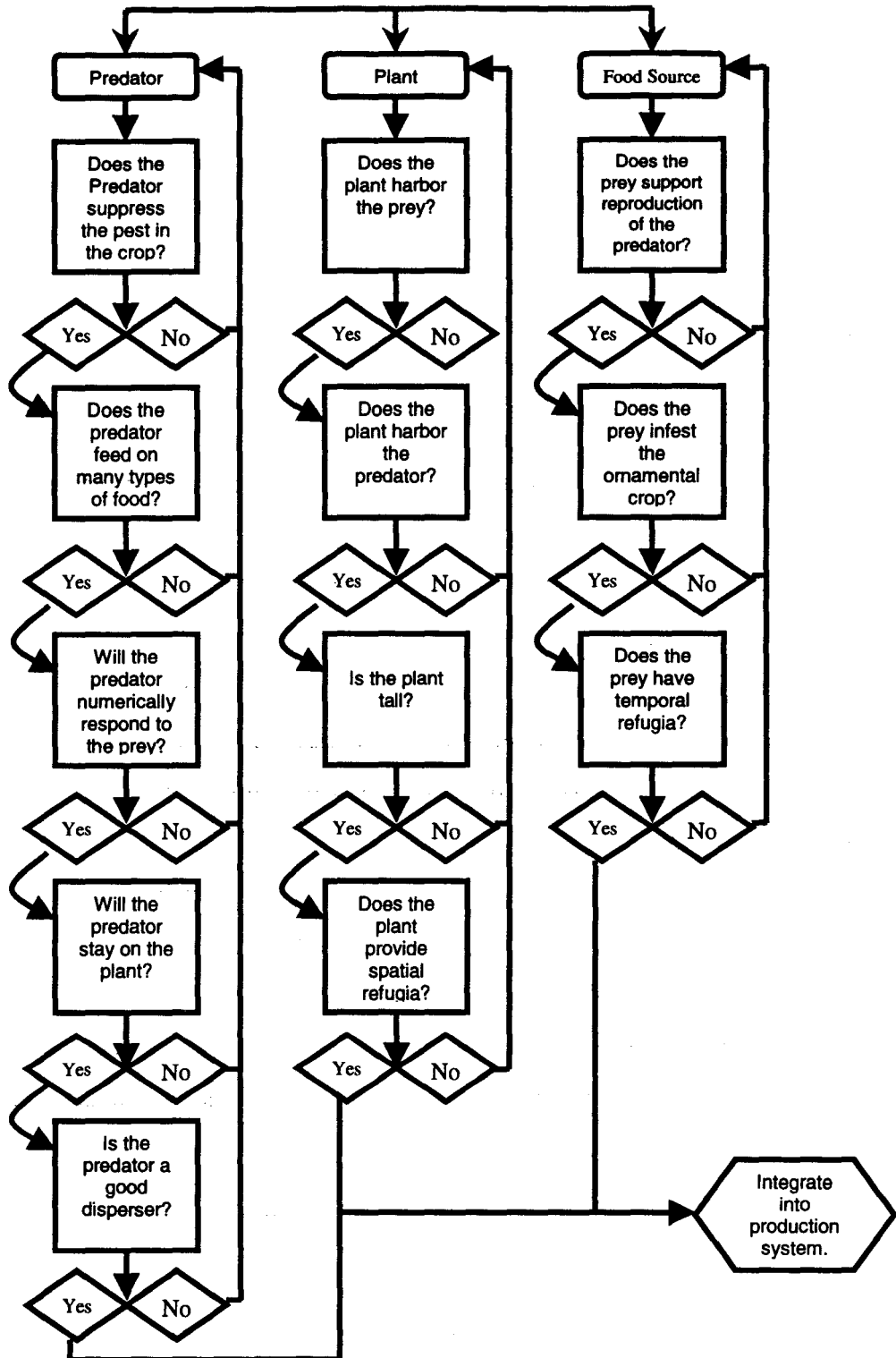


Figure 12. Flowchart describing attributes of three main components in a banker plant system. Components are not mutually exclusive and evaluations of each should consider impacts on the other components.

Will the predator remain on the banker plant? Most arthropods are influenced by substrate types. For instance, predatory mites are affected by leaf domatia, indumentum, plant turgor, pollen availability, extrafloral nectaries, overwintering sites etc. (Walter and O'Dowd 1992, Pemberton 1998). For this reason, selection of a banker plant must account for the acceptability and long-term colonization by the predator.

Is the predator a good disperser? Aerial dispersal among predatory mites is accomplished by entering the air currents and dropping to foliage downwind (Helle and Sabelis 1985). Behavioral and morphological adaptations among predatory mites may increase the dispersal distance of some species (Johnson and Croft 1979, Pratt et al. 1998). For example, body size, body shape, setal length, and behavioral adaptations such as different forms of “posturing” are believed to affect rates and distance of dispersal of these mites (Jung and Croft 1999). Knowledge of the distance and rate of dispersal by the predatory mite will influence the location and number of banker plants that are necessary in the nursery system.

6.2.2. The Banker Plant

Is the banker plant an adequate host for the prey? A suitable prey for the predator must develop and reproduce on the banker plant. If prey densities are greatly affected by inferior banker plant quality then the densities of dispersing predatory mites will be similarly affected. Degradation of the banker plant to an inadequate state will reduce the longevity of the system.

Is the banker plant tall (or can it be maintained in an elevated position)? Because dispersal of phytoseiid mites is determined in part by the height of the take-off location, tall banker plants may aid in long distance dispersal of the predatory mite. Increasing the height or elevation of the banker plant may increase the distance between banker plants and thereby decrease the number of plants that are required to achieve coverage with predators in the nursery system.

Does the banker plant provide spatial refugia? Population reductions or extinction of prey or alternate food by over exploitation by the predator will affect longevity of the banker plant system (continued dispersal of predators). One method to maintain the dispersing predator population is if the banker plant possesses refugia for the prey (Hawkins et al. 1993). For instance, the stems on new shoots of some rhododendron varieties possess a sticky material that impedes colonization of predators of the new leaves. In contrast, *Oligonychus illicis* (McGregor), the prey mite, does not appear to be as negatively affected and consequently it can develop large populations in a refuge on new leaves (Pratt, unpublished data).

6.2.3. The Prey or Alternate Food

Can the prey negatively affect the ornamental crop? If spider mites are used, it is quite probable that the prey on the banker plant will disperse to the surrounding environment. Therefore, the prey must not cause any negative effects on the ornamental crop of interest. If information on host range of the banker plant prey is not available, preliminary studies must be performed to determine this risk.

Is the prey synchronized with the predator? Prey or alternate food must be available to the predator for development and reproduction. Data suggests that some spider mites have lower developmental thresholds and therefore can develop appreciably while the predator is unable to develop (Helle and Sabelis 1985). Similarly, pollen and other foods may only be available or acceptable for specific intervals. This asynchrony may negatively affect the densities of predators produced and dispersing from the banker plant.

Does the prey or alternate food have temporal refugia from the predator? As previously mentioned, long-term production of prey may be accomplished with refugia. Stages of the prey or alternate food that are not available for predation may serve as refugia for the prey. For instance, it has been documented that the egg stages of some spider mites are inaccessible to the predator (Helle and Sabelis 1985).

Refugia of this type may reduce overexploitation of the food source and improve continued predator dispersal.

In the experiments described hereafter, we sought to evaluate several of the criteria for a good banker plant system that were raised in this general section. Specific objectives of our studies included to: 1) measure the ability of *N. fallacis* to numerically increase on banker plants and disperse to mite infested leaves downwind, 2) determine if reintroduction of spider mites into the banker plants would increase the duration and quantity of dispersed *N. fallacis*, 3) measure the effect of a pesticide refugium on the dispersal interval of *N. fallacis* and 4) determine distance traveled by predators when dispersing from a banker plant.

6.3. Materials and Methods

6.3.1. Mite Sources, Greenhouse Facilities and Receiver Plants.

Predatory mites used in these studies were provided by Biocontrol Works of Jefferson Oregon, USA. Predatory mites were reared on bean plants that had been infested with *T. urticae* and collected just prior to extinction of the prey (Pratt et al. 1998). Bean leaves containing all life stages of *N. fallacis* and a few individuals of *T. urticae* were placed in the canopy of each respective banker plant at rates described below. The prey mites, including *Oligonychus ilicis* (McGregor) and *O. ununguis* (Jacobi), were collected in mid May from field grown ornamental plants. *T. urticae* was taken from a laboratory culture that was periodically mixed with field collected specimens.

In the initial 3 studies, a pair of identical 10 X 4 m greenhouse rooms with internal conditions of 26:21 (± 10) °C (D:N), photoperiod 16:8 (L:D) h, and 75% (± 10) R.H. were used. Four 1 X 3 m benches were placed 1.5 m apart in each of the greenhouse rooms. A 1.5 m high muslin curtain was hung above each bench so that

the curtain created 2 isolated cubicles (1 X 1.5 X 1.5) on top of each bench. The bottom 10 cm of the curtains rested in a 10 cm deep water moat within the benches, thus saturating the 4 muslin walls of each cubicle with water. A fan, placed against one of the walls of each cubicle, produced wind speeds of approximately 2.4 m/s (Fig. 13).

Receiver plants consisted of a dense canopy of lima bean (*Phaseolus lunatus* L.) leaves covering a circular area of 0.3 m diam (± 5 cm) each. These receiver plants were designed to catch predatory mites as they dispersed from banker plants (Pratt et al. 1998). To make the receiver plants, a total of 55 (± 3) seeds were planted into a polyethylene bag (30 cm diam) that was filled with a potting mixture of pumice,

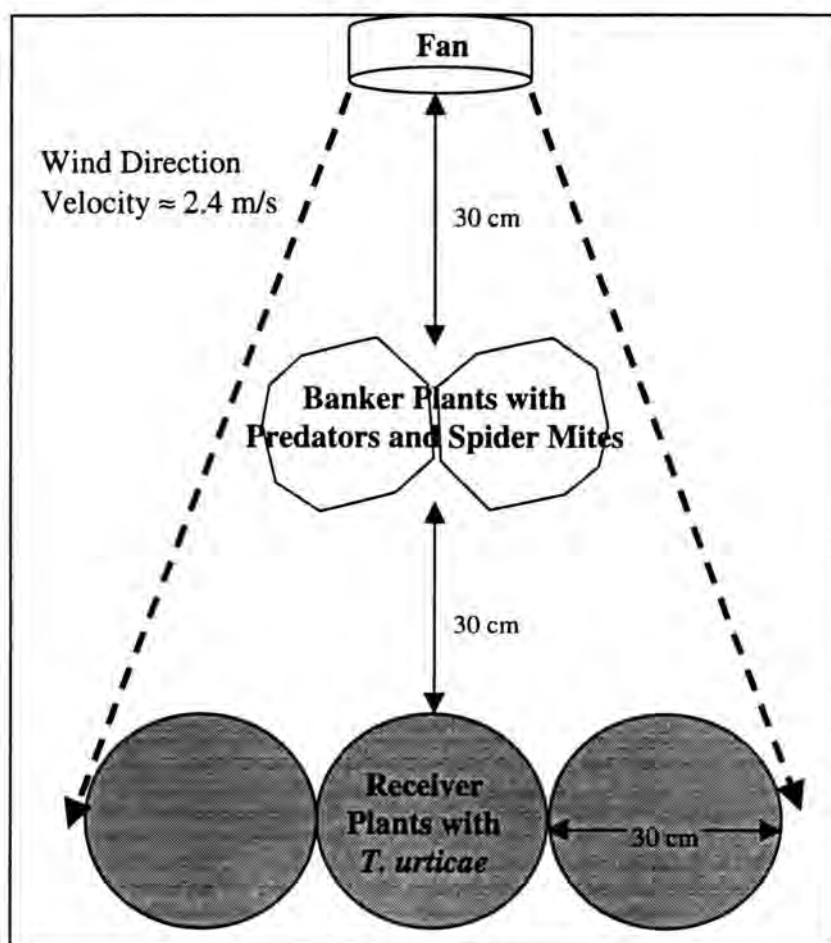


Figure 13. Experimental design of a 1 X 1.5 m cubical used in small-scale banker plant studies.

sand, peat moss, and soil (2:1:1:1) (Strong and Croft 1995). Seeds germinated in 1 wk and 1 wk later each leaf of each plant was inoculated with 50-100 mixed life stages of *T. urticae*.

6.3.2. Dispersal from Banker Plants and Reintroduction of Prey.

To determine if the predator *N. fallacis* would numerically respond to prey on a banker plant and disperse downwind to receiver plants, we used the greenhouse system as described above. Sixteen arborvitae plants (*Thuja occidentalis* 'Pyramidalis'; height: 1 m \pm 5 cm, diam: 23 cm \pm 3 cm, potted in 3.8 L plastic containers) were inoculated with 2000 (\pm 150) *O. ununguis* and 30 days later populations had increased to 450 (\pm 23) spider mites (all stages) per 6 cm terminal. As described in Figure 13, two arborvitae (placed in close proximity to each other) and 3 receiver plants were randomly assigned each of 8 cubicles that served as replicate environmental units. The arborvitae banker plants were placed in the trajectory of the wind between the fan and the receiver plants (Fig. 13). The lateral distance separating the fan and the receiver plants from the banker plants was 30 cm. Five hundred mixed life stages of *N. fallacis* were inoculated into each of the banker plants. Leaves of the receiver plants were viewed every day for 37 days and the number of predatory mites found in receiver plants per replicate was recorded. When predatory mites were found on leaves of the receiver plants, the leaf was excised and taken out of the greenhouse. Receiver plants were sufficiently dense with bean leaves that vacant areas in the canopy were not created by destructive sampling. Because of possible oviposition from a few dispersing female predators that were not removed in sampling, receiver plants were replaced every 5 days (minimum development time of predator from egg to adult; Pratt et al. 1998). Life stages of dispersing *N. fallacis* were only recorded 1 day after receiver plants were replaced. Relative densities of predator and spider mites on each banker plant were estimated by removing the terminal 6 cm of foliage from 3 randomly selected branches each wk and recording mites under a 40X microscope.

Eight rhododendron plants ('Ana Krushke'; height: 0.5 m \pm 6 cm, diam: 30 cm \pm 5 cm, 3.8 L plastic containers, and 45 (\pm 6) leaves per plant) were inoculated with ca. 500 *O. illicis* and 30 days later populations had increased to 125 (\pm 32) per leaf. Two plants were randomly placed in each of 4 cubicles, as explained above, and 250 predatory mites (of all life stages) were released onto each rhododendron. Sampling and replacement of receiver plants were preformed as in the arborvitae study. Relative densities of predatory and spider mites on the rhododendrons were estimated by scanning 5 randomly selected leaves on each plant once a wk under a 40X microscope.

Without the presence of any alternative foods such as pollen or plant fluids, *N. fallacis* is dependent on spider mite prey for continued reproduction and development (McMurtry and Croft 1997, Croft et al. 1998). For this reason we suspected that dispersal of *N. fallacis* individuals into receiver plants would be minimal at the onset of the experiment, increase as predators depleted the prey source and would again decline as prey were driven to extinction. We questioned if the number and interval of *N. fallacis* dispersants could be extended by reintroducing prey. We randomly selected 4 arborvitae banker plants from the previous study and reinoculated each with ca. 50,000 *T. urticae* (mixed life stages) 21 days after release of *N. fallacis* into the banker plant. Reinoculation was accomplished by placing spider mite infested bean leaves (*P. lunatus*) directly into the arborvitae foliage. Dispersal of *N. fallacis* from reinoculated banker plants to receiver plants was compared to that of the remaining 4 untreated banker plants.

6.3.3. Prey Refugia in an Arborvitae Banker Plant

As described previously, spatial or temporal refugia for the prey mite or alternate food may increase the period of continuous predator dispersal from a banker plant system. If one is not apparent, artificial refugia may be created by applying a selective pesticide to parts of the banker plant to eliminate colonization by the

predator (Lester et al. 1998, Croft and Slone 1997). For instance, predatory mites are known to be susceptible to most pyrethroid pesticides but spider mites are not (Croft 1990, Appendix III). Therefore, we hypothesized that applying a pyrethroid to a portion of the banker plant foliage would reduce overexploitation of prey by *N. fallacis* and thereby extend the dispersal interval into receiver plants. To test this we acquired 8 arborvitae plants (as described above) and to 4 randomly selected plants we applied a 0.1 field rate of permethrin (Pounce® 3.2 EC, 0.03 l per ha) to the top 25 cm of foliage. To ensure that the pesticide did not contaminate the remaining foliage, a 3 ml sheet of polyethelene plastic covered the lower portion of each plant during application (Lester et al. 1998). The experimental design was exactly like the initial arborvitae experiment except that only a single arborvitae plant was placed into each cubicle, predatory mites were only inoculated to the lower portion of each banker plant and sampling was performed every 5 days.

6.3.4. Dispersal of *N. fallacis* from Banker Plants in the Field

In the prior experiments *N. fallacis* numerically responded and dispersed to receiver plants held downwind, but distances that mites dispersed were very short. In this final test we measured dispersal of *N. fallacis* from an arborvitae banker plant held in the field and evaluated over much greater distances. Again, we acquired 4 arborvitae plants ('Emerald'; height 1.25 ± 0.11 m; diam near plant base: 35.45 ± 5.2 cm) and inoculated each plant with ca. 500 *O. ununguis* adult females. Thirty days later $103.8 (\pm 14.5)$ spider mites were on each 6 cm terminal branch. Each banker plant was placed in a large open field with more than 200 m separating replicates. Receiver plants were placed at distances of 10, 20, and 30 m from each banker plant in 4 cardinal directions (N, S, E, W). The maximum distance for the receiver plants were chosen according to reported dispersal distances of *N. fallacis* in strawberry fields approximately 10 wks after release (Coop and Croft 1995). To ensure that the probability of landing in receiver plants in each directional sample was equal at each distance, we adjusted the number of receiver plants proportionally to the distance

from the banker plant (10 m= 1 receiver plant, 20= 2 and 30= 3). Again, sampling and replacement of receiver plants was performed as described in the pyrethroid refugia experiment above. All predators collected from receiver plants were mounted on glass slides and identified according to morphological characters (Schuster and Prichard 1963). To estimate contamination of our receiver plants by dispersal of *N. fallacis* from the surrounding habitat, we also placed 8 additional receiver plants approximately 100 m from the outer most receiver plants.

6.3.5. Statistical Analysis

Repeated measures analysis of variance (ANOVA) was used to compare the dispersants recovered in receiver plants over time (von Ende 1993). The Huynn-Feldt adjustment was used when the covariance matrix of the data did not meet the assumption of sphericity (SAS Institute 1990). The dispersal index was calculated by dividing the number of individuals dispersed per day by the total number of *N. fallacis* inoculated into the system.

6.4. Results

6.4.1. Dispersal from Banker Plants and Reintroduction of Prey.

In tests run in replicated greenhouse cubicles, an average of 25 (± 6.08) *N. fallacis* individuals dispersed from arborvitae banker plants into receiver plants on day 7 and 10 days later the average increased to 180 (± 12.77) (Fig. 14). The number of *N. fallacis* found in receiver plants decreased to 18 (± 4.83) over the next 5 days and the cumulative number of dispersed individuals over the first 21 days was 1620 (± 8.09). The dispersal index was 0.02 or greater for days 7-21. After reintroduction of spider mites into arborvitae banker plants on day 21, a 5 day decrease in dispersal of *N. fallacis* occurred which was followed by a second dispersal event, peaking at 66 (± 5.15) individuals. In the banker plants where spider mites were reintroduced,

the dispersal index was 0.02 or greater for 8 days as compared to 3 days for the control. When compared with a repeated measures ANOVA, the reintroduction of *T. urticae* into the arborvitae banker plants significantly increased the number of *N. fallacis* found in receiver plants as compared to the control ($P=0.023$, $F=41.89$, $df=1$).

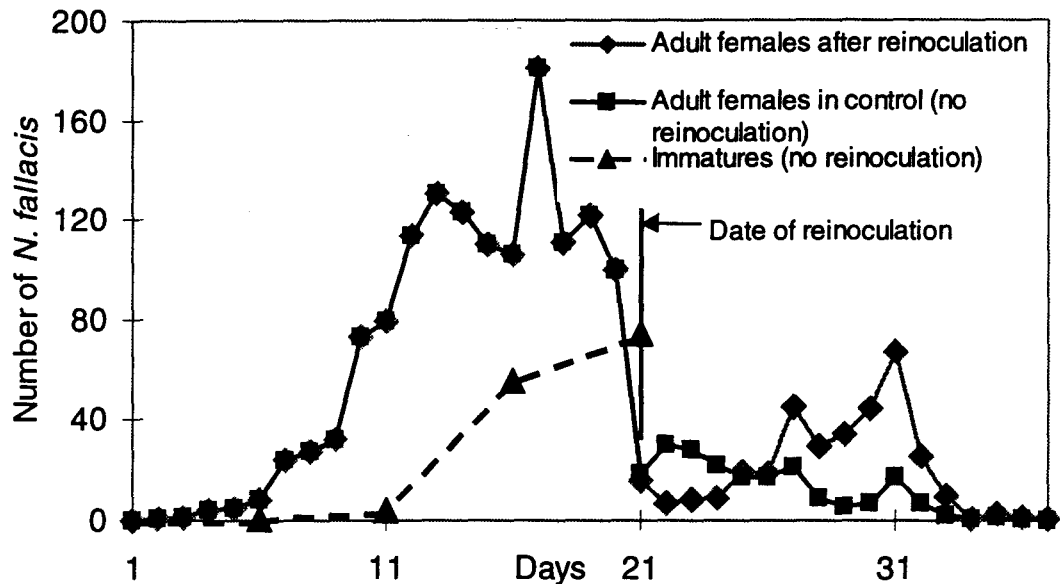


Figure 14. Dispersal of the predatory mite *N. fallacis* from *T. occidentalis* 'Pyramidalis' banker plants to spider mite infested bean plants down wind. Reinoculation of the banker plant was performed on day 21 and resulted in extending the dispersal interval and number of dispersants of the predatory mite.

The number of dispersing immatures appeared to increase over time, but in a delayed way compared to the adult females (Fig. 14). Less than 1% of the total population of dispersing *N. fallacis* were immatures in the first 10 days of the experiment (Fig. 14). As the prey density decreased in the arborvitae banker plants during the next 10 days, the proportion of immatures dispersing increased to 75% of the total mites collected in receiver plants.

The number of *N. fallacis* dispersing from rhododendron banker plants into the receiver plants in small greenhouse cubicles increased to $27 (\pm 4.58)$ individuals

on day 15 and remained above 20 individuals dispersed for 4 days (Fig. 15). The cumulative number of *N. fallacis* dispersed from rhododendron plants during the entire study was 368 (± 10.30). The dispersal index was 0.02 or greater for days 12-25. During this study, new plant growth developed and was determined to be unsuitable for *N. fallacis* due to the sticky substance on the branches and leaves. This substance slowly deteriorated and on day 28 spider mites were found on the new growth of the rhododendron. Predators were not found on this new growth.

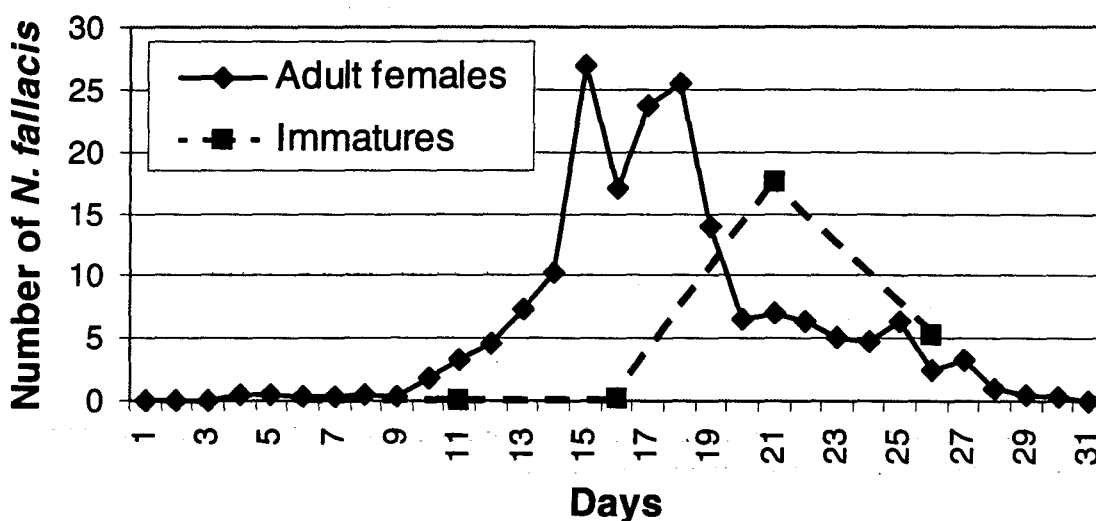


Figure 15. Number of *N. fallacis* dispersing from a rhododendron banker plant to receiver plants downwind.

Again, the ratio of immatures to adult females dispersing from rhododendron plants increased over time (Fig. 15). When prey densities were high in the banker plants in wks 1 and 2, only 4% of the dispersants were immatures. As prey densities decreased in banker plants on wks 3 and 4, 81% of the predators found in receiver plants were immatures.

6.4.2. Prey Refugia in an Arborvitae Banker Plant

The addition of pyrethroid based refugia did not increase the length of time that predators persisted and dispersed from the arborvitae banker plant system (Fig.

16). Three wks after inoculation of *N. fallacis* into banker plants, the number of predators dispersing into receiver plants in the refugia treatment peaked at 63.75 (± 18.75). Dispersal of predators peaked at 58.75 (± 18.98) one wk later in receiver

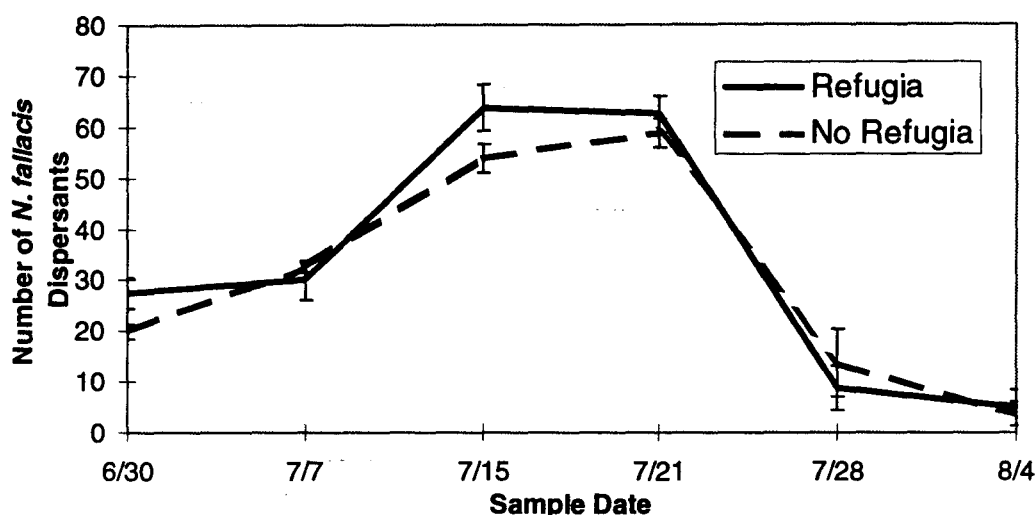


Figure 16. Dispersal of *N. fallacis* from banker plants with pyrethroid based refugia.

plants of the control treatment. Dispersal from banker plants into receiver plants in both treatments ended on August 4. Similarly, predators were not found among refugia or control banker plants on August 18. The number of cumulative dispersants was 197.5 for plants possessing the pyrethroid refugia as compared to 182.5 for the control. When sampling mite densities on banker plants, spider mites were present in the pyrethroid treated area but predators were not present.

6.4.3. Dispersal of *N. fallacis* from Banker Plants in the Field

Significant differences were found among the number of *N. fallacis* collected over time from receiver plants at 10, 20 and 30 m ($F= 3.42$; $df\ 2,45$; $P=0.04$) after adjusting for the amount of surface area available for colonization at each distance sampled. The number of *N. fallacis* collected from receiver plants spaced 10 m from the banker plant was higher over all sample dates combined than those at the 20 and

30 m distance ($P > 0.05$; Fig. 17). No immatures were collected from receiver plants during these experiments, which was in marked contrast to the more short-distance dispersal study (section 6.4.1). In addition, no *N. fallacis* were collected from receiver plants placed 100 m distant from the banker plants, indicating that there were no native *N. fallacis* within the dispersal range of these experiments.

6.5. Discussion

The inoculation of *N. fallacis* into spider mite infested arborvitae and rhododendron banker plants resulted in an increase of predatory mites and dispersal of biological control agents to spider mite infested plants downwind. With respect to rearing of predators, approximately 1000 more *N. fallacis* were collected from receiver plants than were initially inoculated into arborvitae banker plants. These increases in predators produced are conservative when considering that some individuals may have been lost in water or muslin barriers. In addition, >5 *N. fallacis* per day dispersed from arborvitae and rhododendron plants for 28 and 13 days,

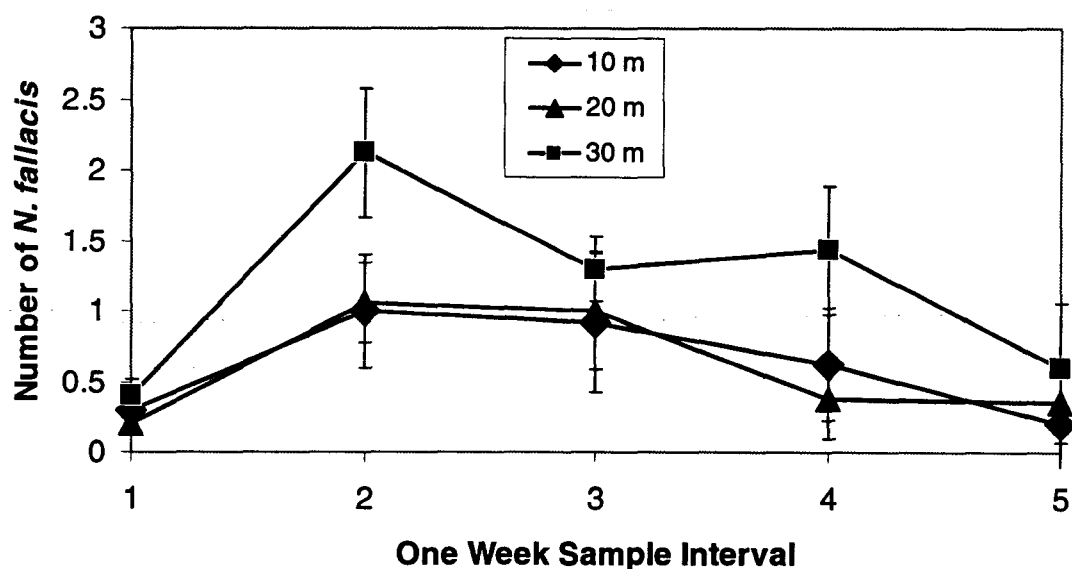


Figure 17. Dispersal of *N. fallacis* from a *T. occidentalis* banker plant to receiver plants spaced 10, 20 and 30 m distant.

respectively. This long period of predatory mite release into plants may aid in synchronization of predator-prey interactions for control of spider mites.

