Banker Plants: Evaluation of Release Strategies for Predatory Mites[1]

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Abstract

Spider mites (Tetranychidae) are among the most injurious pests of commercial landscape plant nurseries. The introduction of predaceous mites (Phytoseiidae) into nursery crops for control of spider mites can be an effective alternative to pesticides. We sought to evaluate the use of banker plants as a method of rearing and dispersing predatory mites for the control of spider mites in landscape nursery systems. Banker plants include any plant addition that aids in development and dispersal of predators for control of herbivorous pests. Addition of the predatory mite *Neoseiulus fallacis* (Garman) into spider mite infested arborvitae and rhododendron banker plants held in replicated greenhouse cubicles resulted in more predatory mites dispersing to spider mite infested plants downwind than were originally inoculated. To improve persistence and subsequent dispersal of predatory mites in an arborvitae banker plant, we evaluated the use of adding supplemental prey (spider mites) and applying a portion of the plant foliage with a pyrethroid to provide a refuge for the prey. Reintroduction of prey increased the dispersal duration of *N. fallacis* but the pyrethroid-based refuge did not. Predatory mites dispersing from arborvitae banker plants of approximately 1.25 m (4.1 ft) tall were collected from receiver plants at 10, 20 and 30 m (10.9, 21.9 and 32.8 yd) down wind. Integration of a banker plant system into a landscape nursery operation is discussed.

Index words: biological control, integrated pest management, Tetranychidae, Phytoseiidae, *Neoseiulus fallacis*, dispersal, landscape.

Species used in this study: *Neoseiulus fallacis* (Garman); two spotted spider mite, *Tetranychus urticae* (Koch); southern red mite, *Oligonychus ilicis*; spruce spider mite, *Oligonychus ununguis*; arborvitae, *Thuja occidentalis* 'Pyramidalis' and 'Emerald'; *Rhododendron*, 'Ana Kruschke'; bean, *Phaseolus lunatus*.

Significance to the Nursery Industry

Spider mites cause severe damage to landscape nursery plants worldwide. The use of predatory mites for suppression of these pests can be an effective alternative to chemical control methods. In this report we discuss the use of banker plants as a means of rearing and dispersing predatory mites within landscape nursery systems. The use of these banker plants may enhance persistence of predatory mites in landscape nurseries, thereby improving biological control of spider mites.

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Introduction

Spider mites (Tetranychidae) are among the most injurious pests of commercial landscape nurseries (2, 18, 24). Historically, landscape plant producers have relied on chemical applications (acaricides) to suppress spider mites in these high value plants (2, 18, 30). An alternative to chemical control is the introduction of predaceous mites (Phytoseiidae) into nursery crops. Recent studies have evaluated the use of *Neoseiulus fallacis* (Garman) to control spider mites on landscape plants and have demonstrated that inoculative releases of this biological control agent can suppress mite populations, often rendering acaricide applications unnecessary (20, 21, 24).

Limited attention has been given to identifying methods of releasing predatory mites into nursery systems. Although other methods occasionally have been used (16), introduction of predatory mites typically consists of purchasing predators and distributing them, by hand, into infested foliage (P.D. Pratt, personal observation). This procedure can be labor intensive and expensive, especially when multiple releases per season are required (2, 3). In addition, improper timing of releases has been implicated in many biological control failures (1, 31). In landscape nursery systems, releases of predatory mites in the absence of prey may result in starvation of the predator and release of predators when an abundance of prey is available may result in unacceptable damage on the landscape plants.

Ramakers and Voet (26) 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. We sought to evaluate the use of banker plants as a method of rearing and dispersing predatory mites for the control of spider mites in outdoor landscape nursery systems.

To give perspective to our research, it is important to describe a 'banker plant system.' The three basic components of a banker plant system are the predatory mite, the banker plant and the prey or alternative food. Each is dependent and influences the others in complex ways. Several factors must be considered when selecting predators, banker plants, prey and alternate food sources:

Does the predator suppress the pest in the nursery crop? The ultimate objective is to control spider mites in landscape plants. 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-prey-crop plant interactions must be conducted prior to incorporating a predator into a banker plant system (24).

