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)

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ABSTRACT - Three different release rates and timings of the phytoseiid *Neoseiulus californicus* (McGregor) were evaluated for *Oligonychus perseae* Tuttle, Baker, and Abbatiello control on avocado trees in a commercial orchard in southern California, USA. Densities of natural enemies and *O. perseae* were monitored on trees for 34 weeks that were treated with either one, two, or three releases of 500, 1000, or 2000 *N. californicus*, or two applications of 5% narrow range (NR) 415 petroleum oil. Predator releases were made when 50% (release one), 75% (release two), or 95% (release three) of sampled leaves were infested with one or more motile *O. perseae*. Densities of *O. perseae* on trees treated with *N. californicus* or petroleum oil were compared to control trees that received no treatments for *O. perseae* suppression. Release of a minimum of 2000 *N. californicus* per tree was necessary to significantly reduce *O. perseae* densities in comparison to control trees. Releasing 1000 *N. californicus* twice or 2000 *N. californicus* once provided *O. perseae* control similar to petroleum oil treatments and to trees treated with cumulative releases totaling more than 2000 predators per tree. This result indicated that releases totaling more than 2000 *N. californicus* per tree did not substantially improve *O. perseae* control and the cumulative number of predators released per tree is more important than the number of times *N. californicus* is released for controlling *O. perseae*.

Key words - Acari, Tetranychidae, Phytoseiidae, *Oligonychus perseae*, *Neoseiulus californicus*, *Persea americana*, avocado, inoculative natural enemy releases, USA.

INTRODUCTION

Oligonychus perseae Tuttle, Baker and Abbatiello (Acari: Tetranychidae) is the most serious foliar pest of exotic origin attacking avocados (*Persea americana* Miller [Lauraceae]) in California, USA. Colonial feeding by immature and adult *O. perseae* within silk nests on the lower surfaces of leaves results in the production of characteristic brown necrotic spots (Aponte and McMurtry, 1997). Once necrotic tissue caused by *O. perseae* feeding exceeds 8% of the leaf surface area, the probability of mature leaves defoliating increases substantially (Kerguelen and Hoddle, 1999a). *Oligonychus perseae* populations typically exhibit rapid growth during mid-summer and populations decline markedly over the period of late summer to mid-fall. Similar unimodal-type population trends are observed in avocado orchards in Michoacan, Mexico (the presumed country of origin of this pest [Tuttle *et al*., 1976]) where pesticides are applied to control several native avocado pests (Hernandez *et al*., 1999). *Oligonychus perseae* population declines in California probably occur because of summer heat-waves in inland desert areas (Aponte *et al*., 1997) or possible over-exploitation of resources which results in a shortage of nesting sites on leaves and subsequent lack of food (Hoddle *et al*., 1999; Kerguelen and Hoddle, 1999a).

Although several phytoseiid mites (e.g. *Eusieus hibisci* [Chant], *Neoseiulus californicus* [McGregor], *Galendromus helveolus* [Chant], and *G. annectens* [De Leon]) occur naturally on avocado in southern California they do not respond in a significant density dependent manner to increasing *O. perseae* densities. *Eusieus hibisci* although common in avocado orchards at certain times of the year is not an effective natural enemy of *O. perseae* as it is unable to invade silk nests and is classified as a specialized pollen feeder (McMurtry and Croft, 1997). Consequently, population growth of *O. perseae* is unregulated by upper trophic level organisms. Foreign exploration efforts for biological control agents of *O. perseae* in Latin America to be used in a classical biological control program have been unsuccessful. However, seasonal inoculative releases of commercially available phytoseiids, in particular *N. californicus* and *G. helveolus*, onto avocado trees in full production orchards have proven extremely effective in controlling *O. perseae* (Kerguelen and Hoddle, 1999a). *Neoseiulus californicus* significantly reduced *O. perseae* population densities in comparison to control treatments (no predator release trees) and trees sprayed with petroleum oil, the industry standard for controlling *O. perseae*. Although *G. helveolus* suppressed *O. perseae* densities as equally well as *N. californicus*, *G. helveolus* did not hold leaf damage below the 8% threshold needed to minimize the probability of leaf drop whereas *N. californicus* did. Furthermore, *N. californicus* is 33% cheaper to purchase than *G. helveolus* thus making it the natural enemy of choice for use against *O. perseae* (Kerguelen and Hoddle, 1999a).

