BIOLOGICAL CONTROL OF *OLIGONYCHUS PERSEAE* (ACARI: TETRANYCHIDAE) ON AVOCADO: IV. EVALUATING THE EFFICACY OF A MODIFIED MISTBLOWER TO MECHANICALLY DISPENSE *NEOSEIULUS CALIFORNICUS* (ACARI: PHYTOSEIIDAE)

Miwa Takano-Lee and Mark S. Hoddle[1]

Department of Entomology, University of California, Riverside, 92521. 1. Author to whom correspondence should be addressed: Phone No. (909) 787-4714, Fax (909) 787-3086, E-mail mark.hoddle@ucr.edu

ABSTRACT - A Stihl SR400 backpack mistblower was modified to mechanically dispense the phytoseiid predator, *Neoseiulus californicus* (McGregor) onto artificial and actual avocado trees. The ability of the mistblower to broadcast *N. californicus* vertically was initially evaluated on a group of four artificial trees (4 m height). Distribution of corn grits, the carrier material in which *N. californicus* is commercially packaged, was unevenly distributed. Analysis of sticky cards arranged at 0.5 m intervals on artificial trees indicated that 75% of grits adhered to cards at heights ranging from 1.5-3.5 m. In an avocado orchard, the efficacy of three treatments for dispensing *N. californicus* was assessed: (1) mistblower application of phytoseiids mixed with corn grits with water setting on 0.5 (provided a fine spray to adhere predators and grits to leaves); (2) mistblower application of phytoseiids mixed with corn grits with water setting on 1.0 (provided a coarse spray); and (3) 4-point hand-release of predators into 10 paper cups placed evenly around trees at shoulder height. Each release strategy used about 19,000 predators and all treatments were compared to control trees that were not treated with *N. californicus* to determine naturally occurring densities of this predator on experimental trees. The mistblower successfully dispensed viable *N. californicus* mixed with corn grits onto avocado trees. Predators on trees treated with the mistblower were recovered in the field up to 16 days post-application. However, 5-fold higher levels of *N. californicus* were recovered from hand-release applications. These tests on artificial trees and avocado trees demonstrated the potential of the mistblower for field applications of viable phytoseiids for control of spider mites on trees.

Key words - Phytoseiidae, *Neoseiulus californicus* (McGregor), *Oligonychus perseae* Tuttle, Baker, and Abbatiello, mechanical release, avocado, USA.

INTRODUCTION

Oligonychus perseae Tuttle, Baker, and Abbatiello (Acari: Tetranychidae), has been a pest in southern California avocado orchards since 1990 (Bender, 1993). Large populations of *O. perseae* can defoliate avocado trees, resulting in premature fruit drop or sunburn to exposed tree trunks (Bender, 1993). In addition, defoliation is often followed by a growth flush of new leaves, which may promote population outbreaks of another pest species, *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae), that utilizes young leaves for feeding and oviposition (Hoddle *et al.*, 1999).

Oligonychus perseae feeds on the undersides of avocado leaves in silk nests and necrotic spots are characteristic symptoms of feeding damage. Nests are typically found along leaf midribs or veins and mites aggregate within nests where they feed and reproduce (Aponte and McMurtry, 1997).

Potential biological control agents for *O. perseae* have been identified. Both *Neoseiulus californicus* and *Galendromus helveolus* (Chant), which are commercially available, have demonstrated an ability to suppress *O. perseae* densities to levels comparable to those achieved with refined insecticidal oils (Kerguelen and Hoddle, 1999; Hoddle *et al.*, 2000). Of these two species, *N. californicus* presents itself as a more practical biological control agent because it is less expensive to purchase from commercial insectaries and has high activity levels that result in higher rates of prey encounter (Pratt *et al.*, 1998; Takano-Lee and Hoddle, 2000). However, only hand-releases of these phytoseiid species have been investigated, and though successful, hand-releases are labor-intensive, time-consuming, and only a narrow band within the tree canopy is initially inoculated. Mechanical dispensation may uniformly distribute phytoseiids in canopies and at heights not easily achieved with hand-releases (Hoddle *et al.*, 2000). Increased tree canopy distribution of natural enemies through mechanized releases may enhance predator efficacy and reduce numbers of predators that need to be purchased and released, as predators would not have to disperse from a narrow release zone to provide canopy-wide pest suppression as is the case with hand releases.

Mechanical distribution of predaceous insects and mites has been accomplished through a variety of methods (Ables *et al.*, 1979; Sargent, 1998). Sprayers and hand-held atomizers have been used to dispense lacewing eggs (Sengonca and Lochte, 1997), tractor-mounted mechanical systems have distributed predator mites onto row crops (Giles *et al.*, 1995), and aerial dispensing methods have been used to release phytoseiids in classical and augmentative biological control programs (Pickett *et al.*, 1987; Herren *et al.*, 1987; Drukker *et al.*, 1993).

Several factors may be important in achieving successful pest control with mass-release of natural enemies with mechanical dispensers. These factors include: (1) optimal frequency, timing, and rate of application of predators against target pests; (2) adequate packaging and storage of predators prior to and during release to maintain viability; (3) efficient mechanical distribution that does not reduce predator efficacy; and (4) ease of use of equipment in the field (Glenister and Hoffman, 1998). For *O. perseae* control with *N. californicus*, factors 1 and 2 have been determined (Hoddle *et al.*, 1999; Kerguelen and Hoddle, 1999; Hoddle *et al.*, 2000). Factors 3 and 4 have not been studied due to a lack of equipment designed specifically to dispense phytoseiids onto perennial tree crops like avocados. Mechanical dispensing of predator mites has the potential to facilitate predator releases into tree canopies if the mechanized system is designed to minimize damage and mortality to predators. Here we report on the feasibility and practicality of mechanically dispensing *N. californicus* onto artificial trees and actual avocado trees with a modified backpack mistblower equipped with a novel prototype dispensing unit. The mistblower we used is commercially available and utilized by avocado growers to apply pesticides.

During the course of orchard evaluations of mistblower predator applications, we also recorded the vertical population distribution of the naturally occurring predators, *Euseius hibisci* (Chant) and *Galendromus annectens* (De Leon), as well as that of *O. perseae* in avocado trees.

MATERIALS AND METHODS

Mistblower description - A single cylinder 2-stroke Stihl SR 400 engine mistblower was modified for use in our experiments (Fig. 1). The mistblower weighs 11 kg (without water), is carried on the applicator's back, and has a 13 liter water reservoir. The mistblower was chosen for its aerosolized water application method, which, when coupled with a strong airflow, can transport small moistened particles in the airstream for long distances. When the finger-operated trigger is pulled, the engine can create airflow up to 655 m^3/h, with a range of 20 m. The mistblower has six water settings, ranging from 1 (lightest) to 6 (heaviest). We used an alternate water setting of 0.5, in which the stop cock controlling a full-release at a water setting of 1.0 was placed only halfway. Water flowed from the reservoir through a hose and was continuously released just behind the applicator nozzle prior to the airstream exiting the barrel. The fine layer of mist produced by the sprayer was expected to facilitate adhesion of predator mites mixed with corn grits to leaves by temporarily trapping them until the aerosolized water evaporated.

