Screening of Predatory Mites as Potential Control Agents of Pest Mites in Landscape Plant Nurseries of the Pacific Northwest[1]

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Abstract

To select a biological control agent for suppression of spider mites on landscape plants in western regions of the Pacific Northwest, we compared life history traits of *Galendromus occidentalis* Nesbitt, *Neoseiulus californicus* (McGregor) and *Neoseiulus fallacis* (Garman). We also evaluated abilities of these predatory mites to suppress spider mites in 4 landscape plant species under field conditions. Comparing life history traits from the literature, intrinsic rate of increase was similar between the 2 *Neoseiulus* species but lower for *G. occidentalis*. Prey killed per day was greatest for *G. occidentalis* > *N. fallacis* > *N. californicus*. For overwintering abilities, *N. fallacis* and *G. occidentalis* are indigenous to the Pacific Northwest and will survive winter assuming overwintering sites are available, but survival of *N. californicus* is unlikely. *Neoseiulus californicus* has the widest prey range, *G. occidentalis* the narrowest, with *N. fallacis* intermediate. When inoculated into spider mite infested landscape plants, *N. fallacis* was equally effective at suppressing spider mites as *G. occidentalis* in either *Malus* rootstock or *Acer* shade trees. Further tests with *N. fallacis* or *N. californicus* on *Spiraea* and *Rhododendron* plants suggested that *N. fallacis* is equally or more effective at suppressing pest mites, respectively. Compared with the other candidates, *N. fallacis* was equally effective at controlling pest mites and has a wider prey range than *G. occidentalis*. *Neoseiulus fallacis* appears to be the best candidate for biological control of multiple spider mite species on landscape plants in these parts of the Pacific Northwest.

Index words: integrated pest management, Tetranychidae, Phytoseiidae, *Neoseiulus fallacis*, *Neoseiulus californicus*, *Galendromus occidentalis*, biological control.

Species used in this study: *Galendromus occidentalis* (Nesbitt); *Neoseiulus californicus* (McGregor); *Neoseiulus fallacis* (Garman); the two spotted spider mite, *Tetranychus urticae* (Koch); the southern red mite, *Oligonychus illicis* (McGregor); *Malus* (MM.106EMLA) rootstock; *Acer* x *freemanii* 'Jeffersred'; *Spiraea bumalda* 'Crispa'; *Rhododendron* 'Hotie'.

Significance to the Nursery Industry

Our investigations have focused on the identification, evaluation and conservation of a predatory mite targeted for control of spider mites in landscape nursery systems of the Pacific Northwest. We compared 3 indigenous predatory mites and concluded that *N. fallacis* appears to be best suited for suppression of various pest mites found on landscape plants in the region. In 3 of 4 field tests, *N. fallacis* controlled spider mites below economic levels, suggesting that inoculative releases of this predator can be an effective alternative to pesticides.

Introduction

Spider mites of the Tetranychidae are major pests of landscape plant nurseries worldwide. Foliar damage caused by spider mite feeding renders plants unsightly and unmarketable (13, 22). To protect these high value plants from spider mite damage, nurserymen have traditionally relied on synthetic pesticides to suppress population outbreaks (35). 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 landscape plant nursery systems (27).

An alternative to pesticides for suppression of spider mites is the inoculative release of predatory mites from the family Phytoseiidae. Predatory mites are important biological control agents of spider mites in many agricultural systems (15). Phytoseiids are effective at suppressing pests in landscape plants grown in greenhouse systems (32), but few studies have tested their ability to suppress pest mites on landscape plants grown outdoors. Recent studies evaluated the use of *Phytoseiulus persimilis* Athias-Henriot for the suppression of *Tetranychus urticae* Koch in landscape species grown in semi-tropical regions of the United States (2, 3). Results suggest that *P. persimilis* can reduce *T. urticae* on landscape plants below economic levels. However, this predator is not an ideal biological control agent for all production regions. For instance, *P. persimilis* may not overwinter in important temperate growing regions of the United States (e.g., the Pacific Northwest; 19). In addition, *P. persimilis* is a specialist of *Tetranychus* species and may not control other pests in the spider mite complex (16).