The reintroduction of prey into the arborvitae banker plant increased the dispersal duration of *N. fallacis* (Fig. 14). Further field studies are needed to determine if reinoculation of spider mites is necessary or if repeated introductions of spider mites or alternate food might create a perpetual, season-long banker plant. Also of interest was the 5 day reduction in dispersal of *N. fallacis* directly after reintroduction of spider mites. Possibly, starving *N. fallacis* stopped dispersing in response to spider mite induced plant volatiles or that the physical presence of prey caused them to start feeding again and stop dispersing (Sabelis 1985, Maeda et al. 1998). *Neoseiulus fallacis* has also been shown to develop and reproduce when held with pollen and other alternative foods (Pratt et. al. 1999, Zhang and Li 1989, Ch. 3). Addition of pollen may increase the number and duration of *N. fallacis* in the banker plant similarly as when spider mites were added.

Immatures of *N. fallacis* appeared to increase their rate of movement from plants as spider mite prey decreased in banker plants. These studies in a small cubicle with a short distance between the banker plants and receiver unit do not distinguish between active dispersal and dislodgment of immatures from the plant substrate. Immature stages become more active in searching for food as prey levels decrease and subsequently may have higher rates of dislodgement from the banker plant. This explanation is consistent with within-plant movement studies of *N. fallacis* immatures (Croft et al. 1995). Another possible explanation, but a less likely one, is that immatures may enter an active aerial dispersal phase, similar to that of the adult females. When measuring the aerial dispersal from banker plants in the field (section 6.4.3), no immatures were collected in receiver plants at 10, 20 or 30 m distant, suggesting that long range dispersal of immatures is minimal.

As mentioned previously, prey refugia may lengthen the duration of prey and predator production, especially when the predator is known to overexploit its prey. In this study the pyrethroid-based refugia did not improve persistence and dispersal of

the predator in arborvitae banker plants. Possibly, *N. fallacis* overexploited the prey in the non-treated area and dispersed (or starved) before prey migrated from the refugia to the untreated area. Another explanation may be that predators avoided spider mites that were treated or were feeding on pyrethroid treated foliage (Croft and Brown 1975). Further studies are needed to evaluate the usefulness of refugia in banker plant systems.

The distance a phytoseiid disperses is directly related to the height from which it is launched (Johnson and Croft 1979, Jung and Croft 1999). Our findings suggest that with banker plants of approximately 1.25 m tall, *N. fallacis* will disperse to infested ornamental plants ≥ 30 m. These findings have relevance to the location of banker plants in nurseries. For instance, banker plants may be widely separated (30 m) and yet provide adequate dispersal of predatory mites to mite infested plants.

Integration of a banker plant system into an ornamental nursery operation is a site-specific phenomenon. Although similarities exist among all such systems, each nursery facility has a unique set of factors that must be considered. For instance, the ornamental crops for which control is needed, cultural practices and physical layout must be considered in the banker plant design. One attribute of banker plants that is highly desirable is plant mobility. By producing the banker plants in plastic containers the system can be spatially redistributed or elevated to increase long range dispersal of the natural enemy. Also, mobility of the banker plant may allow them to be removed from direct application by harmful pesticides or fertilizer applications (Croft 1990, Appendix III). Banker plants also can be developed from existing hedgerows within the ornamental production facility. Various commercial nurseries have arborvitae surrounding portions of the production site and, assuming these hedgerows contain spruce spider mites, *N. fallacis* can be inoculated into the hedgerow. The use of an existing hedgerow would require fewer adjustments to current cultural practices of the nursery.

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7. OVERWINTERING AND COMPARATIVE SAMPLING OF NEOSEIULUS FALLACIS ON ORNAMENTAL NURSERY PLANTS

7.1. Introduction

Predatory mites of the family Phytoseiidae are important biological control agents of plant inhabiting pest mites (Helle and Sabelis 1985). Among the Phytoseiidae, only the adult female enters diapause, which in temperate zones is manifest as an arrestment in activity and reproduction (Overmeer 1985). Overwintering sites sought out by diapausing female phytoseiids within plant systems commonly have been assessed. In early studies, Chant (1959) suggested that overwintering females do not fall with leaves in autumn but move in fall to sites such as in splintered twigs, crevices or under bark. Putman (1959) collected phytoseiids from peach orchards and found that overwintering sites varied greatly among species, ranging from orchard weeds to many locations on trees. In a review on overwintering, Overmeer (1985) suggested that most phytoseiid species show a locational preference for overwintering on a plant. For instance, *Typhlodromus pomi* (Parrot) and *Amblyseius umbraticus* (Chant) preferred small twigs (Kinsley and Swift 1971) whereas *Typhlodromus bakeri* (Garman) and *Typhlodromus pyri* Scheuten were found primarily under apple trunk bark.

In this study, we sought to assess tendencies of *Neoseiulus fallacis* (Garman) to overwinter among ornamental coniferous, shade tree, evergreen shrub, deciduous shrub and herbaceous perennial plants in temperate regions of western Oregon, USA. This species is distributed throughout North America and is an important predator of spider mite on many plant types (McMurtry and Croft 1997). In Oregon, inoculative releases of *N. fallacis* are commonly made to reduce spider mites in apple, corn, hops, strawberry, peppermint and most recently, nursery plants (Strong and Croft 1995, Morris et al. 1996, Croft and Coop 1998, Pratt and Croft 1998, Ch. 2). In Michigan under severe winter conditions, Croft and McGroarty (1977) found that *N. fallacis* overwintered mainly in ground cover of apple orchards. In New York apple

orchards under similar conditions, Nyrop et al. (1994) found that *N. fallacis* overwintered on apple twigs and occasionally in ground cover. Morris et al. (1996) found that in more mild, arid areas of Oregon *N. fallacis* overwintered on peppermint leaves in early winter but as temperatures decreased, adult females either moved or only survived in debris near the soil surface.

To our knowledge, no studies have characterized suitability of plant types for overwintering of phytoseiids under similar environmental conditions. In natural or multi-cropping systems, such as ornamental nurseries, many plants occur and certain types (conifers, herbaceous perennials, etc.) may provide better overwintering sites than others. In ornamental nurseries, plant types are interspersed and various cultural practices are employed to minimize plant damage from extremes of temperature, wind and precipitation. For instance, ornamentals may be placed under protective plastic sheets, held in greenhouses or left out of doors (unprotected) during winter. Specific objectives of our study were: 1) to compare methods of sampling ornamental plants for overwintering *N. fallacis*, 2) to measure frequency of overwintering by *N. fallacis* among 10 species of plants that included five general types, 3) to determine overwintering location of *N. fallacis* within a plant and 4) to compare effects of plastic coverings, unheated greenhouses and unprotected plants on overwintering success of *N. fallacis*. Knowledge concerning the overwintering behaviors of predator and prey mites is integral to developing IPM strategies both within a single season and over several years (Hoy and Flaherty 1970).

7.2. Materials and Methods

Ten ornamental species (with 8 replicate plants each) ranging from coniferous to herbaceous perennials (Table 6) were obtained from nurseries on 1 Oct. 1997 and placed into a 10 X 10 m glasshouse at temperatures of $22:18 \pm 5$ °C L:D (Light:Dark), photoperiod 16:8 h light and dark (L:D), and $75 \pm 10\%$ relative humidity (RH). All plants were potted in plastic containers (Table 6) and watered

daily. The spider mites *Oligonychus illicis* (McGregor), *O. ununguis* (Jacobi), or *Tetranychus urticae* Koch were collected from field grown ornamental plants and reared at 25 °C, 60 ±10% R.H. and 16:8 (L:D) for at least one generation and then inoculated into each test plant within the glasshouse on 2 Oct. *Neoseiulus fallacis*, in an inert granular media, were provided by Biotactics Inc. (Grand Terrace, CA USA 92324) and, upon arrival, were allowed to disperse onto lima bean leaves infested with *T. urticae*. Bean leaves were scanned using a 40X microscope to quantify densities of *N. fallacis* and multiple leaves containing 100 *N. fallacis* adult females were inoculated into each test plant within the glasshouse on 8 Oct. 1997. To evaluate mite densities after release of *N. fallacis*, we sampled (without removal from the plant) 5 leaves or branches per replicate of each plant species every 7 days for two wks (Table 6). To condition mites to external weather and possibly induce diapause, we incrementally decreased day length by 2 h every 10 days and adjusted temperatures within the glasshouse until they approached those of the external environment. On 3 Nov. we removed the test plants from the glasshouse and randomly placed them outside on a gravel substrate (bed). We also monitored daily high and low temperatures and rainfall during Oct.-Feb. 1997-98 to compare with the previous 36 yearly averages.

Two methods of extracting overwintering phytoseiids from plant material were compared: 1) placing plant materials in Berlese funnels or 2) washing plant materials with ethanol and collecting predators through filtration. On 15 Feb. we extracted *N. fallacis* from 4 randomly selected replicates of each plant species by placing either leaves, branches, trunks/crowns parts, or the top 3 cm of soil and associated litter into separate Berlese funnels for 5 days under a 40 watt light bulb (Morris et al 1996). Temperatures were 25 ±2 °C within the funnel. Within the base of each funnel we placed a bouquet of lima bean plants with the stems resting in a 0.5 l jar filled with water. Bean leaves were infested with *T. urticae* and leaves thoroughly covered the funnel base to prevent predators from falling into the water. Bean leaves were scanned every 24 h and each individual phytoseiid mite was

mounted on glass slides for identification under a phase-contrast microscope at 200X magnification.

The plant washing method was also evaluated on 15 Feb. It consisted of placing the previously mentioned plant parts, but not soil and associated litter, in separate one l jars and adding 300 ml of 70% ethanol (Calkin 1991, Zacharda et al. 1989). Lids were placed on jars and shaken manually for 2 min, left to rest for 1 min and then shaken again for 2 min. Plant material was removed with forceps and slowly rinsed with 70% ethanol over the jars. The ethanol and associated contents were poured into a Whatman #4 filter paper funnel, gravity filtrated and scanned for mites within 5 min under a binocular microscope at 40 X magnification. All phytoseiid mites washed from plant parts were mounted on glass slides for identification. Spider mites washed from plants were also recorded.

To measure the effect of cultural practices on overwintering *N. fallacis*, we collected 15 plants of either *Viburnum davidii* or *Picea glauca* 'Conica' on 3 Oct. 1998. Plants size, selection, inoculation of spider mites and predators, identification of predators and conditioning in the glasshouse were performed as before. Plants were removed from the glasshouse on 5 Nov. 1998 and 5 plants from each ornamental species were randomly assigned to either an unheated greenhouse, placed under a sheet of protective plastic or, as in the previous test, left unprotected. The greenhouse consisted of an unlighted 15 x 7 m enclosed structure with a shade cloth drawn over the roof to reduce solar radiation. Unprotected plants were placed 10 m from the greenhouse in an outdoor nursery bed exactly as in 1997-1998 tests. The last treatment was similar to the unprotected except a 3 mil white plastic sheet was drawn over the plants and rested on the foliage. The plastic sheet contained 0.5 cm holes spaced 0.5 m apart and held secure with 20 cm stakes in corners of the plastic. As is consistent with nursery production, the plastic was removed on days when temperatures exceeded 20°C but was replaced each night. In all cases, ornamental plants were placed directly on a gravel and irrigated below the foliage once a wk. In addition, max-min air temperatures were recorded 3 times a wk in the greenhouse,

under the plastic and near the unprotected plants. Only the washing method was used to extract *N. fallacis* from overwintering sites in this test.

To compare sampling methods, we pooled all within-plant samples and transformed the number of overwintering *N. fallacis* extracted from each method with $\log(x+1)$. We then used a paired t-test to determine if one method sampled significantly more predators than the other. To graphically compare methods, we subtracted the densities of predatory mites found using the Burlese method from those of the washing method and regressed the difference on the washing values. To compare overwintering *N. fallacis* among the 10 plant species or among protective cultural practices we $\log(x+1)$ transformed all values as above and used analysis of variance (ANOVA) and Tukey's HSD to distinguish differences. Simple linear regression was used to estimate the correlation of spider and predaceous mite densities. When comparing *N. fallacis* on different plant types or locations within a plant, conventional parametric statistics are not appropriate because of unequal sample sizes and unknown underlying distributions of mites. One alternative to parametric tests is a randomization test, which Manly (1991) found more powerful than other non-parametric tests. Therefore, we randomly reordered the numbers of *N. fallacis* found within each plant type or plant part 1000 times and acquired the mean and standard deviation for respective distributions. We then compared the distributions of plant types and among plant parts with two-sample t-test for means (Ramsey and Schafer. 1997). We used the Sidak inequality formula to maintain a 0.05 experiment-wise α level when comparing overwintering within and between plants (Jones 1984). Caution should be used when drawing inferences from statistical comparisons among plants because data were not standardized to adjust for differences in plant size, morphology, humidity within plant canopies or other parameters that may influence overwintering.

7.3. Results and Discussion

Washing plants with ethanol extracted more *N. fallacis* than did the Berlese funnel extraction method ($t = 2.67$, $P = 0.005$, $df = 39$). When graphically compared (Fig. 18), both methods appeared equally effective at low predator densities, although washing recovered more *N. fallacis* than the Berlese when *N. fallacis* densities were high. These findings are consistent with previous reports that washing and filtering is as effective as visually scanning plant material when sampling phytoseiids (Calkin 1991). In addition, washing recovered spider mite adults and overwintering eggs (Table 6). Therefore, this technique may be well suited for monitoring overwintering pest and predator mite densities on a variety of plant types with many different forms (Calkin 1991).

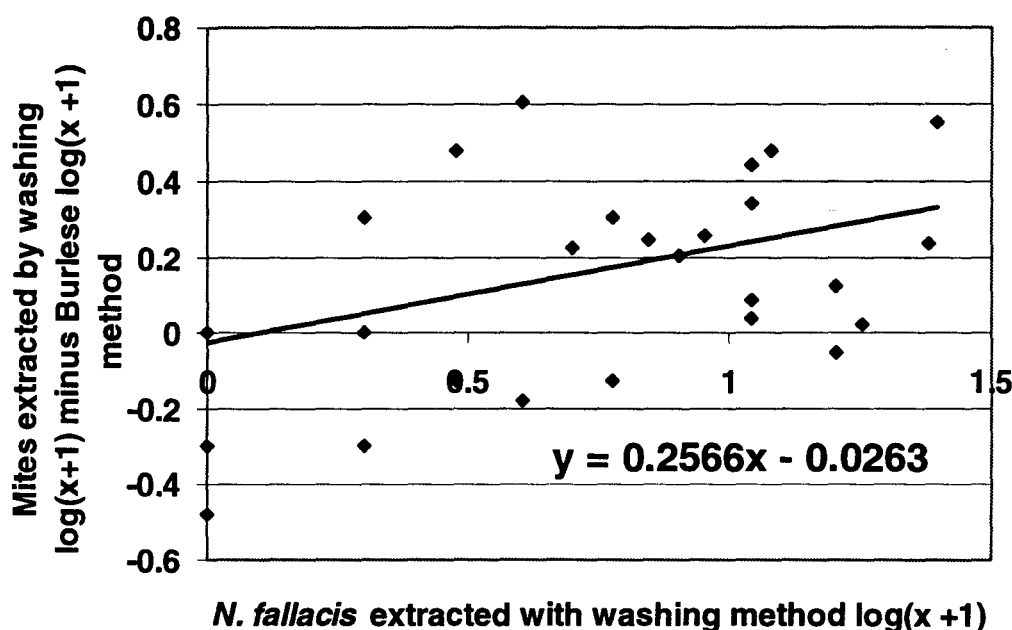


Figure 18. Comparison of methods for extraction of overwintering *N. fallacis* from ornamental plants.

Winter temperatures for the study period fell within one standard deviation of the average of the previous 36 years in the Willamette Valley except during Nov.,

which was warmer (Fig. 19). Similarly, precipitation fell within one standard deviation of the 36 year average except Dec., which was somewhat lower. These data suggest that during this study, *N. fallacis* experienced winter conditions that were typical for ornamentals grown in the region. With respect to diapause of *N.*

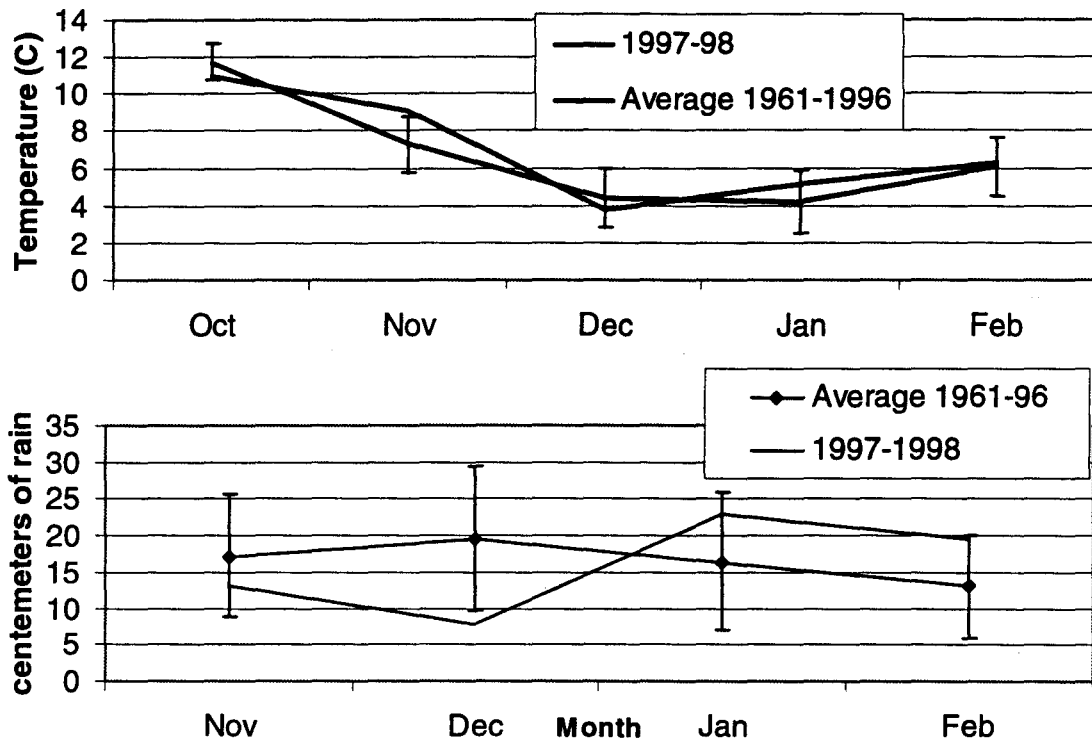


Figure 19. Comparison of temperature and precipitation for the winter months of 1997-98 versus the mean of the previous 36 years in the Willamette Valley.

fallacis, Rock et al. (1971) found the critical photoperiod of two strains was between 11.75 and 12 h day light at 15.6 °C, which is within the range of this study. In addition, all predators recovered by either method of extraction appeared to be consistent with the descriptions of diapausing phytoseiids: pale colored, dorsally flattened females without eggs in their abdomen (Veerman 1992). Therefore we assumed that *N. fallacis* had entered diapause during this study.

Among individual plants, *N. fallacis* was more abundant on *Picea glauca* than all others tested except *Thuja occidentalis* and *Viburnum davidii* (Table 6).

Table 6. Overwintering of *N. fallacis* on 10 ornamental plants with comparison of sampling methods.

Ornamental Species	Plant Type	Plant Parts ^a	Container size ^b	Plant Height ^c	Plant Diameter ^d	Pest Mite	Spider Mite Densities on:		Predator Densities ^e	
							Oct. 10	Feb. 15	Washing Ave. (SD) ^e	Funnel Ave. (SD) ^f
<i>Picea glauca</i> 'Conica'	Conifer	B, T, (S)	3.8	48	23	<i>Oligonychus ununguis</i>	25.3	34.3	19.75 (4.43)a	13.00 (4.97)a
<i>Thuja occidentalis</i> 'Pyramidalis'	Conifer	B, T, (S)	3.8	42	23	<i>Oligonychus ununguis</i>	18.5	15.1	10.75 (2.99)ab	6.50 (3.70)ab
<i>Viburnum davidii</i>	Evergreen Shrub	L, B, T, (S)	3.8	46	43	<i>Tetranychus urticae</i>	37.1	2.7	7.75 (2.63)ab	5.75 (2.75)ab
<i>Ilex crenata</i> 'Convexa'	Evergreen Shrub	L, B, T, (S)	3.8	66	48	<i>Tetranychus urticae</i>	8.5	1.26	5.25 (4.19)b	2.25 (0.58)bc
<i>Rhododendron</i> 'Ana Kruschke'	Evergreen Shrub	L, B, T, (S)	3.8	53	46	<i>Oligonychus illicis</i>	16.2	10.1	3.75 (2.22)bc	3.00 (2.16)bc
<i>Hemerocallis</i> hybrid 'Mary Todd'	Herbaceous Perennial	C, (S)	3.8	71	56	<i>Tetranychus urticae</i>	35.7	0	1.00 (1.15)cd	0.00 (0.00)d
<i>Viburnum opulus</i> 'Sterile'	Deciduous Shrub	B, T, (S)	3.8	41	25	<i>Tetranychus urticae</i>	10.2	0	0.75 (0.96)cd	0.25 (0.50)cd
<i>Acer x freemanii</i> 'Jeffersred'	Shade Tree	B, T, (S)	18.9	229	76	<i>Tetranychus urticae</i>	18.3	0	0.25 (0.50)d	0.50 (1.00)cd
<i>Euonymus alata</i> 'Compacta'	Deciduous Shrub	B, T, (S)	3.8	53	36	<i>Tetranychus urticae</i>	22.7	0	0.25 (0.50)d	0.25 (0.50)cd
<i>Corylus avellana</i> 'Contorta'	Deciduous Shrub	B, T, (S)	3.8	102	30	<i>Tetranychus urticae</i>	11.5	0	0.00 (0.00)d	0.25 (0.50)cd
									P<0.0001	P<0.0001

^a= Plant parts used for extraction of *N. fallacis*; L= leaves; B= branches; T= trunk; C= crown; (S)= soil, soil was only used in the Berlese extraction method.

^b= Plastic plant container (pot) size in liters.

^c= Average height of plants (n=8).

^d= Average diameter of plants (n=8).

^e= Average number of *N. fallacis* extracted with the alcohol wash method.

^f= Average number of *N. fallacis* extracted with the Berlese funnel method.

^g= Means followed by different letters are significant at $\alpha=0.05$ (Tukey's HSD).

Among conifers, 54% more *N. fallacis* were recovered from *P. glauca* than *T. occidentalis*. Using the washing method, more *N. fallacis* were recovered from *V. davidii* and *I. crenata* than *Hemerocallis* and the broad leaf deciduous species. Irrespective of the extraction method, few *N. fallacis* were recovered from *Hemerocallis* and broad leaf deciduous plants. Also, both sampling methods provided an identical

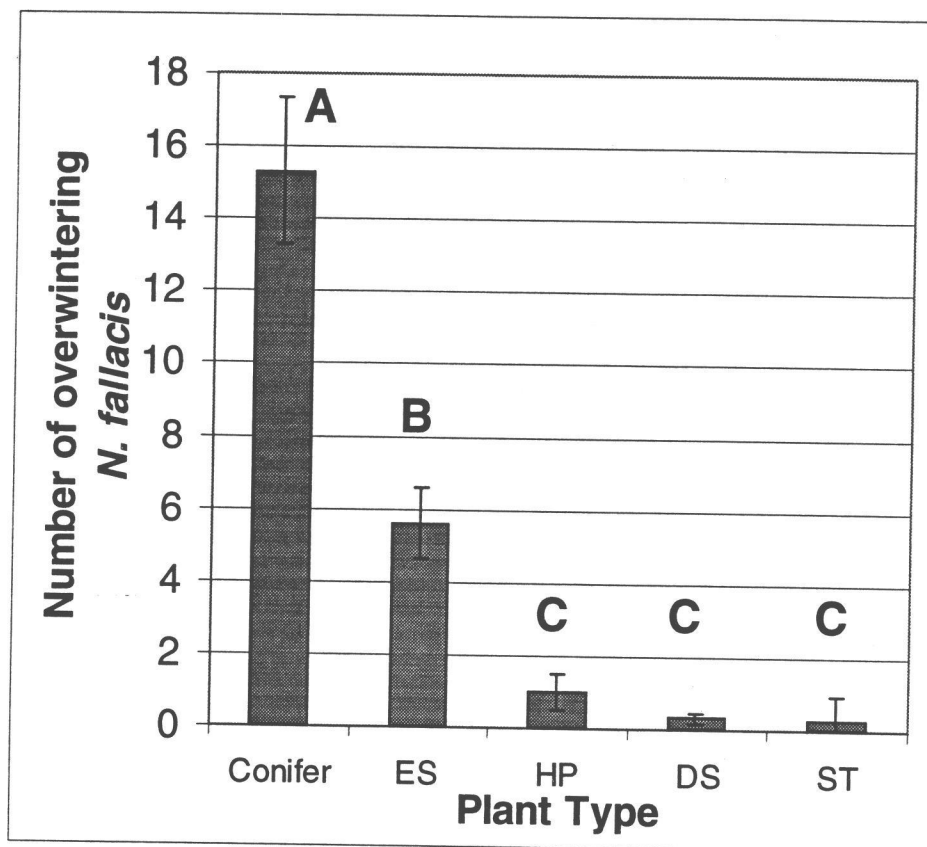


Figure 20. Number of *N. fallacis* overwintering on 4 different plant types after inoculation of 100 adult females in late autumn. ES= Evergreen Shrub, HP= Herbaceous Perennial, DS= Deciduous Shrub, ST= Shade Tree. Columns followed by different letters are significant at $\alpha=0.05$

ranking of the 5 plant species harboring the most *N. fallacis* (Table 6).

When data were pooled for plant types, *N. fallacis* overwintered most on conifers (Fig. 20). These data were surprising considering that *N. fallacis* is not common on conifers in the region (Hadam et al. 1986, Calkin 1991). However, in the eastern

USA, this species is found on conifers and can provide adequate control of *O. ununguis* (Boyne and Hain 1983). Broad leaf evergreens harbored more *N. fallacis* than herbaceous perennials and deciduous plants ($t= 5.44$, $P< 0.001$, $df= 26$; $t= 4.25$, $P= 0.001$, $df= 14$, respectively). Among broadleaf evergreens, *N. fallacis* were common

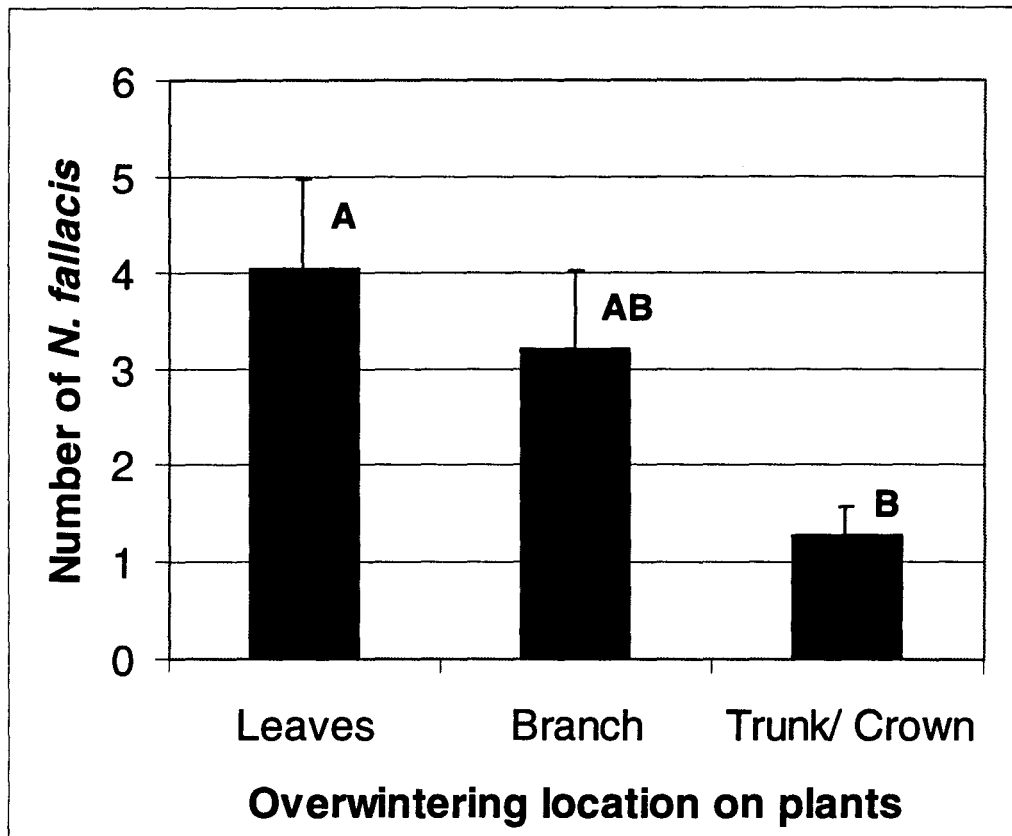


Figure 21. Overwintering location of *N. fallacis* within 10 ornamental plants.

among *V. davidii* but scarce on *I. crenata* and the rhododendron (Table 6). Herbaceous perennials and broadleaf deciduous plants did not differ in densities of *N. fallacis* ($t= 1.19$, $P= 0.25$, $df= 18$).

When comparing overwintering locations, more *N. fallacis* were on leaves than trunks ($t= 2.89$, $P= 0.001$, $df= 46$); levels of predators on branches did not differ from either leaves or trunks (Fig. 21). With the Berlese, no *N. fallacis* were extracted from soil and associated litter. This is contrary to reports that *N. fallacis* commonly overwinters in the litter or soil (Putman 1959, Morris et al. 1996). One explanation may

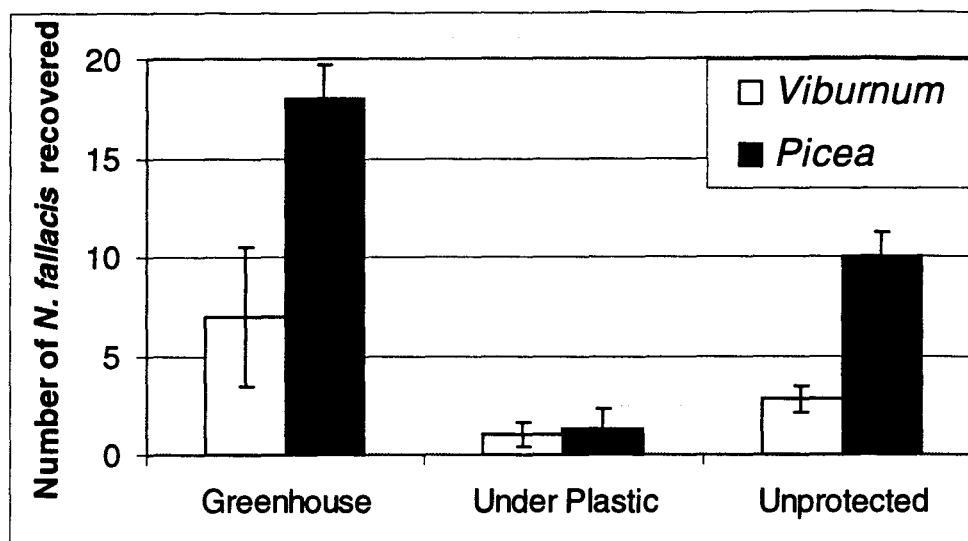


Figure 22. Densities of *N. fallacis* collected from *Viburnum davidii* and *Picea glauca* under different protective cultural practices.

be that there were different environmental conditions present among these studies, which may affect the depth of diapause entered by the *N. fallacis* (Veerman 1992). For example, Morris et al. (1996) showed that *N. fallacis* moved from leaves to the soil as temperatures decreased. The affect of temperature on selection and persistence in overwintering sites is unclear.