Mechanized phytoseiid dispensing unit - Phytoseiids were placed in a clean plastic 0.5 liter bottle that was inverted and screwed into a plastic platform placed 20 cm from the end of the mistblower spray nozzle; this platform remained stationary at all times. Beneath the plastic platform was a moving plate that contained an oblong aperture (1 cm diameter for the artificial tree trial and enlarged to 2 cm (length) x 1 cm (width) for actual avocado tree trial). A metered measuring device, powered by a 9-volt battery, was electronically connected to the engine's throttle trigger. When the throttle was pulled to accelerate the sprayer's engine, the metering device moved the inverted bottle, dispensing aliquots of predators and corn grits (0.46 ml of corn grits for the artificial tree trial, 1.2 ml of corn grits and predators for the avocado tree trial) through the oblong aperture in the bore of the mistblower nozzle hosing. An extension tube (diam = 1 cm; height = 5 cm) attached to the oblong aperture protruded into the bore of the nozzle hosing and dispensed material passed through the tube into the airstream. This extension tube was necessary to introduce predators and corn grits into the air stream and to minimize particle blow through out of the entrance aperture as air moved through the nozzle hosing to exit the barrel.

Air-propelled particles were coated with a fine mist of water prior to exiting the nozzle hosing in the airstream.

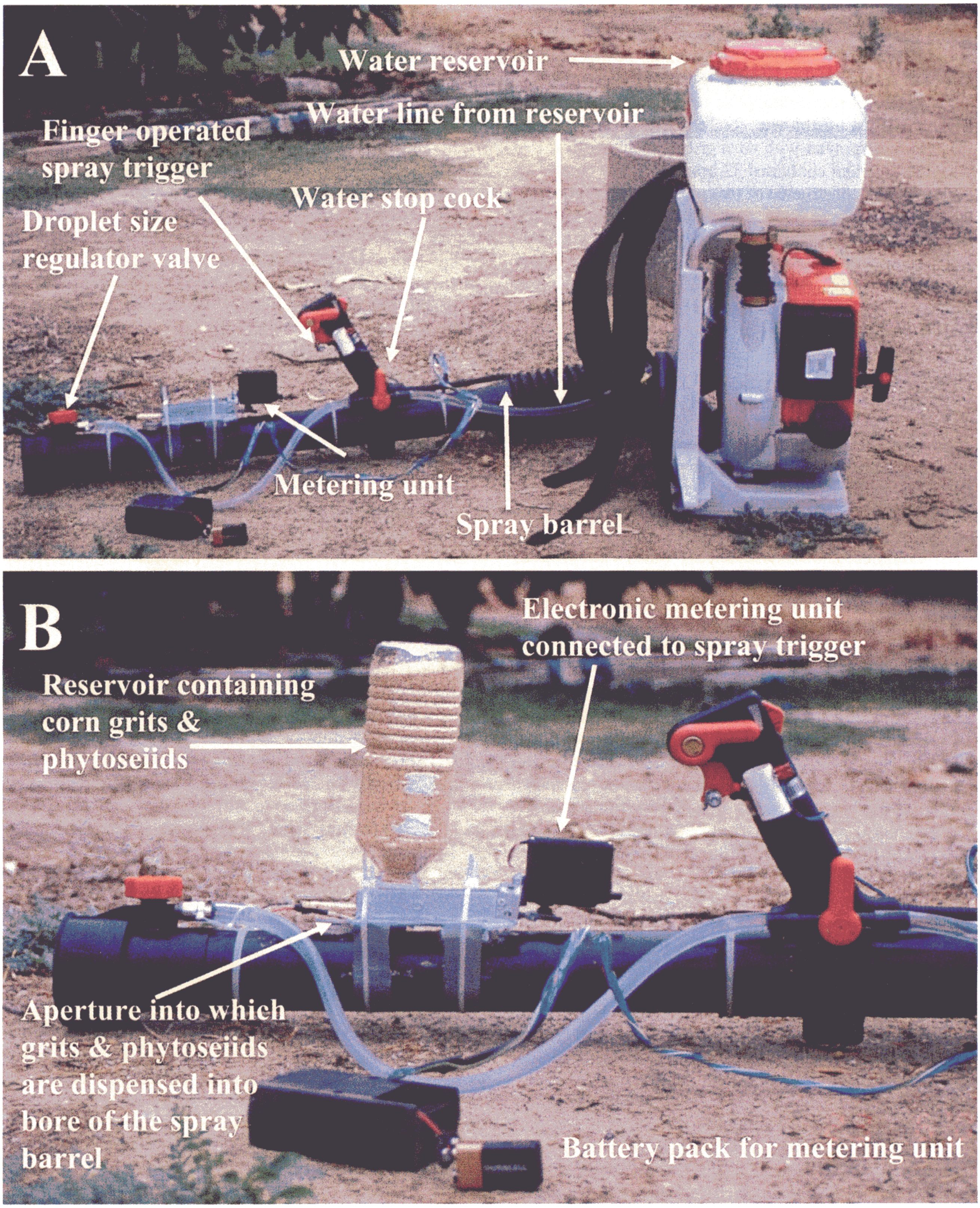

Fig. 1. Stihl SR400 mistblower modified for applying phytoseiids to avocado trees (A) and the prototype electronic metering unit attached to the mistblower (B).

Water vapor density or wetness was controlled with a water regulator valve that released water into the airstream. We ran our trials on water vapor setting number 1, which dispensed approximately 130 ml water/min.

Artificial tree trials - To test the dispersal pattern of the modified mistblower, four artificial trees were constructed and sprayed with corn grits. Each artificial tree was 4 m high and contained 32 branches. The "trunk" of each tree was constructed of two pieces of interconnected PVC conduit tubing (2.5 cm diameter). "Branches" were wooden dowels (90 cm length, 0.8 cm diameter) inserted into drilled holes placed at 90° angles at every 0.5 m interval along the PVC conduit tubing. The PVC pipe was placed in a hollow concrete brick (15 x 15 x 20 cm) and filled with concrete. The four trees were arranged in a square so that they were close, but not in direct contact with one another to produce a three-dimensional "tree".

Two double-sided white sticky cards (19.5 x 16 cm) were secured to each branch with twist-ties and binder clips. Two single-sided sticky cards on top of 1 m stakes were placed at 1.5 and 3.0 m intervals from the base of the trees in each cardinal direction, to monitor blow-through of corn grits (i.e., corn grits that were not trapped on sticky cards attached to branches).

Commercial insectaries supply 1000 *N. californicus* in plastic vials with about 45 ml of corn grits. We dispensed 270 ml of corn grits with the mistblower to simulate the release of 6,000 predators onto the artificial tree. Corn grits were dispersed by walking around and spraying the four artificial trees at a 1 m distance, until all grits were released. Sticky cards were labeled, removed from branches, placed in clear plastic bags, and returned to the laboratory. The mean number of corn grits trapped on each sticky card at each height placement was determined. The number of corn grits on sticky cards was compared between tree branch heights after transforming the data [square-root (x+1)] and analyzing it with ANOVA. Statistical significance was determined at the 0.05 level with Tukey's Studentized Range test.