McMurtry and Croft (21) classified 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 spider mites in the family Tetranychidae, Type III phytoseiids are generalist predators and Type IV species are specialist on pollen but may also feed on mites. The objective of this study was to identify a phytoseiid mite from the Type II predator classification for biological control of multiple spider mites in outdoor landscape nurseries of the Pacific Northwest. We first compared

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life history traits from the literature for three species that appeared to be suitable candidates. From among the candidates that possessed the most promising characteristics, we performed field tests to compare their effectiveness at controlling spider mites when released into landscape plants of 4 representative types.

Materials and Methods

Selection criteria. Three Type II selective predators of tetranychids that are indigenous to the western United States are *Galendromus occidentalis* Nesbitt, *Neoseiulus californicus* (McGregor) and *Neoseiulus fallacis* Garman (12, 21). 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. Although *Tetranychus* species, and especially *Tetranychus urticae* Koch, are major pests in landscape nurseries, we were also interested in comparing prey range of selected phytoseiids for non-*Tetranychus* diets (i.e., *Oligonychus*, *Schizotetranychus*, *Panonychus*, etc.). Unfortunately, comparative data for prey range among phytoseiids is limited (6, 7). Therefore, we estimated prey range by calculating the sum of non-*Tetranychus* prey references from the literature citation index (LCI) of Croft et al. (6). Our assumption that the LCI adequately describes the prey range of Type II phytoseiids is based on recent comparisons between LCI and actual prey range tests for a limited number of species (26).

Predaceous mite cultures. Laboratory cultures of *G. occidentalis*, *N. californicus* and *N. fallacis* used in this study were originally collected from agricultural crops in the Willamette Valley, OR (12). These cultures have been maintained for 3–6 years with regular additions from field-collected mites. Cultures were held at 25 ± 5C, 16:8 light:dark (L:D), and 80 ± 10% relative humidity (RH), and mites were fed mixed life stages of *T. urticae* 3 times per wk. Predators for inoculative releases in field tests originated from laboratory cultures and were mass reared 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 (31).

To compare the 3 candidate phytoseiid species under field conditions, we performed tests of 2 or more of these species in 4 spider mite infested landscape plant types. These plant types consisted of stoolbed rootstock, shade tree, deciduous shrub and evergreen shrub. These types were selected because they represent a range of plant architectural types and harbor a diversity of mite pest species.

Malus rootstock. The study site was located near Gervis, OR (45.1N and 122.8W). *Malus* rootstocks (MM.106 EMLA) were cultivated in a 7.3 ha stoolbed field with 400 (± 22) plants per m^2 and 1 m between each row (for a general description of stoolbeds see 14). Plants emerged from the perennial roots in early spring, and by May continuous dense canopies of leaves were created within rows and nearly between rows. Plants were sprinkler irrigated as needed according to soil moisture sensors.

In 1995 we tested the ability of *G. occidentalis* and *N. fallacis* to control *T. urticae* in small plots. Fifteen 1000 m^2 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 from each replicate every 14 days. By June 27, 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 40× microscope was used to count pest and predator mites. All predators found on sampled leaves were mounted on glass slides and identified by morphological characteristics (29). 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) (33).

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* in deciduous shade trees. The study site was located near Dayton, OR (45.2 N and 123.1W) and consisted of a 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), with 3 trees used as a border between each of the replicates. On July 2, *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 tree within release blocks. Mite populations were estimated by scanning 3 randomly selected leaves from basal, intermediate and apical portions of each tree with an optical visor at 10× magnification. Predator identification and data analysis were performed as described above.

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

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 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 July 2, 1996, *T. urticae* populations reached 1.9 (± 0.3)

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per leaf and 5 adult female predators were released into the center of the canopy of each release block. Samples of 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.