Densities of overwintering *N. fallacis* collected on 15 Feb. were positively correlated with those of spider mites ($F = 33.87$; $P = 0.0004$; $df = 1,8$; Fig. 6). Highest densities of *N. fallacis* were associated with *O. ununguis*, a species that develops large populations in spring and fall (Regan 1990, Calkin 1991). These results may indicate overwintering survival of *N. fallacis* is related, in part, to feeding on warm winter days. Insufficient prey densities during warm periods or early spring may result in starvation or dispersal of the predator from the plant (Pratt et al. 1998). In other studies of different plants and climates, overwintering sites of *N. fallacis* varied according to severity of conditions and the presence of prey. For example, in mild temperature fruit growing regions of New Zealand the major winter mortality of *N. fallacis* was thought to be overexploitation of prey and starvation rather than cold temperatures (Penman and

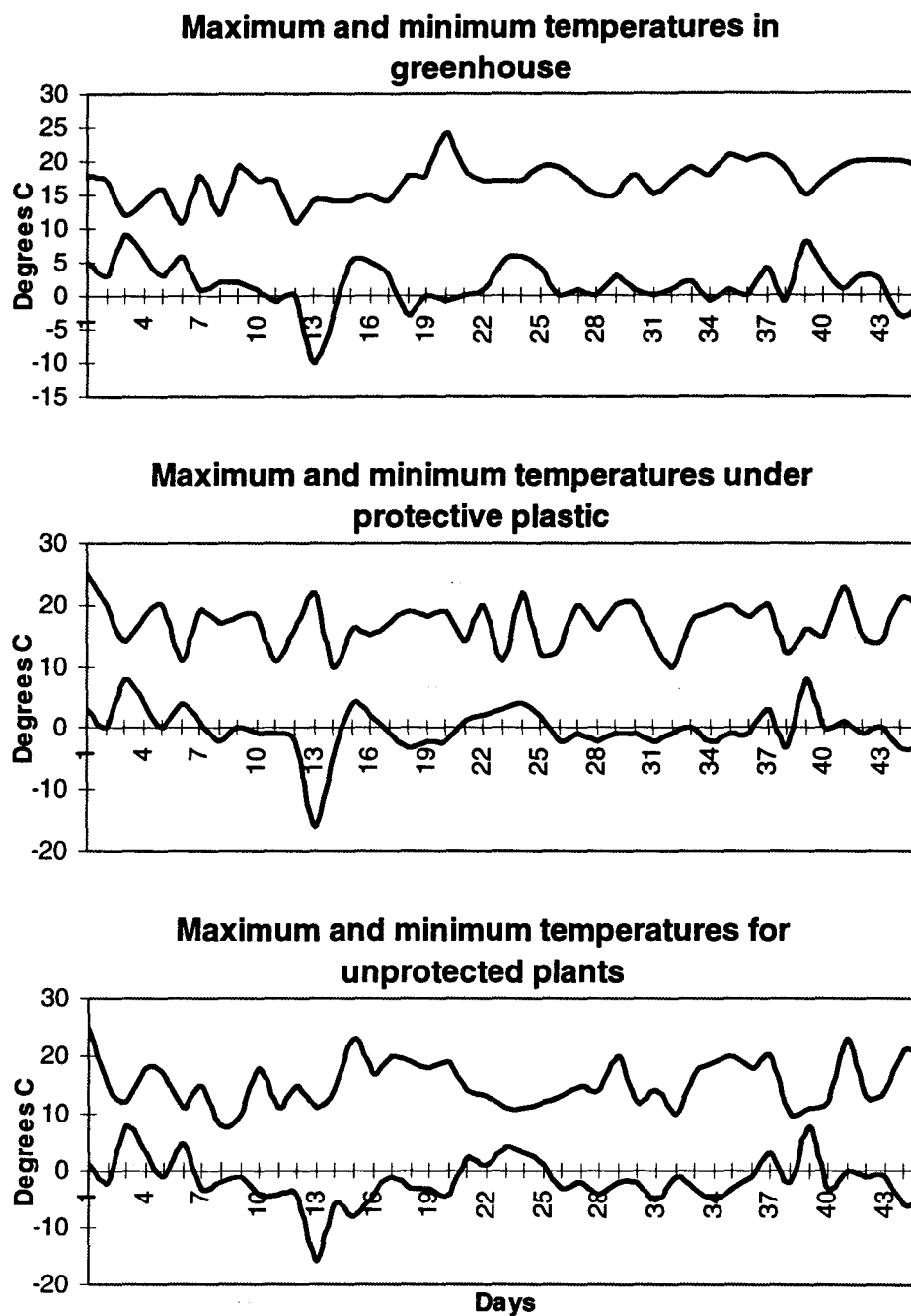


Figure 23. Maximum and minimum temperatures recorded under 3 winter cultural practices.

Chapman 1980). In the more severe temperature fruit growing regions of New York USA, Nyrop et al. (1994) found that *N. fallacis* overwintered within orchard trees when prey were present but dispersed to the ground cover or orchard margins in the absence

of prey. Similarly, Morris et al. (1996) showed that overwintering *N. fallacis* were most prevalent when high densities of spider mites were also collected and that as colder temperatures occurred, diapaused mites moved from leaves to more protected sites in the debris near the soil. As previously reported, various non-spider mite foods will enhance survival of *N. fallacis* when tetranychid mite densities are low (Pratt et al. 1999, Ch. 3). What role these alternative foods play in overwintering survival is unknown.

Significantly more *N. fallacis* were collected from plants in the greenhouse than under protective plastic or unprotected (Fig. 22). One explanation may be the less variable and warmer temperatures within the greenhouse (Fig. 23). Also, there was very little wind in the greenhouse and this may have reduced the aerial dispersal of predatory mites from plants (Pratt et al. 1998, Ch. 6). Lowest levels of overwintering mites were found under protective plastic (Fig. 22). On warm days, some predators that move from the foliage to the plastic may not return to the plants. As described above, warmer conditions may have caused predators to come out of diapause and feed more on spider mites, thus depleting the food supply (Pruszyński and Cone 1973). These findings suggest that covering cold sensitive plants with protective plastic may negatively affect overwintering of *N. fallacis* in ornamental plants.

In summary, our findings on overwintering survival of *N. fallacis* have relevance to cultural practices, biological control and overall ornamental IPM. Increased predator densities in early spring improves biological control of some pest mites (Collyer 1964). Using plants that are known to harbor overwintering *N. fallacis* may aid in the conservation of the predator within the agricultural system. For instance, coniferous trees (e.g. *Thuja occidentalis*) are common hedgerows of ornamental systems and, in our study, this plant type provided the highest overwintering survival. Strategically placed hedgerows may also assist in the colonization of spider mite infested plants via aerial dispersal (Jung and Croft 1999, Ch. 6). The manipulation of these highly managed systems to enhance overwintering of phytoseiid mites needs more study (Veerman 1992).

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8. NEW SPIDER MITE PESTS OF ORNAMENTALS AND BIOLOGICAL CONTROL BY *NEOSEIULUS FALLACIS*

8.1. Introduction

Ornamental nurseries are dynamic systems where plant material is regularly exchanged among facilities around the world. Although efforts are made to reduce the exchange of pests, the probability that a new spider mite species will be introduced on contaminated plant material and subsequently establish in a major ornamental growing region is high. For this reason, as well as the diversity of pest mites currently found in ornamental systems, specific emphasis was placed on selecting a biological control agent that would suppress various genera of spider mites. In 1997, two spider mite species that were not known from the Pacific Northwest were collected during surveys of area ornamental nurseries. The discovery of these spider mites, the geographic range and potential for biological control by *N. fallacis* are described in the remaining 2 sections.

8.2. *Panonychus citri* on Ornamental *Skimmia*

8.2.1. Introduction

Spider mites are pests in ornamental nurseries (Weidhaas 1979, Mizell & Short 1992), where they can reduce growth and can render plants unsightly and unmarketable (Schiffauer & Mizell 1988, Smitley & Peterson 1991). Although the ornamental plant *Skimmia japonica* Thunberg, produces chemicals (e.g., furanocoumarins) that deter feeding by some arthropods (Tanaka et al. 1985, Escoubas et al. 1993), two spotted spider mite (*Tetranychus urticae* Koch) commonly infest this plant. In 1996-1997, samples of *S. japonica* were found to harbor high levels of another spider mite, *Panonychus citri* (McGregor) (citrus red mite), in nurseries and outdoor landscapes in western Oregon (P. D. P., unpublished). *Panonychus citri*

infests citrus plants of the subfamily Aurantioideae, but plants in the Toddaliodeae, the subfamily of *S. japonica* (Mabberley 1987) were not previously recorded as hosts. Previously known distributions of *P. citri* in the U.S. include semi-tropical parts of California, Texas, and Florida (Jeppson et al. 1975, French & Hutchinson 1980), but not Oregon.

Panonychus citri and associated predaceous phytoseiid mites occurring on citrus are well documented (McMurtry 1985), but they do not include species that are commonly found in western Oregon (Hadam et al. 1986). For example, *Euseius* spp. are most common on citrus but they are of semi-tropical and tropical distribution (McMurtry & Croft 1997). The combination of an introduced pest on a non-native ornamental caused us to question whether the most common native phytoseiids of western Oregon, including *Amblyseius andersoni* Chant, *Metaseiulus occidentalis* (Nesbitt), *Neoseiulus fallacis* (Garman), and *Typhlodromus pyri* Scheuten (Hadam et al. 1986), could suppress *P. citri* populations. *Neoseiulus fallacis* is widely released on ornamentals and other crops to control spider mites (McMurtry & Croft 1997). Our objectives in this study were: 1) to assess the ability of *N. fallacis* to reproduce and develop on *P. citri* compared to a highly preferred prey, *T. urticae* and similar abilities of *A. andersoni*, *M. occidentalis*, and *T. pyri*, on *P. citri*; and 2) to assess whether *N. fallacis* could suppress *P. citri* on *S. japonica* in an ornamental production nursery.

8.2.2. Materials and Methods

Identification of P. citri infesting S. japonica.-- Spider mites found on *S. japonica* were monitored at three ornamental nurseries and two landscape sites in western Oregon in 1996 and 1997. Nurseries were near Salem, Oregon and landscapes were near Salem and on the campus of Oregon State University in Corvallis. Mites were sampled by taking 100 leaves at random from 20 plants located in an X pattern across 5-10 beds. Mites in landscapes were sampled by removing 20-50 leaves at random from each of 10 *S. japonica* plants in a hedgerow. Leaves were placed in a cooler, transported to the laboratory, and mites were examined with a 40X microscope.

An unidentified spider mite species was found at all sites in 1996 and 1997. Adults of both sexes were mounted on glass slides and identified by J. A. McMurtry and G. W. Krantz of Oregon State University. Specimens were placed in the acarology collection of Oregon State University.

Feeding tests of four predatory mites.-- Laboratory cultures of *A. andersoni*, *N. fallacis*, and *T. pyri* were originally collected from agricultural crops in the Willamette Valley, Oregon (Hadam et al. 1986). *Metaseiulus occidentalis* was collected from an apple orchard near Hood River, Oregon (Croft et al. 1992). These cultures have been maintained for five years or more with yearly additions from field-collected specimens. Cultures were held at 25 ± 5 °C, 16:8 L:D, and 75-95% RH, and mites were fed mixed life stages of *T. urticae* three times per wk. Prior to the experiment, all predatory mites were held without food for 24 h to produce similar levels of hunger.

Tests for *A. andersoni*, *M. occidentalis*, *N. fallacis*, and *T. pyri* against *P. citri* were conducted simultaneously on 2.5 X 2.5 cm arenas constructed of waterproof paper and replicated eight times per species (Monetti & Croft 1997). Three adult female mites of a single species of about the same age were transferred to each arena. Excess mixed life stages of *P. citri* were provisioned every 24 h and arenas were placed in a 1 x 2 m environmental chamber at 25 ± 1 °C, 80 ± 10 % RH, and 16:8 L:D for 7 d. *Neoseiulus fallacis*, the predator of greatest interest, was also fed the optimal (with respect to reproduction) prey *T. urticae* or given no food. Arenas were briefly removed from chambers every 24 h to assess survivorship, activity (ambulation in the arena), cumulative oviposition per female per d, and cumulative production of immatures (larvae, protonymphs, deutonymphs). An index for survivorship of immatures was calculated on d 3-7 by dividing the number of immatures by the number of eggs present two days prior to the sampling of immatures (Croft et al. in press). Means of each measured attribute were analyzed by analysis of variance (ANOVA) and Tukey's HSD.

Biological control of P. citri by N. fallacis on S. japonica in a nursery.--

Preliminary feeding tests showed that *N. fallacis* would feed, reproduce, and develop on *P. citri*, but at lower rates than when provisioned with *T. urticae*. Because *N. fallacis* is often inoculated into crops, we were interested in its ability to control *P. citri* on *S. japonica*. In 1997, 10 three year old *S. japonica* ('Female') plants were potted in 3.8 L containers. Plants were inoculated with *P. citri* to ensure uniform levels per plant. A randomized design was used within a single irrigation system and treatments were either release of three adult female *N. fallacis* per plant or no release (control). On 2 Jul, *P. citri* averaged 12 ± 3 (all life stages) per leaf and three adult female *N. fallacis* were released into the canopy of each *S. japonica* plant (Strong & Croft 1995). To estimate population densities, five leaves were randomly selected per plant (without replacement) every wk for five wks. Leaves were placed in a cooler, taken to the laboratory, and processed within two h. A 40X microscope was used to count mites. To adjust for sampling the same populations over time, data were analyzed by repeated measures ANOVA (von Ende 1993).

8.2.3. Results

Identification of P. citri on S. japonica.-- As noted, specimens of the unknown pest mite infesting *S. japonica* in western Oregon were identified as *P. citri*. Routine sampling in both 1996 and 1997 indicated that *P. citri* was infesting *S. japonica* at all five locations that were sampled, suggesting that *P. citri* successfully overwinters in western Oregon. Although not documented to species, nursery growers had been aware of this pest mite and the damage it was causing for about five yrs (J. Mellot, personal communication).

Feeding tests of predatory mites.-- When comparing food types of *N. fallacis*, survivorship was significantly different when mites were provisioned with *T. urticae* > *P. citri* > starvation treatments ($P < 0.05$). Starvation increased the activity of *N. fallacis* but activity rates were similar when held with either prey mite ($P < 0.05$, Table 7). *Neoseiulus fallacis* produced more eggs and immatures per d when held with *T.*

Table 7. Survival, activity, oviposition and immature production of *Neoseiulus fallacis*, *Metaseiulus occidentalis*, *Typhlodromus pyri*, and *Amblyseius andersoni* when held with unlimited numbers of prey over 7 days.

Predator mite	Prey	Survivorship ^a	Activity ^b	Egg/Female/day ^c	Imm./female/day ^d	index ^e
		Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD
<i>Neoseiulus fallacis</i>	<i>T. urticae</i>	1.00 \pm 0.036a ^f	0.174 \pm 0.112a	2.854 \pm 0.399a	2.867 \pm 3.429a	1.036 \pm 0.1566a
	Starvation	0.363 \pm 0.076c	0.571 \pm 0.132b	0.071 \pm 0.099c	0.0 \pm 0.0d	0.0 \pm 0.0b
	<i>P. citri</i>	0.729 \pm 0.132b	0.092 \pm 0.089a	1.262 \pm 0.246b	1.210 \pm 0.469b	1.022 \pm 0.450a
<i>Galendromus occidentalis</i>	<i>P. citri</i>	0.701 \pm 0.098b	0.170 \pm 0.116a	1.499 \pm 0.474b	1.388 \pm 0.829b	0.775 \pm 0.517a
<i>Typhlodromus pyri</i>	<i>P. citri</i>	0.667 \pm 0.132b	0.128 \pm 0.097a	1.607 \pm 0.698b	0.982 \pm 0.456bc	0.575 \pm 0.293ab
<i>Amblyseius andersoni</i>	<i>P. citri</i>	0.315 \pm 0.137c	0.054 \pm 0.059a	0.333 \pm 0.196c	0.384 \pm 0.484dc	0.765 \pm 1.018ab
	P-value ^f	<0.0001	<0.0001	<0.0001	<0.0001	=0.0028

^a Percent female survival after 7 days in arenas.

^b Percent female activity (ambulation) within arena per 1 min observation per d.

^c Cumulative number of eggs produced per female per d.

^d Cumulative number of immatures produced per female per d.

^e Survivorship of immatures calculated on d 3-7 by dividing the number of immatures present by the number of eggs present 2 days prior to count.

^f Means of all tests were analyzed simultaneously by ANOVA, d.f.=5, 42.

^g Means followed by different letters are significant at $\alpha=0.05$ (Tukey's HSD).

urticae vs. *P. citri* ($P<0.05$), and egg production nearly ceased when predators were starved (Table 7). Immature survival was not different when *N. fallacis* was held with *P. citri* vs. *T. urticae*, but it was lower for the starvation treatment of *N. fallacis* ($P<0.05$).

Survivorship of mites fed on *P. citri* was similar for *N. fallacis*, *M. occidentalis*, and *T. pyri*, but significantly lower for *A. andersoni* ($P<0.05$). Survivorship for all predators feeding on *P. citri* was $<73\%$ (Table 7). Activity did not differ among the four mite species ($P<0.05$). Oviposition per d was similar for *N. fallacis*, *M. occidentalis*, and *T. pyri*, but lower for *A. andersoni* ($P<0.05$). *Neoseiulus fallacis* and *M. occidentalis* produced more immatures than *A. andersoni* ($P<0.05$), but immature production did not differ among *T. pyri* and the other three phytoseiids. The index of immature survival was similar among all four predaceous mites when provisioned with *P. citri*.

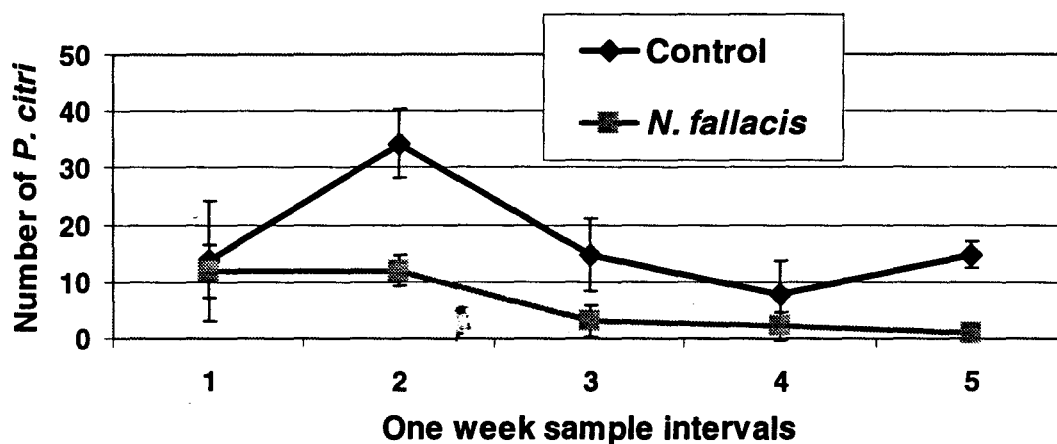


Figure 24. Population levels of *P. citri* on *S. japonica* 'Female' after release of the predatory mite *N. fallacis* on wk one.

Biological control of P. citri by N. fallacis in an outdoor production nursery.-- *Neoseiulus fallacis* significantly reduced *P. citri* on release plants of *S. japonica* when compared to control plants over five sample dates ($P=0.0001$; $df=1,38$; $F=43.42$). In control plants, *P. citri* increased to $35(\pm 9)$ mixed life stages per leaf before decreasing to $15(\pm 5)$ at the end of the test (Fig. 24). The decrease in pest mites in control plants

may have been due to declining vigor or host suitability. In plants with *N. fallacis*, spider mites were reduced to 1.4 (\pm 2) per leaf 3 wks after the release of predators and remained low thereafter.

8.2.4. Discussion

We report establishment of *P. citri* on the ornamental, *S. japonica*, in western Oregon. Although this pest has overwintered successfully in this region, its long term survival potential over a cold winter is open to speculation. Our results suggest that *P. citri* can feed and reproduce on *S. japonica*, a plant that is only distantly related to citrus. Physiological effects on *P. citri* when feeding on *Skimmia* are unknown.

Feeding tests suggest that *N. fallacis* will survive and reproduce on *P. citri*, but it is more adapted to feed on *T. urticae*. These results are similar to those from other studies that compared predation of *N. fallacis* on *Panonychus ulmi* (McGregor) vs. *T. urticae* (Croft et al. in press). Both assessments indicated that *N. fallacis* may prefer species of *Tetranychus*, which are prone to spin more copious webbing than other spider mite species. These data confirm the life type classification for *N. fallacis* as a Type II selective predator that prefers *Tetranychus* over other tetranychid genera (Croft et al. in press, Croft & McMurtry 1997). Our studies show that at least three of the four predator species could feed, reproduce and develop on *P. citri*, but survivorship in some was less than maximal. One explanation for low survival of *N. fallacis* may be the ability of *P. citri* to sequester antifeedants of *S. japonica* (Escoubas et al. 1993, Tanaka et al. 1985). Reduced survival was surprising considering that all four species are effective biological control agents of the related *P. ulmi* (Croft et al. in press, McMurtry & Croft 1997). Overall, life history data should be viewed with caution, because searching by predators on paper arenas might be quite different from searching on leaves in nature.

Activity was similar among all four predatory mites when given *P. citri* and like *N. fallacis* when held with *T. urticae*, suggesting that each predator probably was arrested by *P. citri* (Croft et al. in press, Monetti & Croft 1997). *Amblyseius andersoni* had the lowest level of activity, but this measurement was affected considerably by increased mortality and morbidity of the predator. Although *M. occidentalis* and *T. pyri*

demonstrate potential as predators of *P. citri*, more studies are needed to determine if these predators can maintain *P. citri* at low levels under actual field conditions. In limited field tests, *N. fallacis* was able to suppress *P. citri* infesting *S. japonica* below damaging levels. Recent studies have demonstrated the ability of *N. fallacis* to reproduce on many pests in nursery systems (i.e., several mites and insects) (Croft et al. in press, P.D.P., unpublished). These earlier studies and the data presented here suggest that *N. fallacis* may effectively control multiple pests when inoculated into these and other plant systems.

8.3. *Schizotetranychus celarius* on Bamboo.

8.3.1. Introduction

Establishment of an exotic pest may depend on the absence of native predators that are adapted to it (Goeden and Louda 1976). Also, changes in local environmental conditions caused by a pest can improve microclimates or retard predators, and thereby enhance its establishment. *Schizotetranychus celarius* (Banks) is a common pest of bamboo in Japan and in semi-tropical areas of Florida, Georgia and California, USA (Jeppson et al. 1975, Saito 1990). Upon finding a feeding site, this spider mite builds a densely webbed nest within which it reproduces. Saito suggested that the dense webbing and fecal deposits of *S. celarius* protect it from predators (Saito 1983), although webbing of some spider mites is attractive to many predaceous phytoseiid mite species (Schmidt 1976). Saito (1990) reported feeding and adaptations of *Typhlodromus* (*Anthoseius*) *bambusae* Ehara, a native phytoseiid associated with *S. celarius* in Japan and concluded that it had coevolved with *S. celarius* to feed and maneuver within the nest of the pest. No studies to date have reported any endemic phytoseiids in the USA that are associated with *S. celarius*.

Recent inspections of bamboo revealed infestations of an unknown spider mite in the coastal-temperate regions of Oregon and Washington USA, where ornamentals

are widely grown. Preliminary observations of the nesting behavior of the pest indicated that it was *S. celarius*. We sought to confirm this identification and, in the absence of *T. bambusae*, to measure the ability of a native phytoseiid mite to exploit the nest habitat and suppress this spider mite. In temperate-humid areas of the USA, *Neoseiulus fallacis* (Garman) is widely released on ornamentals and other crops to control spider mites (Pratt and Croft 1998). Objectives of this study were to measure: 1) propensities of *N. fallacis* to enter the nest of *S. celarius*, 2) attractiveness of *N. fallacis* to webbing, feces or eggs of *S. celarius*, 3) ability of *N. fallacis* to reproduce on *S. celarius* and 4) whether *N. fallacis* could suppress *S. celarius* on bamboo plants under normal growing conditions.

8.3.2. Materials and Methods

Identification of *S. celarius* and predator mite cultures. Initially, an unknown spider mite was collected from commercial bamboo near Coos Bay and Portland, OR, USA. Adults of both sexes were mounted on glass slides and sent to J. A. McMurtry and J. DeAngelis, Department of Entomology, Oregon State University for identification. Predators for releases (*N. fallacis*) had been collected from crops in the Willamette Valley, Oregon (Hadam et al. 1986). These cultures had been held for six years or more with yearly additions of field-collected mites. Predator cultures were held at 25(±5) °C, 16:8 L:D (light:dark), and 75-95% RH, and fed mixed life stages of the common spider mite, *Tetranychus urticae* Koch three times per week. Only gravid female predators were selected for use in tests. To adjust for possible dissimilar levels of hunger among predator mites, all *N. fallacis* adult females were held without food for 24 hours just prior to feeding experiments (below).

Invasion of nests by *N. fallacis* and attraction to products of *S. celarius*. To quantify the ability of *N. fallacis* to enter webbed nests of *S. celarius*, 2.5 X 2.5 cm arenas were created on bamboo leaves (underside up) using a water soaked cotton barrier (Saito 1990). To allow nest construction, 3-4 *S. celarius* adult females were added to each of 16 arenas held at 25(±1) °C, 75(±10) RH, and 16:8 L:D. We randomly

selected 8 arenas and placed a single gravid *N. fallacis* on each after 5 days of nest construction. The other 8 arenas received a single female *N. fallacis* after 10 days. Sites of entrance of the predator into the nest, resting locations of *N. fallacis* and number and sites of predator eggs were measured at 2, 4, 6, 8, 10, 12, 24, and 36 hours after transfer of predators. Mode of entrance was scored as either entering via existing openings on either side of the nest or boring an entrance into the nest through the webbing. To compare frequencies of these 2 binomial measured attributes, we used a binomial test with the null hypothesis frequency of 0.5. A *P*-value <0.10 was considered evidence that the null hypothesis was false.

To test attraction and arrestment of *N. fallacis*, dual choice arenas were used (Schmidt 1976). Arenas consisted of 2 X 2 cm tile substrate ringed with water-soaked cotton and replicated 18 times (MacRae and Croft 1993). *S. celarius* eggs, webbing or feces were removed with different forceps from bamboo leaves [*Sasaella hidaensis* (Makino and Uchida) var. 'Murai'] and placed near two diagonal corners and the other *S. celarius* product pair was placed near the remaining two corners. Treatments were eggs vs. webbing, webbing vs. feces or eggs vs. feces. Unlike *T. urticae*, *S. celarius* defecates outside the nest and any mixing of fecal pellets and webbing can be avoided. A single *N. fallacis* adult female was placed in the center of each arena and location of the predator while searching or resting and number and location of predator eggs were monitored at 1-12, 24 and 36 hours after transfer of the predator. To compare relative attractiveness of the spider mite products, we used a binomial test and significance levels as before.

Feeding and ability of *N. fallacis* to control *S. celarius* on bamboo. To measure the ability of *N. fallacis* to feed, reproduce and develop on *S. celarius* we constructed 2.5 X 2.5 cm waterproof arenas ringed with a sticky material (Tanglefoot®, The Tanglefoot Co., Grand Rapids MI 49504) and replicated tests eight times (Monetti and Croft 1997). Three adult female predators of about the same age were transferred to each individual arena and excess mixed life stages of *S. celarius* were provisioned every 24 h. For comparisons, *N. fallacis* was also held with excess amounts of *Tulipa gesneriana* L. and *Pseudotsuga menzesii* (Mirbel) pollen grains. Arenas with mites and

treatments were held at $25(\pm 1)$ °C, $70(\pm 5)$ RH, and 16:8 L:D for 7 days. Assessments of survivorship, activity (ambulation), oviposition per female per day, and production of immatures (larvae, protonymphs, deutonymphs) per female per day were measured every 24 hours. An index for survivorship of immatures was calculated on day 3-7 by dividing the number of immatures by the number of eggs present two days prior to the sampling of immatures (Croft et al. 1998). We compared our results with reported values for *N. fallacis* when held under identical conditions with the optimal prey *T. urticae* or no food (Pratt et al. 1999). Means of each measured attribute and food type were compared by analysis of variance (ANOVA) and Tukey's HSD.

Preliminary tests showed that *N. fallacis* would feed, reproduce and develop on *S. celarius*. Because *N. fallacis* is often used to control pest mites in other ornamental plant systems, we were interested in the ability of *N. fallacis* to suppress *S. celarius* on bamboo. In May, 1998, 10, two-year *S. hidaensis* 'Murai', of $64(\pm 17.4)$ culms each, were potted in 4 liter plastic containers and inoculated with $50(\pm 12)$ adult female *S. celarius*. Plants were placed in a shaded nursery bed and randomly assigned either release of three adult female *N. fallacis* per plant or no predator release (control). By June 11, *S. celarius* averaged $9.6(\pm 3.1)$ colonies per plant and three adult female *N. fallacis* were released onto each plant (Strong and Croft 1995). Infestation of new leaves after release (or non-release) of *N. fallacis* were estimated by marking each *S. celarius* colony and scanning for new colonies every 7 days. The initially marked colonies of *S. celarius* and 10 randomly selected (with replacement) uninfested leaves per plant were monitored for *N. fallacis* every 7 days. To adjust for sampling the same populations over time, data were analyzed by repeated measures ANOVA (von Ende 1993).

8.3.3. Results

Identification of *S. celarius*. The unknown spider mite that was collected was *S. celarius*. Although infestations by this pest on ornamental bamboo had been observed for about 5 years before this study was begun, this was the first taxonomic identification

for these temperate-coastal regions of Oregon. Also, no phytoseiids were associated with *S. celarius* within Oregon.

Invasion of nests by *N. fallacis* and attraction to products of *S. celarius*. *N. fallacis* readily invaded nests of *S. celarius* when webbing was minimal but was somewhat less invasive when webbing was denser (Table 8). When measuring the entrance into nests, *N. fallacis* used both natural openings and created new holes equally as often after 5 or 10 days of web construction. *N. fallacis* laid significantly more eggs within the nest than without, irrespective of the nest construction time (Table 8). When comparing attraction to prey products, *N. fallacis* was associated more with webbing than eggs either when searching ($P=0.082$) or resting ($P=0.052$). With feces and eggs, *N. fallacis* searched more near feces ($P=0.059$) although it was equally probable for them to rest among either product ($P=0.855$). Webbing and feces were equally attractive to *N. fallacis* when either searching or resting ($P=1.0, 0.2$ respectively).

Table 8. Invasions of *Schizotetranychus celarius* nests by the phytoseiid predator *Neoseiulus fallacis*.

Nest Construction Period ^a	Attribute of <i>N. fallacis</i> ^b		Proportion	P-Value ^c
5 days	Observed location	Within Nest	0.65	0.08
		On Leaf	0.35	
10 days		Within Nest	0.47	0.72
		On Leaf	0.53	
5 days	Mode of Entrance	Natural Opening	0.33	0.68
		Break-in	0.67	
10 days		Natural Opening	0.73	0.22
		Break-in	0.27	
5 days	Egg Placement	Within Nest	0.85	0.02
		Without Nest	0.15	
10 days		Within Nest	1.00	<0.001
		Without Nest	0.00	

^a Duration of nest construction period after inoculation of 3-4 adult female *S. celarius* onto a 2.5 X 2.5 cm arena.

^b Attributes of *N. fallacis* measured after introduction into colonies of *S. celarius*.