Is the predator oligophagous? Preferably, the prey or the alternative food on the banker plant will be different than mite pests that feed on the landscape plant. Thus, phytoseiid predators possessing a wide prey or food range may be more easily integrated into a banker plant system (25).

Will the predator increase numerically in response 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 minimal if the predator numerically responds (reproductively) 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.

Will the predator remain on the banker plant? Plant substrate types influence most arthropods. For instance, predatory mites are affected by leaf domatia, indumentum, plant turgor, pollen availability, extrafloral nectaries, overwintering sites etc. (19, 22, 34). For this reason, selection of a banker plant must take into consideration the acceptability of the plant and long-term colonization by the predator.

Is the predator a good disperser? Aerial dispersal by predatory mites occurs mostly when adult females enter air currents and drop to foliage downwind (11). Behavioral and morphological adaptations among predatory mites may increase the dispersal distance of some species (12, 23). 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 (12). 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.

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 overexploits the host plant and their 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 needed 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 a spatial refuge? Population reductions (or extinction) of prey or alternate food from over exploitation by the predator will affect continued dispersal of predators into the surrounding environment. One method to maintain the dispersing predator population is if the banker plant possesses a refuge for prey (10). 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 by the sticky material and can develop large populations in a refuge on new leaves (Pratt, unpublished data).

Can the prey negatively affect the landscape plant? If spider mites are used as prey for the predatory mites, 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 landscape plant of interest. If information on host range of the prey in the banker plant 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. Some spider mites have lower temperature developmental thresholds and therefore can develop appreciably while the predator is unable to develop (11). 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 a temporal refuge from the predator? As previously mentioned, long-term production of prey may be accomplished with a refuge. Some spider mite stages are inaccessible to predatory mites and may serve as refuge for the prey. For instance, it has been documented that the egg stages of some spider mites are inaccessible to some predators (11). A refuge 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 banker plant criteria mentioned above. 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 refuge on the dispersal interval of *N. fallacis* and 4) determine distance traveled by predators when dispersing from a banker plant.

Materials and Methods

Mite sources, greenhouse facilities and receiver plants. Predatory mites used in these studies were provided by Biocontrol Works. Predatory mites were reared on bean plants that had been infested with the spider mite *Tetranychus urticae* (Koch) and collected just prior to extinction of the prey (23). 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, *O. ilicis* and *Oligonychus ununguis* (Jacobi), were collected in mid May from field-grown landscape 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 × 4 m (32.8 × 13.1 ft) greenhouse rooms with internal conditions of 26:21 (± 10)C (78.8:69.8F; Day:Night), photoperiod 16:8 (Light:Dark) h, and 75% (± 10) relative humidity (RH) were used. Four 1 × 3 m (3.2 × 9.8 ft) benches were placed 1.5 m apart in each of the greenhouse rooms. A 1.5 m (4.9 ft) high muslin curtain was hung above each bench so that the curtain created 2 isolated cubicles (1 × 1.5 × 1.5 m) on top of each bench. The bottom 10 cm (3.9 in.) of the curtains rested in a 10 cm (3.9 in.) 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. 1).

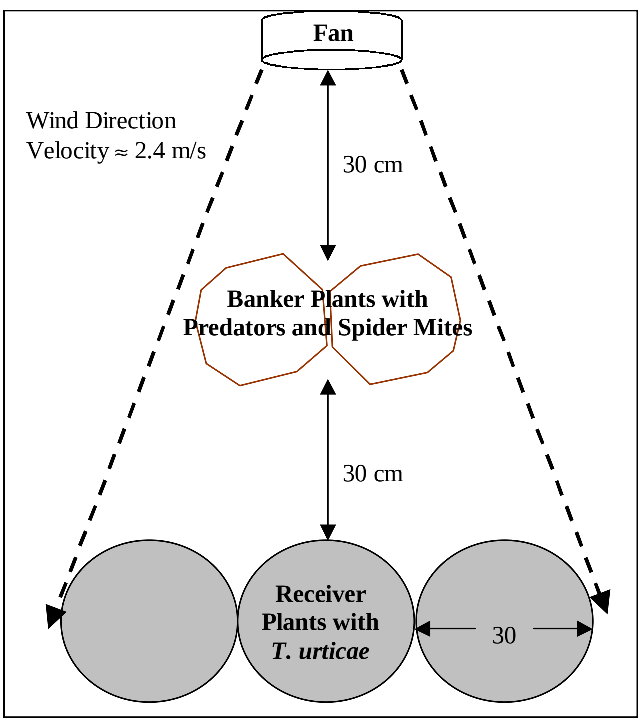

Fig. 1. Experimental design of a 1 × 1.5 m cubical used in small-scale banker plant studies.