Rhododendron 'Hotie'. As mentioned above, we questioned if the predatory mites would also suppress other, non-*Tetranychus* spider mites found in the landscape nursery system. *Oligonychus illicis* (McGregor) is a major pest of rhododendrons in the United States (20). In addition, leaves of most rhododendrons are smooth and lack morphological characteristics known to affect phytoseiid behavior (such as pronounced hair on the underside of leaves or domatia; 34). Therefore, we compared the ability of *N. fallacis* and *N. californicus* to suppress *O. illicis* on rhododendron plants.

The study site was located near Corvallis, OR, (44.5 N and 123.3W). Four-yr-old *Rhododendron* 'Hotie' plants were grown in a 5 × 10 m plot with plants spaced approximately 0.5 m apart. Fifteen replicate plants were randomly assigned one of three treatments: release of *N. californicus*, *N. fallacis* or no release. Predatory mites were inoculated into release plants on April 17. 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.

Results and Discussion

Selection criteria. When comparing life history data from the literature, values of intrinsic rate of increase were similar among *N. fallacis* and *N. californicus* when feeding on *Tetranychus* prey, but lower for *G. occidentalis* (Table 1). In contrast, Friese and Gilstrap (11) found the number of prey killed per day was higher for *G. occidentalis* than *N. californicus*. In an unrelated study, prey killed per day for *N. fallacis* appeared to be intermediate to that of the other phytoseiids (1). 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 (12). While *N. californicus* occurs in California, it has not been found in the Pacific Northwest and its successful overwintering in this region is unlikely (12, 19).

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 (Table 1). While commercial availability from producers is similar for all 3 species, their humidity tolerances are different. *Galendromus occidentalis* eggs are tolerant of much lower humidities than either *Neoseiulus* species (Table 1).

When comparing life history traits, our findings suggest that each species has one or more traits that may be limiting and that selection based on literature alone is difficult (10). 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 landscape plant 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.

Introduction of the predators *G. occidentalis* and *N. fallacis* into *Malus* rootstock plants significantly reduced populations of *T. urticae* when compared to the control (*P* < 0.001; Fig. 1). 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. 1). 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.

Release of the predatory mites into spider mite infested *Acer* x *freemanii* 'Jeffersred' plants significantly reduced the populations of *T. urticae* when compared to control treatments (*P* < 0.001; Fig. 1). Although treatments were not significantly different (*P*-value > 0.05), spider mite densities were slightly higher in *G. occidentalis* treatments than tests with the 2 *Neoseiulus* species. While some dispersal of predatory mites did occur from the release treatments into the control treatment late in the experiment, biological control was not realized in the control treatment.

When compared to the control treatment, the predatory mites *N. fallacis* and *N. californicus* significantly reduced populations of *T. urticae* in the landscape shrub *S. bumalda*

Table 1.   Characteristics of potential biological control agents targeted for spider mites infesting landscape nursery systems of the Pacific Northwest.

Phytoseiid predator	Predator type	Intrinsic rate of increase	Prey killed/ female/d	Over-wintering[t]	Prey range[s]	Commercially available	Humidity tolerance (RH$_{50}$ of eggs)	Humidity tolerance reference[r]
Galendromus occidentalis	II[z]	0.228[y]	14.39[v]	Yes	0.373	Yes	28.41	12
Neoseiulus californicus	II	0.287[x]	10.05[v]	Unknown	0.564	Yes	73.73	5
Neoseiulus fallacis	II	0.298[w]	11.40[u]	Yes	0.419	Yes	69.65	12

[z]Type II selective predator of tetranychid spider mites (24).

[y]Average r_m calculated from 6 estimates as reported in Sabelis and Janssen (30).

[x]as reported in reference 21.

[w]as reported in reference 8.

[v]Fed excess eggs of *T. cinabarinus*.

[u]Fed excess eggs of *T. urticae*.

[t]Winter survival in Pacific Northwest.

[s]Prey range estimated as a summation of the literature citation index of non-*Tetranychus* diets from Croft et al. (9).

[r]Reference number for literature cited.