^c P-value calculated from binomial test, null hypothesis frequency = 0.5

Feeding and ability of *N. fallacis* to control *S. celarius* on bamboo. *N. fallacis* survived equally well when held with either the optimal prey *T. urticae* or with *S. celarius*, but significantly lower survival occurred when held with other treatments (Table 9). Activity of *N. fallacis* was similar between the two species of spider mites but significantly lower when with pollen or starved. Activity of *N. fallacis* was higher when with pollen as compared to the starvation treatment, which may be due to the increased

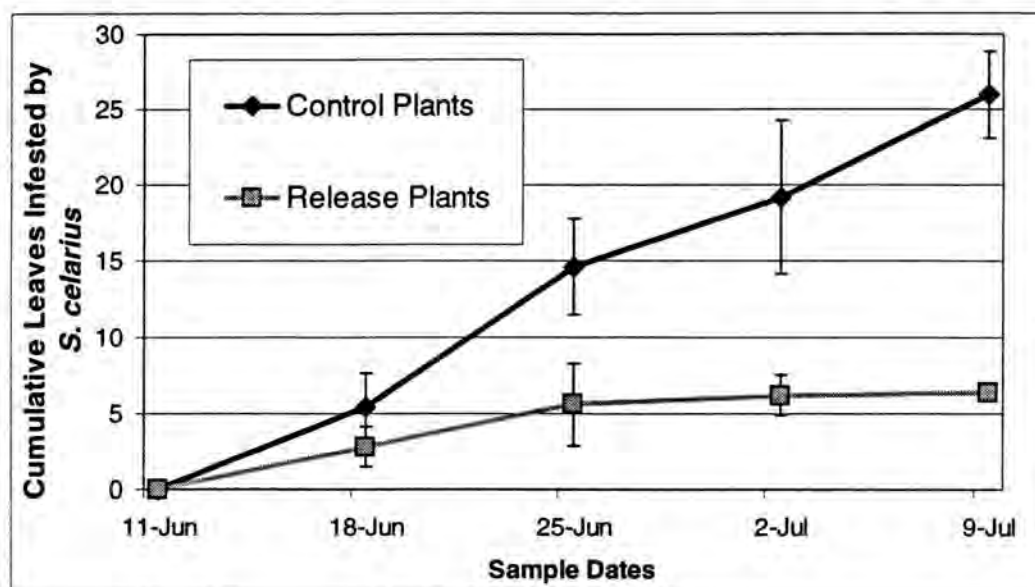


Figure 25. Cumulative number of leaves per plant infested by *S. celarius* after introduction of *N. fallacis* on June 11.

morbidity and mortality of the predator near the end of the 7 d test (Pratt and Croft 1998). Oviposition rates and immature production were similar when held with either

S. celarius or *T. urticae* but significantly lower when with pollen or in the starvation treatment. Immature *N. fallacis* had significantly greater survival when with *T. urticae* and the remaining treatments were ordered: *S. celarius* > pollen = starvation.

The introduction of *N. fallacis* into bamboo significantly reduced the infestation levels of *S. celarius* ($P=0.0002$, $F=42.87$, d.f.=1,8) and the rate of population increase of the pest. Four weeks after predator releases were made, control plants without predators had a 3-fold increase of new pest colonies (Fig. 25). When infested versus uninfested

leaves were compared, those with pest mites quickly reached 60% occupancy by *N. fallacis* after one week and then to above 80% towards the end of the test, whereas on uninfested leaves, predators only increased from 26% to 62% over the 4 weeks (Fig.

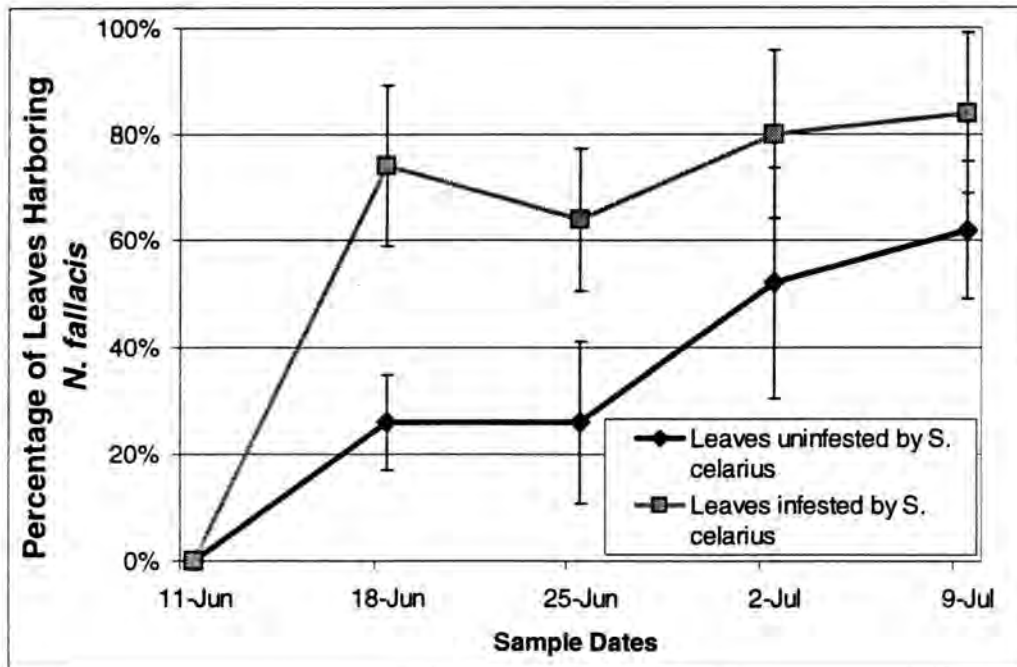


Figure 26. Percentage of leaves harboring *N. fallacis* on either *S. celarius* infested or uninfested leaves.

26). Clearly, the spatial distribution of *N. fallacis* was closely associated with that of the spider mite prey.

8.3.4. Discussion

We report establishment of *S. celarius* on ornamental bamboo in western Oregon, USA. Although this pest overwinters successfully in this region, its long-term survival over a cold winter or multiple cold winters is uncertain because, for the past 5 years, such severe winters have not occurred (unpublished weather records). However, as observed in these studies, *S. celarius* seems to survive well in the semi-enclosed nurseries that are used to grow bamboo in the region. Also, contrary to earlier reports

Table 9. Survival, activity, oviposition rates and immature production of *Neoseiulus fallacis* when held with unlimited numbers of prey-food over 7 days.

Prey	Survivorship ^a	Activity ^b	Egg/Female/day ^c	Imm./female/day ^d	Index ^e
	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD	Mean \pm SD
<i>T. urticae</i> ^h	1.00 \pm 0.04a ^g	0.17 \pm 0.11a	1.78 \pm 0.40a	1.15 \pm 0.25a	1.86 \pm 0.29a
<i>S. celarius</i>	1.00 \pm 0.11a	0.34 \pm 0.09a	1.85 \pm 0.22a	1.16 \pm 0.11a	1.50 \pm 0.22b
<i>T. gesneriana</i>	0.87 \pm 0.09b	0.84 \pm 0.10c	0.06 \pm 0.04b	0.03 \pm 0.03b	0.28 \pm 0.30c
<i>P. menziesii</i>	0.89 \pm 0.11b	0.67 \pm 0.19bc	0.04 \pm 0.04b	0.012 \pm 0.02b	0.025 \pm 0.07c
Starvation ^h	0.36 \pm 0.07c	0.57 \pm 0.13b	0.04 \pm 0.03b	0.00 \pm 0.00b	0.00 \pm 0.00c
P-value ^f	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

^a Percent female survival after 7 days in arenas.

^b Percent female activity (ambulation) within arena per 1 min observation per d.

^c Eggs produced per female per d.

^d Mobile immatures produced per female per d.

^e Survivorship of immatures calculated on d 3-7 by dividing the number of immatures present by the number of eggs present 2 days prior to count.

^f Means of all tests were analyzed by ANOVA, d.f.=5, 42.

^g Means followed by different letters are significant at $\alpha=0.05$ (Tukey's HSD).

^h From Pratt et al. 1999.

(Young and Haun 1961), this pest is now of economic importance because of the reduction in marketability of spider mite-infested bamboo, and the potential for dissemination of the pest by nursery workers, plant collectors, and home owners is high. Also, the presence of this pest may hamper development of bamboo cultivation for other purposes within the region.

N. fallacis successfully invaded and preferentially oviposited within the specialized web nest of *S. celarius*. These findings are consistent with *N. fallacis* being classified as a Type II specialist predator of spider mites that produce copious amounts of webbing (McMurtry and Croft 1997). *N. fallacis* apparently is well adapted to entering nests of this pest via natural openings at ends of the nest structure or by making openings by brute force anywhere in the nest. The reason for a reduction of within-nest occurrence of *N. fallacis* after 10 days of nest building by *S. celarius* is unclear. Possibly the denser webbing increases the difficulty in making new openings or in entering a more complex natural opening that results from the longer colonization period. Also, Saito (1990) reported attacks by the males of *S. celarius* on larvae of the native phytoseiid *T. bambusae* (Saito 1990). In this study there were no instances when males of *S. celarius* attacked larvae of *N. fallacis*, even when specific assessments were made for this type of predator-prey interaction (unpublished data).

N. fallacis appears well adapted to feeding and reproducing on *S. celarius*. When comparing oviposition rates, *N. fallacis* produced similar levels of eggs when with either *S. celarius* or *T. urticae*. In addition, oviposition rates when feeding on *S. celarius* are similar for *N. fallacis* (1.8 ± 0.4) and the co-adapted *T. bambusae* (1.7 ± 0.2) (Saito 1990). In our study, *N. fallacis* was not given free water and therefore the value reported may be conservative for oviposition when feeding on *S. celarius* (unpublished data). Although others have reported that *N. fallacis* can do well when feeding on pollen (Zhang and Li 1989), reproduction was negligible on the types that were assessed in this study. Again, this discrepancy may be because

free water was not available to predators or that there are different nutritional values of pollens to *N. fallacis* (Pratt et al. 1999).

Our results are relevant to control of *S. celarius*. Dicke et al. (1990) suggested that attractiveness of mite products might be a useful indicator for selection of predators as biological control agents. In this study, *N. fallacis* was highly attracted to products of *S. celarius*, it readily entered nests, it reproduced as well on *S. celarius* as on *T. urticae*, and it reduced levels of *S. celarius* on densely infested bamboo plants. These findings suggest that *N. fallacis* may be a good candidate for biological control of *S. celarius* in temperate-humid climates.

To our knowledge, this is the first report that quantifies the attractiveness of a phytoseiid to tetranychid feces versus uncontaminated webbing. Before, Schmidt (1976) found that mixed webbing and feces were more attractive than eggs of *T. urticae* to *Phytoseiulus persimilis* Athias-Henriot. Using an olfactometer and *T. urticae* as the prey, Sabelis et al. (1984) found that feces were more attractive to *P. persimilis* than webbing (slightly contaminated with feces) and exuvia. We found that webbing and feces of *S. celarius* were similarly attractive to *N. fallacis*, webbing was more attractive than eggs and, when searching, feces were more attractive than eggs. Our results do not support the hypothesis that webbing and feces may protect *S. celarius* from phytoseiids (Saito 1983). Rather, webbing and feces attracted *N. fallacis* and aided in locating *S. celarius* during search (Sabelis et al. 1984). Although dense, mature nests may reduce nest entries of *N. fallacis*, the placement of fecal material near the natural openings of the nest may actually direct this predator into the nest. To determine evolutionary benefit of fecal placement outside of the nest, tests like those with *N. fallacis* are needed for the coevolved *T. bambusae*.

8.4. References

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9. CONCLUSIONS

The goal of this study was to identify and evaluate a phytoseiid biological control agent for suppression of spider mites in ornamental nursery systems of the Pacific Northwest. Historically, selection of phytoseiids in high value greenhouse or outdoor ornamental nursery crops has focused on Type I specialist predators of *Tetranychus* species (i.e. *Phytoseiulus persimilis*) (Van de Vrie 1985, McMurtry 1982, Mizell and Short 1992, McMurtry and Croft 1997). Due in part to their specialization on *Tetranychus* mites and lack of feeding on other types of foods, Type I predators may overexploit their prey and starve or rapidly disperse from the crop of interest as prey levels decrease (McMurtry 1992, Walzer and Schausberger 1999, Helle and Sabelis 1985). For this reason, multiple inundative releases during a single growing season are often needed to ensure that sufficient densities of specialist predators are maintained in the crop (Cashion et al. 1994, McMurtry 1991). Type I phytoseiids also have narrow prey ranges and may be ineffective at controlling other important spider mite pests of these systems (Pratt et al. 1999, McMurtry and Croft 1997, Ch. 3). Finally, there are no native Type I predators in the Pacific Northwest and the probability of successful overwintering is minimal (Hadam et al. 1986, McMurtry and Croft 1997).

We wished to develop a more sustainable biological control program for multiple spider mite pests in outdoor ornamental nurseries. The first objective was to identify a biological control agent. We hypothesized that a Type II selective predator of tetranychids would enhance the long-term control of spider mites in these systems. Type II predators have a broader prey range than Type I species and alternative foods have been shown to extend survivorship and reproduction of these phytoseiids (Overmeer 1985, Pratt et al. 1997, Ch. 3). Therefore, we first compared life history traits from the literature for several native Type II species, including: *Galendromus occidentalis*, *Neoseiulus californicus* and *N. fallacis*. For these species, we went on to perform field tests to compare the effectiveness of these predators when released into ornamental plants of 4 representative types. *G. occidentalis* has the narrowest

prey range of the candidates and was less effective at suppressing spider mites when compared to the other species in field tests. *Neoseiulus californicus* does not successfully overwinter in the northern regions of the Pacific Northwest (Pratt, unpublished data), it dispersed or starved when released into *Oligonychus illicis* infested rhododendron plants and did not persist to the end of a growing season. *N. fallacis* has a wider prey range than *G. occidentalis*, is native to the Pacific Northwest and was equally or more effective at suppressing spider mite pests than the other candidates when released into a range of ornamental plants. These traits make *N. fallacis* a logical biological control candidate for spider mites in ornamental systems.

Evaluation of a biological control agent targeted for multiple pests in a polyculture system is complex. Factors influencing effective biological control of spider mites may include: the prey range of the agent, compatibility with the host plant on which pest suppression is to occur, cultural practices and the interaction of these variables. Extensive testing of each of these factors simultaneously is unfeasible. Therefore, we measured the prey range of *N. fallacis* when held with 29 ornamental pests or alternative foods under laboratory conditions. We also performed 30 small-scale tests of spider mite susceptible plants from within the major morphological plant types grown in ornamental nurseries of the Pacific Northwest and among 2 propagation methods. In feeding studies, survival, reproduction and development were consistently highest, and activity lowest, when held with *Tetranychus* species. Reproduction was limited when with non-tetranychid species although representatives from nearly all prey-food types provided for reproduction that was higher than at starvation conditions (Table 2, Appendix I). In plant tests, we demonstrated that *N. fallacis* will control spider mites among most ornamental types tested (Table 5). For instance, spider mite suppression was “acceptable” in 81% of the small scale tests (Table 4), which represent a major subset of the susceptible plants found in ornamental nurseries of the Pacific Northwest. Limitations in control of spider mites occurred in tall, vertical growing plants with little foliar canopy.

These systems probably have little canopy humidity, a component that appears to be essential to the reproduction and survival of *N. fallacis*. Our findings suggest that *N. fallacis* is an effective biological control agent of multiple spider mites, particularly in shrub and herbaceous plant types (e.g. low-growing plants). Having established that *N. fallacis* is capable of controlling multiple spider mites in a range of ornamental plants, we wished to investigate methods of releasing this predator into ornamental nurseries. An obstacle limiting success of biological control agents is improper timing of release of the agent (Beirne 1975, Stilings 1993). In addition, current release methods consist of purchasing predatory mites and distributing them, by hand, into infested foliage (Pratt, personal observation). We investigated releasing *N. fallacis* at ultra low prey densities and the production and dispersal of predators from banker plants. The introduction of *N. fallacis* at low prey densities was successful at reducing populations of the pest mite *T. urticae* and produced similar levels of control when compared to releases into moderate prey densities. In small scale banker plant studies, high densities of *N. fallacis* were produced on banker plants and dispersed to downwind receiver plants (Fig. 14). In field tests with receiver plants placed at greater distances, *N. fallacis* readily dispersed to distances of 30 m or more. The effectiveness of releases at low prey densities and the incremental inoculation of predatory mites from banker plants into surrounding ornamentals may aid in properly synchronizing phytoseiid releases targeted for control of spider mites.

Conserving natural enemies is a vital component of sustainable biological control programs (Barbosa 1999). The ability to locate adequate overwintering sites within ornamental nurseries may increase the conservation of *N. fallacis* in these systems (Veerman 1985). When comparing the number of overwintering adult females among plant types, *N. fallacis* was more abundant on conifers, intermediate on evergreen shrubs and minimal on herbaceous perennials, deciduous shrubs and shade trees (Fig. 20). We also found that covering plants with protective plastic during winter months negatively affected overwintering survival of *N. fallacis* (Fig.

23). In addition, model simulations suggest that when spider mite prey is scarce conservation of predators in ornamental systems is greatest in fields possessing homogeneous borders. These findings suggest that altering cultural practices that improve overwintering survival and reduce passive emigration from ornamental crops may enhance conservation of *N. fallacis*.

Applications of broad-scale pesticides may be the most limiting factor to integration of phytoseiid biological control agents into control programs of these high value plants. For instance, routine insecticide applications for root weevils (*Otiorhynchus* spp.) can preclude the long-term establishment of *N. fallacis* in treated plants (Appendix III). Possibly the most effective way of integrating *N. fallacis* into ornamental nursery systems is to identify and use pesticides that have little or no effect on the ability of the predator to control spider mite pests (Ruberson et al. 1998, Hull and Beers 1985). Results from pesticide selectivity screening tests suggest that pesticides registered for use in Oregon ornamental nurseries range from non-toxic to highly toxic active ingredients (Table 13). Among the least toxic to *N. fallacis* include two new products recently registered for ornamental use: hexythiazox and spinosad. In addition, acephate and lindane appear to be only mildly toxic to *N. fallacis* and may be candidates for IPM strategies. Consistent with field observations, carbaryl, carbofuran, chlorpyrifos, and permethrin are highly toxic to *N. fallacis* and should not be used in conjunction with releases of the predatory mite (Appendix III). An alternative method of integrating *N. fallacis* into these systems may be accomplished by avoiding direct application of the pesticide to the predator. For example, the use of banker plants that can be removed during applications or reside on the periphery of sprayed areas may serve as refugia for predatory mites. Finally, the use of pesticide resistant strains of *N. fallacis* (Croft 1990) has not been evaluated as a method of conserving predators within ornamental nurseries.

During the evaluation of *N. fallacis* as a biological control agent of spider mites, *Panonychus citri* and *Schizotetranychus celarius* were collected on *Skimmia japonica* and many genera of bamboo, respectively. These spider mites had not been

previously collected in the Pacific Northwest and are considered to have recently established in this region. Biological control of these pests by *N. fallacis* was evaluated by performing laboratory based feeding studies and releases of the predator into spider mite infested plants in ornamental nurseries. In both cases, *N. fallacis* fed and reproduced on the new mites, although to a greater extent on *S. celarius*. In field tests, *N. fallacis* suppressed both spider mites below economic levels and resulted in marketable plants. Although efforts are made to reduce the exchange of pests, the probability that a new spider mite pest will be introduced and establish in the ornamental growing region of the Pacific Northwest is high. For this reason, as well as the diversity of pest mites currently found in ornamental systems, specific emphasis was placed on selecting a biological control agent that would suppress various genera of spider mites. The ability to predict biological control of future spider mite pests invasions by *N. fallacis* may be determined by performing feeding studies and plant compatibility tests as described herein.

In conclusion, our findings suggest that *N. fallacis* can be a commercially effective biological control agent against multiple spider mites in low growing and selected vertical ornamental plants of the Pacific Northwest. In view of its humid adapted nature, inferences to other more arid climates of the growing region may be limited, although ornamental systems can be manipulated to improve these restrictions. Further evaluations of this predator in similar climatic regions, both nationally and internationally, may be of relevance for other polyculture, multi-pest systems.

In the future, biological control of spider mites will need to be tested over multiple years on entire nursery systems to determine the persistence of *N. fallacis*. To guide management efforts accurately, an improved understanding of predator release rates into the diversity of plant and prey combinations is needed. In addition, modified cultural techniques that improve biological control in vertical growing plants must be explored. And to be a truly effective program, biological control of

other key ornamental pests or ornamental nurseries must be developed and integrated into management practices.

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APPENDICES

**Appendix I. Oviposition Rates, Calculations of Feeding Proportions, and
References for Five Species of Phytoseiid Mites.**

Species	Prey-Food Group ^a	Prey-Food	E/F/D ^b	Group Mean ^c	Group Proportion ^d	Reference ^e
<i>P. persimilis</i>	TSM	<i>T. cinnabarinus</i>	3.80			Pickett & Gilstrap 1986
		<i>T. pacificus</i>	3.15			McMurtry 1977
		<i>T. pacificus</i>	3.69			Takafuji & Chant 1976
		<i>T. pacificus</i>	2.91			Amano & Chant 1977
		<i>T. pacificus</i>	2.69			Badii & McMurtry 1984
		<i>T. urticae</i>	3.16			Kennett & Hamai 1980
		<i>T. urticae</i>	4.30			de Moraes & McMurtry 1985
		<i>T. urticae</i>	4.10			Beglyarov 1967
		<i>T. urticae</i>	3.80			Friese & Gilstrap 1982
				3.51	0.81	
	OSM	<i>O. ununguis</i>	0.80			Ashihara et al. 1978
				0.80	0.19	
	OM		No data			
	ERIO		No data	0	0	
	INS		No data	0	0	
	POL	<i>H. croceus</i>	0	0	0	McMurtry 1977
				0	0	
<i>N. fallacis</i>	TSM	<i>T. urticae</i>	2.2			Ballard 1954
		<i>T. urticae</i>	2.1			McClanahan 1968
		<i>T. urticae</i>	3.5			Ball 1980
		<i>T. urticae</i>	3			Croft and Blyth 1979
		<i>T. urticae</i>	1.2			Lee 1972
		<i>T. spp.^h</i>	3.2			Smith 1961
				2.53	0.62	
	OSM	<i>P. ulmi</i>	1.5			Burrell and McCormick 1964
		<i>B. arborea</i>	0			Burrell and McCormick 1964
		<i>O. ununguis</i>	2.5			Boyne and Hain 1983
		<i>O. pratensis</i>	2.1			Heintz 1988
				1.52	0.37	
	OM		No data			
				0	0	
	ERIO		No data			
				0	0	
	INS		No data			
				0	0	

	POL		No data	0	0	
<i>T.pyri</i>	TSM	<i>T. urticae</i>	1.00			Engel & Ohnesorge 1994
				1.00	0.22	
	OSM	<i>B. arborea</i>	0.76			Herbert 1961
		<i>E. carpini</i>	1.18			Duso & Camporese 1991
		<i>E. tiliarium</i>	0.43			Kropczynska et al.1988
		<i>P.ulmi</i>	0.40			Engel & Ohnesorge 1994
		<i>P.ulmi</i>	1.02			Duso & Camporese 1991
		<i>P.ulmi</i>	0.68			Herbert 1961
				0.75	0.17	
	OM	<i>K.aberrans</i>	0.30			Schausberger 1997
		<i>E. finlandicus</i>	0.08			Schausberger 1997
				0.19	0.04	
	ERIO	<i>C. vitis</i>	1.28			Engel & Ohnesorge 1994
		<i>C. vitis</i>	1.24			Duso & Camporese 1991
		<i>E. vitis</i>	1.45			Engel & Ohnesorge 1994
		<i>E.tristriatus</i>	1.18			Kennett & Hamai 1980
				1.29	0.29	
	INS	<i>D. reuteri</i>	0.57			Engel & Ohnesorge 1994
		<i>Q. perniciosus</i>	0.49			Schausberger 1998
				0.53	0.12	
	POL	Average of 18 Pollens	0.64 ^f			Engel & Ohnesorge 1994
		<i>M. criniflorum</i>	1.01			Duso & Camporese 1991
				0.65 ^g	0.15	
<i>E. finlandicus</i>	TSM	<i>T. urticae</i>	0.56			Schausberger 1992
				0.56	0.10	
	OSM	<i>P. ulmi</i>	0.81			Schausberger 1991
		<i>E. tiliarium</i>	0.69			Kropczynska et al. 1988
				0.75	0.14	
	OM	<i>K.aberrans</i>	0.35			Schausberger 1997
		<i>T. pyri</i>	0.04			Schausberger 1997
				0.19	0.03	
	ERIO	<i>C. ribis</i>	1.72			Schausberger 1992
		<i>D. gigantorhynchus</i>	1.50			Amano & Chant 1986
				1.61	0.29	
	INS	<i>Q. perniciosus</i>	0.68			Schausberger 1998
				0.68	0.12	
	POL	<i>B. pendula</i>	1.88			Schausberger 1992
		<i>Prunus sp.</i>	1.67			Schausberger 1992
		<i>M. domestica</i>	1.15			Schausberger 1992
		Cattail	2.27			Kostianinen & Hoy 1994
				1.74	0.31	
<i>E. hibisci</i>	TSM	<i>T. cinnabarinus</i>	0.37			McMurtry & Scriven 1964
		<i>T. cinnabarinus</i>	1.05			Swirski et al. 1970
				0.71	0.14	
	OSM	<i>P. citri</i>	1.00			McMurtry & Scriven 1964
		<i>P. citri</i>	0.64			Zhao & McMurtry 1990

	<i>O. punicae</i>	1.22			McMurtry & Scriven 1964, 1965
	<i>E. orientalis</i>	0.93			Swirski et al. 1970
			0.94	0.18	
OM	<i>B. phoenicis</i>	0.71			Swirski et al. 1970
			0.71	0.14	
ERIO	<i>P. oleivora</i>	0.14			McMurtry & Scriven 1964
	<i>P. oleivora</i>	0.00			Swirski et al. 1970
			0.07	0.01	
INS	<i>H. lataniae</i>	0.40			McMurtry 1963
	<i>A. aurantii</i>	0.70			Swirski et al. 1970
	<i>B. tabaci</i>	0.70			Swirski et al. 1970
	<i>B. tabaci</i>	0.40			Meyerdirk & Coudriet 1985
	<i>R. syriacus</i>	0.55			Swirski et al. 1970
	<i>F. occidentalis</i>	1.70			Van Houten et al. 1995
	<i>S. littoralis</i>	0.04			Swirski et al. 1970
	<i>P. citri</i>	0.01			Swirski et al. 1970
	<i>E. ceratoniae</i>	0.01			Swirski et al. 1970
			0.64	0.13	
POL	<i>Mesembryanthemum</i>	2.10			McMurtry & Scriven 1964
	<i>M. crocea</i>	1.80			Zhao & McMurtry 1990
	<i>Z. mays</i>	1.11			Swirski et al. 1970
	<i>C. edulis</i>	1.05			Swirski et al. 1970
	<i>P. amygdalus</i>	1.02			Swirski et al. 1970
	<i>Quercus sp.</i>	2.00			Kennett & Hamai 1980
	<i>M. crocea</i>	2.22			Tanigoshi 1981
	<i>C. annuum</i>	2.80			Van Houten et al. 1995
			2.04	0.40	

^a As described in Croft et al. (1998b).

^b Eggs per female per day.

^c Mean within prey-food group.

^d Proportion of the group mean as divided by the sum of group means within species.

^e References as found in Kostianinen & Hoy (1996), if not full citation found in reference section herein.

^f Pooled mean of all oviposition rates in reference

^g Group mean was calculated by including all oviposition rates in reference and not from pooled mean.

^h Mixture of the tetranychid mites *T. yusti* and *T. desertorum*.

Appendix II. Biological Control of Spider Mites by *Neoseiulus fallacis* at Small Spatial Scales.

Plant: *Abies procera* (Nobel Fir)

Date of Release: May 27th

Period of Assessment: 5/27-8/26

Sample Type: 3, ten-inch terminal branches per tree.

Planting: Planted in 1989

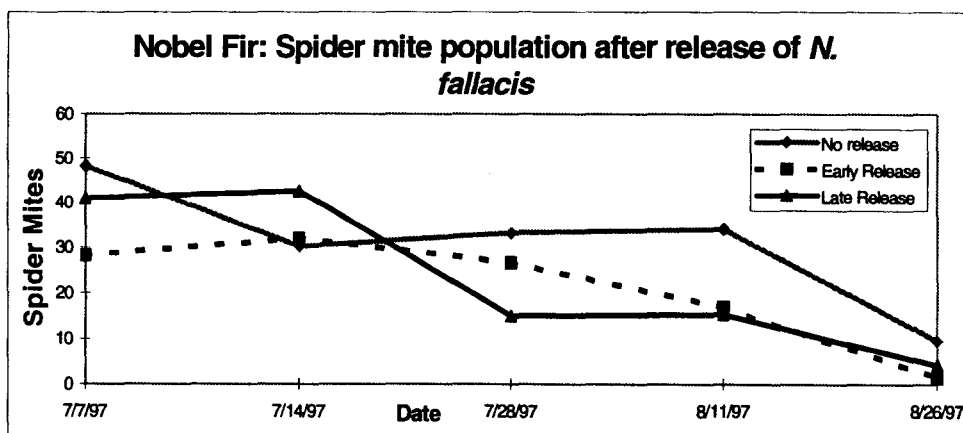
Predatory Mite: *N. fallacis*

Methods: Noble fir trees are grown by many ornamental nurseries in the Willamette Valley for either Christmas or specimen tree production. These trees are highly susceptible to the spruce spider mite (SSM), *Oligonychus ununguis* (Jacobi). Populations of SSM increase during early spring and late fall, possibly entering a summer diapause during the hottest months of the year (Regan 1990). After years of seasonal sprays for spider mites, an area nurseryman contacted us for options in reducing his pesticide applications.

Predatory mites have been released to reduce spider mites populations in many agronomic crops of the Willamette Valley, such as corn, mint, strawberry, hops, and fruit trees (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* has been used with a great deal of success and has become the predominate predator released for control of various spider mite outbreaks. In addition, *N. fallacis* has been described as an effective predator of SSM in other regions of the USA (Boyne and Hain 1983).

To measure the effectiveness of *N. fallacis* in noble fir plantings we identified 15 trees that were approximately 6 feet tall and all had similar levels of SSM. These 15 trees were randomly assigned 1 of 3 treatments: No release (Control), early release of *N. fallacis* (6-13-97), and late release of *N. fallacis* (7-15-97). Three, 4-inch terminal branches, ranging from the base to the top of the tree, were randomly removed every two weeks and a 40X microscope was used to identify all life stages of mites. Spider mite densities among treatments were compared using repeated measures ANOVA.

Results: Spider mite densities were very high at the beginning of the study and remained fairly constant during most of the test, irrespective of treatments. The last sample taken showed a marked reduction in the population of the SSM, which may be a factor of the release of the predator. *N. fallacis* was found in release trees during each sample but was absent in the control until the last two samples. Therefore, the marked reduction in the control plants may be attributed to the dispersal of *N. fallacis* from release trees to control trees. Another explanation may be that the natural physiology of the mite caused the population to crash. It has been shown that SSM begins to overwinter in late August and early September (Calkin 1991). With respect to the biological control of SSM by *N. fallacis*, the early and late release of the predatory mite significantly suppressed the population of SSM as compared to the control ($P=0.002$). The timing of the release, early or late, was not significantly different ($P>0.05$).