Receiver plants consisted of a dense canopy of lima bean (*Phaseolus lunatus* L.) leaves covering a circular area of 0.3 m (1 ft) dia (± 5 cm) each. These receiver plants were designed to catch predatory mites as they dispersed from banker plants (23). To make the receiver plants, a total of 55 (± 3) seeds were planted into a polyethylene bag (30 cm [11.8 in] dia) that was filled with a potting mixture of pumice, sand, peat moss, and soil (2:1:1:1 by vol) (32). 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*.

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 ± 5 cm, diam: 23 cm ± 3 cm, potted in #1 plastic containers) were inoculated with 2000 (± 150) *O. ununguis* and 30 days later populations had increased to 450 (± 23) spider mites (all stages) per 6 cm terminal. A pair of arborvitae trees placed in close proximity to each other and 3 receiver plants were randomly assigned to 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. 1). The lateral distance separating the fan and the receiver plants from the banker plants was 30 cm (11.8 in). Five-hundred mixed life stages of *N. fallacis* were inoculated into each of the banker plants. Leaves of the receiver plants were scanned with a 10× optical visor 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 destructive sampling did not create vacant areas in the canopy. Because of possible oviposition from a few dispersing female predatory mites that were not removed in sampling, receiver plants were replaced every 5 days (minimum development time of predator from egg to adult; 23). Immature 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 40× microscope.

Eight rhododendron plants ('Ana Kruschke'; height: 0.5 m ± 6 cm, diam: 30 cm ± 5 cm, potted in #1 plastic containers, and 45 (± 6) leaves per plant) were inoculated with ca. 500 *O. illicis* (all life stages) and 30 days later populations had increased to 125 (± 32) per leaf. Two plants were placed in each of 4 randomly assigned 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 40× microscope.

Without the presence of alternative foods (such as pollen or plant fluids), *N. fallacis* is dependent on spider mite prey for continued reproduction and development (8, 17). 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. To determine if reintroducing prey could extend the number and interval of *N. fallacis* dispersants. 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.

Prey refuge in an arborvitae banker plant. As described previously, a spatial or temporal refuge for the prey mite or alternate food may increase the period of continuous predator dispersal from a banker plant system. If such a refuge is not available, an artificial one may be created by applying a selective pesticide to parts of the banker plant to eliminate colonization by the predator (7, 14). For instance, predatory mites are known to be susceptible to most pyrethroid pesticides but spider mites are not (5). 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 idea 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 liter per ha) to the top 25 cm (9.8 in) 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 (14). This is similar to the previous 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.

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 and not indicative of what might be achieved using a banker plant in an outdoor setting with landscape plants. To determine mite dispersal from banker plants in a more realistic field situation, 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 (± 14.5) spider mites were on each 6 cm (2.3 in) terminal branch. Each banker plant was placed in a large open field with more than 200 m (218 yd) separating replicates. *Phaseolus lunatus* receiver plants were placed at distances of 10, 20, and 30 m (10.9, 21.9 and 32.8 yd) 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 (4). 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 refuge experiment above. All predators collected from receiver plants were mounted on glass slides and identified according to morphological characters (29). 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.

Statistical analysis. Repeated measures analysis of variance (ANOVA) was used to compare the dispersants recovered in receiver plants over time (33). The Huynn-Feldt adjustment was used when the covariance matrix of the data did not meet the assumption of sphericity (28). 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.

Results and Discussion

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 increased to 180 (± 12.77) by day 17 (Fig. 2). The number of *N. fallacis* found in receiver plants decreased to 18 (± 4.83) over the next 4 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 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).

