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**Abstract**

Adequate distribution of natural enemies is necessary for successful augmentative biological control. In California greenhouse cut roses produced using the bent shoot system, the predatory mite *Phytoseiulus persimilis* is widely used for control of the phytophagous mite *Tetranychus urticae*. One purported advantage of the bent shoot method is that the dense foliage of the lower canopy creates interplant bridges that facilitate predator movement. However, gaps in lower canopy interplant contact can occur in young plants or can result from varietal growth habit or seasonal cessation of growth in established plants. We observed an average of 1.63 ± 0.10 interplant contacts in the lower canopy across five rose varieties, with the average lower canopy gap being 3.52 ± 0.42 cm wide. We evaluated the use of interplant bridges of plastic flagging tape as a method to enhance dispersal of the *P. persimilis* predator. We determined that about three times as many predators moved from the plant on which they were released to adjacent plants when those plants were connected by bridges compared to those that were not. Finally, we tested the use of interplant bridges and a mechanical dispenser to determine if the use of a dispersal aid could enhance the efficacy of biological control. After 3 weeks in the greenhouse the number of leaves infested with *T. urticae* was reduced by approximately 50% using interplant bridges or a mechanical dispenser in comparison to controls without dispersal aid, although there was no difference between dispersal methods.

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**1. Introduction**

Classical biological control in perennial crops that employ phytoseid predators (Acari: Phytoseiidae) for control of tetranychid mites (Acari: Tetranychidae) seeks to maintain a balance between pest and predator populations such that both are always present at low densities. Dispersal is considered necessary to achieve an appropriate balance between predator and prey to obtain satisfactory long-term control (Bellows and Hassell, 1999).

In ornamental crops, however, growers are concerned primarily with the speed at which natural enemies cause mortality of their prey rather than the maintenance of a balance between their population densities (Heinz, 1998). In greenhouse cut roses, the phytoseid predator, *Phytoseiulus persimilis* Athias-Henriot is often used for control of the tetranychid pest, *Tetranychus urticae* Koch. Rose growers appear willing to bear the cost of regular predator releases (Casey et al., in press) and are less concerned about long-term maintenance of predator populations and more concerned about increasing predator dispersal to rapidly reduce *T. urticae* density. The Tetranychidae have well-developed aerial and crawling dispersal mechanisms (Kennedy and Smitley, 1985).

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Movement through phoresy is also more common for *T. urticae* than for *P. persimilis* (Sabelis and Laane, 1986). To be effective biological control agents, specialist phytoseid predators must have a mechanism by which they can locate and move to prey whose distribution is always changing. It has been shown that local and long-distance host finding by phytoseid mites is accomplished by orientation to prey volatiles (Sabelis and Van de Baan, 1983; Sabelis et al., 1984a,b). Wind speed in the greenhouse is often too low for effective aerial dispersal (Zemek and Nachman, 1999), which suggests that enhancing predator movement will give more effective mite control in the greenhouse. Lack of leaf contact (a route of predator dispersal) has been cited as the cause of biological control failure in roses by both Burnett (1979) and Gough (1991).

A new cut rose production system has come into use in the past few years that has important implications for predator dispersal in this crop. Roses were traditionally grown in soil with all shoots growing upward from the base. The new system, called shoot bending, was developed in Japan (Ohkawa, 1992; Ohkawa et al., 1999). For this technique, plants are grown in raised containers using artificial media in a recirculating system. The weaker stems that would be pruned out on standard roses are bent downward at the crown to intercept more light, leaving the strongest stems to grow upward and produce flowers. This creates a perennial lower canopy of foliage and an annual upper canopy of harvested flower stems. One supposed advantage of the shoot bending method of greenhouse cut rose production is that the dense foliage of the lower canopy creates interplant bridges that facilitate predator movement. In practice, gaps in the lower canopy occur in young plants due to crop spacing, varietal growth habit, or seasonal cessation of growth.