Plant: *Acer x freemanii*

Date of Release: July 10

Variety: Jeffersred

Period of Assessment: 7/6-8/6

Planting: Field

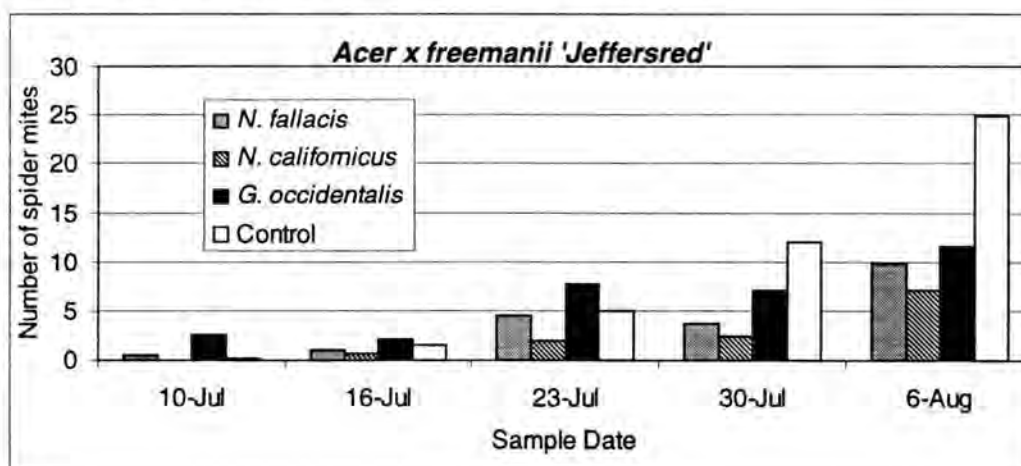
Sample Type: 3 leaves per tree

Predatory Mite: *N. fallacis*, *N. californicus* and *G. occidentalis*

Methods: Spider mites are major pests of ornamental plants, including shade trees. The shade tree *Acer x freemanii* 'Jeffersred' is considered resistant to leafhoppers but is very susceptible to spider mite damage (Bentz and Townsend 1999). In general, miticides are routinely used to limit pest mite damage to the terminal growth of this variety. An alternative to miticides is the introduction of predatory mites. For instance, predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *Neoseiulus fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. *N. fallacis* has become the predominate predator released for control of various spider mite out breaks in the Willamette Valley. Unfortunately, *N. fallacis* is sensitive to arid conditions that may occur in the weakly canopied shade trees. Therefore, we questioned if the more arid adapted *Neoseiulus californicus* or *Galendromus occidentalis* would be more effective at suppressing spider mites in these plants.

To test this we randomly selected a single tree row from a large field planting of 1 yr. old (since budding) saplings. One hundred and fifty trees were randomly assigned one of four treatments: release of *G. occidentalis*, *N. californicus*, *N. fallacis* or no release (control). Three trees were used in each replicate and 2 trees served as a border between replicates. On July 7th densities of the two spotted spider mite reached 1.1 mite per leaf and 2 adult females of a single species were added to a basal leaf of each tree within the release blocks. Estimates of the mite populations were made by scanning 3 randomly selected leaves from basal, intermediate and apical portions of each tree. Comparisons among treatments were made with repeated measures ANOVA and Fishers LSD.

Results: Release of the predatory mites significantly reduced the populations of the two spotted spider mite when compared to the control ($P < 0.01$). When comparing among predatory mites, it appears that *N. californicus* was more effective at suppressing spider mites in this system. Regardless of the predator used, spider mite densities in all treatments were unacceptable and a chemical spray was used to avoid damage to the terminal growth of the trees. These findings suggest that predatory mites may not be effective alternatives for suppression of spider mites in shade tree systems. One reason for this may be due to the arid conditions of the sparse canopy. Further studies are needed to determine the range of plants compatible these biological control agents.



Plant: *Astilbe simplicifolia*

Date of Release: June 20

Period of Assessment: 6/20-8/16

Sample Type: 5 leaves per plant

Variety: Sprite

Planting: Container

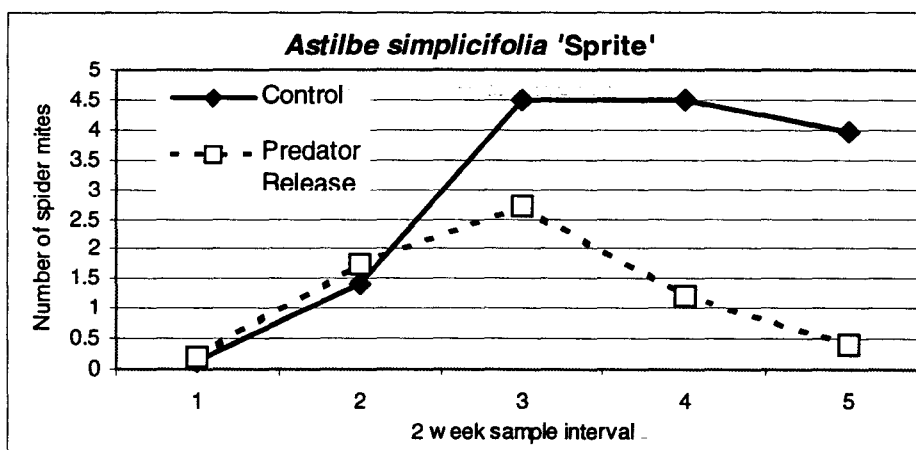
Predatory Mite: *N. fallacis*

Methods: Production of herbaceous perennial plants is becoming more prevalent among ornamental nurseries in the Pacific Northwest. Many of these plants are highly susceptible to spider mite damage. For instance, *Astilbe simplicifolia* is routinely treated with miticides to control the two spotted spider mite (*Tetranychus urticae*).

Predatory mites have been released to reduce spider mites populations in many agronomic crops of the Willamette Valley, such as corn, mint, strawberry, hops, and fruit trees (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. Recently, *N. fallacis* has been used in ornamental nurseries and has become the predominate predator released for control of various spider mite out breaks.

To determine if *N. fallacis* is an effective predator of two spotted spider mite in Astilbes we selected 10, one gallon plants which were maintained in the "can yard" of an area nursery. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 20th of June, spider mite populations had increased to approximately 0.25 spider mites per leaf and one week later 3 adult female predatory mites were added to half of the plants. Samples of 10 leaves were randomly removed from each plant weekly and a 40X microscope was used to identify predator and pest mites. Repeated measures ANOVA was used to compare the 2 treatments.

Results: The inoculation of *N. fallacis* significantly reduced the number of spider mites infesting *Astilbe* plants ($P < 0.01$). Spider mite densities reached 2.7 mites per leaf six weeks after release of *N. fallacis* but were quickly suppressed below 0.5 after week 10. Near the end of the test, predatory mites were located on nearly half of the leaves sampled. The effectiveness of *N. fallacis* in *Astilbes* may be related to the dense foliar canopy, which may provide high humidity levels conducive to reproduction and survival of the predator. In contrast, spider mites remained about 3.5 mites per leaf from week six until the end of the experiment. The fourth sample (week 8) revealed that *N. fallacis* had dispersed into the control plants and began to suppress pest mites in these plants also. Surprisingly, very little foliar damage was visible in either plants control or predator release plants. This result may indicate that these plants are quite tolerant of low levels of spider mites. In all treatments, a few whiteflies and aphids were present and the application of pesticides to control these pests may negatively affect *N. fallacis* and long term biological control.



Plant: Azaleas

Date of Release: June 17th

Period of Assessment: 6/17-7/16

Sample Type: Leaves, 10 per rep.

Variety: Vuyks Scarlet

Planting: Container Grown

Predatory Mites: *N. californicus* and *N. fallacis*

Methods: Azaleas are susceptible to two spot spider mite (*Tetranychus urticae*) and out breaks of spider mites often require a control treatment of a miticide to avoid damage to the plant (Ron Lapotin, personal communication). Azaleas are also susceptible to the southern red mite (*O. illicis*) but we have not seen any infestations from this pest.

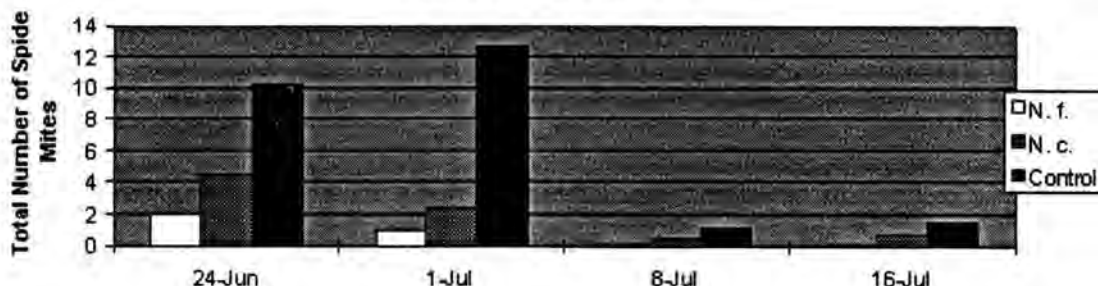
Predatory mites have been effective in controlling spider mites found in greenhouse and other ornamental crops (Helle and Sabelis 1985, Krips et al. 1995, Hamlen and Lindquist 1981). Some of the criteria for choosing a predatory mite for a particular system are adaptability to humidity, feeding rates and dispersal characteristics. *Neoseiulus fallacis* and *Neoseiulus californicus* were chosen for this study not only from the criteria mentioned above but also for their commercial availability.

The test area consisted of 950 one gallon containers of azalea plants (Vuyks Scarlet). The plants were one year old and placed in a shaded hoop house. On July 15th large numbers of spider mites (4 per leaf) were found and the planting was randomly assigned three treatments: *N. californicus*, *N. fallacis* and no release. The treatments were replicated four times with in the block and predators were released on July 17th. The number of predators released per replicate was 20 adult females, this quantity was used to reduce the population quickly. Weekly samples of each treatment were taken by removing ten leaves per replicate and viewing the leaves under a microscope for spider mites and predatory mites. The data gathered from the sampling was analyzed by ANOVA and Fisher's LSD to determine differences between treatments.

Results: One week after the release of the predatory mite, spider mite densities were significantly different than the control (p-value <0.05). Spider mites in release treatments were not significantly different from each other in the first sample but there appears to be a trend that suggest that *N. fallacis* reduced the population of spider mites faster than *N. californicus* (See graph below). This trend was significantly different in the sample of active spider mites on the 15th of July and spider mites continued to decrease in the treatments and migrated into the control as well. At the end of the experiment, *N. fallacis* had reduced the population of spider mites to an average of 0.125 spider mites per leaf, with *N. californicus* reducing the spider mites to 0.7 and the control being 1.55 spider mites per leaf.

These data suggests that predatory mites are effective at controlling a population of spider mites and that *N. fallacis* may be more effective than *N. californicus* in this system. The azalea block did receive a miticide spray at the end of the experiment to reduce the number of spider mites in the controls and other nontreated areas. We feel that a miticide would not have been necessary if detection of the spider mites and release of the predators was earlier.

Two Spot Spider Mite on Azalea



Plant: *Budlea davidii*

Date of Release: July 10th

Period of Assessment: 7/10-8/6

Sample Type: 3 leaves per plant (1=6"; 2=12"; 3=24")

Variety: White Bouquet

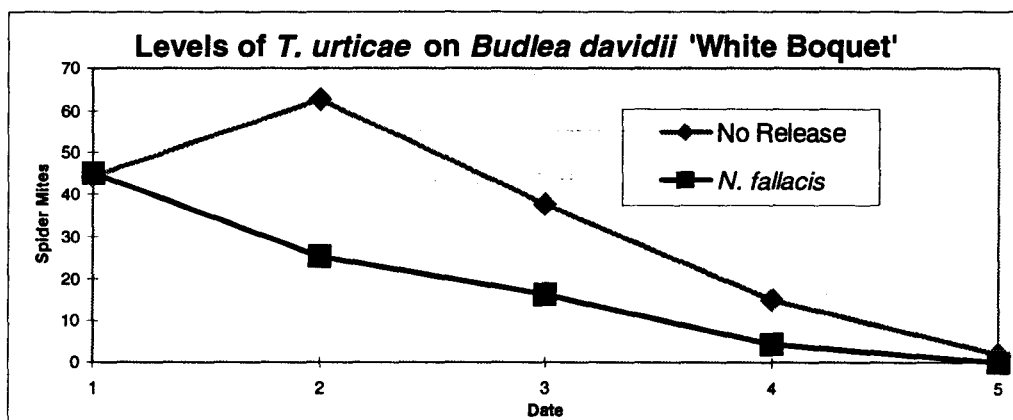
Planting: 1 gallon containers

Predatory Mite: *N. fallacis*

Methods: Willamette valley nurserymen grow approximately 9 varieties of *Budlea davidii*. This plant is found in most nurseries and is popular with the public for it's large flowers, which attract butterflies as well as beneficial insects. Three growers have mentioned that *Budlea davidii* has a recurring infestation with spider mites. Growers typically use miticides to control the two spotted spider mite, *Tetranychus urticae* (Ron Tuckett, personal communication).

Neoseiulus fallacis has been effective at reducing populations of spider mites in other crops of the Willamette Valley. To determine if *N. fallacis* would control spider mites on *Budlea davidii*, we randomly selected 10 one gallon containerized plants of the variety 'White Bouquet'. The grower informed us that the plants may have been slightly water stressed due to warm temperatures in the early season. We randomly assigned each plant one of two treatments: No release (control) or release of *N. fallacis*. Three leaves from each plant were randomly selected at 6, 12, and 24 inches above the crown (soil line) of each plant. Samples were taken once a week for five weeks. Mites were identified by viewing each leaf under a 40X microscope. Repeated measures ANOVA was used to compare treatments.

Results: Spider mite populations averaged 45 individuals per leaf when experiments began. In the plants which were inoculated with *N. fallacis*, spider mite populations per leaf decreased steadily and were significantly different than those in the control ($P=0.0042$). Surprisingly, the spider mite densities per leaf also decreased and reached 0 mites per leaf at the end of the experiment. All leaves, including ones on the control plants, returned to normal healthy color by the 5th sample date. The reason for this reduction in spider mites in the control plots is unclear but regular irrigation on a 24 hour basis may have influenced the pest population. It has been shown that spider mites are positively effected when plants are under water stress (Smitley and Peterson 1991). Water stress may have induced a spider mite out break on these plants and adequate irrigation may have eliminated the pest problem. Even without irrigation practices, *N. fallacis* reduced the population of spider mites faster than no action at all. We suggest that *N. fallacis* is an effective predator of spider mites on *Budlea davidii* 'White Bouquet' and, in this study, we document that proper irrigation may deter pest outbreaks.



Plant: *Euonymus alatus*

Date of Release: July 18th

Period of Assessment: 7/18-8/8

Sample Type: 8 leaves per plant

Variety: Compacta

Planting: 1 gallon containers

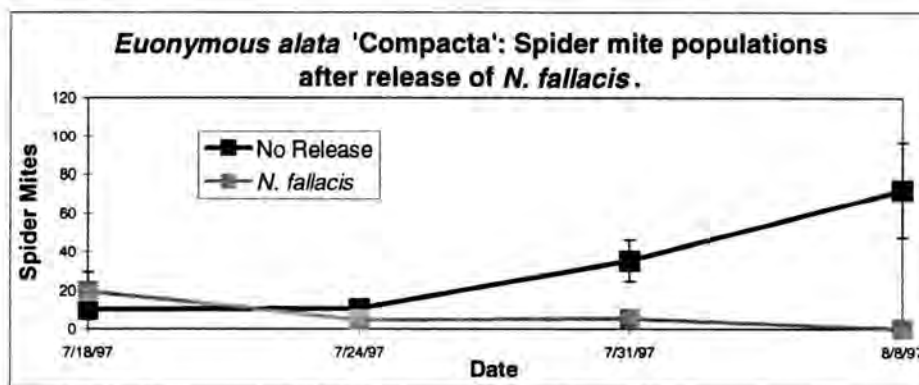
Predatory Mite: *N. fallacis*

Methods: Burning bush is produced in many Willamette valley nurseries where pest managers have identified it as "mite magnet". This plant's reputation for out breaks of the two spotted spider mite (*Tetranychus urticae*) extends beyond Oregon. Ornamental growers in Florida, Georgia, New York, and Indiana have documented the need to spray miticides to reduce the populations of spider mites (Sadof and Alexander 1993, Mizzel and Short 1992, Weidhaas 1979, Brushwein 1991).

Predatory mites have been released to reduce spider mites populations in many agronomic crops of the Willamette Valley, such as corn, mint, strawberry, hops, and fruit trees (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* has been used with a great deal of success and has become the predominate predator released for control of various spider mite out breaks. In addition, *N. fallacis* is mass-produced in the Willamette Valley. Therefore, *N. fallacis* is an ideal candidate for biological control of the two spotted spider mite on *Euonymus alatus* 'Compacta'.

To test the ability of *N. fallacis* to reduce populations of spider mites on burning bush we randomly selected 10 plants, each in 3 gallon containers, from an area nurserymen and randomly assigned one of two treatments: no release (control) or release of *N. fallacis*. 5 adult females were inoculated to half of the plants and 8 randomly selected leaves from each plant were removed once a week for 4 weeks. Leaves were viewed under a 40X microscope to identify all stages of both predatory and spider mites. Treatments were compared over time with repeated measure ANOVA.

Results: Spider mite densities in the control (no release) plants averaged 10 individuals per leaf, which was slightly lower than release plants. Spider mites steadily increased in the control plants, reaching 80 individuals per leaf at the end of the experiment. Spider mite densities steadily decreased in the plants, that received *N. fallacis*, reaching extinction of the spider mites at the end of the four week test. When compared to the control, *N. fallacis* significantly reduced the population of the two spot spider mite on *Euonymus alatus* 'Compacta' ($P=0.0001$).



Plant: *Geranium cinereum*
Date of Release: June 20
Period of Assessment: 6/30-8/16
Sample Type: Ten leaves per plant

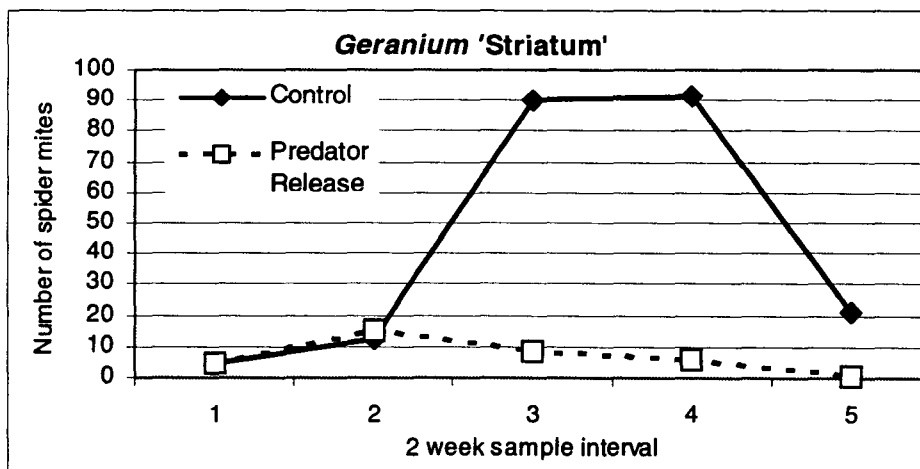
Variety: Ballerina
Planting: Container
Predatory Mite: *N. fallacis*

Methods: Herbaceous perennials are becoming increasingly important among ornamental nurseries in the Pacific Northwest. These plants are projected to become a dominant plant type produced in most nurseries. Unfortunately, many of these plants are highly susceptible to spider mite damage. For instance the hardy geraniums (i.e. *Geranium cinereum*) are routinely treated with miticides to control the two spotted spider mite (*Tetranychus urticae*).

Predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. *N. fallacis* has become the predominate predator released for control of various spider mite out breaks in the Willamette Valley.

To determine if *N. fallacis* is an effective predator of two spotted spider mite in hardy geraniums, we selected 10, one gallon plants that were maintained in the "can yard" of an area nursery. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 18th of June, spider mite populations had increased to approximately 8 spider mites per leaf, much higher than is ideal for biological control. Three adult female predatory mites were added to half of the plants on June 20th. Samples of 10 leaves were randomly removed from each plant weekly and a 40X microscope was used to identify predator and pest mites. Repeated measures ANOVA was used to compare the 2 treatments.

Results: The inoculation of *N. fallacis* significantly reduced the number of spider mites infesting the hardy geranium plants ($P < 0.01$). In plants receiving release of *N. fallacis*, spider mite densities peaked at 15.4 mites per leaf and were suppressed to 0.4 mites per leaf after 10 weeks. In contrast, spider mites increased to 90 mites per leaf in control plants but also decreased on week 10 to approximately 20 per leaf. Reduction of spider mites in control plants may have been caused by *N. fallacis*, which dispersed to the control plants prior to week 8. In addition, damage to the foliage was severe and may have been unacceptable to the spider mites, resulting in dispersal or starvation. Although limited foliar damage was visible on plants with release of *N. fallacis*, leaves were larger than those of the control. Also, new foliage was produced in the release plants but new foliage never fully expanded (and eventually wilted) in control plants. These findings suggest that *N. fallacis* can be an effective biological control agent of spider mites in hardy geraniums.



Plant: *Geum chiloense*

Date of Release: June 30

Period of Assessment: 6/30-8/16

Sample Type: 10 leaves per plant

Variety: Georgenberg

Planting: Container

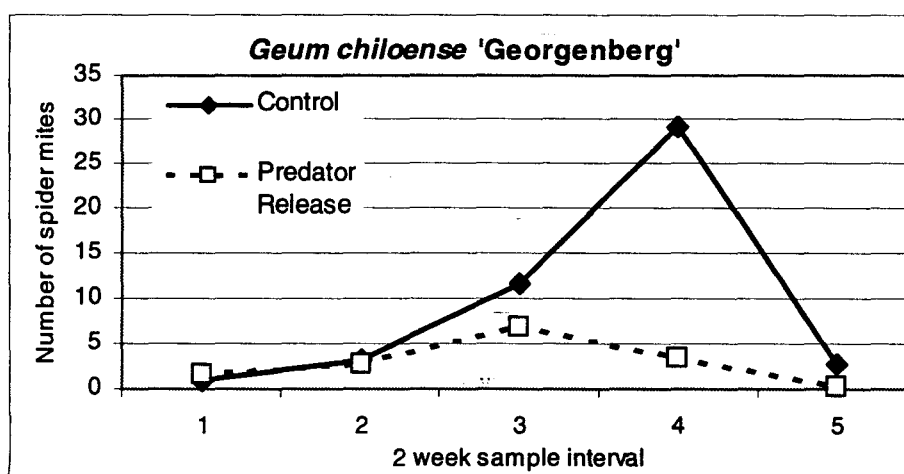
Predatory Mite: *N. fallacis*

Methods: Herbaceous perennials are becoming one of the fastest growing sectors of ornamental nursery production in the Pacific Northwest. These plants can be produced quickly and marketed with limited inputs by the nursery manager. Unfortunately, many of these plants are highly susceptible to spider mite damage. *Geum chiloense* 'Georgenberg', for instance, is routinely treated with miticides to control the two spotted spider mite (*Tetranychus urticae*). The reliance of pesticides for control of spider mites may lead to resistance buildup, environmental degradation, worker hazards and increased production costs.

An alternative to the use of pesticides for control of spider mites is the introduction of predatory mites. Predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. *N. fallacis* has become the predominate predator released for control of various spider mite outbreaks in the Willamette Valley.

To determine if *N. fallacis* is an effective predator of two spotted spider mite in geums, we selected 10, one gallon plants and re-spaced them 2 feet apart in a nursery bed under a sprinkler irrigation system. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 30th of June, spider mite populations had increased to approximately 1.25 spider mites per leaf and three adult female predatory mites were added to half of the plants. Samples of 10 leaves from each plant were randomly removed every 7 days and a 40X microscope was used to identify predator and pest mites. Repeated measures ANOVA was used to compare the 2 treatments.

Results: Spider mites were reduced in geum plants that received the addition of predatory mites ($P < 0.01$). In these release plants, spider mite densities peaked at 6.84 mites per leaf and were suppressed to 0.2 mites per leaf after 10 weeks. In contrast, spider mites increased to 29.2 mites per leaf in control plants but also decreased on week 10 to approximately 2.76 per leaf. These spider mite densities were surprisingly high when considering the leaves of geums are quite small. The reduction of spider mites in control plants may have been caused by *N. fallacis*, which dispersed to the control plants prior to week 6. In addition, damage to the foliage was severe and may have been unacceptable to the spider mites, resulting in dispersal or starvation. Predatory mite densities per leaf often exceeded 5 per leaf, but 11 per leaf were also recorded. Again, aphids were prevalent on the new growth that was produced during this test. The use of pesticides to control these aphids may interfere with biological control of spider mites.



Plant: *Hemerocallis*

Date of Release: June 30

Period of Assessment: 6/30-8/16

Sample Type: Review of 5 leaves per plant

Variety: Happy Returns

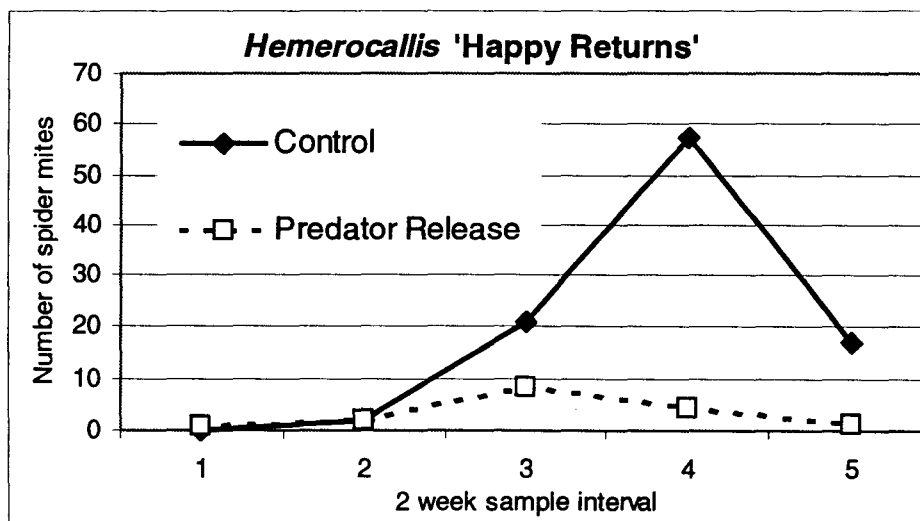
Planting: Container

Predatory Mite: *N. fallacis*

Methods: Daylilies (*Hemerocallis*) are common plants grown in urban landscapes. The increase in production of these plants in ornamental nurseries of the Pacific Northwest reflects the high demand of for daylilies by homeowners. Costs associated with the production of daylilies can be greatly increased by the application of pesticides for control of spider mites. The two spotted spider mite is a common pest of daylilies and routine applications are made by nursery managers.

Predatory mites have been released to reduce spider mites populations in many agronomic crops of the Willamette Valley, such as corn, mint, strawberry, hops, and fruit trees (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* has been used with a great deal of success and has become the predominate predator released for control of various spider mite out breaks. Unfortunately, daylilies have a plant morphology quite different from those that have been shown to be compatible with this predator in the past. To measure the ability of *N. fallacis* in to control the two spotted spider mite on daylilies we randomly selected 10 plants, each in 1 gallon containers, from a nursery bed located near Dayton OR. The plants were transferred to an unused bed and spaced approximately 2 feet apart. All other conditions were similar to normal cultural practices. To ensure that uniform spider mite densities occurred among all plants, 20 spider mite adult females were inoculated to each plant. The 10 plants were randomly assigned 1 of 2 treatments: No release (Control) or release of *N. fallacis*. On June 30th, spider mite densities reached approximately 0.5 spider mites per leaf and 3 adult female predatory mites were inoculated to each plant. Five leaves per plant were removed at 2 week intervals and a 40X microscope was used to identify all life stages of mites. Spider mite densities among treatments were compared using repeated measures ANOVA.

Results: *N. fallacis* significantly reduced the population of spider mites as compared to the control ($P < 0.05$). The spider mites in the control plants peaked at 57 mites per leaf 8 weeks after initiation of the experiment. In contrast, pest mites peaked at 8 mites per leaf in plants possessing *N. fallacis*. Spider mites were eventually suppressed to 1 mite per leaf in release plants near the end of the test. Predatory mites were recovered from control plants on week 8 and may be responsible for the suppression of the spider mites thereafter. Some leaf stippling was observable on all leaves but control plants had consistently more foliar damage. In addition, more flowers were also produced on release plants than control plants. These results suggest that *N. fallacis* can be an effective predator of spider mites in daylily plants.



Plant: *Ilex crenata*

Date of Release: June 26th

Period of Assessment: 6/26-7/17

Sample Type: 10 leaves per plant

Variety: Convexa

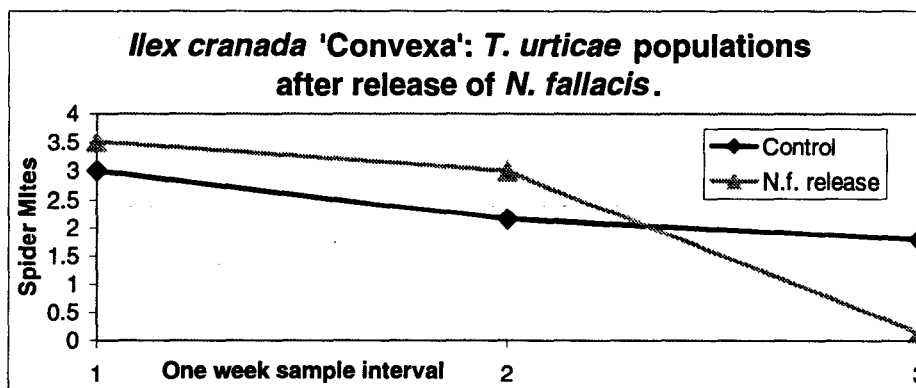
Planting: 1 gallon container

Predatory Mite: *N. fallacis*

Methods: *Ilex crenata* 'Convexa' is a common plant grown by Willamette Valley nurseries. This evergreen shrub has multiple branches and the leaves are convex or cup shaped. The two spotted spider mite (*Tetranychus urticae*) appears to thrive in the leaf habitat and area nurserymen rely on chemical pesticides to reduce spider mite populations. The convex shape of the leaf or the inability of the spray equipment to penetrate the canopy of the plant causes the need for repeated applications during a single growing season. The multiple pesticide applications result in increased risks to workers health and safety, ground water contamination, and pest resistance.

Predatory mites have been effective in various agricultural crops in the Willamette valley, specifically the native predator *Neoseiulus fallacis*. *N. fallacis* has numerically responded to spider mite populations in corn, mint, strawberry, and hops, eliminating or reducing pesticide applications (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). We wanted to determine if *N. fallacis* would control the two spotted spider mite below aesthetic injury levels described by growers. To do this we randomly selected 8 one gallon 'Convexa' plants from within a nursery and randomly assigned one of two treatments: control (no release) or release of the predator *N. fallacis*. 5 adult females were inoculated to the plants and leaves were randomly sampled every week until spider mite populations were eliminated from the release plants. Samples consisted of 15 leaves randomly taken from each plant and mite populations were viewed under a 40X microscope. Data from samples were compared using repeated measures ANOVA.

Results: Spider mite densities in both the control and release plants averaged approximately 3-3.5 individuals per leaf. Spider mites remained nearly constant for the first two weeks of sampling. The third week samples revealed that *N. fallacis* had nearly eliminated the pest from the system ($P=0.021$). It was also noted that neither the controls nor the release plants showed aesthetic damage. These results are encouraging in that moderate levels of spider mites can be controlled quickly by the predatory mite *N. fallacis*.