The number of dispersing immatures increased over time, but in a delayed way compared to the adult females (Fig. 2). Less than 1% of the total population of dispersing *N. fallacis* were immatures in the first 10 days of the experiment (Fig. 2). As the prey density decreased in the arborvitae banker plants during the next 10 days, the proportion of immatures dispersing (or being blown off foliage) 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 (± 4.58) individuals on day 15 and remained above 20 individuals dispersed for 4 days (Fig. 3). The cumulative number of *N. fallacis* dispersed from rhododendron plants during the entire study was 368 (± 30.3). The dispersal index was 0.02 or greater for days 12–25. During this study, new plant growth developed and this substrate was unsuitable for colonization by *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.

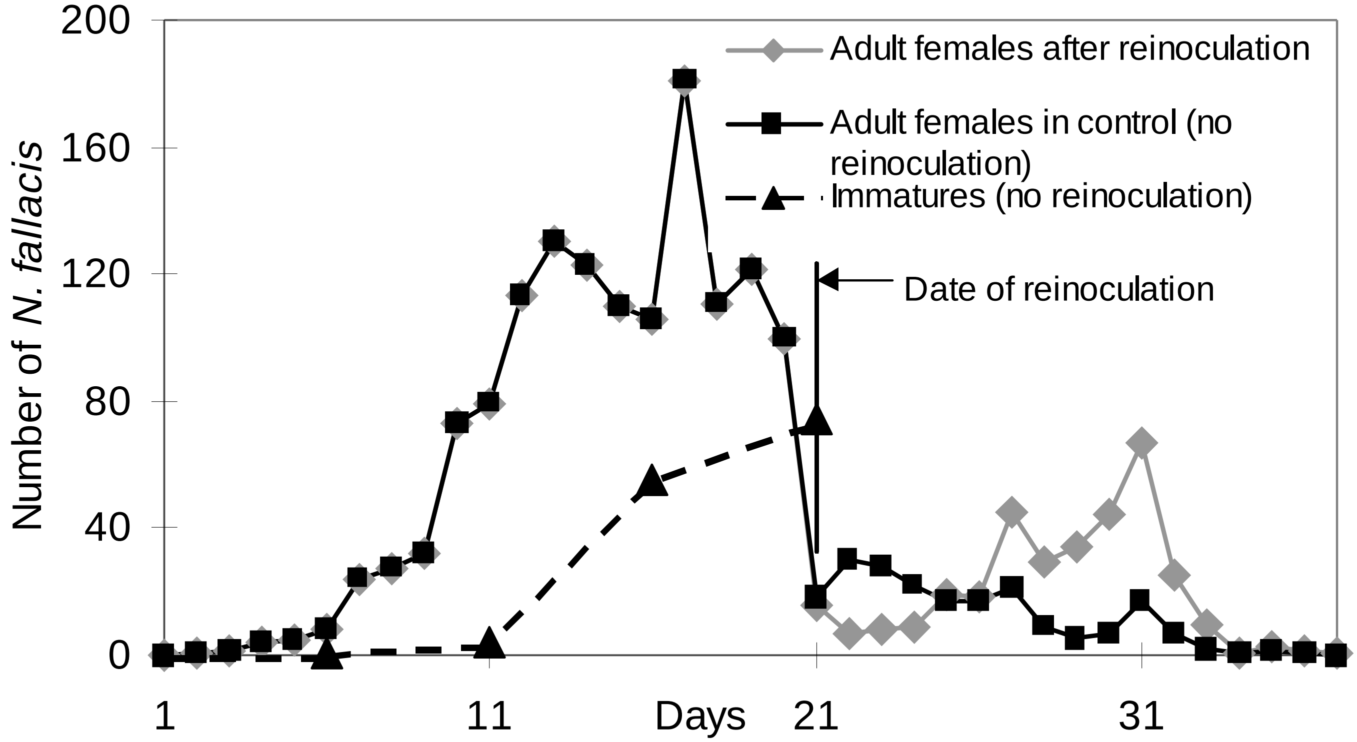

Fig. 2. **Dispersal of the predatory mite *N. fallacis* from *T. occidentalis* 'Pyramidalis' banker plants to spider mite infested *P. lunatus* plants down wind. Reinoculation of the banker plant was performed on day 21.**

Again, the ratio of immatures to adult females dispersing from rhododendron plants increased over time (Fig. 3). When prey densities where 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.