Laboratory studies have investigated the relationship between interplant contact and *P. persimilis* dispersal as a technique to enhance their movement between plants. Takafuji (1977) looked at the interaction between *Tetranychus kanzawai* (Kishida) and *P. persimilis* on kidney bean plants placed pot-to-pot or in groups of four connected by plywood bridges. Prey mites were completely eliminated from the first system by day 31, while they were still present in the second system when the experiment terminated on day 92, demonstrating that enhanced plant-to-plant contact could improve biological control. Zemek and Nachman (1999) enhanced *P. persimilis* dispersal relative to untreated plants by placing bridges of varying length on bean plants. Bridge length did not seem to matter, as most predators reached the periphery of all treated plant groups after 24h. Skirvin and Fenlon (2003) found that more *P. persimilis* moved to adjacent plants as the number of connections between those plants increased. In hops, Strong et al. (1999) observed unstable interactions between *Neoseiulus fallacis* (Garman) and their *T. urticae* prey. This differed from apple, on which synchronous populations were observed. They found that the common cultural practice of removing basal leaves from the hop plants interfered with predator (but not prey) dispersal. Cessation of this practice improved biological control.

Empirical evidence from crop settings suggests that increased foliar contact improves biological control. Van de Vrie (1985) observed that movement of predators between chrysanthemum (*Dendranthema grandiflora* [Tzvelev]) plants was greatly expedited once the plant canopy closed. In standard roses, Gough (1991) observed that *P. persimilis* failed to control *T. urticae* if the number of contacts between plants was too low.

The goal of this work was to examine the role of interplant bridges and a mechanical dispenser in predator dispersal and efficacy in bent shoot roses. Our first objective was to quantify the lower canopy structure of the bent shoot rose plants based on foliar contact and interplant gaps. Our second objective was to determine if interplant bridges could enhance predator movement. Our third objective was to evaluate the use of dispersal aids (interplant bridges or the mechanical dispenser) on efficacy of *P. persimilis* control of *T. urticae*.

### 2. Materials and methods

#### 2.1. Rearing of *P. persimilis*

All *P. persimilis* used in these experiments were provided by Syngenta Bioline (Oxnard, CA). They were raised on bean (*Phaseolus vulgaris* L.), packaged in vermiculite in 30 ml vials, and released within 24 h of arrival. All *T. urticae* were from a laboratory colony raised on miniature rose (*Rosa × hybrida* L. ‘Charming’). All rose plants were grown using the shoot-bending method. The mechanical dispenser (Ag Attack, Visalia, CA) was developed to release the predator *P. persimilis* in a vermiculite carrier to individual plants in a greenhouse (Fig. 1). The vial containing the predator–vermiculite mixture is inverted and placed in the dispenser. Each time the release lever is depressed a sliding plate moves, allowing a small amount of the predator–vermiculite mixture to drop out of the dispenser. The plate closes automatically after 90 s to stop the release of predators, permitting a controlled amount to be released each time.

#### 2.2. Characteristics of the bent shoot rose lower canopy

The number of interplant contacts at the uppermost leaf of the bent shoot was quantified in five rose cultivars at a commercial nursery in Watsonville, CA. This is typically the area on the plant where predatory mites are released. The plants were grown in coconut coir (Hydro-Organic Wholesale, Chico, CA) in 1 m high aluminum trays under ambient light. Each tray was 30 m long and...
Plants were grown on 3 m long × 40 cm deep greenhouse benches, with two replicates per bench. There were two treatments: bridges absent (control) or bridges present, each replicated five times in a completely randomized design. A replicate consisted of five buckets placed so that the sides of the pots were touching along their 30 cm depth as is typical in commercial production. There was no contact between foliage and stems of adjacent plants. The bridges were made of 2.5 cm wide orange plastic flagging tape (Gempler’s, Belleville, WI). The bridge was attached to the outside edge of the left-hand bucket and placed across all five plants in the replicate so that the tape was in contact with one leaf at the top of the bent portion of each plant. The bridge was then attached to the outside edge of the right-hand bucket. The only contact between plants in the control treatments was along the pot rims. There was no contact between replicates on the greenhouse bench.