Wind speed and direction at time of application was measured with a Dwyer wind meter (Dwyer Instruments Inc., Michigan City Indiana, USA).

Predator release treatments - Mechanical releases of *N. californicus* were conducted in an avocado orchard ("Hass" variety) in Irvine California, USA. Seventeen trees, 3.0 m in height, were selected for predator releases. Four treatments were tested: (1) mistblower application of predators with water setting on 0.5 (n = 4 trees); (2) mistblower application of phytoseiids with water setting on 1.0 (n = 5 trees); (3) 4-point hand-release of predators (n = 4 trees). The hand-release method consisted of pouring the contents of vials (*N. californicus* and carrier grits) into ten 104 ml paper cups that were distributed symmetrically at 4 release points around the periphery of the tree canopy. Two or three cups were fastened to branches in each quadrant of the tree canopy with binder clips and cups remained on trees until the conclusion of the experiment, and (4) control (no *N. californicus* released) (n = 4). The mistblower application technique was described in the previous section.

Predator quality control - The quantity of *N. californicus* in vials received from a commercial insectary (Biotactics, Perris California, USA) was verified before release. From each of three vials containing *N. californicus* and corn grits, five aliquots of 1.25 ml (i.e., ¼ teaspoon) were removed and placed on a white sheet of paper. The number of motile *N. californicus* was counted in each of fifteen 1.25 ml aliquots. By determining the average number of *N. californicus* per 1.25 ml aliquot at 53.6 ± 2.0, a release of about 19,000 *N. californicus* (in 225 ml of corn grits) was made per tree. Large numbers of phytoseiids were released to facilitate the likelihood of predator recovery to provide data for evaluations. Predators were released in the field 17 h after the quality control check.

Assessing predator releases - Twenty mature avocado leaves were randomly collected from three different strata within the canopy, these being: the lower (0.0-1.0 m), middle (1.0-2.0 m), and upper (2.0-3.0 m) thirds of each experimental tree. A total of 60 leaves per tree per sampling period was collected. Leaves within the upper-third strata were collected with the aid of a 2 m pole pruner. Collections of leaf samples for each of the four treatments were made 5 min, 1 d, 3 d, 8 d, and 16 d post-release of phytoseiids. Leaves from each experimental tree by stratum were placed in labeled bags, returned to the laboratory, and examined for predators. All phytoseiids found on leaves were slide-mounted in Hoyer's solution and identified to species.

Data analysis for leaf counts - Phytoseiid counts by species were square-root (x+1) transformed prior to comparison of sampling interval, stratum, and treatment types by ANOVA. Tukey's Studentized Range test was conducted to determine effect at the 0.05 level of significance. Significance of interactions between stratum, treatment, and sampling interval were determined with a general linear ANOVA and testing at the 0.05 level of significance.

Blow-through monitoring - To measure blow-through of grits (i.e., corn grits with predators that passed through the tree canopy without adhering to sticky cards) and *N. californicus*, eight white sticky cards on stakes 1.0 m high were placed at distances of 3.0 and 6.0 m in each cardinal direction from each experimental tree treated with the mistblower.

Monitoring ground dispersal of *N. californicus* - Preliminary experiments had demonstrated that an unquantified volume of corn grits would not adhere to leaves and would fall to the bases of trees. We sought to quantify dispersal of *N. californicus* from the ground by monitoring (1) phytoseiid presence within the ground cover beneath experimental trees and (2) directional movement of phytoseiids upward or downwards on the trunks of experimental trees. At 1 d and 3 d post-treatment, about 600 ml samples of ground cover were removed from beneath each experimental tree. Samples were placed in Berlese funnels and heated with a 40-watt bulb for 4 days. Specimens recovered from Berlese extractions were collected in 70% ethyl alcohol. Recovered phytoseiid mites were slide-mounted in Hoyer's solution and identified to species.

After approximately 5 min postpredator application, half of the trees for each of the four treatments were wrapped with two pieces of double-sided sticky carpet tape (Manco Inc., Avon, Ohio, USA), to monitor upward and downward movement of *N. californicus*. After 16 days, carpet tapes were removed and examined for *N. californicus*. Phytoseiids adhered to carpet tape were removed by dissolving the adhesive with WD-40 (WD-40 Company, San Diego California, USA) before being slide-mounted in Hoyer's solution and identified to species.

Distribution and abundance of *Euseius hibisci* and *Galendromus annectens* - All phytoseiid predators were removed from collected leaves, slide-mounted in Hoyer's solution, and identified to species. Statistical analysis comparing the distribution of *E. hibisci* and *G. annectens* in the three tree strata was performed with ANOVA after square-root (x+1) transformation. All experimental trees across sampling intervals were pooled for analysis of strata distribution of *E. hibisci* and *G. annectens*.

Distribution and abundance of *O. perseae* - In addition to collecting phytoseiid predators, the number of motile *O. perseae* and eggs were recorded and compared across each sampling interval and strata. Data were square-root transformed (x+1) before analysis with ANOVA. All experimental trees at each sampling interval were pooled for analysis of strata distribution of *O. perseae*.

Temperature, humidity, and wind monitoring - Temperature and relative humidities in the orchard were recorded from day 1 to day 16 of the experiment in the canopy of an untreated tree every 30 min with a HOBO Data Logger (Onset®, Bourne Massachusetts, USA). Wind speed and direction at time of mechanical application of phytoseiid mites were determined with a Dwyer anemometer.

RESULTS

Artificial tree trials - When this trial was run, the wind was blowing in a north-northeast direction at 6-10 km/hr. Consequently, the wind carried corn grits past artificial trees onto the two north-direction sticky cards measuring blow through (1.5 m = 172 grits; 3.0 m = 283 grits). All other directional cards that measured blow-through had a mean of 3.2 ± 1.9 grits (range = 0-12 grits).

Mechanical application of 270 ml corn grits being dispensed in 0.46 ml aliquots required 15-20 min to spray onto artificial trees. Dispersal of corn grits on sticky cards on artificial trees varied slightly; most sticky cards received similar amounts of corn grits (77.8 ± 3.3 grits; range = 0-360 grits) except those placed at 0.5 m height (mean = 41.2 ± 5.5), which received significantly fewer corn grits than branches at 1.5-3.5 m (F = 6.52; df = 7, 421; $P < 0.05$) (Fig. 2).

Table 1. Numbers of recovered predators from avocado leaf samples.