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Malus Rootstock

Legend:
- ■ *G. occidentalis*
- ▨ (gray) *N. fallacis*
- □ Control
- ▨ (hatched) *N. californicus*

T. urticae

Sample dates: 18-Jul, 31-Jul, 10-Aug, 19-Aug, 26-Aug, 6-Sep

Acer x freemanii 'Jeffersred'

T. urticae

Spider mites per leaf

Sample dates: 10-Jul, 16-Jul, 23-Jul, 30-Jul, 6-Aug

Spiraea bumalda 'Crispa'

T. urticae

Sample dates: 2-Jul, 9-Jul, 17-Jul, 22-Jul, 30-Jul, 6-Aug, 13-Aug, 20-Aug

Rhododendron 'Hotie'

O. illicis

Sample dates: 17-Apr, 1-May, 15-May, 3-Jun, 18-Jun
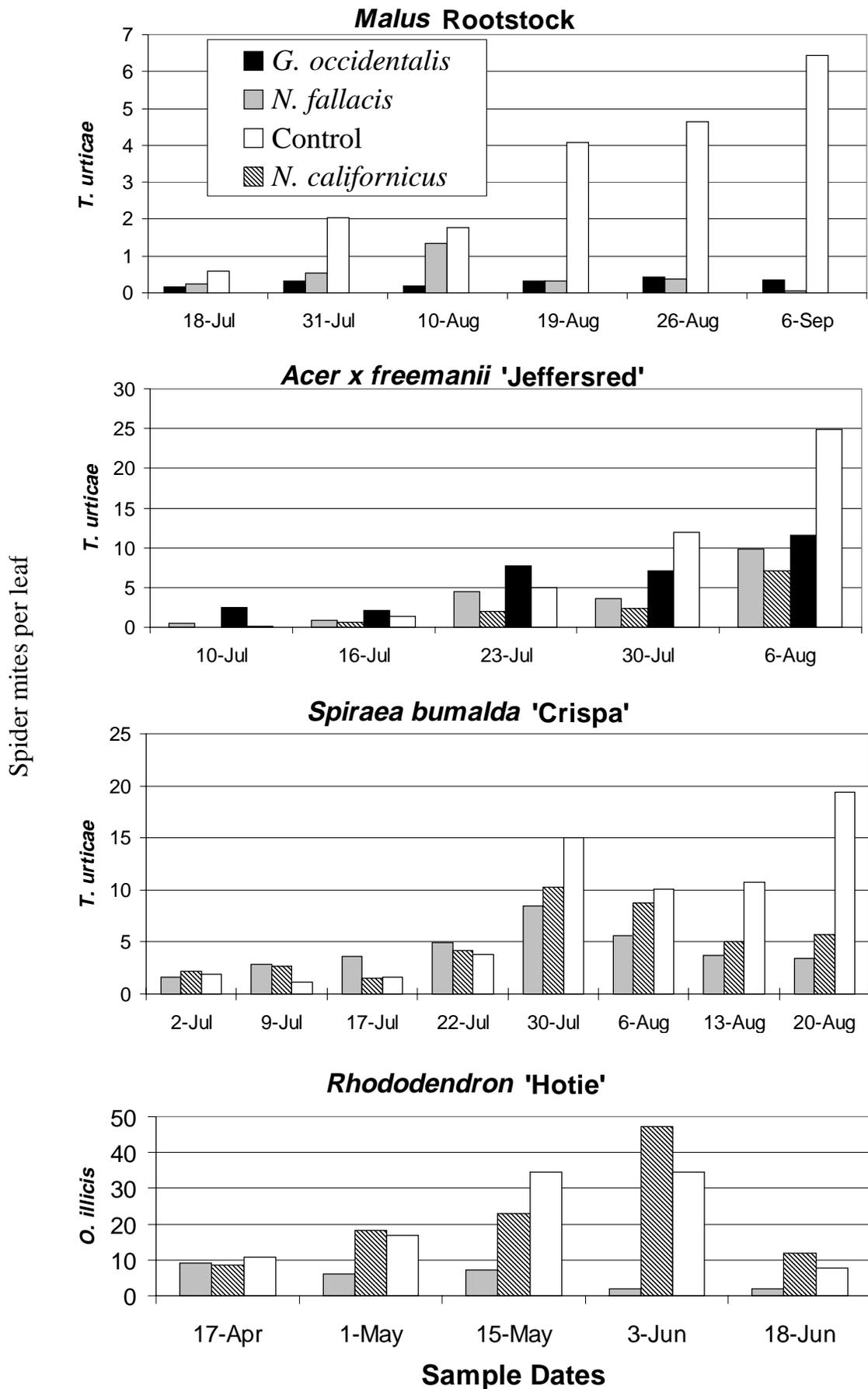
Sample Dates