Plant: *Magnolia stellata*

Date of Release: July 8, 1996

Period of Assessment: 7/8-8/13

Sample Type: Leaves, 5 per replicate

Variety: Royal Star

Planting: Field Grown

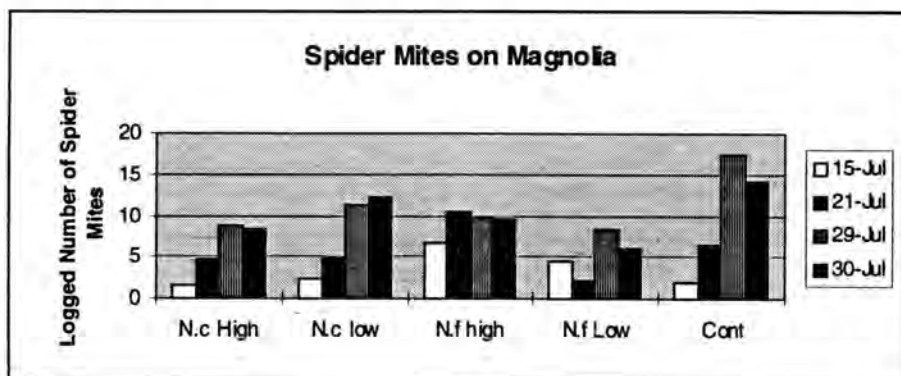
Predatory Mite: *N. californicus*, *N. fallacis*

Methods: Magnolias are very common among nursery plantings yet very little research has been done with the potential biological control of its key pests. One of the major pests of Magnolias is two spot spider mite (*Tetranychus urticae*) (Ron Lopotin, personal communication). The plant morphology and the leaf characteristics suggests that predatory mites may be effective in controlling spider mites. *Neoseiulus fallacis* and *Neoseiulus californicus* have controlled spider mites in other crops and possess qualities that are important for nursery systems (dispersal rate, prey consumption, adaptable to humidity). Predator mites were mass reared on OSU campus under green house conditions similar to those of Strong and Croft (1995). Predatory mites are reared on two spot spider mites which have infested bean plants. When the predatory mites have almost eliminated the spider mites on the bean plant the predators are released into the field.

The experimental plot consisted of 40 plants that were spaced approximately 2 feet apart. The plants were monitored for spider mites beginning in May and on July 8th the population had reached the threshold for release. The block was randomly assigned five treatments, *N. californicus* released high on the plant, *N. californicus* released low on the plant, *N. fallacis* released high on the plant, *N. fallacis* released low, and no release. Each treatment was replicated four times with one plant serving as a buffer between replicates. Two adult female predatory mites were released on each treated plant. Samples of five leaves were taken weekly and viewed under a microscope to count predators and spider mites. The data gathered from the sampling were analyzed by ANOVA and Fisher's LSD to determine differences between treatments.

Results: The treatments were not significantly different until the third sample date (July 29th) although a trend was apparent by the second sample (see figure below). On the July 21st sample *N. californicus* high and low along with *N. fallacis* low appears to be controlling the populations of spider mites. One week later, all treatments are significantly different from the control (p-value <0.06) except *N. californicus* low. On the fourth sample date predators were found in the controls and the treatments were no longer significantly different. After the fourth sample was taken a miticide was sprayed on the surrounding plants and it is believed that the drift from this spray killed all the predators in the experiment.

Under these conditions, the results suggest that placing *N. fallacis* high on the plant (easier for laborers) is as effective as low on the plant. The data also suggests that when placed high on the plant *N. californicus* and *N. fallacis* can reduce a population of spider mites. It is believed that the predatory mites would have continued to disperse through the test area and suppress the population.



Plant: *Malus* Rootstock
Date of Release: June 27th
Period of Assessment: 7/18-9/6
Sample Type: 50 leaves per plot

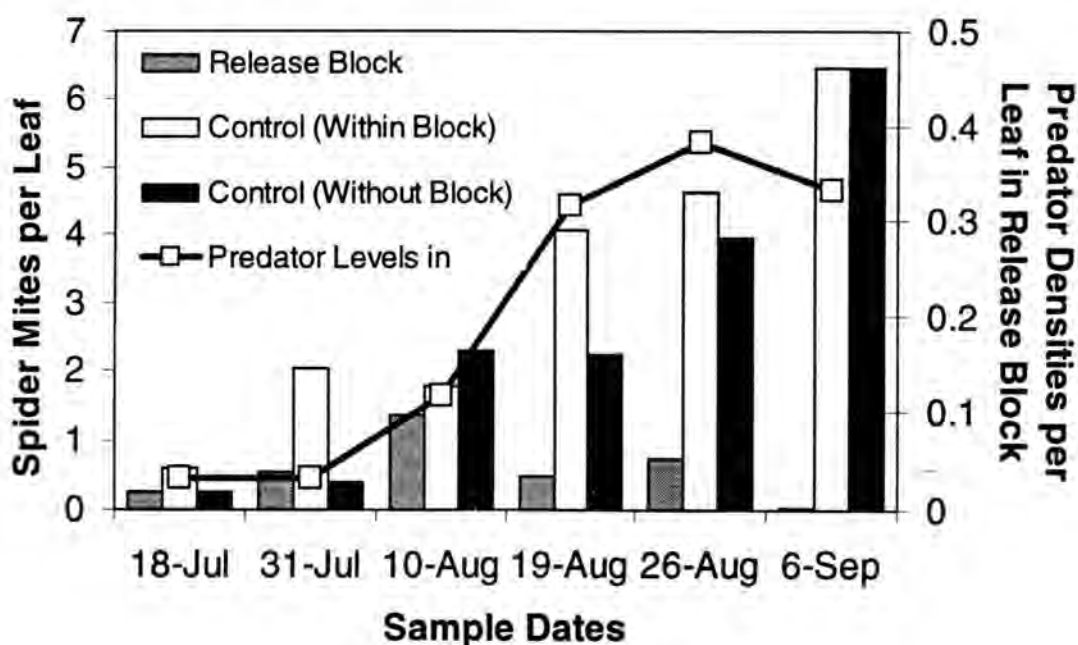
Variety: EMLA 106
Planting: Field
Predatory Mite: *N. fallacis*

Methods: The production of rootstocks for grafting of ornamental or fruit tree production is an important agricultural sector of the Pacific Northwest. Because the aesthetics of rootstock are not of ornamental value, foliar damage in these systems is less of a concern than typical ornamental systems. In contrast, quality grading of rootstocks is commonly made in part by the diameter (or caliper) of the rootstock. Therefore, plant damage that reduces the diameter of the sapling must be controlled. Spider mites are common pests of rootstock systems and growers typically treat these planting on a seasonal basis.

As an alternative to pesticides, predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. *N. fallacis* has become the predominate predator released for control of various spider mite outbreaks in the Willamette Valley.

We questioned if the introduction of *N. fallacis* is an effective alternative to the use of miticides for control of spider mites in rootstock systems. To test this we acquired permission to use a section of a stoolbed rootstock systems near Gervis OR. Ten 1000 square yard plots were randomly assigned on of two treatments: release of 210 adult female *N. fallacis* or no release (control). We monitored each replicated by removing 50 leaves in an X type pattern across each plot every 14 days. We also monitored the neighboring apple rootstock field that served as an external field control. On June 27th spider mite populations had increased to a moderate density of 0.60 per leaf and *N. fallacis* were released into the plots. Comparisons among plots with *N. fallacis* and without were made with repeated measures ANOVA.

Results: The introduction of *N. fallacis* into apple rootstock plants significantly reduced populations of the two spotted spider mite ($P < 0.01$). Pest mites were reduced as much as 95% when compared to the control plots. In release plots, spider mite populations levels peaked in early august at 1.34 per leaf with predator populations peaking at 0.48 per leaf 16 days later. Spider mite levels in control plots reached 6.45 per leaf by early September.



Plant: *Picea glauca*

Date of Release: June 30

Period of Assessment: 6/30-8/13

Sample Type: 4 inch terminal branch

Variety: Conica

Planting: Container

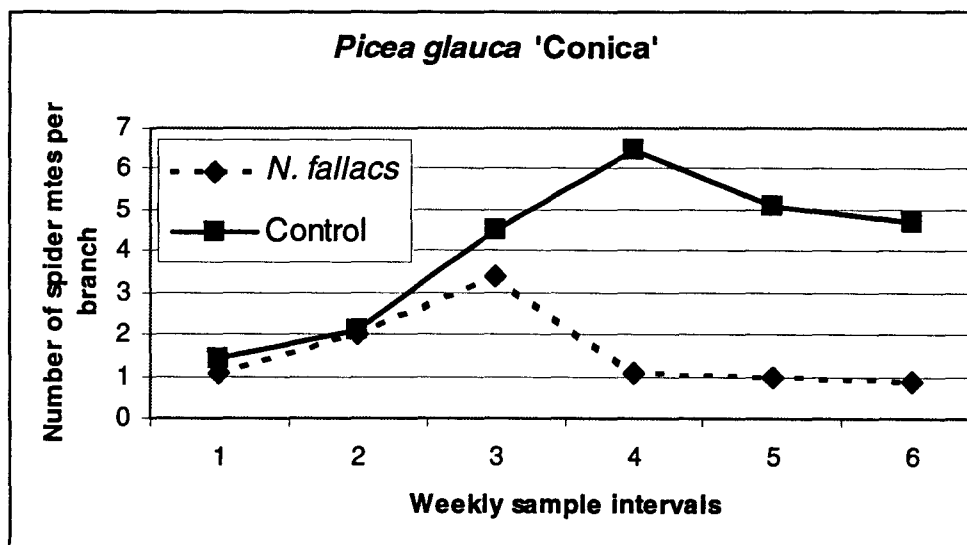
Predatory Mite: *N. fallacis*

Methods: One of the most common conifers produced by ornamental nurseries in the Pacific Northwest is the dwarf Alberta spruce (*Picea glauca* 'Conica'). This plant is susceptible to the spruce spider mite (*Oligonychus ununguis*), a major pest of conifers nationwide. To control the spruce spider mite on Alberta spruce, area nurserymen typically treat plants with miticides annually. Many ornamental producers are seeking alternatives to these costly and potentially hazardous pesticide applications.

Predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) in order to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* has been used with success and has become the predominate predator released in the Pacific Northwest for control of various spider mite outbreaks.

To determine the ability of *N. fallacis* to control the spruce spider mite in Alberta spruce plants, we conducted a small scale test under typical nursery conditions. An area nurseryman provided space in a production "can yard" and supplied ten 1 gallon Alberta spruce plants. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 30th of June, spider mite populations had increased to approximately 1.5 spider mites per 4 inch branch and 5 adult female predatory mites were added to half of the plants. Samples of 5 branches from each plant were randomly removed from each plant at one week intervals and a 40X microscope was used to identify all life stages of the predator and pest mites. A repeated measure ANOVA was used to compare the 2 treatments.

Results: The inoculation of *N. fallacis* into spider mite infested Alberta spruce plants resulted in significantly lower levels of spider mites than controls ($P < 0.05$). Spider mite densities exceeded three mites per branch three weeks after release but were subsequently reduced to below one mite per branch after week six. In contrast, spider mite densities peaked at six mites per leaf in control plants. Predatory mites were recovered in the control plants on week four and the reduction of spider mites in the control near the end of the test may be due to suppression by predators. The reduction in spider mite densities in release plants was considered sufficiently low that the nursery manager was not inclined to treat the plants with a miticide prior to marketing. These findings are consistent with previous tests describing the ability of *N. fallacis* to control the spruce spider mite in conifers.



Plant: *Potentilla fruticosa*

Date of Release: June 25th

Period of Assessment: 6/25-8/6

Sample Type: 15 leaves per plant

Variety: Gold Finger

Planting: 2 gallon container.

Predatory Mite: *N. fallacis*

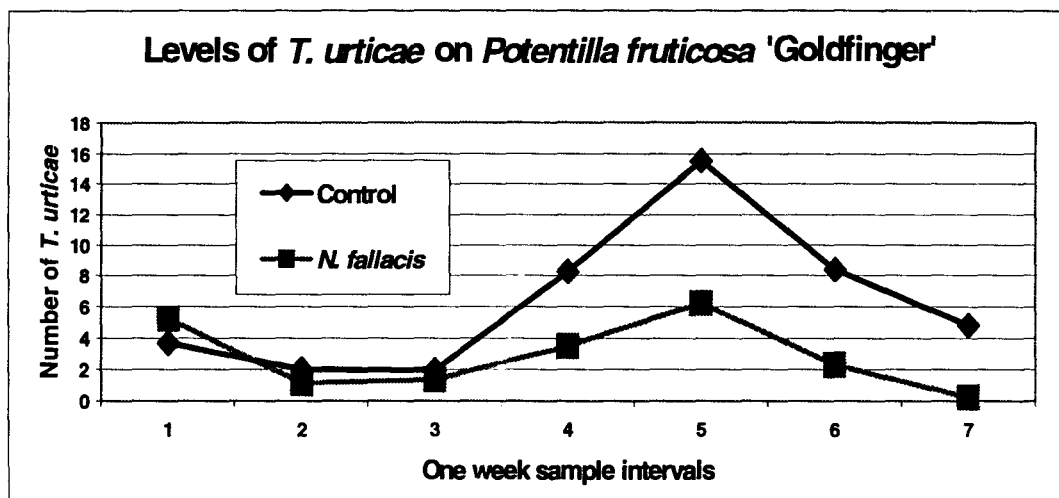
Methods: *Potentilla fruticosa* is a common plant in the Willamette valley nurseries. A popular variety of *Potentilla* is 'Gold Finger', which is very susceptible to infestations of the two spotted spider mite, *Tetranychus urticae* (Ben Noid, Ron Tuckett; personal communication). Typically, spider mites infest 'Gold Finger' in June and reach damaging levels in mid July (Weidhass 1979, Mizell and Short 1992). Spider mite damage causes bronzing of the leaves and eventual leaf drop if not controlled. Area nurserymen typically spray 'Gold Finger' varieties with pesticides 1-3 times during each growing season for spider mite control (Ron Tuckett, personal communication).

Predatory mites have been released in many agronomic crops of the Willamette valley (i.e.: corn, mint, strawberry, hops, and fruit trees) in order to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* has been used with success and has become the predominate predator released for control of various spider mite outbreaks.

We were interested in measuring the effectiveness of *N. fallacis* as a predator of two spotted spider mites in *Potentilla fruticosa* 'Gold Finger'. An area nurseryman provided space in a production "can yard" and supplied 10 plants of the 'Gold Finger' variety. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 25th of June, spider mite populations had increased to approximately 4 spider mites per leaf and 5 adult female predatory mites were added to half of the plants. Samples of 15 leaves from each plant were randomly removed weekly and a 40X microscope was used to identify all stages of the predator and pest mites. Repeated measure ANOVA was used to compare the 2 treatments.

Results: The population of two spotted spider mites remained similar for the first 3 weeks (see graph). The 4th sample revealed that *N. fallacis* was indeed suppressing the population of spider mites. Spider mites did increase to six individuals per leaf but quickly dropped to 0 within 2 weeks. In the plants, spider mites increased to 15 individuals per leaf and decreased to 5 spider mites per leaf near the end of the test. We suggest that the reduction of spider mites in the control plants near the end of the test is due to plant damage and leaf drop.

These data suggest that *N. fallacis* is an effective predator of spider mites in the *P. fruticosa* 'Gold Finger' system ($P=0.0001$). The foliage in these plants was very dense and the plants contained many branched stems. This dense plant structure may have aided in the effectiveness of *N. fallacis* at suppressing the population of spider mites.



Plant: *Potentilla fruticosa*
Date of Release: July 18th
Period of Assessment: 7/18-8/6
Sample Type: 5 leaves per plant

Variety: Gold Finger
Planting: 1 gallon container.
Predatory Mite: *N. fallacis*

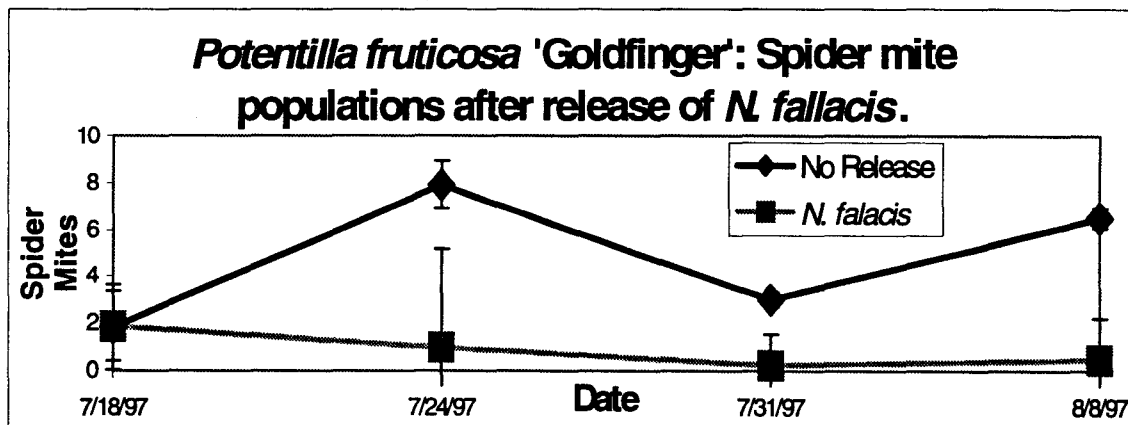
Methods: It has been brought to our attention that *Potentilla fruticosa* 'Gold Finger' is very susceptible to infestations of the two spotted spider mite (*Tetranychus urticae*). Many area nurserymen have indicated that this species of plant must be sprayed with pesticides routinely to avoid spider mite damage. Typically, spider mites infest 'Gold Finger' in June and reach damaging levels in mid July (Weidhass 1979, Mizell and Short 1992). Spider mite damage causes bronzing of the leaves and eventual leaf drop if not controlled.

Predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. *N. fallacis* has become the predominate predator released for control of various spider mite out breaks in the Willamette Valley.

We have previously described the biological control of the two spotted spider mite on large, multi stemmed 'Gold Finger'. We were interested in measuring the effectiveness of *N. fallacis* on the smaller canopy of one gallon 'Gold Finger'. From within a nursery we randomly selected 10, 1 gallon plants. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 18th of June, spider mite populations had increased to approximately 2 spider mites per leaf and 5 adult female predatory mites were added to half of the plants. Random samples of 5 leaves from each plant were removed weekly and a 40X microscope was used to identify all life stages of predator and pest mites. Repeated measure ANOVA was used to compare the 2 treatments.

Results: One week after the release of *N. fallacis*, the spider mites in the release plants were significantly reduced as compared to the control plants ($P=0.001$). This trend continued during the entire 4 week experiment. After three weeks spider mites were nearly eliminated from the release plants. Populations of spider mites in the controls were variable but all control plants demonstrated signs of aesthetic damage after four weeks. It should also be noted that *N. fallacis* migrated to control plants after week four but population trends were not monitored for the later interaction.

We determined that the density of the canopy does not determine the effectiveness of *N. fallacis* at controlling the two spotted spider mite. *N. fallacis* reduced spider mite populations in both the large (3 gal.) and small (1 gal.) *P. fruticosa* 'Gold Finger'.



Plant: Rhododendron

Date of Release: April 9, 1996

Period of Assessment: 4/9-7/15

Sample Type: Leaves, 5 per plant

Variety: Hotie

Planting: Field Grown

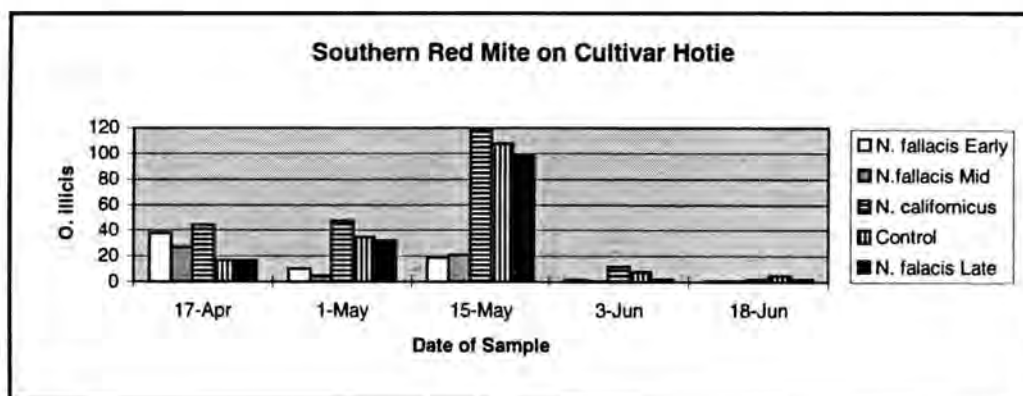
Predatory Mites: *N. californicus* and *N. fallacis*

Methods: Rhododendrons susceptibility to spider mites varies greatly between cultivars. Some cultivars are some what tolerant to spider mites but the majority are not (Jim Todd, personal communication). The predominate spider mite that is found in Rhododendron plantings of the Willamette valley is the southern red mite (*Oligonychus illicis* McGregor) (Pratt, unpublished). This spider mite is often found in high numbers and causes stippling of the leaves and eventual leaf drop if the pest is not controlled (Smith 1939). The cultivar Hotie is very susceptible to the southern red mite and at the test location the grower has a yearly infestation.

Predatory mites (Phytoseiidae) are effective in controlling spider mites in many crops in the Willamette Valley (Hadam et al 1986, Strong and Croft 1995, Coop and Croft 1995) *Neoseiulus californicus* and *Neoseiulus fallacis* were chosen for this experiment for their adaptability to arid and humid conditions and the speed to which they control spider mites.

The test area was 40 X 20 foot planting with each plant spaced approximately two feet apart. The plants were four years old and had received miticidal sprays on a yearly basis. In mid March high populations of southern red mite were found and the test area was divided into a randomized block design. The treatments were: 1. Early release of *N. fallacis* (April 9th), 2. Mid release of *N. fallacis* (April 17th), 3. Late release of *N. fallacis* (May 1st), 4. Mid release of *N. californicus* (April 17th) and 5. No release. Samples of spider mite and predatory mite populations were taken every two weeks from the time of release. The data was analyzed using ANOVA and Fisher-s LSD test to determine differences between treatments.

Results: The population of southern red mites decreased and remained low in the *N. fallacis* Early and Mid releases but increased in the other three treatments. There was no significant difference between *N. fallacis* released Early and Mid (p-value >0.05). Late releases of *N. fallacis*, *N. californicus* and the control treatments were not significantly different from each other but were different from *N. fallacis* Early and Mid. This data suggests that *N. fallacis* can effectively control southern red mite if the predator is released early in the season. *N. californicus* is not an effective predator in this system but should not be excluded from other potential systems. The experiment concluded prematurely due to a frost that occurred on the 8th of May. The foliage dropped approximately three weeks later and left only new growth with few spider mites and no predators. We continued to monitor the cultivar long after the defoliation but found no new infestations during this period.



Plant: Rhododendron
Date of Release: April 17, 1996
Period of Assessment: 4/17-7/2
Sample Type: Leaves, 5 per plant

Variety: Ana Krushke
Planting: Field Grown
Predator Mites: *N. californicus*, *N. fallacis*

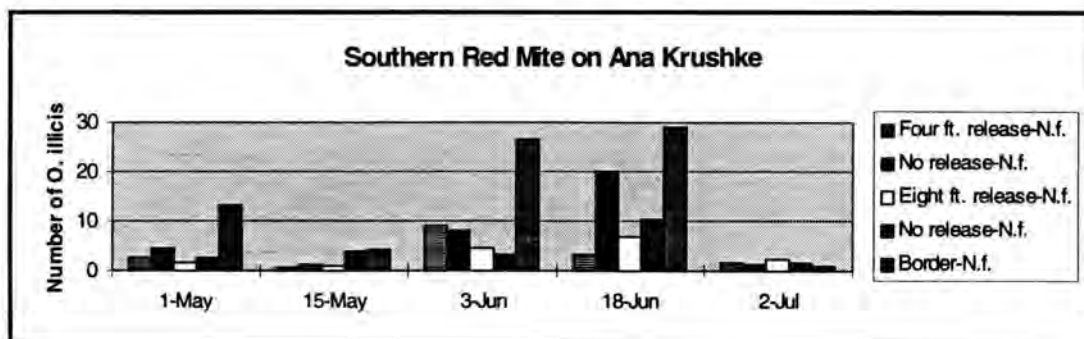
Methods: The rhododendron cultivar Ana Krushke is very susceptible to the southern red mite (*Oligonychus ilicis*, McGregor) (Jim Todd, personal communication). Southern red mite has been detected in the test site by the grower for the past three years and this cultivar has received a miticide spray each season. This spider mite increases rapidly during the early season and can defoliate the plant if not treated (Smith 1939).

Predatory mites are an alternative method of controlling spider mites and have been used in other crops such as hops, strawberry, mint and corn (Strong and Croft 1995, Coop and Croft 1995, Hadam et al. 1986). *Neoseiulus fallacis* and *Neoseiulus californicus* were mass reared on the Oregon State University campus as described by Strong and Croft (1995).

The test area was a 20X20 foot planting with two feet between plants. The cultivar was three years old at the time of the experiment. Monitoring of the spider mites started in mid March and by April 17th the southern red mite had reached sufficient levels for release. The test area was divided into four blocks, which received one of two release rates: predators placed every four feet or every eight feet. Each block also contained a border between treatments that represents no release. Predatory mites were placed near the center of the canopy in the release plants. Spider mite populations were monitored every two weeks by removing five leaves from each release plant and five leaves from a plant adjacent to the release plant in order to determine the rate at which they moved into unreleased plants. Leaves were viewed under a microscope to examine eggs and active stages. The data derived from sampling were analyzed using one way ANOVA and Fisher's LSD test to determine differences between treatments.

Results: *N. fallacis* controlled the southern red mite in the release plants (p -value < 0.05) and quickly moved into the adjacent plants. The number of spider mites in the release and the adjacent plants was considerably lower than in the border. This suggests that *N. fallacis* is capable of moving between plants and controlling spider mite outbreaks in the near vicinity. There is little evidence suggesting that a release every four feet is more effective than every eight feet. *N. californicus* did not control the southern red mite and was not different from the control, thus the graph does not include this treatment.

N. fallacis was not found in the border until the June 18th sample. On the July 2nd sample, *N. fallacis* predator numbers had increased and flooded through the planting. We continued monitoring the system but have found no increase in the number of southern red mite in the block. The grower felt that it was unnecessary to spray a miticide because of the low number of spider mites in the block.



Plant: *Salvia superba*
Date of Release: June 30
Period of Assessment: 6/30-8/16
Sample Type: 5 leaves per plant

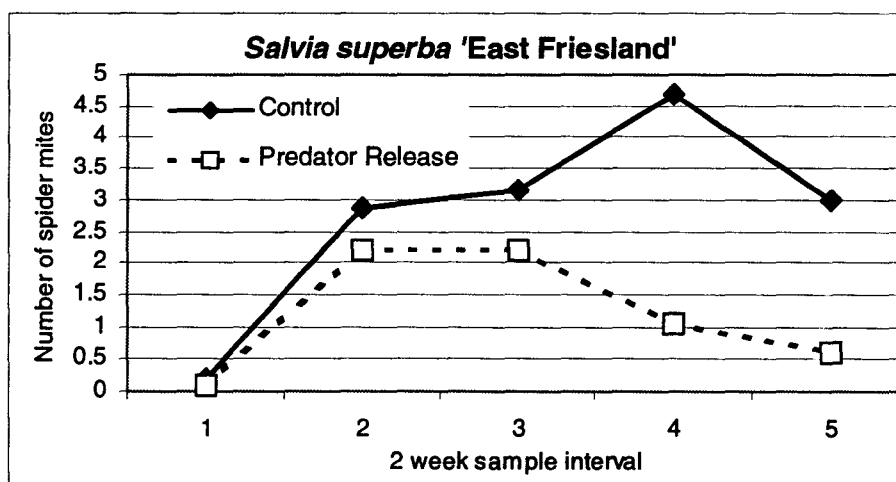
Variety: East Friesland
Planting: Container
Predatory Mite: *N. fallacis*

Methods: The production of ornamental sage, like most herbaceous perennials, has increased in most ornamental nurseries in the Pacific Northwest. Unfortunately, *Salvia* in general is susceptible to spider mite damage. For instance, *Salvia superba* plants are routinely treated with miticides to control the two spotted spider mite (*Tetranychus urticae*). The reliance on pesticides to control spider mites may lead to spider mite resistance, environmental degradation and possible worker hazards.

As an alternative, predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. *N. fallacis* has become the predominate predator released for control of various spider mite out breaks in the Willamette Valley.

To determine if *N. fallacis* is an effective predator of two spotted spider mite in ornamental sage, we selected 10, one gallon *Salvia superba* 'East Friesland' plants from among a "can yard" of an area nursery. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 25th of June, spider mite populations had increased to approximately 0.5 spider mites per leaf and three adult female predatory mites were added to half of the plants on June 30th. Samples of 10 leaves from each plant were randomly removed every week and a 40X microscope was used to identify predator and pest mites. Repeated measures ANOVA was used to compare the 2 treatments.

Results: The inoculation of *N. fallacis* significantly reduced the number of spider mites infesting the *Salvia* plants ($P < 0.01$). In plants receiving release of *N. fallacis*, spider mite densities peaked at 2.2 mites per leaf and were suppressed to 0.6 mites per leaf after 10 weeks. In contrast, spider mites increased to 4.68 mites per leaf in control plants but also decreased on week 10 to approximately 3 per leaf. Spider mites were generally located on the upper leaves of the plants, in contrast to the predators, which were evenly distributed throughout the plant. Damage to the foliage was minimal in all plants, irrespective of the treatment. Thrips and aphids were common on leaves and may have served as alternate food for *N. fallacis* as spider mite prey decreased. The application of pesticides to control these other pests may negatively affect biological control of spider mites. Ensuring that compatible pesticides are used in conjunction with *N. fallacis* is requisite for long term establishment of a biological control program.



Plant: *Sasaella hidaensis*

Date of Release: June 11th

Period of Assessment: 6/11-7-9

Sample Type: 10 leaves per plant

Variety: Murai

Planting: Container

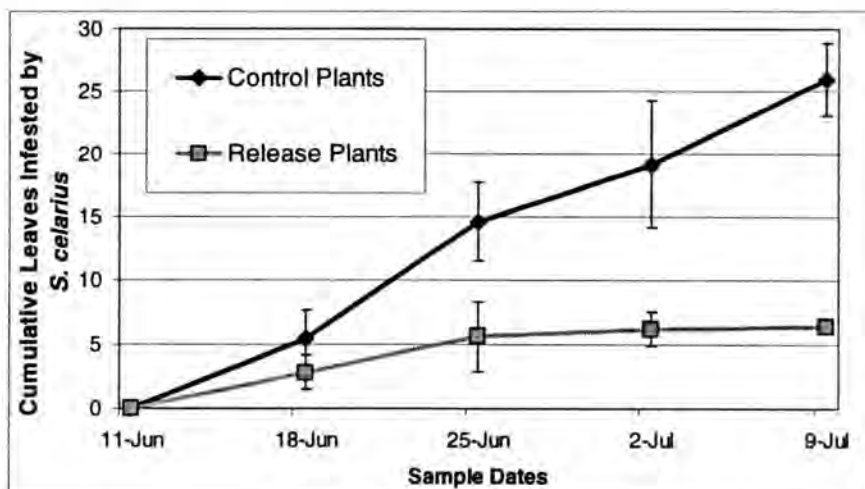
Predatory Mite: *N. fallacis*

Methods: The bamboo spider mite, *Schizotetranychus celarius*, is a major pest of bamboo grown in southern regions of the USA. Until recently, this spider mite has not infested ornamental bamboo in the Pacific Northwest. Recent inspection of bamboo revealed infestations of the bamboo spider mite in both nursery facilities and homeowner's properties. The spider mite causes stippling of the leaves in characteristic bands (see <http://www.ent.orst.edu/urban/Bamboo%20Spider%20Mite.html>). Chemical control of these spider mites is difficult due to the tightly woven webbed nest produced on the underside of leaves.