Treatment	Phytoseiid Status	Total No. Predators	*Euseius hibisci*	*Galendromus annectens*	*Neoseiulus californicus*
Control	Live	216	196	13	7
	Dead	14	14	0	0
Mistblower application (water setting = 0.5)	Live	177	119	20	38
	Dead	16	12	1	3
Mistblower aplication (water setting = 1.0)	Live	266	183	20	63
	Dead	23	16	3	4
Hand-release	Live	396	154	24	218
	Dead	18	12	0	6
Total	Live	1055	652	77	326
	Dead	71	54	4	13
Total across all treatment classes		1126	706	81	339

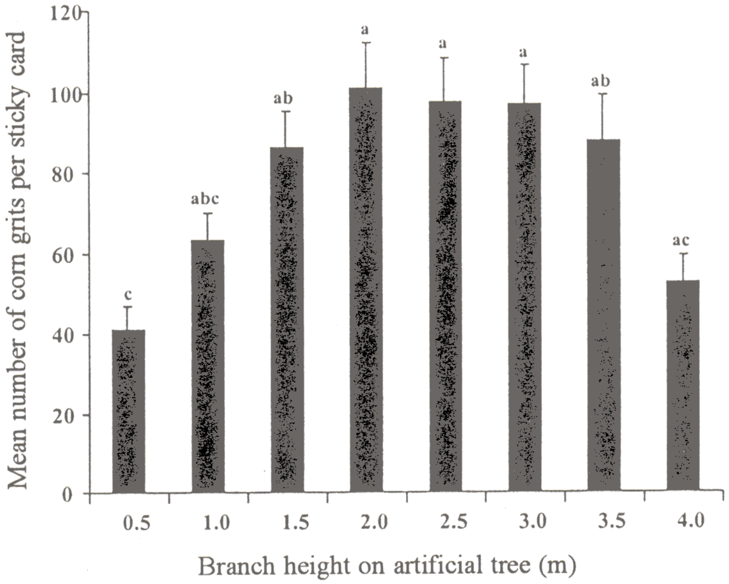

Fig. 2. Mean number (± SEM) of corn grits per sticky card at various heights on artificial trees.

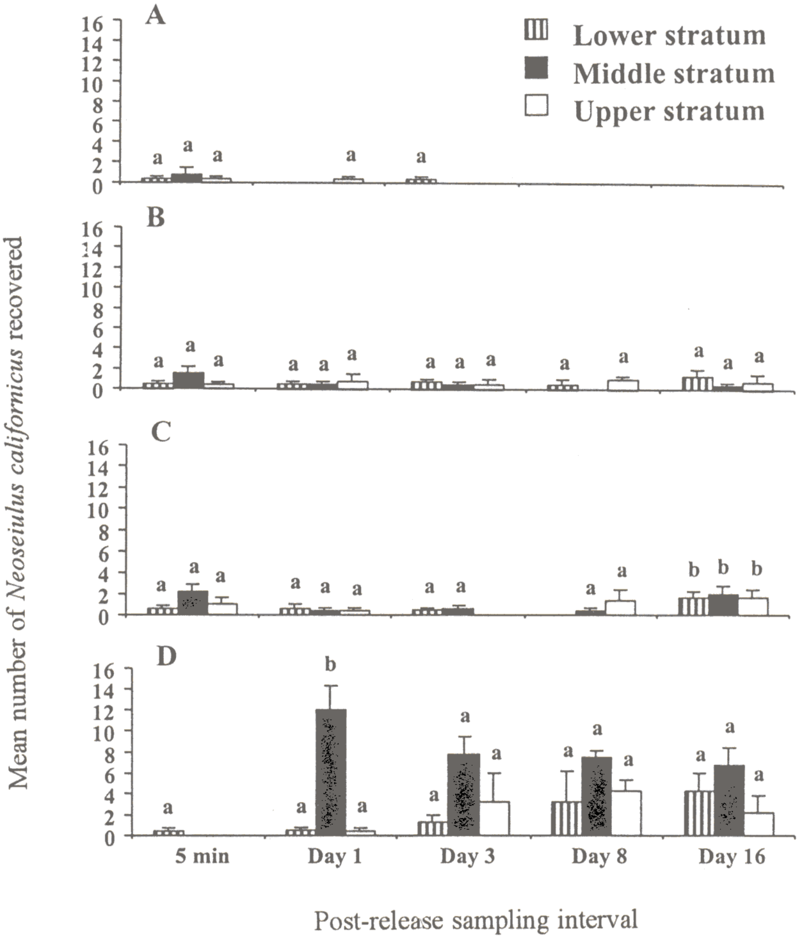

Fig. 3. Mean number (± SEM) of *Neoseiulus californicus* recovered per strata and sampling interval per 20 leaves for control trees: no treatments (A), mistblower application water setting 0.5 (B), mistblower application water setting 1.0 (C), and 4-point hand-release (D).

Table 2. Mean number (± SEM) of corn grits caught on sticky cards 1 m above ground level at 3.0 and 6.0 m intervals from the base of avocado trees receiving mechanical applications of *Neoseiulus californicus*.

Treatment	Distance from tree	
	3.0 m	6.0 m
Mean number of grits at 0.5 water setting	4.19 ± 1.96	0.56 ± 0.30
Mean number of grits at 1.0 water setting	4.05 ± 2.26	0.25 ± 0.20

Predator release treatments on avocado trees - Mechanical application of about 19,000 predator mites (dispensed in 225 ml corn grits) required 18-20 min application time per tree. A total of 339 *N. californicus* were collected from all leaf samples across all treatments, over the 16 days following *N. californicus* release (Table 1). Of those *N. californicus* recovered, 108 (32%) were collected from the 9 trees receiving mechanically-dispersed mites, 224 (66%) were from hand-release trees and 7 (2%) were collected from control trees. On mechanically-treated trees, 94% of *N. californicus* were recovered alive. On hand-release trees, 97% of released predators recovered were alive at time of collection. *Euseius hibisci* was the most common phytoseiid collected (Table 1).

Differences within treatments - No significant differences existed in number of *N. californicus* recovered within the control treatment for the various strata levels (F = 0.26; df = 2, 9; *P* = 0.78) [5 min], F = 1.00; df = 2, 9; *P* = 0.41 [day 1], F = 1.00; df = 2, 9; *P* = 4.1 [day 3], F = N/A [counts all zeroes] [day 8], F = N/A [counts all zeroes] [day 16]), different sampling days (F = 1.89; df = 4, 55; *P* = 0.13), or between the three strata over the entire experiment (F = 0.02; df = 2, 33; *P* = 0.98 (Fig. 3A).

There were no significant differences within the mistblower application (water setting = 0.5) for the number of *N. californicus* mites collected between the different strata on each sampling day and F = 2.15; df = 2, 9; *P* = 0.17 [5-min]; F = 0.02; df = 2, 9; *P* = 0.98 [day 1]; F = 0.24; df = 2, 9; *P* = 0.79 [day 3]; F = 0.59; df = 2, 9; *P* = 0.19 [day 8]; and F = 0.59; df = 2, 9; *P* = 0.57 [day 16]), the number of predators collected on different sampling days (F = 0.14; df = 4, 55; *P* = 0.97, respectively), or the number of predators collected between the three strata over the entire experiment (F = 0.16; df = 2, 57; *P* = 0.86) (Fig. 3B).

or the number of predators collected between the three strata over the entire experiment (F = 0.16; df = 2, 57; *P* = 0.86) (Fig. 3B).

The mistblower application at the water setting of 1.0, however, yielded significantly greater recovery of *N. californicus* mites on day 16 than on days 1, 3, or 8 (F = 5.10, df = 4, 70; *P* < 0.005) (Fig. 3C).