Fig. 1.   Biological control of spider mite pests by inoculative releases of phytoseiid mite species in four ornamental nursery plant systems.

'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. 1). In contrast, *N. californicus* dispersed from release locations to border plants earlier than did *N. fallacis* ($P < 0.05$).

The introduction of *N. fallacis* significantly reduced populations of *O. illicis* on *Rhododendron* when compared to either the control or release of *N. californicus* ($P < 0.001$; Fig. 1). 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 May 15, *N. fallacis* was collected from control and *N. californicus* treatments. The decrease in pest densities in 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. 1).

Results from our field studies demonstrated that *N. fallacis* was equally effective as *G. occidentalis* at suppressing the two spotted 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 the two spotted spider mite or southern red mite, respectively (Fig. 1). 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*. Thus, considering that *N. fallacis* will reproduce on a wider range of pest mites than *G. occidentalis* and is as effective in the field as the other 2 species, we suggest that it is the best candidate for biological control of multiple spider mite pests of landscape plants in the region.

As described by Raupp et al. (27), 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 ornamental plants. 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 landscape 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 of tetranychids 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. 1). In related studies, Pratt et al. (26) measured the ability of *N. fallacis* to survive, feed and reproduce on a range of landscape plant pests and alternative foods under laboratory conditions. Their findings show that measured attributes were highest when held with tetranychid mites, but alternative foods (i.e. other mites, pollen, thrips, etc.) also provided for greater survival and reproduction than when starved. Studies are needed to determine how alternative foods may enhance predator conservation in landscape nursery systems (20).

Compatibility with plant types and microhabitats also may be as important to biological control success as are the abilities of a predator to feed and reproduce on a pest (10). For instance, morphological differences in pea plants can affect the ability of *Coccinella septempunctata* to suppress aphids (17). Similarly, tritrophic level effects have been described among phytoseiid, their prey and leaves possessing domatia and nectaries (34). In this study, *N. fallacis* was less effective in shade trees than on lower profile plants (rootstocks and shrubs). These findings are consistent with recent studies comparing biological control of spider mites by *N. fallacis* among 30 plant varieties ranging in morphological types (24). In general, limitations in control occurred mostly in tall, vertical growing plants that had little foliar canopy (24). Modified cultural techniques may be used to improve these restrictions.

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. (25) observed that *N. californicus* dispersed over a greater distance than *N. fallacis*. In the studies reported herein, *N. californicus* dispersed into contiguous *Spiraea* border plants earlier than *N. fallacis*, suggesting that *N. californicus* dispersed more throughout the plots as 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 for this predator than for *N. fallacis* (Fig. 1). Dispersal of biological control agents influences the rate of pest control, area of pest control and sampling protocols (7, 25).

Our decision to focus on *N. fallacis* is consistent with other studies that sought a predator of spider mites in agricultural systems of inland valley regions of western Oregon. Strong (30) selected *N. fallacis* over *G. occidentalis* for control of *T. urticae* in hops in western Oregon and Washington. Similarly, introductions of *N. fallacis* into strawberry fields resulted in marked reductions of *T. urticae* and the cyclamen mite *Phtyonemus pallidus* (Banks) in this region (8). Morris (23) selected *N. fallacis* for biological control of *T. urticae* in peppermint systems in both humid and arid regions of the western United States. The use of a single biological control agent in multiple agricultural systems within a common region may facilitate area-wide conservation strategies for *N. fallacis*.

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