On November 8, 2001, T. urticae were placed on two leaves above the crown of each plant except the center plant in each replicate. Five adult females were placed on each leaf, as this was the nominal threshold for this mite on roses (Casey, 2002). On November 15, 2001, the bridges were installed and 400 P. persimilis were released onto the center plant in each replicate. There is evidence that P. persimilis will move towards leaves that contain T. urticae or their volatiles (Sabelis and Van de Bunt, 1983; Zhang and Sanderson, 1992), so the central plant was left mite free to encourage predator dispersal. To release the predators, a 5 cm long piece of the same type of flagging tape used to make the bridges was inserted into the top of the vial containing the predators. They were counted as they crawled out of the vial and when the appropriate number had moved onto the tape it was placed on the uppermost leaf of the bent portion of the center plant. The number of predators released was much greater than the number that would be used under commercial conditions (400 P. persimilis per replicate of five plants versus the typical commercial rate of 1–5 P. persimilis per plant) to recover sufficient P. persimilis for statistical analysis. The number of predators per plant was counted in situ with a 10× hand lens after 24 h using a 2-min timed search of each plant. Analysis of variance was used to determine the effect of the treatment and direction on predator movement.

2.4. Efficacy of the dispenser and interplant bridges in greenhouse experiments

Two-year-old bent shoot rose (Rosa × hybrida L.) plants of the variety ‘Orlando’ grown in 11-L buckets (Agrodynamics, Eatontown, NJ) in coconut coir (Hydro-Organic Wholesale, Chico, CA) over drainage pebbles (Easy Green, Eschborn, Germany) under ambient light were used in this experiment. Temperature ranged between 10 and 30°C and relative humidity ranged from

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2.3. Interplant bridges and predator dispersal

Two-year-old bent shoot rose (Rosa × hybrida L.) plants of the variety ‘Orlando’ grown in 11-L buckets (Agrodynamics, Eatontown, NJ) in coconut coir (Hydro-Organic Wholesale, Chico, CA) over drainage pebbles (Easy Green, Eschborn, Germany) under ambient light were used in this experiment. Temperature ranged between 15 and 33°C and relative humidity ranged from 50 to 95% over the course of the experiment. This work took place at a research greenhouse in Davis, CA with plants grown according to standard commercial practices except that no pesticides were applied. All plants were cut back to the crown prior to each experiment to ensure that pest free foliage of a known, uniform age was used.

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Fig. 1. The mechanical dispenser used to release predatory mites.
50 to 95% over the course of the experiment. This work took place at a research greenhouse in Davis, CA with plants grown according to standard commercial practices except that no pesticides were applied. All plants were cut back to the crown prior to each experiment to ensure that pest free foliage of a known, uniform age was used. There were three treatments: hand release (control), interplant bridges as a dispersal aid, and the mechanical dispenser as a dispersal aid. Each was replicated seven times in a completely randomized design. Each replicate consisted of three buckets placed so that the sides were touching along their 15 cm depth. There was no contact between foliage and stems of adjacent plants. The bridges were as described above. The only contact between plants in the control treatments was along the pot rims. There was no contact between replicates on the greenhouse bench. On January 15, 2002, five adult female *T. urticae* were placed on two leaves above the crown on each plant. The experiment began January 29, 2002. All arthropod counts were done in situ using a 10× hand lens. The number of leaves per plant with more than five mobile *T. urticae* was recorded. The bridges were then placed on the appropriate plants as described above, and finally the predators were released. They were applied only to the center plant of the control and bridge treatments, and to all plants in the dispenser treatments. In a separate experiment, the average number of predators released per plant in a single pass of the dispenser was determined to be 25.9 ± 5.8 (SE, n = 20). We thus applied approximately 25 predators (i.e., one dispenser pass) to each of the three plants in each dispenser treatment replicate and 75 predators to only the center plants in each control and bridge treatment replicate to ensure that all treatments received an equivalent number of predators. The number of infested leaves was counted one and 2 weeks after predator release. At the same time, a 2-min timed search per plant was used to count the number of predators per plant. Analysis of variance was used to determine if there was a significant effect of dispersal method on the number of *T. urticae* infested leaves and the number of predators recovered.

3. Results and discussion

3.1. Characteristics of the bent shoot rose lower canopy

There was no effect of rose variety on the number of interplant contacts (Fig. 2A), but there was a significant effect of variety on the size of lower canopy gaps (*F* = 3.20, *df* = 4, 109, *P* = 0.02, Fig. 2B). There was no relationship between the number of contacts (x) and the size of the lower canopy gaps (y) (*F* = 0.10, *df* = 1, 109, *P* = 0.75).