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 in-

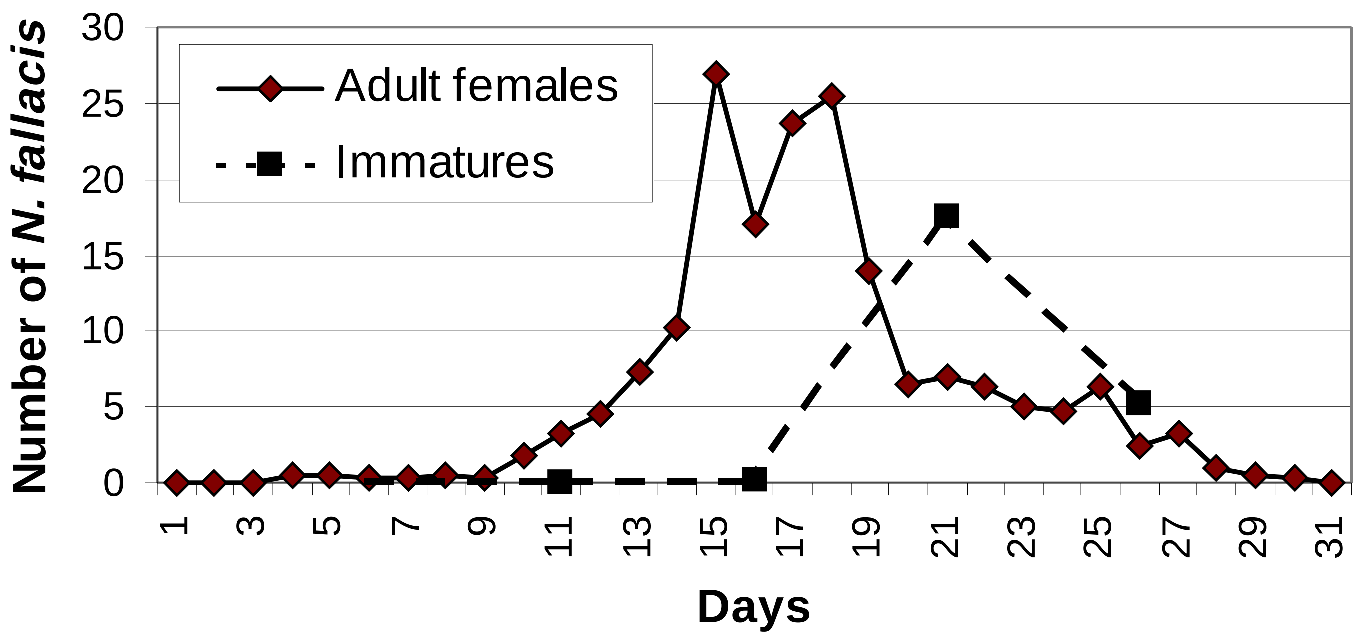

Fig. 3. **Number of *N. fallacis* dispersing from a rhododendron 'Ana Kruschke' banker plant to receiver plants downwind.**