In contrast, the number of phytoseiids collected from hand-release treated trees had significantly greater levels of *N. californicus* recovery on day 1 within the middle strata versus the lower and upper strata (F = 46.94; df = 2, 9; *P* < 0.005) but not on any other day postrelease (Fig. 3D). Over all sampling intervals, the number of pooled *N. californicus* collected from the middle strata of hand-release trees was significantly greater than collections from the lower or upper strata (F = 4.17; df = 4, 55; *P* < 0.005). Significantly more *N. californicus* were recovered at days 3, 8, and 16 than immediately after application (post-5-min), independent of strata (F = 4.17; df = 4, 55; *P* < 0.005).

Differences between treatments - Significantly greater numbers of *N. californicus* were recovered from hand-release trees across all strata than either of the mechanical applications or control trees. More *N. californicus* were recovered from mistblower application (water setting = 1.0) than control trees (F = 29.58; df = 3, 251; *P* < 0.005) (Fig. 4). Overall, releasing *N. californicus* by hand resulted in recovery of more than 4-fold, 5-fold, and 31-fold as many predators per tree than the 0.5 and 1.0 water settings and control applications, respectively (Fig. 4).

Table 3. Mean number (± SEM) of corn grits landing on sticky cards placed 1.0, 2.5, and 4.0 m high above ground level and 3 m from center of each experimental avocado tree, in each cardinal direction, receiving mechanical applications of *Neoseiulus californicus*.

Treatment	Height		
	1.0 m	2.5 m	4.0 m
Mean number of grits at 0.5 water setting	7.25 ± 4.61	60.25 ± 56.93	1.75 ± 0.85
Mean number of grits at 1.0 water setting	26.6 ± 24.13	1.00 ± 0.55	0.80 ± 0.80

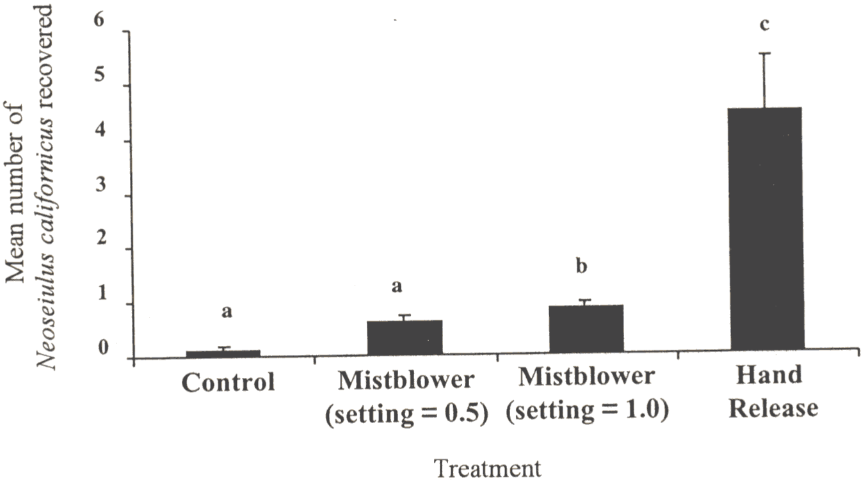

Fig. 4. Mean number (± SEM) of *Neoseiulus californicus* recovered per 60 leaves per treatment.

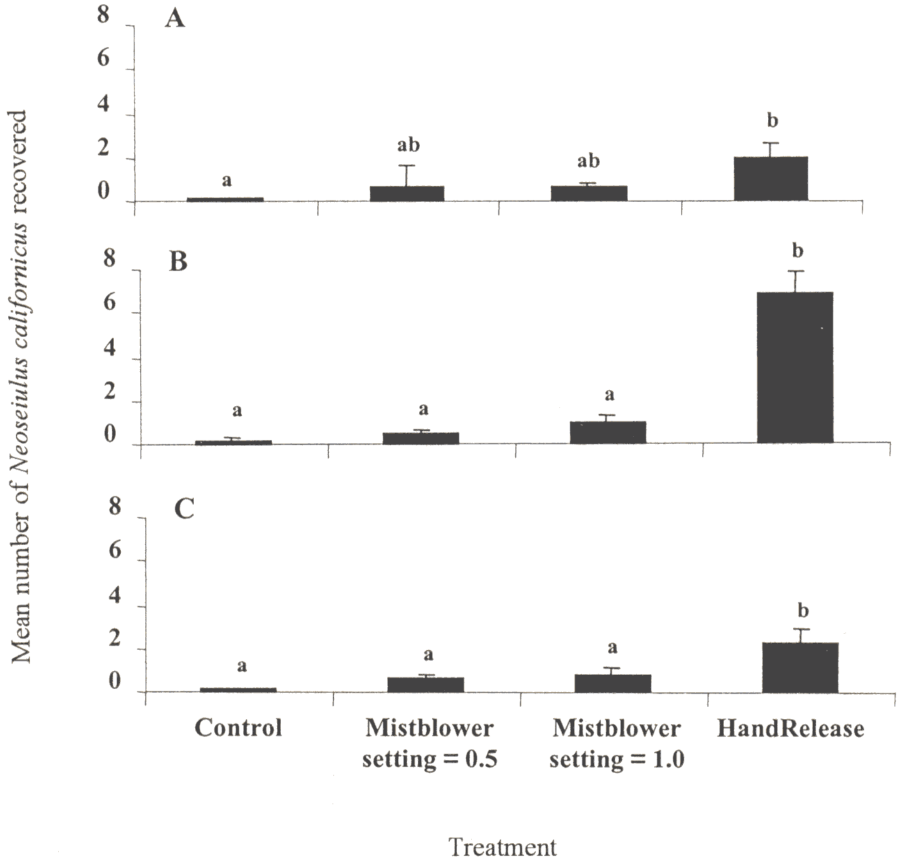

Fig. 5. Mean number (± SEM) of *Neoseiulus californicus* recovered per 20 leaves per treatment for lower strata (A), middle strata (B), and upper strata (C).