An alternative to chemical applications for spider mite control is the introduction of predatory mites into infested plant foliage. Predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) in order to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* has been used with success in many ornamental crops and has become the predominate predator released in the Pacific Northwest

The objective of this study was to measure the ability of *N. fallacis* to suppress the bamboo spider mites under normal nursery production conditions. To do this we randomly selected ten, 1 gallon *Sasaella hidaensis* plants from a production bed of an area nurseryman. These plants were spaced 2 feet apart and held in a shade house under normal irrigation systems. To ensure that all plants had similar levels of spider mite densities we inoculated each plant with approximately 50 bamboo mites. Plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the June 11th spider mite colonies averaged approximately 10 per leaf and 3 adult female predatory mites were added to half of the plants. Samples of 10 leaves from each plant were randomly removed from each plant weekly and a 40X microscope was used to identify all life stages of the predator and pest mites. A repeated measure ANOVA was used to compare the 2 treatments.

Results: The introduction of *N. fallacis* into the bamboo plants significantly reduced spider mite densities ($P < 0.01$). Four weeks after predator releases were made, control plants without predators had a 3-fold increase of new pest colonies. Colonization of new leaves ceased three weeks after the introduction of *N. fallacis* and spider mites were eliminated from these plants. These findings suggest that *N. fallacis* is capable of entering the nest and controlling the bamboo spider mite under these conditions. We predict that large scale releases of *N. fallacis* into spider mite infested bamboo plants would have similar results.



Plant: *Skimmia japonica*

Date of Release: July 2nd

Period of Assessment: 7/2-8/6

Sample Type: 5 leaves per plant

Variety: Female

Planting: 1 gallon containers

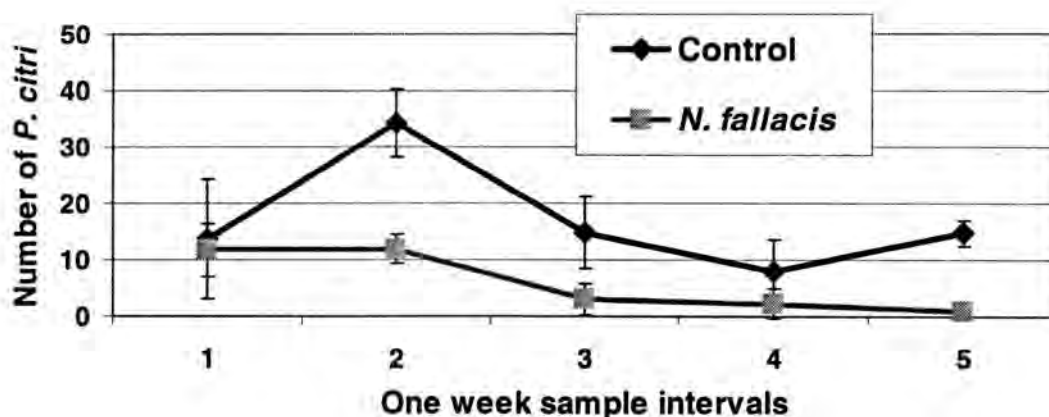
Predatory Mite: *N. fallacis*

Methods: *Skimmia japonica* is a common plant produced in most ornamental nurseries in the Willamette valley. Because of the intolerance to direct sunlight, many area growers produce *Skimmia japonica* in protected growing houses. Even in these protected facilities *Skimmia japonica* is consistently infested with spider mites of two types: the two spotted spider mite (*Tetranychus urticae*) or the citrus red mite (*Panonychus citri*). Occasionally we have found both mites coexisting of the same foliage. Growers treat both of these pests with pesticides to reduce populations and avoid aesthetic damage.

Neoseiulus fallacis, a predatory mite, has been effective at reducing populations of various spider mites in the Willamette valley (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). *N. fallacis* is a native predatory mite which suggests that it will overwinter in nursery systems if suitable hibernation sites are located and cultural practices are conducive. In addition, *N. fallacis* is commercially available in the Willamette valley. These characteristics suggest that *N. fallacis* is an ideal candidate for biological control of pest mites.

Ten 1 gallon *Skimmia japonica* 'Female' plants were supplied along with space in a production "can yard" by an area nurseryman. These plants were randomly assigned to one of two treatments: No release (control) or release of *N. fallacis*. On the July 2nd, spider mite populations had increased to approximately 12 mites per leaf and 10 adult female predatory mites were added to half of the plants. Samples of 5 leaves from each plant were removed from each plant weekly and a 40X microscope was used to identify all life stages of the predator and pest mites. A repeated measure ANOVA was used to compare the 2 treatments.

Results: Citrus red mite populations increased in control (no release) plots after at the second sample date but steadily decreased during the next two sample dates. In plants that were inoculated with *N. fallacis*, spider mite populations decreased and remained below damaging levels. *N. fallacis* did have a significant effect on the spider mite population ($P=0.0001$) although the reduction of spider mites in the control is somewhat confusing. One explanation may be a normal summer diapause in which the spider mites stop reproducing and ceases most activity. Summer diapause has not been described for this pest in the Oregon climates.



Plant: *Skimmia japonica*

Date of Release: June 23rd

Period of Assessment: 6/20-8/18

Sample Type: 15 leaves per treatment

Variety: Female

Planting: 2 gallon containers

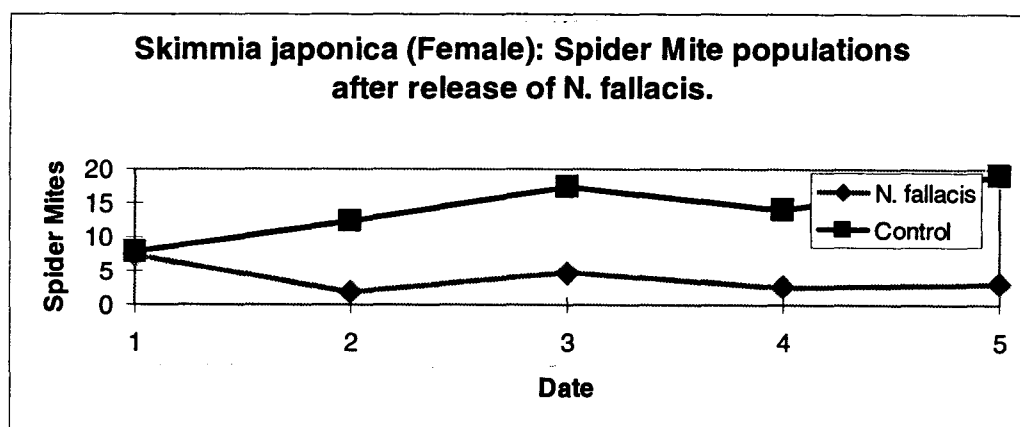
Predatory Mite: *N. fallacis*

Methods: *Skimmia japonica* is a very popular ornamental grown in Willamette valley nurseries. This plant is somewhat intolerant of direct sunshine during the mid summer months and for this reason *S. japonica* is grown in shaded houses. An area nurseryman requested our assistance in assessing the effectiveness of releasing predatory mites for control the two-spotted spider mite (TSSM) *Tetranychus urticae*. The grower had difficulty reducing spider mites in populations with miticides in the can tight shade houses. He was also interested in measuring the compatibility of Hexythiozox (Hexagon®) with predatory mites.

The predatory mite *N. fallacis* is effective at controlling spider mites in other agricultural commodities like hops, corn, strawberry, apple, and mint (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). *N. fallacis* is commercially available in the Willamette valley and is a native beneficial of Oregon. In addition, *N. fallacis* has been shown to be compatible with other pesticides in agricultural use (Pratt et al. 1998). Therefore, *N. fallacis* is an ideal candidate for biological control of spider mites in nursery crops.

To test if *N. fallacis* can control TSSM in the *S. japonica* system, 180 two gallon plants were blocked into 6 groups of 30 plants and randomly assigned 1 of 2 treatments: No release (control) or release of *N. fallacis*. Predatory mites were released into the center most plants (10 plants per rep) of three of the 6 replicate blocks. Samples were taken every two weeks. Samples consisted of randomly removing 15 leaves on the center most plants and counting mite densities under a 40X microscope. Treatments were compared using repeated measures ANOVA.

Results: Spider mite populations were relatively high at the beginning of the test and steadily increased in the control plants. The plants in the control showed visual damage from the spider mite densities after the 3rd sample date but no damage was evident in the plants which received *N. fallacis*. *N. fallacis* significantly reduced populations of spider mites on *S. japonica* as compared to control ($P=0.0001$). Apparently, *N. fallacis* continued to effectively feed and reproduce even though plants had been sprayed with hexthiozox 3 days prior. Therefore we suggest that residuals of hexythiozox is not highly toxic to *N. fallacis* and may be used in combinations with release of this mite (Appendix III).



Plant: *Spiraea bumalda*

Date of Release: July 7, 1996

Period of Assessment: 7/2-9/10

Sample Type: Leaves, 10 per replicate

Variety: Crispa

Planting: Field Grown

Predatory Mite: *N. californicus*, *N. fallacis*

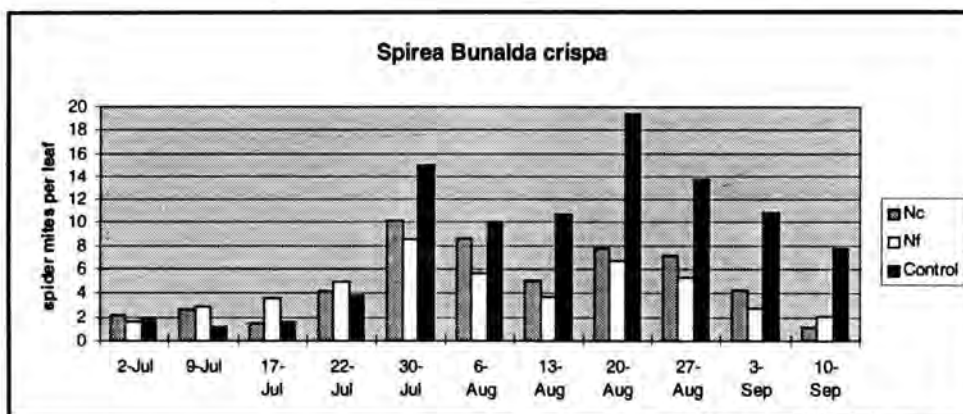
Methods: *Spiraea bumalda* is a common plant grown in Oregon nurseries and is susceptible to spider mite infestations (Marisela Vasquez, personal communication). The spider mite that has been observed on *Spiraea* of the Willamette Valley is *Tetranychus urticae* (two spot spider mite). This spider mite can cause damage to many ornamentals by damaging leaves and stunting growth (Krips et al. 1995, Marisela Vasquez, personal communication). Predatory mites have been effective at controlling spider mites in other crops that are planted in a similar way as *Spiraea* (i.e. strawberry, mint, beans).

Predatory mites are an alternative method to controlling spider mites of the Willamette Valley. Two predator mites that have been effective at controlling spider mites in culturally similar crops are *Neoseiulus fallacis* and *Neoseiulus californicus* (Strong and Croft, 1995; Coop and Croft, 1995; Hadam et al, 1986). These two predators are mass reared on the OSU campus as described by Strong and Croft (1995).

The test area was a single row of *Spiraea bumalda* Crispa approximately 35 meters in length. The plot was two years old and was irrigated by overhead sprinkler. Monitoring of the plot began in mid May and by June 7th a population of spider mites had infested the field. A randomized block design was used to organize the three treatments of *N. californicus* and *N. fallacis* and the control (no release). The treatments were replicated four times and a half meter border separated the replicates. Five adult female predators were released into the center most portion of the canopy of each release block and samples of the borders and replicates were taken every week to measure the spider mite and predator mite populations. Samples consisted of ten leaves per replicate, which were viewed under a microscope. The data derived from the samples were analyzed using a one way ANOVA and Fisher's LSD test to determine differences between treatments.

Results: *N. fallacis* and *N. californicus* were not significantly different from the control until July 30th when *N. fallacis* was lower than the control (p-value<0.05). This trend also occurred on August 6th where *N. fallacis* was significantly different from the control (p-value<0.05) but *N. californicus* was not. On August 13th both *N. californicus* and *N. fallacis* were significantly different from the control (p-value< 0.05).

The slow response of the predators in the early stages of the experiment may have been because of the cool temperatures and low overall numbers of prey. It is known that *N. californicus* disperses through a continuous plant system much quicker than *N. fallacis* and this may be the reason for the differences between the predators.



Plant: *Spiraea bumalda*

Date of Release: July 5

Period of Assessment: 7/5-8/3

Sample Type: 10 leaves per plant

Variety: Gold Mound

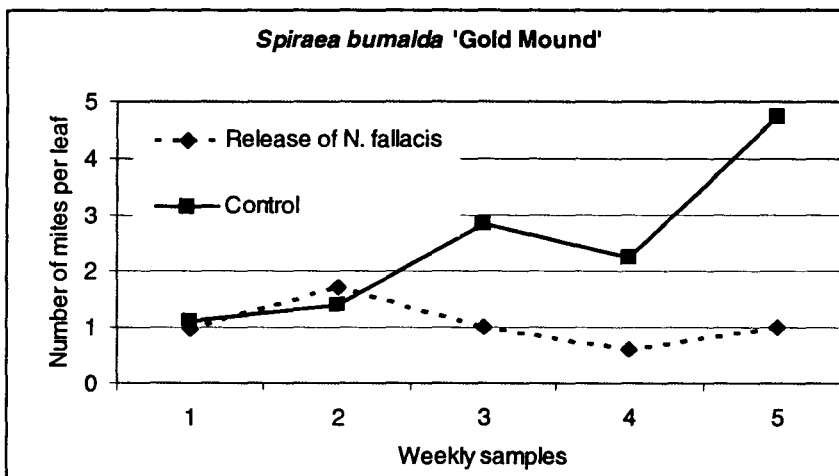
Planting: Container

Predatory Mite: *N. fallacis*

Methods: *Spiraea bumalda* is a common plant grown in Oregon nurseries and many varieties are susceptible to spider mite infestations (Marisela Vasquez, personal communication). The two spotted spider mite infests many varieties on a seasonal basis and can cause damage to leaves as well as stunt plant growth (Krips et al. 1995, Marisela Vasquez, personal communication). Predatory mites have been effective at controlling spider mites in other crops and limited tests suggest that *N. fallacis* is effective at controlling spider mites in the vertical growing *S. bumalda* 'Crispa'. In contrast, the variety 'Gold Mound' is a more globular, low growing plant and nurseryman have suggested that these canopies can be difficult to achieve complete coverage of miticides on the undersides of the leaves. Therefore, we questioned if *N. fallacis* would be an effective alternative for control of spider mites.

To test this we selected 10, one gallon *Spiraea bumalda* 'Gold Mound' plants from a "can yard" of an area nursery. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 28th of June, spider mite populations had increased to approximately 1.2 spider mites per leaf and three adult female predatory mites were added to half of the plants on July 5th. Samples of 10 leaves from each plant were randomly removed every week and a 40X microscope was used to identify predator and pest mites. Repeated measures ANOVA was used to compare the 2 treatments.

Results: The inoculation of *N. fallacis* significantly reduced the number of spider mites infesting the Gold Mound plants ($P < 0.01$). In plants receiving release of *N. fallacis*, spider mite densities peaked at 1.8 mites per leaf and were suppressed to 1 mite per leaf after 5 weeks. In contrast, spider mites increased to 4.8 mites per leaf in control plants. After reviewing the plants at week 5, the nursery manager concluded that the plants were marketable and did not need a "clean up spray". These findings suggest that *N. fallacis* can be an effective alternative to chemical controls in *Spiraea bumalda* 'Gold Mound' plants.



Plant: *Thuja occidentalis*
Date of Release: April 14th
Period of Assessment: 4/14-5/12
Sample Type: 4-inch terminal branch.

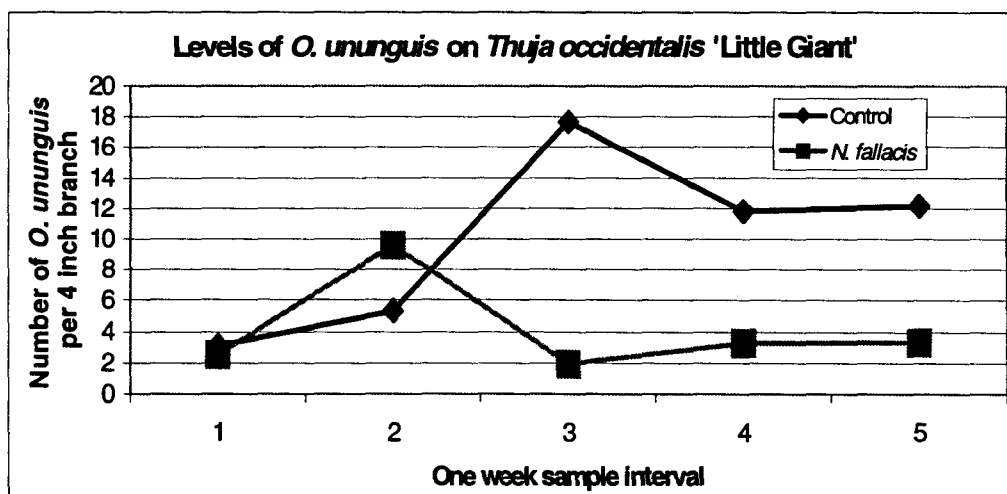
Variety: 'Little Giant'
Planting: 1 gallon container
Predatory Mite: *N. fallacis*

Methods: The spruce spider mite (*Oligonychus ununguis*) is considered the most damaging phytophagous mite in conifer systems (Boyne and Hain 1983, Furniss and Carolin 1977, Johnson and Lyon 1988, Calkin 1991). In many Willamette valley nurseries, *Thuja occidentalis* is routinely treated with miticides to reduce populations of the spruce spider mite (SSM). Populations of SSM increase during early spring and late fall, and may enter a summer diapause during the hottest months of the year (Regan 1990).

Neoseiulus fallacis (Garman), a predatory mite, has been effective in controlling spider mites in various agronomic crops of the Willamette valley (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). *N. fallacis* is predominately released in agricultural crops for control of two spotted spider mite (*Tetranychus urticae*) in the warm months of July and August.

To determine if *N. fallacis* is effective at reducing populations of SSM during the early season (cool temperatures: 45-60°F), 10 *T. occidentalis* 'Little Giant' plants were randomly selected from a nursery bed. Plant foliage was approximately 1 foot in height and 10 inches in diameter. Each plant had been pruned and was in a one-gallon container. On April 14th each plant was randomly assigned one of two treatments: *N. fallacis* or control (no release). The treatments were replicated five times and each plant was placed approximately 24 inches from other plants or any other structure. 5 adult female *N. fallacis* were added to the release plants and sampled once a week for five weeks. Samples consisted of removing 4 inches of foliage from both the lower 6 inches and upper 6 inches of each plant. We hoped that by sampling the plants in this method we could determine if SSM (and the predator) populations migrated to upper or lower regions of the plants. Each life stage of SSM and *N. fallacis* was identified under a microscope (40X). Treatments were compared with repeated measures ANOVA.

Results: After the first sample, it appeared that the release of *N. fallacis* had no effect on the population of SSM (see graph). The 4 later samples revealed that *N. fallacis* was indeed suppressing the population of SSM ($P=0.0034$). This data suggests that *N. fallacis* is effective at reducing the population of spruce spider mites under spring temperatures. In addition, SSM populations appeared to be more abundant on the top of the plant as compared to the bottom foliage ($p=0.0003$). Unfortunately, *N. fallacis* did not eliminate the population of SSM, which may suggest that some uncoupling of the predator-prey may occur at low prey densities and cool temperatures.



Plant: *Thuja occidentalis*

Variety: 'Little Giant'

Period of Assessment: 6/15-7/14

Sample Type: 4-inch terminal branch.

Date of Release: June 15th

Planting: 1 gallon container

Predatory Mite: *N. fallacis*

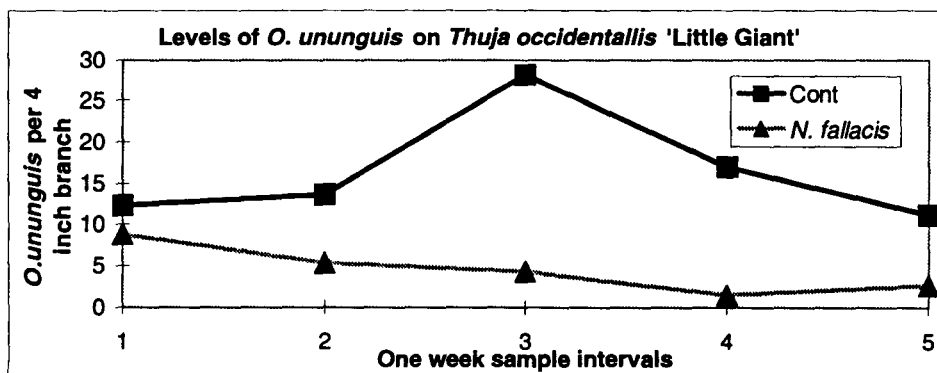
Methods: The spruce spider mite (*O. ununguis*) causes damage in conifers throughout the world and has been described as the most economically important mite in coniferous systems (Boyne and Hain 1983, Furniss and Carolin 1977, Johnson and Lyon 1988, Calkin 1991). Many Willamette Valley nurseries routinely spray varieties of *Thuja occidentalis* each year for control of the spruce spider mite (SSM). The common variety 'Little Giant' is one of the many cultivars that is highly susceptible to SSM.

Predatory mites have been used to suppress populations of spider mites in many agronomic crops of the Willamette valley, such as corn, mint, strawberry, hops, and fruit trees (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *Neoseiulus fallacis* (Garman) is an effective predator for these systems due to its ability to numerically respond to prey, overwintering capabilities, and commercial availability. Previous studies under cold, early season (45-60°F) temperatures showed that *N. fallacis* did suppress SSM but the predator never eliminated the pest population. We were interested in determining the effectiveness on *N. fallacis* at reducing the SSM in containerized nursery plants during warm, mid season temperatures (60-90°F).

10 *Thuja occidentalis* 'Little Giant' 1 gallon containerized plants (approx. 1 foot height and 10 inches in diam.) were randomly selected from an area nurserymen who identified the planting as having a history of high spider mite populations. Plants were monitored for 2 weeks until pest populations reached approximately 10 SSM per 4 inch branch. The 10 plants were randomly assigned one of two treatments: control (no release) or release of *N. fallacis*. Five adult female *N. fallacis* were inoculated to half of the plants on June 15th and foliage was sampled once a week for 5 weeks. Samples consisted of randomly removing a 4-inch terminal branch of both the lower and top portion of the plant as described before. All life stages of both predatory mites and SSM were identified on samples using a 40X microscope. Repeated measures ANOVA was used to compare treatments.

Results: Under warm conditions, *N. fallacis* significantly reduced the population of SSM as compared to the control ($P = 0.0001$). In the control, SSM increased to nearly 30 individuals per 4" stem and then decreased due to degradation of the plant material or in response to high temperatures (see graph). Again, *N. fallacis* did not eliminate the pest population during the 5-week test, although the numbers of pest mites were extremely low. Continued sampling of release plants showed that *N. fallacis* did eventually reduce the population of SSM to a level that could not be estimated by these sample methods. In addition, *N. fallacis* remained in the plant canopy for up to 2 months after this test.

This test suggests that *N. fallacis* is an effective predator of spruce spider mite and is compatible with the plant characteristics of *Thuja occidentalis* 'Little Giant'. This study does not suggest that *N. fallacis* will be as effective with all varieties of *Thuja occidentalis*, where humidity may differ from the globe shaped 'Little Giant'.



Plant: *Tilia cordata*

Date of Release: July 2, 1996

Period of Assessment: 7/2-10/3

Sample Type: Leaves, 3 per plant

Variety: Greenspire

Planting: Field Grown

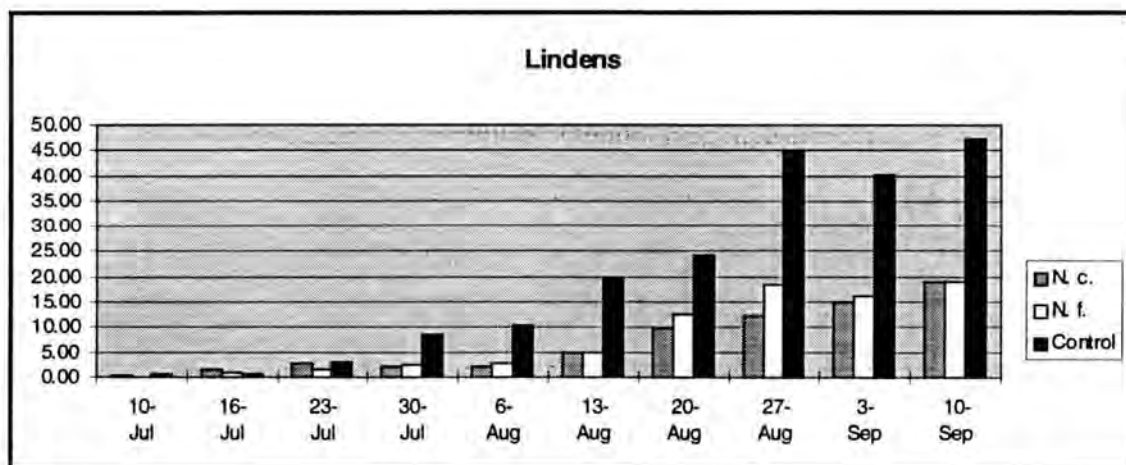
Predator Mites: *N. californicus*, *N. fallacis*

Methods: Linden shade tree saplings are susceptible to the two spot spider mite (Marisela Vasquez, personal communication). The variety Greenspire is very susceptible and often receives chemical control of the pest to prevent damage to the terminal growth.

The experimental site consisted of 150, one year old Lindens. Monitoring began in May and continued until July 2nd, when two spot spider mite (*Tetranychus urticae*) began to colonize the trees. The experimental design was a randomized block design with three treatments (*N. californicus* and *N. fallacis* and no release), replicated five times. Two adult females were released on the treatment plants and monitored every week. Sampling was performed by viewing three leaves on each tree with magnification lenses. The data derived from sampling were analyzed using one way ANOVA and Fisher's LSD test to determine differences between treatments.

Predator mites were mass reared on OSU campus under green house conditions similar to those of Strong and Croft (1995). Predatory mites are reared on two spot spider mites that have infested bean plants. When the predatory mites have eliminated the spider mites on the bean plant the predators are released into the field.

Results: *N. californicus* and *N. fallacis* consistently had lower populations of spider mites than the control ($p\text{-value} < 0.05$) during the last three sample dates (see figure below) but the populations in the release plots were not significantly different from each other. Movement of predators into the controls was first noticed in the August 6th sample and did not control the spider mites in the no release plots (control).



Plant: *Viburnum opulus*

Date of Release: July 3, 1996

Period of Assessment: 4/17-7/2

Sample Type: Leaves, 5 per plant

Variety: Sterile

Planting: Container

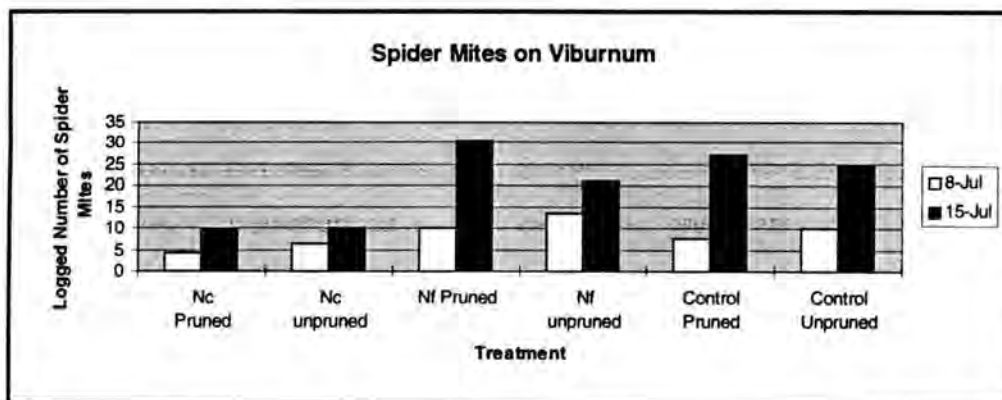
Predatory Mites: *N. californicus* and *N. fallacis*

Methods: One of the common plants grown in Oregon nurseries are Viburnums and in some locations this plant is infested with spider mites on a yearly basis (Ron Lapotin, Marisela Vasquez, personal communication). We have observed high levels of spider mite damage in field grown and container grown plants yet very little information is known about the potential for biological control in these systems.

Neoseiulus fallacis has been observed overwintering in Viburnum (Rosetta, unpublished data) but its effectiveness to control spider mites has not been studied. *N. californicus* is very effective in dry conditions which may be similar in container grown plants. *N. californicus* and *N. fallacis* were chosen for these reasons and their ability to reduce populations of spider mites. Both of these predatory mites are mass reared on the OSU campus under conditions similar to those explained by Strong and Croft (1995).

The test area consisted of 48 one gallon *Viburnum* plants. The containers were arranged in a random block design with four replicates of three treatments (*N. californicus*, *N. fallacis*, and no release). The average number of spider mites at the beginning of the experiment was 5 per leaf, which is higher than optimal for this system. Five predatory mites were released per replicate. Five leaves were removed from each replicate every week to determine the amount of predators and spider mites in the treatments. The data acquired from the samples were analyzed using one way ANOVA and Fisher's LSD to find differences between treatments. Consistent with normal cultural practices, we pruned half of the replicates on July 3.

Results: The data from the first sample on July 8th suggests a trend that *N. californicus* is slightly more effective at controlling the pest than *N. fallacis* and the control (See graph below). One week later the trend continued with *N. californicus* being statistically different (p-value < 0.01) than the pruned and unpruned *N. fallacis* and the controls. The differences between the pruned and unpruned *N. californicus* treatments are not different but it appears that *N. californicus* may be more effective on pruned plants. After the second sample the spider mites were reaching damaging numbers in the controls and *N. fallacis* treatments so the plot was sprayed with a miticide. It is believed that earlier detection of spider mites and release of predators may have avoided a high infestation.



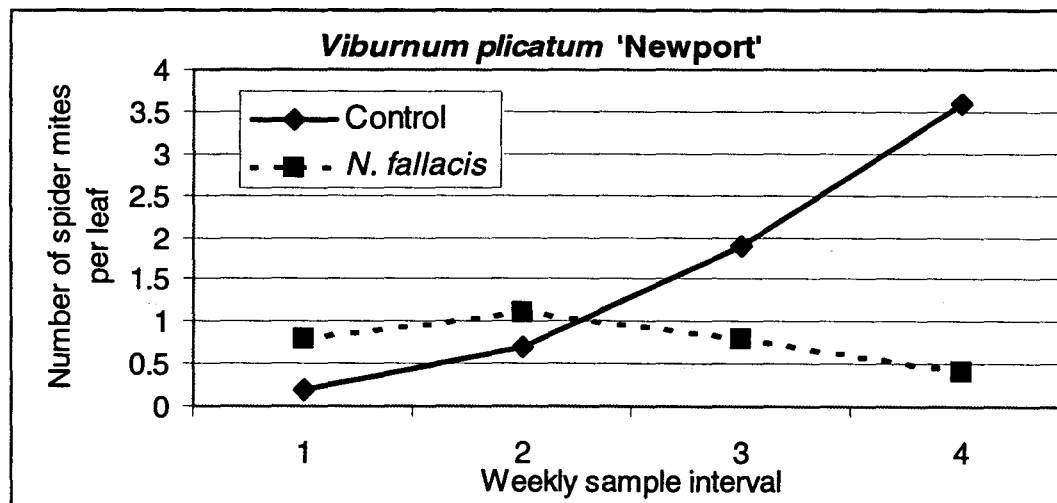
Plant: *Viburnum plicatum*
Date of Release: June 15th
Period of Assessment: 6/15-7/18
Sample Type: 5 leaves per block

Variety: Newport
Planting: Field
Predatory Mite: *N. fallacis*

Methods: Spider mites are major pests of ornamental shrubs. For instance, *Viburnum* plants are very susceptible to spider mites and ornamental producers rely on routine miticides to control these pests. Continued reliance on miticides may be limited when considering recent governmental restrictions on many products currently used in these systems. An alternative to the use of pesticides for the suppression of spider mites is the introduction of predatory mites. Predatory mites have been released in many agronomic crops of the Willamette Valley (i.e.: corn, mint, strawberry, hops, and fruit trees) to reduce spider mites populations (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *Neoseiulus fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. *N. fallacis* has become the predominate predator released for control of various spider mite out breaks in the Willamette Valley.