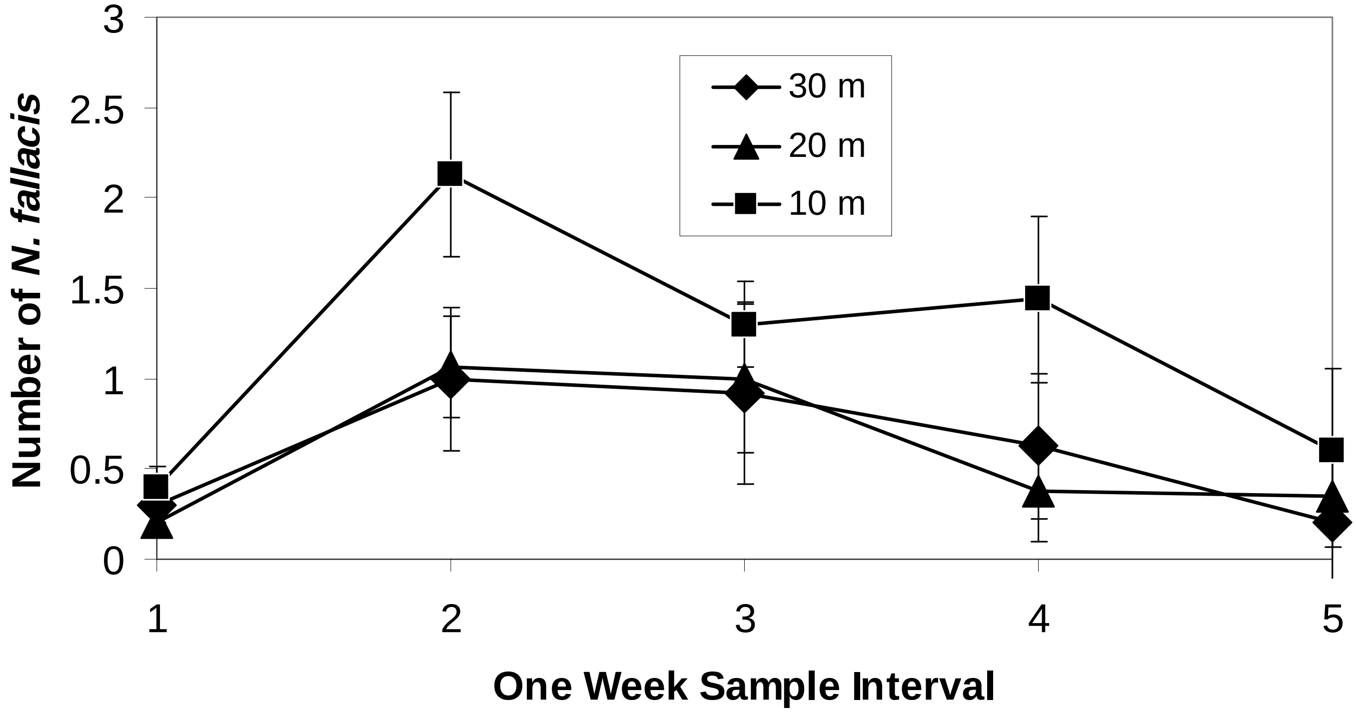

Fig. 4. Dispersal of *N. fallacis* from a *T. occidentalis* banker plant to receiver plants spaced 10, 20 and 30 m distant.

oculated into arborvitae banker plants. This estimate of predators produced in the banker plants is 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, 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. 2). 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. Starving *N. fallacis* may have stopped dispersing in response to spider mite induced plant volatiles or physical contact with the prey caused them to start feeding again and stop dispersing (15, 27). *Neoseiulus fallacis* has also been shown to develop and reproduce when held with pollen and other alternative foods (25, 35). 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 (9). 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.

As mentioned previously, a refuge for prey 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 refuge did not improve persistence and dispersal of the predator in arborvitae banker plants. Three wks after inoculation of *N. fallacis* into banker plants, the number of predators dispersing into receiver plants in the refuge treatment peaked at 63.75 (± 18.75). Dispersal of predators peaked at 58.75 (± 18.98) one wk later in receiver plants of the control treatment. Dispersal from banker plants into receiver plants in both treatments ended on August 4. Predators were not found among refuge or control banker plants on August 18. When sampling mite densities on banker plants, spider mites colonized the pyrethroid treated area but predators were not present. One explanation for this result may be that *N. fallacis* overexploited the prey in the non-treated area and dispersed (or starved) before prey migrated from the refuge to the untreated area. Another explanation may be that predators avoided spider mites that were treated or were feeding on pyrethroid treated foliage (6). The number of cumulative dispersants was 197.5 (± 25.4) for plants possessing the pyrethroid refuge as compared to 182.5 (± 22.1) for the control. Further studies are needed to evaluate the usefulness of a refuge in banker plant systems.

With banker plants of approximately 1.25 m tall, 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; $P = 0.04$). 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. 4). These findings have relevance to the location of banker plants in nurseries. For instance, banker plants may be widely separated and yet provide adequate dispersal of predatory mites to spider mite infested plants. No immatures were collected from receiver plants during these experiments, which was in marked contrast to the more short-distance dispersal study. 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.

Integration of a banker plant system into a landscape 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 landscape 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 (5, 24). Banker plants also can be developed from existing hedgerows within the landscape plant 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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