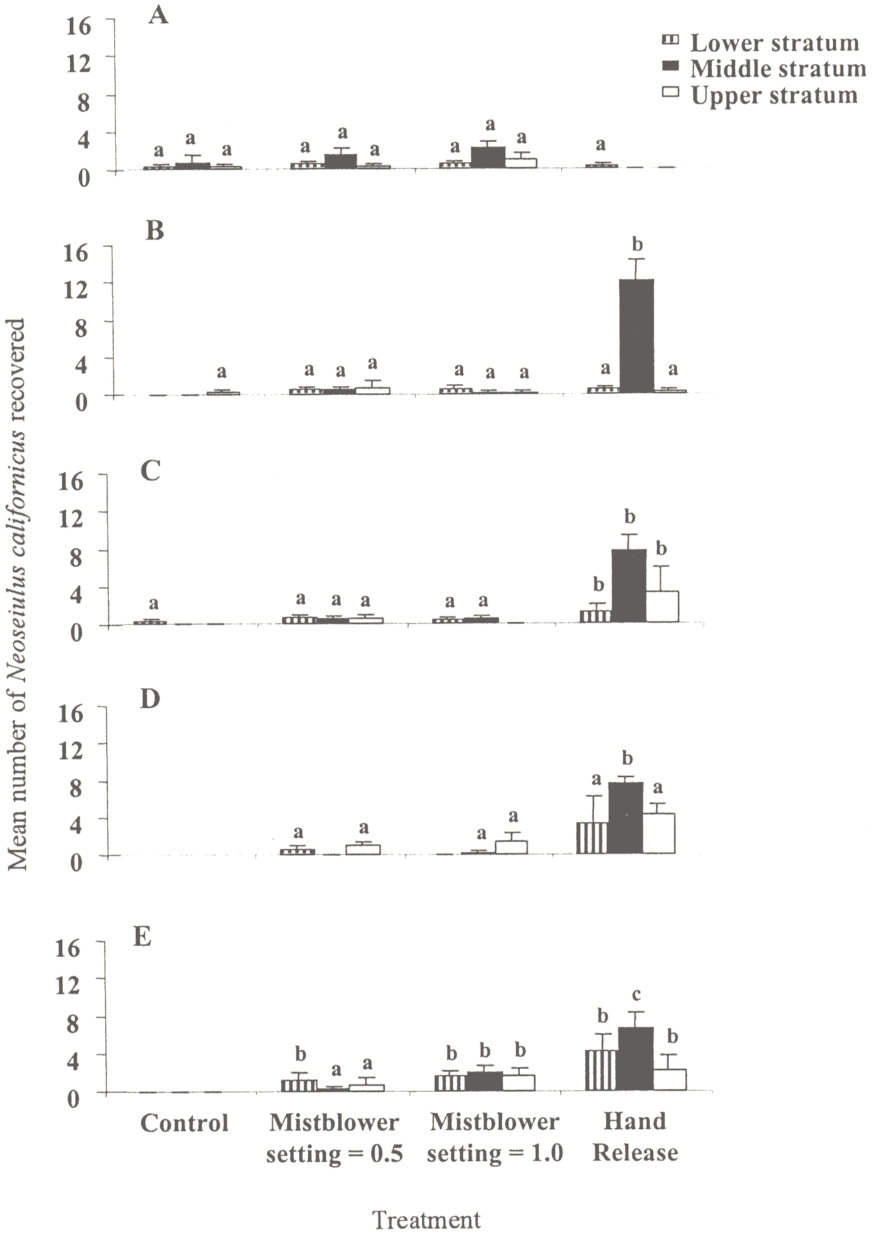

Fig. 6. Mean number (± SEM) of *Neoseiulus californicus* recovered per 20 leaves per stratum; 5-min post-release (A), day 1 (B); day 3 (C); day 8 (D); day 16 (E) post-release.

Mean numbers of *N. californicus* collected from hand-release trees were significantly greater than those from control trees for lower strata (F = 4.51; df = 3, 81; $P < 0.05$) (Fig. 5A) and upper strata (F = 4.38; df = 3, 101; $P < 0.05$) (Fig. 5C). Significantly more *N. californicus* were collected from middle strata on hand release trees (F = 23.43; df = 3, 101; $P < 0.005$) (Fig. 5B).

There were no significant differences for *N. californicus* collected between strata and various treatments at 5-min postapplication (Fig. 6A). However, the hand-release method was particularly effective within the middle stratum; the number of *N. californicus* recovered at day 1 (Fig. 6B) and 8 (Fig. 6D) were all significantly greater than all other treatments (F = 54.34; df = 3, 13; $P < 0.005$ and F = 43.33; df = 3, 13; $P < 0.005$, respectively. On day 3 (Fig. 6C), significantly more *N. californicus* were recovered from trees receiving hand-release applications than all other application types, at the lower (F = 6.82; df = 3, 13; $P < 0.05$), middle strata (F = 24.12; df = 3, 13; $P < 0.005$), and upper strata (F = 3.43; df = 3, 13; $P < 0.05$). On day 16 (Fig. 6E), the hand-release was also more effective than the other treatments, but the mistblower application (water setting = 1.0) was also significantly more effective than the other mistblower application

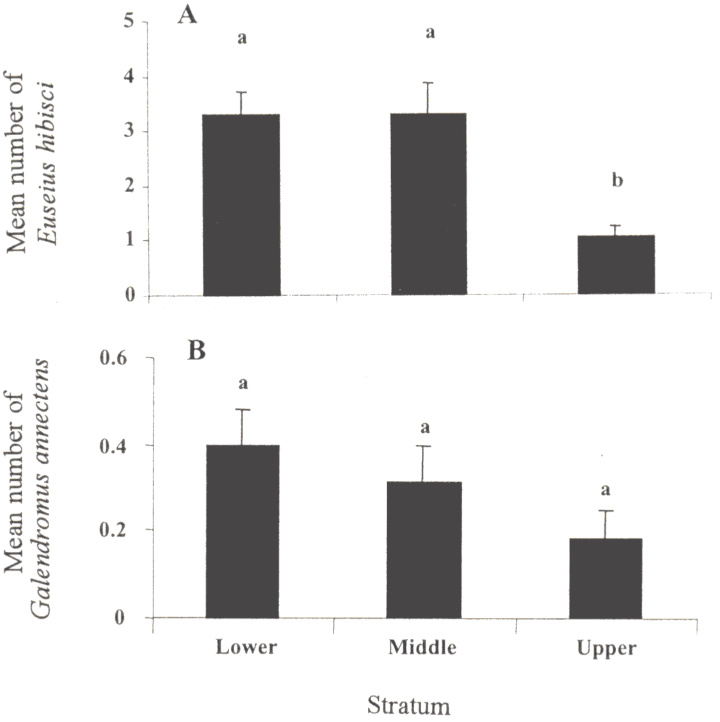

Fig. 7. Mean number (± SEM) of *Euseius hibisci* (A) and *Galendromus annectens* (B) within strata of avocado trees.

(water setting = 0.5) and the control within the middle strata (F = 36.88; df = 3, 13; $P < 0.005$), but within the upper strata, the efficacy of hand-releases was comparable to one of the mistblower applications (water setting = 1.0) but significantly greater than the mistblower application (water setting = 0.5) and the control (F = 5.81; df = 3, 13; $P < 0.005$). On this last day (Fig. 6E), significantly more *N. californicus* were recovered from the lower strata of hand-release treated trees than any other treatment (F = 4.14; df = 3, 13; $P < 0.05$).

Blow-through monitoring - Sticky cards trapped 7.5 - 16 times more grits at 3.0 m from avocado trees treated with mistblower application than at 6.0 m (Table 2). One *N. californicus* was found on a single sticky card 3.0 m east of one experimental tree and 42% of deployed sticky cards trapped corn grits.

Though not statistically significant, more grits were caught on sticky cards 2.5 m above the ground for the mistblower applications with 0.5 water setting (F =0.92; df = 2, 9; $P = 0.43$). and more corn grits (F = 1.39; df = 2, 12; $P = 0.29$) were caught 1.0 m above ground when water setting was 1.0 (Table 3).

Monitoring ground dispersal of *N. californicus* - Some *N. californicus* were found in Berlese samples. Two *N. californicus* were found from day 1 samples (one each at mistblower application at water setting = 0.5 and 1.0) and one was recovered from a day 3 sample (mistblower application at water setting = 0.5). One *N. californicus* was found on the carpet tape (water setting = 0.5). There were no significant differences in the numbers of *N. californicus* recovered from leaves on trees bearing carpet tape to trap *N. californicus* and those that did not have carpet tape (F = 0.57; df = 1, 138; $P = 0.45$). Vertical colonization of trees by *N. californicus* landing on the ground after mechanical release was insignificant.