Two questions relating to the use of *N. californicus* need to be resolved before this predator can be recommended for *O. perseae* control on avocados. Specifically, these issues are: (1) What is the minimum number of *N. californicus* that should be released per tree to provide suppression of *O. perseae*? (2) What are the minimum number of predator releases necessary to inoculate trees with adequate numbers of predators to provide acceptable suppression of *O. perseae*?

To determine the minimum release rate and release frequency, we investigated the efficacy of three release rates of *N. californicus* combined with three different release frequencies against *O. perseae* in a commercial avocado orchard in southern California. The level of control obtained by varying release rates and frequencies of *N. californicus* was compared to suppression of *O. perseae* attained with petroleum oil applications and to population growth on trees where no control measures were implemented.

MATERIALS AND METHODS

Study site and experimental design -This study was conducted in a commercial avocado orchard in Irvine, Orange County, California, USA from Feb. 26, 1999 to Oct. 26, 1999 inclusive. The trial was run in a 2.6 ha plot planted with 660 'Hass' avocado trees 5-7 years of age. All trees in this plot were subjected to commercial cultural practices (*i.e.*, fertilization and irrigation).

Seventy seven trees were randomly selected throughout the study plot. Each tree was separated from other experimental trees by at least one tree and a 12 m strip of bare dirt between each row of trees. After 24 weeks of bi-weekly monitoring, 66 trees were blocked into 11 groups of 6 trees of comparable average *O. perseae* densities and 11 trees were discarded. Within each block, trees were randomly assigned to one of the following 11 treatments:

1. 500 Cal x 1 - one release of 500 *N. californicus* when 50% of all (n = 660) sampled leaves were infested with one or more motile *O. perseae*.
2. 500 Cal x 2 - two sequential releases of 500 *N. californicus* when 50% (release 1) and 75% (release 2) of all sampled leaves (n = 660) had one or more motile *O. perseae*.
3. 500 Cal x 3 - three sequential releases of 500 *N. californicus* when 50% (release 1), 75% (release 2), and 95% (release 3) of all sampled leaves (n = 660) had one or more motile *O. perseae*.
4. 1000 Cal x 1 - Same as treatment 1, except 1000 *N. californicus* were released at the first treatment threshold.
5. 1000 Cal x 2 - Same as treatment 2, except 1000 *N. californicus* were released at each treatment threshold.
6. 1000 Cal x 3 - Same as treatment 3, except 1000 *N. californicus* were released at each treatment threshold.
7. 2000 Cal x 1 - Same as treatment 4, except 2000 *N. californicus* were released at the first treatment threshold.
8. 2000 Cal x 2 - Same as treatment 5, except 2000 *N. californicus* were released at each treatment threshold.
9. 2000 Cal x 3 - Same as treatment 6, except 2000 *N. californicus* were released at each treatment threshold.
10. Oil - Trees received two sequential applications of narrow range (NR) 415 Supreme spray oil (Leffingwell, Kirkiland Washington, USA) at 5% in water (1.92 l/tree applied at 0.13 l/min with air velocity of 101 m/s) applied by hand with a Stihl power sprayer to simulate application by helicopter (i.e. agitation of canopy with airstream from power sprayer imitated helicopter prop wash). Sprays were applied when 50% (August 24, 1999) and 75% (October 1, 1999) of all sampled leaves were infested with one or more motile *O. perseae*.