Gough (1991) determined that fewer than 0.7 contacts per plant resulted in failure of *P. persimilis* to control *T. urticae* in standard roses. Although he did not measure interplant gaps, he observed many isolated shoots or plants at this level of interplant contact. When there were 1.7–3.0 contacts per plant, biological control was always successful. In our study, we observed a mean of 1.63 ± 0.10 (SE) contacts across five varieties, suggesting that the use of interplant bridges could enhance biological control. Different rose varieties can have different growth forms (Pertwee, 1997), which were reflected in the significant effect of variety on the size of lower canopy gaps (*F* = 3.20, *df* = 4, 109, *P* = 0.02). Varieties with the same letter are not significantly different (means separation with Tukey’s HSD).

3.2. Interplant bridges and predator dispersal

Significantly more predators moved to adjacent plants from the central release point when plants were connected by bridges, although a substantial number of
predators also dispersed among the plants without bridges ($F = 10.74$, $df = 1, 8$, $P = 0.01$, Fig. 3). Fig. 4 shows that all predators reached the periphery of the treatment area after 24 h, as was also observed by Zemek and Nachman (1999). This figure also indicates that most of the significant treatment effect was due to movement onto plants 3 and 4.

3.3. Efficacy of the dispenser and interplant bridges in greenhouse experiments

Three weeks after predator release there were significantly more mite infested leaves on the control plants than on the treated plants ($F = 3.19$, $df = 2, 60$, $P = 0.05$), but there was no difference in the infestation level between the bridge and dispenser treatments (Fig. 5).

We observed enhanced control of T. urticae in roses when dispersal aids were used, although there was no effect of treatment on the number of P. persimilis recovered. There was no difference between the tape or bridge treatments in final T. urticae density. The dispenser did not appear to cause predator mortality, and release by dispenser is ~3 times faster than the hand release used with interplant bridges (unpublished data). The greenhouse area used in this study was 15 m$^2$, while the typical house in a rose range is 929 m$^2$. Over a larger greenhouse area than was used in this study, the dispenser may prove to be more effective. To minimize release time (and thus cost), current grower practice is to release P. persimilis only onto plants with visible T. urticae damage. P. persimilis are recognized as effective dispersers that will move towards spider mite volatiles (Kennedy and Smitley, 1985). They exhibit straight-line movement while starved (Bernstein, 1983), which changes to an area-restricted search when a prey patch is encountered (Eveleigh and Chant, 1982). Predators released only in obvious areas of mite infestation will not reach isolated populations, leading to mite outbreaks. Use of the dispenser to make broadcast predator releases could overcome this limitation and lead to more effective biological control. Van Driesche et al. (2002) evaluated a different mechanical dispenser to release Neoseiulus (Amblyseius) cucumeris (Oudemans) for western flower thrips, Frankliniella occidentalis (Pergande), control in commercial
greenhouses. They observed no significant difference in the level of thrips control between mechanical and hand application of predators. There was a 47% reduction in application time with the mechanical dispenser.

Some California rose growers have expressed interest in having plant breeders consider growth form (and thus suitability for biological control) as new varieties are developed (C. Casey, pers. obs.). While this may be considered in the future, most growers and breeders today are interested only in features related to marketability, e.g., flower size, color, and vase life. This study indicates that techniques are available to improve the efficacy of biological control when plant growth habit does not favor predator dispersal.

The possibility that biological control will be more costly than chemical control leaves many growers hesitant to adopt IPM programs. Biological control costs in the greenhouse include natural enemy purchase and release labor. This study, along with the work of Van Driesche et al. (2002) cited above, suggests that simple, low-cost tools are available to expedite natural enemy release, thereby reducing labor costs. Although this work dealt with cut rose production, these techniques are appropriate for many types of greenhouse crops. For example, one method of irrigation uses flood trays or floors in which the growing bench or floor is flooded with water. A dispenser or interplant bridges would clearly aid predator dispersal in these situations, especially if there is no plant canopy contact. Finally, this work looked only at enhancing predator dispersal to reduce release time and improve control efficacy. Future studies will investigate the use of dispersal aids to reduce the number of predators that need to be released, further enhancing the cost-effectiveness of biological control.

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References