Distribution and abundance of *Euseius hibisci* and *Galendromus annectens* - Significantly more (F = 14.76; df = 2, 252; $P < 0.005$) *E. hibisci* were collected from lower and middle strata in comparison to upper strata of avocado trees (Fig. 7A). There was no significant difference between *G. annectens* collection within the lower, middle, or upper strata (F = 2.39; df = 2, 252; $P = 0.09$) on experimental trees (Fig. 7B).

Distribution and abundance of *O. perseae* - There were no significant differences between strata for densities of *O. perseae* motile stages (F = 0.59; df = 2, 252; $P = 0.56$) (Fig. 8A) or eggs (F = 1.12; df = 2, 252; $P = 0.33$) (Fig. 8B). Distribution of *O. perseae* appears to be relatively uniform, as no tree height preference by life stage was observed.

Temperature, humidity, and wind monitoring - Daily minimum and maximum temperatures were relatively stable during this experimental period, each varying less than 6 °C. Minimum daily relative humidities varied by less than 11%, but maximum relative humidities were consistently 100% (Fig. 9).

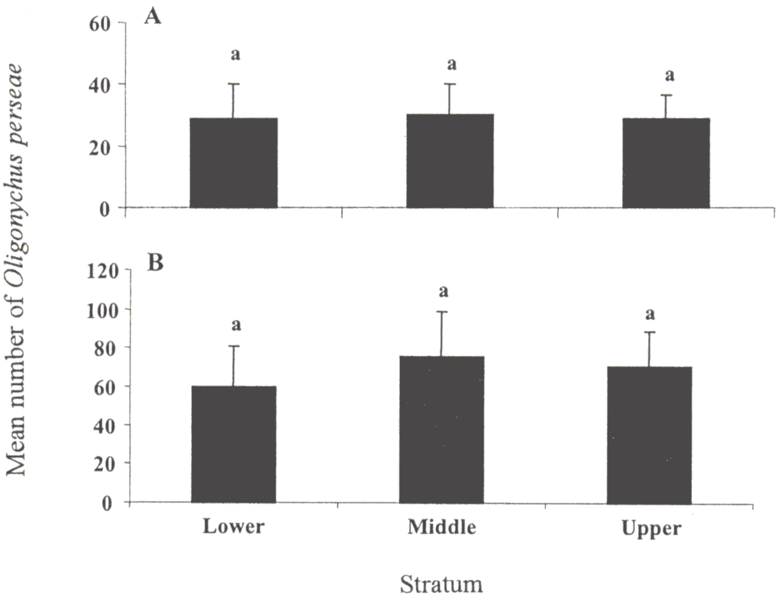

Fig. 8. Mean number (± SEM) of *Oligonychus perseae* motiles (A) and eggs (B) within strata of avocado trees.

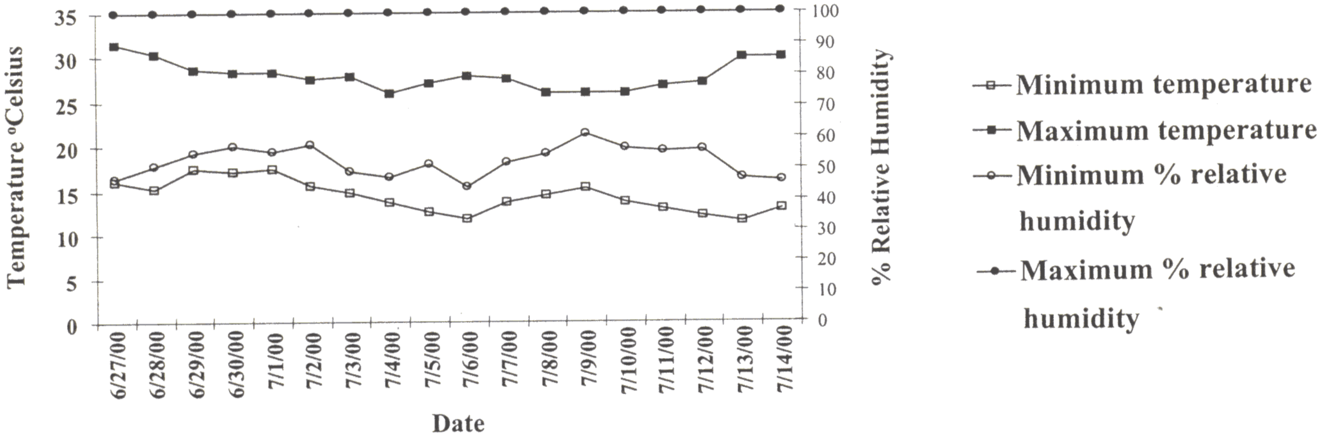

Fig. 9. Mean daily maximum and minimum temperatures and % relative humidities in the canopy of an avocado tree over June 26 to July 14, 2000.

DISCUSSION

The modified mistblower mechanically dispensed corn grits with a biased distribution that favored heights around the center of the artificial tree. Corn grits adhered to sticky cards indicated that the modified mistblower was able to spray grits vertically to distances ≥ 4-m in height and horizontally beyond trees to distances ≥ 6 m.

Our data indicate that the hand-release method is still superior to mechanical application by a modified mistblower equipped with the current dispensing technology for releasing *N. californicus* onto avocado trees. Only after one sampling interval (5 min postapplication) did the 1.0 m water setting produce significantly greater numbers of recovered *N. californicus*. Though hand-releases did result in higher numbers of recovered *N. californicus* within the middle strata of avocado trees, the differences between strata decreased over time. Distribution of hand-released *N. californicus* reached uniform levels throughout experimental trees, 1 to 3 days post-release.

Mechanical applications of *N. californicus* at both water settings resulted in recoveries of this predator more frequently than control trees over the course of this experiment, thereby illustrating that mechanical application of phytoseiids to inoculate avocado trees is possible.

The differences in numbers of *N. californicus* recovered between the two mistblower mechanical applications (water settings = 0.5 and 1) were insignificant although slightly greater numbers were recovered from trees treated with water setting = 1.0. Given the low numbers of *N. californicus* recovered on avocado trees following mechanical application, it is possible that it might be necessary to use a greater volume of water, (i.e. water valve setting = 2 or 3) in order to increase the number of predators adhering to leaves.

Water setting 0.5 resulted in corn grit deliveries being concentrated at heights around 2.5 m while grits saturated with more water (setting 1.0) were concentrated around 1.0 m. Increasing the volume of water into which grits and phytoseiids are blown may result in fewer predators being delivered to the middle and top of trees because of increased particle weights due to moisture. Furthermore, it is possible that increasing the volume of applied water to facilitate increased predator adhesion may cause increased mortality of *N. californicus* by drowning. Differences in corn grit delivery heights may have been affected by tree variability, small sample sizes, and spray applicator skill.

Mechanical dispensing of *N. californicus* combined with the unregulated airspeed of the mistblower may have resulted in predator mortality because of lethal concussion upon impact with leaves and branches. Predators may also be unable to adhere to leaves after application and subsequently fall to the ground, or *N. californicus* may drop out of the airstream before reaching trees because it is lighter than the corn grits with which it is mixed.