We questioned if *N. fallacis* would be an acceptable alternative to the use of miticides for control of spider mites in *Viburnum plicatum* 'Newport'. To test this we selected a single row of contiguous field grown plants from an area nursery. The plants were 2 yrs old and were irrigated with overhead sprinklers. Spider mite densities on these plants were monitored weekly and on June 10th spider mite densities reached approximately 0.5 mites per leaf. The row was randomly divided into blocks of 3 feet in length and three adult female predatory mites were added to alternating blocks on June 15th. Five leaves were removed from each block every 7 days and comparisons of blocks receiving predators from the non treated (controls) was made with repeated measures ANOVA.

Results: Spider mite densities were not significantly different among the treatments the first two weeks after release of the predator. On week three, spider mites were lower in release plots than control plots and this trend continued until the end of the test. Spider mites peaked in the control at 3.6 mites per leaf but never exceeded 1.1 mite per leaf in the release plots. These findings suggest that *N. fallacis* can be an effective control agent of spider mites in field grown *Viburnum plicatum* 'Newport' ornamentals. These findings are consistent with other reports that suggest that *N. fallacis* will suppress spider mites in various varieties of *Viburnum* and possibly overwinter in these plants (Rossetta, personal communication). Although predators did disperse to control plots, a miticide was used to eliminate all spider mites from control blocks prior to marketing.



Plant: *Weigela florida*
Date of Release: July 2nd
Period of Assessment: 7/2-8/6
Sample Type: 5 leaves per plant

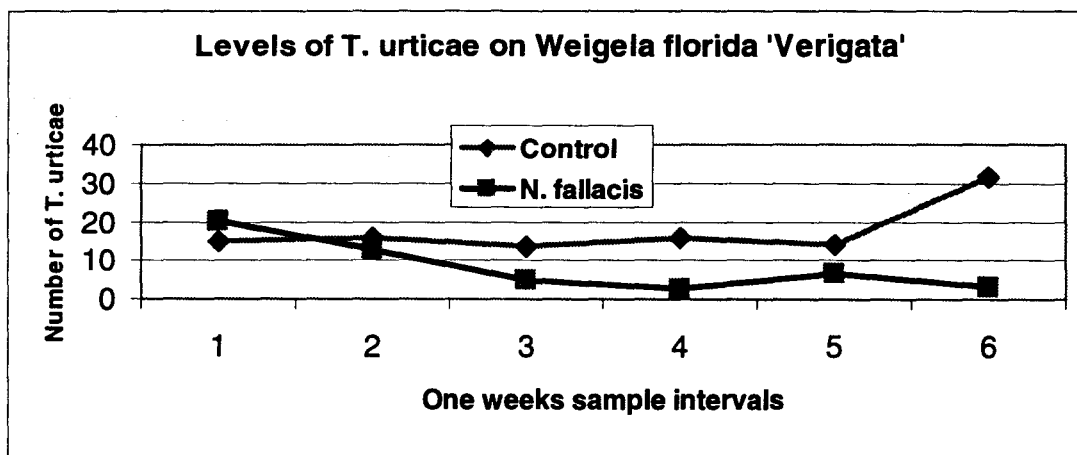
Variety: Verigata
Planting: 1 gallon containers
Predatory Mite: *N. fallacis*

Methods: *Weigela florida* is a commonly grown nursery plant in the Willamette valley. Of the nine varieties of *Weigela* grown by area nurserymen, 'Verigata' appears to be the most susceptible to the two spotted spider mite (*Tetranychus urticae*). Spider mites may be attracted to the cup shaped leaves, which become covered with webbing as populations increase. Although these plants do tolerate high levels of pest mites, spider mite damage causes bronzing of the leaves and eventual leaf drop if not controlled. Area nurserymen typically spray 'Verigata' with pesticides 1-3 times during each growing season for spider mite control (Ron Tuckett, personal communication).

Predatory mites have been released to reduce spider mites populations in many agronomic crops of the Willamette valley, such as corn, mint, strawberry, hops, and fruit trees (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *Neoseiulus fallacis* (Garman) has been used with a great deal of success and has become the predominate predator released for control of various spider mite out breaks. In addition, naturally occurring populations of *N. fallacis* were found in 'Verigata' plants infested with two-spotted spider mite (TSSM) both 1996 and 1997. The naturally occurring predators did not circumvent foliar damage, possibly due to late arrival of the predator.

To determine if *N. fallacis* is an effective predator of TSSM in 'Verigata' an area nurseryman provided space in a production "can yard" and supplied ten 1 gallon plants. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 25th of June, spider mite populations had increased to approximately 15 spider mites per leaf and 5 adult female predatory mites were added to half of the plants. Samples of 5 leaves from each plant were randomly removed from each plant weekly and a 40X microscope was used to identify all life stages of the predator and pest mites. A repeated measure ANOVA was used to compare the 2 treatments.

Results: *N. fallacis* significantly reduced the population of spider mites as compared to the control ($P=0.0001$). The spider mite densities in the control (no release) plants remained nearly constant at 15 TSSM per leaf until near the end of the test when the population increased to over 30 individuals per leaf. In the plants where *N. fallacis* was released, TSSM populations were reduced to non-damaging levels. *N. fallacis* reached surprisingly high densities during this test which may suggest that the leaf type (cupped) is an ideal habitat for this predator. From these data we suggest that *N. fallacis* is an effective predator of two spotted spider mites on *Weigela florida* 'Verigata'.



Plant: *Weigela florida*

Date of Release: June 26th

Period of Assessment: 6/26-8/6

Sample Type: 5 leaves per plant

Variety: Verigata

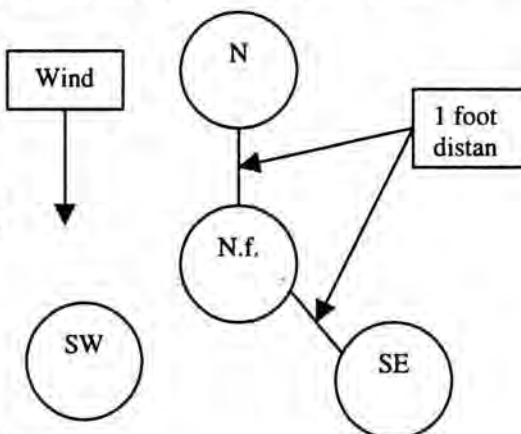
Planting: 1 gallon containers

Predatory Mite: *N. fallacis*

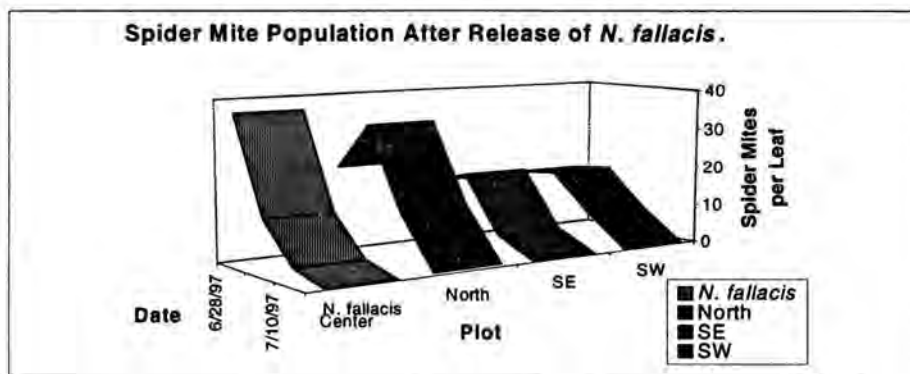
Methods: For many area nurserymen *Weigela florida* 'Verigata' is a new addition to their nursery system. Vertigated *Weigela* appears to be more susceptible to the two spotted spider mite (*Tetranychus urticae* Koch) than other varieties. Spider mites may be attracted to the cup shaped leaves, which become covered with webbing as populations increase. We have mentioned previously that the predatory mite *N. fallacis* can be effective at controlling spider mites in this plant.

We wanted to determine how effective *N. fallacis* was at dispersing between plants in a can yard production system. To test this, we acquired 12, 1 gallon plants from an area nurseryman. We arranged the plants so that one plant was in the center and one plant was placed one foot North, South East, and South West from the center plant. This arrangement allowed us to "catch" the predators as they dispersed from the center plant (see figure at left). This design was replicated four times and all plants were held under normal nursery conditions.

On the 26th of June, spider mite populations had increased to approximately 30 spider mites per leaf and 5 adult female predatory mites were added to the center plants. Samples of 5 leaves from each plant were randomly removed weekly and a 40X microscope was used to identify predator and pest mites.



Results: *N. fallacis* readily dispersed North, Southeast, and Southwest (see graph). This suggests that the predominate wind direction (North to South) did not cause unidirectional dispersal. Spider mites were controlled below aesthetic injury levels in all directions. The graph below shows that after four weeks spider mites on all plants were completely eliminated from the system. This test further suggests that *N. fallacis* is well adapted to dispersing in can yard settings.



Plant: *Weigela florida*
Date of Release: June 26th
Period of Assessment: 6/26-8/6
Sample Type: 5 leaves per plant

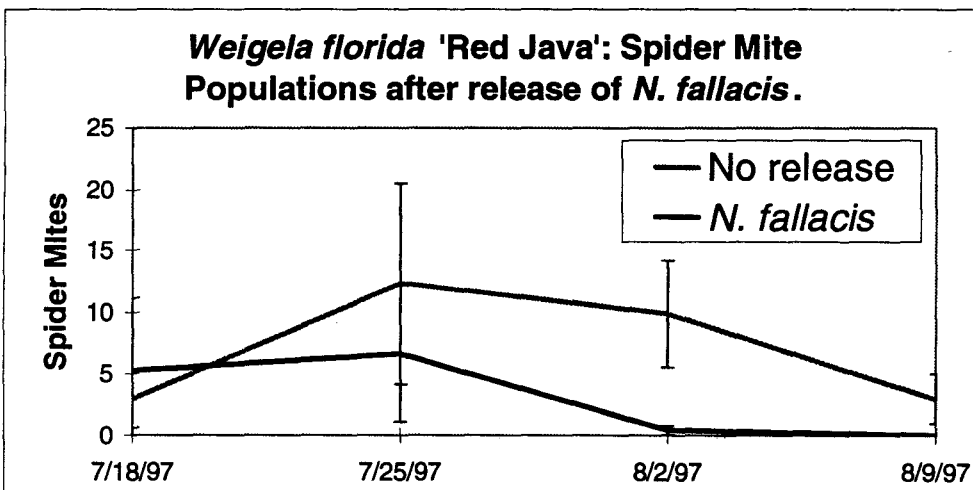
Variety: Red Java
Planting: 1 gallon containers
Predatory Mite: *N. fallacis*

Methods: *Weigela florida* is commonly grown nursery plant in the Willamette valley. Red Java, while not as susceptible as other varieties, does get sprayed with pesticides to reduce populations of the two spotted spider mite (*Tetranychus urticae* Koch). Spider mite damage causes bronzing of the leaves, eventual leaf drop, and inoculates other plants if not controlled. Area nurserymen typically spray 'Red Java' on a yearly basis (Ben Noid, personal communication).

Predatory mites have been released to reduce spider mites populations in many agronomic crops of the Willamette valley, such as corn, mint, strawberry, hops, and fruit trees (Coop and Croft 1995, Strong and Croft 1995, Morris et al. 1996, Hadem et al. 1986). The predatory mite *N. fallacis* is locally mass produced and may overwinter in nurseries or near by landscapes. The predatory mite *Neoseiulus fallacis* has been used with a great deal of success and has become the predominate predator released for control of various spider mite out breaks.

To determine if *N. fallacis* is an effective predator of Two spotted spider mite (TSSM) in 'Red Java' we selected 10, one gallon plants which were maintained in the "can yard" of the nursery. These plants were randomly assigned one of two treatments: No release (control) or release of *N. fallacis*. On the 26th of June, spider mite populations had increased to approximately 5 spider mites per leaf and 5 adult female predatory mites were added to half of the plants. Samples of 5 leaves from each plant were randomly removed from each plant weekly and a 40X microscope was used to identify predator and pest mites. Repeated measures ANOVA was used to compare the 2 treatments.

Results: *N. fallacis* significantly reduced the population of spider mites as compared to the control ($P=0.08$). TSSM increased in the control plants but began to decline after week three. The reason for this natural reduction in pest is unknown but it may have been in response to irrigation or dispersal of the spider mite. In the plants where *N. fallacis* was released, TSSM populations were reduced to non-damaging levels by week 3 and none were found in the samples taken on week 4. These results suggest that *N. fallacis* is an effective predator of spider mites in the 'Red Java' *Weigela* system.



Appendix III. Toxicity of Pesticides Registered for use in Ornamental Nurseries to the Biological Control Agent *N. fallacis*

Introduction

Spider mites (Tetranychidae) are major pests of ornamental plants. Although pesticides are the most common method of suppressing spider mites, biological control programs are currently under development (Cashion et al. 1994, herein). The predominate agent selected for biological control of spider mites are predatory mites in the family Phytoseiidae (Helle and Sabelis 1985, McMurtry and Croft 1997). Preliminary tests suggest that inoculative releases of the predatory mite *Neoseiulus fallacis* (Garman) can adequately reduce spider mite populations in Pacific Northwest ornamentals, rendering miticide applications unnecessary (Pratt and Croft 1998, Pratt and Croft 1999).

One major obstacle that impedes integration of predatory mites into nursery control practices is the use of disruptive pesticides (herbicides, fungicides, insecticides, and miticides). Pesticides cause a range of direct and indirect effects on phytoseiid mites, often resulting in resurgence or secondary outbreaks of the pest (Croft 1990, Ruberson et al. 1998). Current export regulations in some growing regions mandate pesticide use to reduce potential pest invasions (i.e. ORS 571.200). Ruberson et al. (1998) suggested the use of selective pesticides is the most effective method of integrating biological control agents into control programs. Therefore, we sought to evaluate selectivity of pesticides registered for use in nurseries to *N. fallacis*. We gathered pesticide selectivity information from the SELCTV database and recent literature. From this information we measured the general toxicity of pesticide classes (organophosphates, pyrethroids, etc.) to *N. fallacis* and developed a summary table of pesticide selectivity to *N. fallacis*.

Materials and Methods

Selectivity of general classes of pesticides to *N. fallacis*. Extensive pesticide toxicity data exists for natural enemies on SELCTV database housed in the Department of Entomology at Oregon State University (OSU) (Theiling and Croft 1988). To measure toxicity of major chemical classes we searched the SELCTV database for all entries containing *N. (=Amblyseius) fallacis*. Within this criteria 3 strains had been entered (total entries 531): resistant, tolerant and susceptible. Resistant strains refer to populations of *N. fallacis* that have developed resistance to organophosphate agrochemicals (Croft 1990). For purposes of this study we used only resistant and susceptible stains for evaluation. We identified chemical classes that contained 4 or more data entries and measured percent effect (usually mortality) for a single strain. We also included the alternative strain in the analysis regardless of the number of tests preformed. From these data we calculated a mean toxicity rating (with standard deviation) across all entries within the chemical class (Toxicity rating: 1=0% effect, 2< 10%, 3<10 to 30%, 4<30 to 90%, 5> 90%; see Theiling and Croft 1988). We performed this analysis for both the resistant and susceptible strains.

To determine relative susceptibility of the resistant strain of *N. fallacis* to agricultural chemicals as compared to other phytoseiid mites, we followed the same procedure as described above for *Typhlodromus pyri* Scheuten, *Galendromus occidentalis* Nesbitt, and *Phytoseiulus persimilis* A. H.. We narrowed our analysis to the commonly tested chemical classes: carbamate, organochlorine, organophosphate, organotin and pyrethroid.

Caution should be taken when interpreting toxicity of chemical classes in these analyses. The SELCTV database does not include the majority of toxicity testing performed after 1986, thereby incorporating a bias for older testing methods, active ingredients and formulations. Toxicity ratings are derived from different testing methods, treated substrates and routes of exposure, thereby increasing variability among “worst case” and “real world” scenarios (Murphy et al. 1994).

Averaging of toxicity values may also compound potential errors that occur in the SELCTV database. Finally, averaging over different testing methods and active ingredients assumes that all methods and ingredients are equally represented, which we acknowledge that they are not. To determine if the variability of test methods affected average toxicity rating for pooled strains of *N. fallacis* we compared the dip, field and residual test methods for organophosphate, carbamate and organochlorine chemical classes (Croft 1990). Statistical comparisons were performed with the general linear model (Ramsey and Schafer 1997).

Development of the Selectivity Table. A list of pesticides (active ingredients) registered for use on ornamentals in Oregon was obtained from extension publications at OSU (Fisher et al. 1998, William et al. 1998, Pscheidt et al. 1998). First, the SELCTV database (containing only resistant and susceptible strains) was filtered using the list of Oregon registered products. Second, we calculated the average toxicity (with SD) for both strains and all active ingredients that contained: 1) three or more entries, 2) the same formulation, 3) the same rate applied to *N. fallacis* and 4) measured % effect. Again, we included the alternate strain irrespective of the number of entries. We also reviewed recent literature that was not entered into the SELCTV database (post-1986) and calculated an average toxicity rating (with SD) with the same criteria as above. Finally, we averaged all toxicity ratings from the SELCTV database and recent literature to produce a summary toxicity rating.

As described above, caution should be taken when interpreting the averaged toxicity rating summary. These summary values are used to estimate the toxicity of pesticides to *N. fallacis* but may not be appropriate under all environmental conditions. Extrapolation from these data to field systems ignores direct and indirect effects mitigated by ecological (life history) and toxicological (exposure) parameters.

Results and Discussion

Selectivity of general classes of pesticides to *N. fallacis*. Average toxicity ratings for susceptible and resistant strains of *N. fallacis* ranged from < 10% effect (i.e. organosulfur) to > 90% effect (i.e. oxime carbamate) (Table 10). Surprisingly, the resistant and susceptible strains are striking different in their toxicity to benzimidazole (Table 10). The rationale for higher toxicity in the susceptible strain may be due to cross-resistance or variability in the tests preformed (as is apparent in the SD). Surprisingly, toxicity of organophosphates to the resistant strain had a value only slightly lower than that of the susceptible. Again, the reasoning for this lack of difference may be due to

Table 10. Toxicity of general chemical classes to resistant and susceptible strains of *N. fallacis*.

STRAIN ^a	CHEMICAL CLASS	N ^b	AVE. TOX. ^c	SD ^d
Resistant	organosulfur	3	1.43	0.53
Susceptible	organosulfur	4	1.75	0.96
Resistant	benzimidazole	4	2.20	0.79
Resistant	organotin	3	2.20	0.94
Susceptible	organotin	12	2.42	1.24
Resistant	N-trihalomethylthio	1	2.57	1.40
Susceptible	N-trihalomethylthio	4	3.00	1.83
Resistant	organochlorine	2	3.00	1.15
Susceptible	organochlorine	23	3.17	1.23
Resistant	organophosphate	38	3.46	1.27
Susceptible	organophosphate	112	3.75	1.40
Susceptible	carbamate	17	3.88	1.22
Susceptible	benzimidazole	9	4.22	1.30
Resistant	pyrethroid	11	4.39	0.72
Susceptible	pyrethroid	30	4.40	0.67
Resistant	carbamate	7	4.50	0.76
Resistant	oxime carbamate	2	4.75	0.50
Susceptible	oxime carbamate	9	4.78	0.44

^a: Strains of *N. fallacis* categorized as resistant or susceptible to organophosphates.

^b: Number of tests reported in SELCTV database.

^c: Average toxicity, see text for rating system.

^d: Standard deviation

Table 11. Relative susceptibility of phytoseiid predators to agrochemicals.

	<i>Typhlodromus pyri</i>			<i>Galendromus occidentalis</i>			<i>Phytoseiulus persimilis</i>			<i>Neoseiulus fallacis</i>		
Chemical Class	N ^a	Ave. Tox. ^b	SD ^c	N	Ave. Tox.	SD	N	Ave. Tox.	SD	N	Ave. Tox.	SD
carbamate	25	2.92	1.32	16	4.00	1.31	19	2.84	1.26	7	4.50	0.76
organochlorine	18	3.06	1.21	5	4.33	0.52	22	3.26	1.29	2	3.00	1.15
organophosphate	73	3.70	1.28	56	3.26	1.20	65	4.12	1.14	38	3.46	1.27
organotin	14	3.00	0.88	3	3.00	1.73	11	3.64	1.03	3	2.20	0.94
pyrethroid	18	4.67	0.69	32	4.27	0.72	20	3.72	1.49	11	4.39	0.72
Grand Mean		3.47			3.77			3.52			3.51	

^a: Number of tests reported in SELCTV database.

^b: Average Toxicity, see text for rating system.

^c: Standard Deviation.

Table 12. Comparison of toxicity values among testing methods for three chemical classes to *N. fallacis*.

Chemical Class	Dip ^a (N)	Field ^b (N)	Residue ^c (N)	F- Value	df	P- Value
Organophosphate	3.81 (57)	3.88 (16)	3.53 (30)	0.48	2,100	0.62
Carbamate	4.4 (5)	4.75 (4)	3.29 (7)	3.22	2,13	0.07
Organochlorine	2.65 (8)	4.0 (6)	3.0 (8)	2.47	2,19	0.11

^a: Slide dip method

^b: Product application and evaluation under field conditions

^c: Effect of residue (48 hrs).

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variability of testing or inappropriate classification of susceptible strains that are actually resistant. Croft (1990) described the difficulty of encountering susceptible strains of *N. fallacis* in agroecosystems and mis-classification of tested predators.

When comparing pesticide susceptibility of *N. fallacis* to that of other phytoseiids no differences were found ($P > 0.05$; Table 11). These findings suggest that *N. fallacis* exhibits similar levels of susceptibility as other phytoseiid biological control agents and common conservation strategies may be used within agroecosystems.

Comparing toxicity ratings (% effect) among testing methods for three chemical classes showed no differences within the compounds examined ($P > 0.05$; Table 12). This result is surprising when considering that laboratory tests are often described as more toxic than field oriented testing (Murphy et al. 1994). One explanation for this result may be the variability in the testing precision or the variable toxicity of active ingredients within a chemical class, which in this analysis were assumed to be homogeneous.

Development of the Selectivity Table. Summary toxicity ratings for insecticides and miticides registered for use in Oregon ornamental nurseries range from non-toxic to highly toxic active ingredients (Table 13). The average toxicity rating among all active ingredients in Table 13 is 3.67 (SD=1.19; N=33). Among the least toxic to *N. fallacis* includes two recently registered products for ornamental use: hexythiazox and spinosad. Hexythiazox has been used extensively in the fruit industry and as a spider mite ovicide it may be very useful in IPM strategies. Spinosad is a fungal metabolite and is typically used for control of coleopteran and lepidopteran pests. Use of spinosad for root weevil control (*Otiorhynchus* spp.) may improve conservation of *N. fallacis* in ornamental systems. In addition, acephate and lindane appear to be only mildly toxic to *N. fallacis* and may be candidates for IPM strategies. Consistent with field observations, carbaryl, carbofuran, chlorpyrifos, and permethrin are highly toxic to *N. fallacis* and should not be used in conjunction with

releases of the predatory mite. As previously stated, these values should be used as coarse estimates that indicate selectivity in general.

Table 13. Toxicity ratings for insecticide and miticide active ingredients registered for use in ornamental nurseries of Oregon.

INSECTICIDES AND MITICIDES				SELCTV ^b DATA BASE		CURRENT TESTS ^e	
Active Ingredient	Trade Name	Chemical Class	Strain ^a	Ave. Tox. Rating ^c (N)	SD ^d	Ave. Tox. Rating (N)	Summary Tox. Rating ^f
abamectin	Avid	acyclic lactone	R	4.0 (1)			4.0
acephate	Orthene	organophosphate	R	1.0 (1)		4.0 (1)	2.5
			S	5.0 (1)			5.0
azinphos-methyl	Guthion	organophosphate	R	2.6 (14)	1.3	3.0 (1)	2.7
			S	3.1 (27)	1.5		3.1
bifenthrin	Talstar	pyrethroid	R			5.0 (1)	5.0
carbaryl	Sevin	carbamate	R	4.8 (5)	0.4		4.8
			S	4.3 (11)	0.8		4.3
carbofuran	Furadan	carbamate	R	5.0 (2)	0.0	5.0 (1)	5.0
			S	5.0 (1)			5.0
chlorpyrifos	Dursban (Lorsban)	organophosphate	R			5.0 (2)	5.0
			S	5.0 (1)		5.0 (1)	5.0
diazinon	Diazinon	organophosphate	R	3.0 (18)		5.0 (1)	3.2
			S	4.0 (8)	0.8		4.0
dicofol	Kelthane	organotin	R			5.0 (2)	5.0
			S	3.0 (9)	1.3	5.0 (1)	3.4
dimethoate	Dimethoate	organophosphate	R	4.0 (2)	1.4		4.0
dimethoate	Dimethoate	organophosphate	S	4.7 (6)	0.8		4.7
endosulfan	Endosulfan (Thiodan)	organosulfur	R			4.0 (2)	4.0
			S	2.9 (9)	1.1	5.0 (1)	3.4
fenbutatin oxide	Vendex	organotin	R			2.0 (1)	2.0
hexythiazox	Hexygon	organosulfur	R			2.0 (1)	2.0
lindane	Lindane	organochlorine	S	2.0 (1)			2.0
oxydemeton-methyl	Metasystox-R	organophosphate	R			5.0 (1)	5.0
oxythioquinox	Joust (Morestan)	organosulfur	S	3.7 (3)	0.6		3.6
Mineral oil			R	4.0 (2)	0.0		4.0
permethrin	Ambush (Pounce)	pyrethroid	R	4.5 (6)	0.8		4.5
			S	4.5 (11)	0.8		4.5
phosmet	Imidan		R	3.0 (3)	1.7		3.0
			S	2.6 (15)	1.5		2.6
propargite	Omite (Ornamite)	organosulfur	R	1.0 (3)	0.0	1.0 (1)	1.0
			S	1.8 (4)	1.0		1.8
spinosad	Conserve	fungal metabolite	R			2.0 (1)	2.0

^a: R= resistant, S= susceptible to organophosphate insecticides.

^b: Database containing toxicity data of agrochemicals to beneficial organisms.

^c: Average toxicity value calculated from reports (N) in SELCTV, see text for rating system.

^d: Standard Deviation.

^e: Toxicity data gathered from recent literature (post-1986).

^f: Average of all selective and current toxicity ratings.

Table 14. Selectivity of fungicides to the biological control agent *N. fallacis*.

FUNGICIDES			SELCTV DATA BASE ^b		CURRENT ^e TESTS		
Active Ingredient	Trade Name	Strain ^a	Ave. Tox. Rating ^c (N)	SD ^d	Ave. Tox. Rating (N)	SD	Summary ^f Tox. Rating
captan	Captan	S	3.0 (4)	1.83			3.0
		R	1.0 (1)	0.0	2.0 (1)	0.0	1.5
dodine	Cyprex	S	2.3 (6)	1.03			2.3
fosetyl-aluminum	Aliette	R			2.0 (1)	0.0	2.0
iprodione	Rovral	R			2.0 (1)	0.0	2.0
metalaxyl	Subdue	R			5.0 (1)	0.0	5.0
myclobutanil	Rally	R			2.0 (1)	0.0	2.0
propiconazole	Tilt	R			1.0 (1)	0.0	1.0
sulfur	Kolo-100/Wetable S	S	3.0 (1)	0.0			3.0
		R			1.0 (1)	0.0	1.0

^a: R= resistant, S= susceptible to organophosphate insecticides.

^b: Database containing toxicity data of agrochemicals to beneficial organisms.

^c: Average toxicity value calculated from reports (N) in SELCTV, see text for rating system.

^d: Standard Deviation.

^e: Toxicity data gathered from recent literature (post-1986).

^f: Average of all selective and current toxicity ratings.

Table 15. Selectivity of herbicides to *N. fallacis*.

HERBICIDES			SELCTV DATA BASE ^b		CURRENT ^e TESTS		
Active Ingredient	Trade Name	Strain ^a	Ave. Tox. Rating ^c (N)	SD ^d	Ave. Tox. Rating (N)	SD	Summary ^f Tox. Rating
bentazon	Basagran	R			1.0 (1)	0.0	1.0
fluazifop	Fulislade	R			3.0 (1)	0.0	3.0
gramaxone	Paraquat/Cyclone	R			5.0 (1)	0.0	5.0
napropamide	Devrinol	R			2.0 (1)	0.0	2.0
oxyfluoren	Goal	R			3.5 (2)	0.7	3.5
pendimethylin	Prowl	R			5.0 (1)	0.0	5.0
sethoxydim	Poast	R			3.0 (2)	0.0	3.0
simazine	Simazine	R	2.0(1)	0.0	2.0 (1)	0.0	2.0

^a: R= resistant, S= susceptible to organophosphate insecticides.

^b: Database containing toxicity data of agrochemicals to beneficial organisms.

^c: Average toxicity value calculated from reports (N) in SELCTV, see text for rating system.

^d: Standard Deviation.

^e: Toxicity data gathered from recent literature (post-1986).

^f: Average of all selective and current toxicity ratings.

The average toxicity rating among all fungicides was 2.28 (SD= 1.18; N=10), significantly lower than that of insecticides and miticides ($P<0.05$, Table 14). The systemic fungicide propiconazole had the lowest toxicity rating, followed by sulfur and captan when tested on resistant strains of *N. fallacis*. In contrast, metalaxyl (Subdue®) had the highest toxicity to *N. fallacis*.

The overall toxicity ratings of herbicides in Table 15 was 3.06 (SD=1.43; N=8), intermediate to the other pesticide types ($P>0.05$). The least toxic herbicide to *N. fallacis* was bentazon, followed by the moderately toxic napropamide and simazine. Use of these products may aid in conservation of *N. fallacis* in nursery systems. In contrast, data for gramoxone and pendimethylin suggest that these herbicides are highly toxic to *N. fallacis*.

The probability that *N. fallacis* will be exposed to active ingredients listed in table 13-15 may differ among pesticide types both spatially and temporally. For instance, insecticides, miticides and fungicides are applied directly to ornamental foliage, in contrast to herbicide application, which typically are not. Assuming *N. fallacis* is associated with spider mites on ornamentals, the probability for exposure to herbicides is minimal. Similarly, early season fungicides and pre-emergent herbicides may be applied prior to releases of *N. fallacis* and, assuming that the residual has no negative affects, may not interfere with biological control.

Conclusion

The phytoseiid mite *N. fallacis* is an effective biological control agent of spider mites in nursery systems (Pratt et al. 1998, Pratt et al. 1999, herein). Disruptive pesticides can interfere with biological control by displacing phytoseiid predators. Proper selection of pesticides, as described in Tables 13-15, will improve the potential for biological control of spider mites by phytoseiid mites and may aid in the integration of control tactics.

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