In the avocado tree trial, the canopy prevented most of the corn grits and possibly *N. californicus* from blowing through to nearby areas and trees. Differences in leaf densities between tree canopies will affect blowthrough rates of corn grits and phytoseiids. Though many corn grits adhered to leaves in a surface film of water, an unquantified volume of moist corn grits fell beneath the tree canopy after colliding with leaves, indicating that in some instances wetness provided by the blower was insufficient to cause corn grits, and presumably phytoseiids, to adhere to leaves irrespective of the water setting used. Low numbers of *N. californicus* (3 total) from ground cover immediately beneath trees receiving mechanically dispensed phytoseiids suggested that some predators were being dispensed beneath trees either directly, by failing to adhere to leaves, or prematurely dropping out of the airstream before being delivered to trees. However, Berlese surveys and carpet tape trapping results were biased in favor of recovering only live phytoseiids that can react to heat (Berlese extraction) or exhibit vertical ambulatory movement (carpet tape trapping). Neither the Berlese nor carpet tape data suggest that live *N. californicus* were actively colonizing avocado trees from the ground following mechanical application.

The modified Stihl mistblower dispensed viable *N. californicus* onto avocado trees, and live predators were recovered immediately post-release and up to 16 days later. Approximately 5.7- and 4.3-fold more *N. californicus* were recovered from hand-release applications than either mistblower application of water setting = 0.5 and 1, respectively. The reasons for lower dispensing efficacy with the modified mistblower have not been elucidated, and hand-releases were less time-consuming than mistblower applications (10.5 ± 2.1 versus 19.3 ± 1.3 min to release 19,000 phytoseiids, respectively) using the current electronic dispensing unit.

Euseius hibisci, a type IV specialized pollen-feeding phytoseiid (McMurtry and Croft, 1997), was most common in the lower-middle strata of avocado trees. Densities of *E. hibisci* may have been greater here because of accumulations of wind-borne pollen grains on lower leaves. *Galendromus annectens*, on the other hand, was uniformly distributed in the avocado canopy, suggesting it may have been responding to the uniform canopy-wide distribution of *O. perseae,* which is potential prey for this phytoseiid. The uniform distribution of *O. perseae* motiles and eggs in the tree canopy emphasize the need to be able to uniformly and quickly distribute natural enemies when making augmentative phytoseiid releases against this pest.

The modified mistblower demonstrated that there is potential for mechanically applying *N. californicus* to avocado trees. However, the time required to mechanically treat each tree with the current technology is almost twice as long as hand-releases. Treatment times per tree could potentially be reduced by increasing the volume of predators released by the metering device into the bore of the mistblower hosing. Further work is required to quantify predator mortality rates via concussion, drowning, falling prematurely from the airstream, or blowthrough following mechanical application to trees. Results of mortality studies may necessitate redesign of the dispensing unit and application technology for applying phytoseiid mites to trees with a modified mistblower.

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REFERENCES

Ables, J.R., B. G. Reeves, R. K. Morrison, R. E. Kinzer, S. L. Jones, R. L. Ridgway and D. L. Bull. 1979.

Methods for the field release of insect parasites and predators. Trans. ASAE (American Society of Agricultural Engineers). 22: 59-62.

Aponte, O. and J. R. McMurtry. 1997. Damage on "Hass" avocado leaves, webbing and nesting behavior of *Oligonychus perseae* (Acari: Tetranychidae). Exp. Appl. Acarol. 21: 265-272.

Bender, G. S. 1993. A new mite problem in avocados. The Avocado Yearbook. Cal. Avocado Soc. 77: 73-77.

Drukker, B., J. S. Yaninek and H. R. Herren. 1993. A packaging and delivery system for aerial release of Phytoseiidae for biological control. Exp. Appl. Acarol. 17: 129-143.

Giles, D. K., J. Gardner and H. E. Studer. 1995. Mechanical release of predacious mites for biological pest control in strawberries. Trans. ASAE. 38: 1289-1296.

Glenister, C. S. and M. P. Hoffman. 1998. Mass-reared natural enemies: scientific, technological, and informational needs and considerations. pp. 242-267. *In:* R. L. Ridgway, M. P. Hoffman, M. N. Inscoe and C. S. Glenister (Eds.). Mass-Reared Natural Enemies: Application, Regulation, and Needs. Ent. Soc. Am. Lanham, Maryland.

Herren, H. R., T. J. Bird and D. J. Nadel. 1987. Technology for automated aerial release of natural enemies of the cassava mealybug and cassava green mite. Insect Sci. Appl. 8: 883-885.

Hoddle, M. S., O. Aponte, V. Kerguelen and J. Heraty. 1999. Biological control of *Oligonychus perseae* (Acari: Tetranychidae) on avocado: I. Evaluating release timings, recovery and efficacy of six commercially available phytoseiids. Internat. J. Acarol. 25: 211-219.

Hoddle, M. S., L. Robinson, and J. Virzi. 2000. Biological control of *Oligonychus perseae* (Acari: Tetranychidae) on avocado: III. Evaluating the efficacy of varying release rates and release frequency of *Neoseiulus californicus* (Acari: Phytoseiidae). Internat. J. Acarol. 26: 203-214.

Kerguelen, V. and M. S. Hoddle. 1999. Biological control of *Oligonychus perseae* (Acari: Tetranychidae) on avocado: II. Evaluating the efficacy of *Galendromus helveolus* and *Neoseiulus californicus* (Acari: Phytoseiidae). Internat. J. Acarol. 25: 221-229.

McMurtry, J. A. and B. A. Croft. 1997. Life-styles of phytoseiid mites and their roles in biological control. Annu. Rev. Entomol. 42: 291-321.

Pickett, C. H., F. E. Gilstrap, R. K. Morrison and L. F. Bouse. 1987. Release of predatory mites (Acari: Phytoseiidae) by aircraft for the biological control of spider mites (Acari: Tetranychidae) infesting corn. J. Econ. Entomol. 80: 906-910.

Pratt, P. D., L. N. Monetti and B. A. Croft. 1998. Within- and between-plant dispersal and distributions of *Neoseiulus californicus* and *N. fallacis* (Acari: Phytoseiidae) in simulated bean and apple plant systems. Env. Entomol. 27: 148-153.

Sargent, W. N. 1998. Strategies for dispersing beneficials in row crops: what works? pp. 227-230. *In*: M. S. Hoddle (Ed.). Proceedings of the First California Conference on Biological Control. June 10-11, Univ. California, Berkeley.

Sengonca, C. and C. Lochte. 1997. Development of a spray and atomizer technique for applying eggs of *Chrysoperla carnea* (Stephens) in the field for biological control of aphids. J. Plant Dis. Prot. 104: 214-221.

Takano-Lee, M. and M. S. Hoddle. 2000. Predation of *Oligonychus perseae* (Acari: Tetranychidae) by *Neoseiulus californicus* (Acari: Phytoseiidae) and *Galendromus helveolus* (Acari: Phytoseiidae). pp. 187-170. *In*: M. S. Hoddle (Ed.). Proceedings of the Second California Conference on Biological Control. July 11-12, Univ. California, Riverside.

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