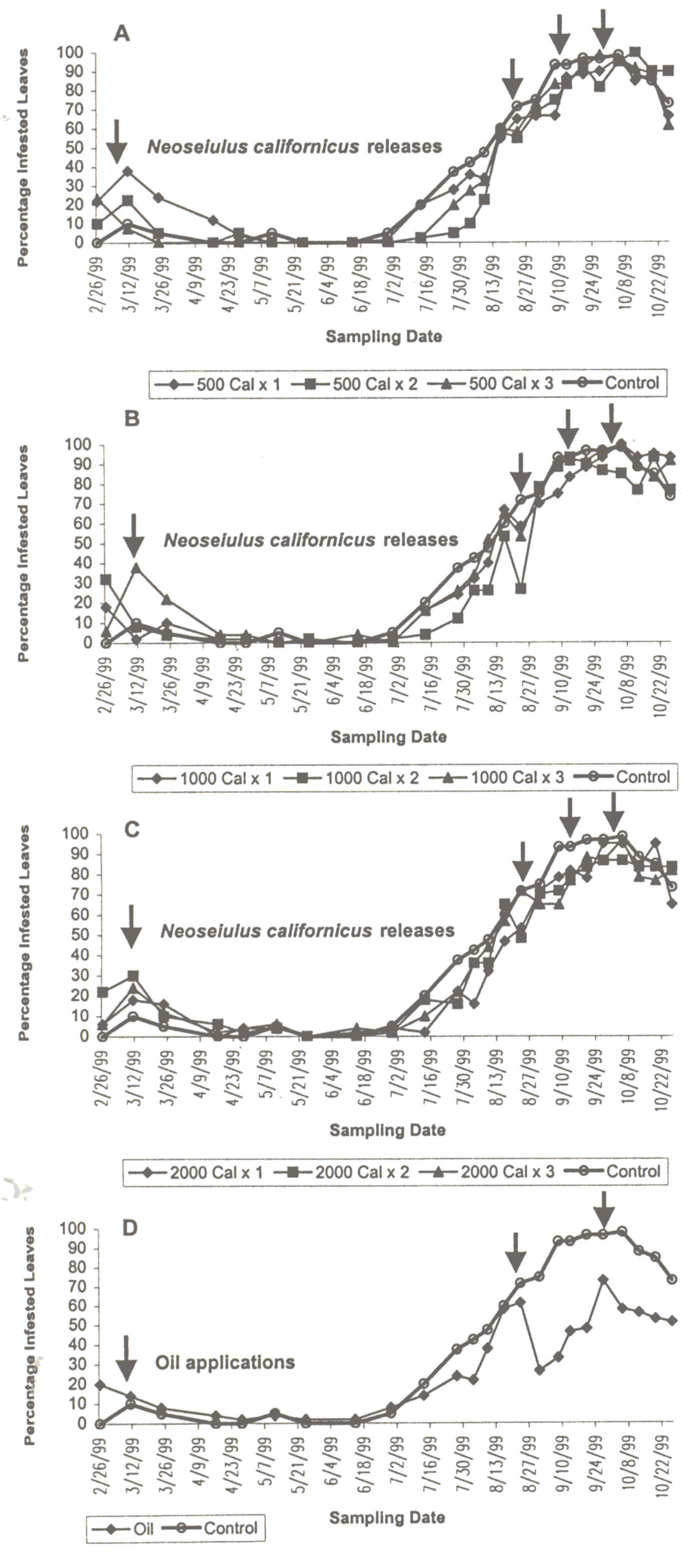

Fig. 1. Weekly percentage of sampled leaves (n= 60) infested with *Oligonychus perseae* on trees treated with (A) 1-3 releases of 500 *Neoseiulus californicus*, (B) 1-3 releases of 1000 *N. californicus*, (C) 1-3 releases of 2000 *N. californicus*, and (D) NR 415 oil. All treatments are compared to control trees (i.e., no treatments).

11. Control - No treatments were applied to suppress *O. perseae* population growth.

Monitoring *Oligonychus perseae* densities and aerial dispersal - Every sampling period, 10 mature leaves were removed from each experimental tree. Leaves were picked randomly at shoulder height around each tree, placed in labeled bags, and returned to the laboratory. Leaves were examined under a dissecting microscope and the number of motile *O. perseae* was recorded per leaf. For each treatment on each sampling date, we calculated the percentage of leaves infested with *O. perseae*, and the average number of *O. perseae* per leaf. Average maximum densities of *O. perseae* were compared among treatments with a nested ANOVA and means were separated with Tukey's Studentized Range Test at the 0.05 level of significance (SAS, 1989).

Aerial dispersal by *O. perseae* was monitored with white sticky cards (19.5 cm x 16 cm). Sticky cards were attached with binder clips to one of four arms (length = 0.6 m) that radiated in each cardinal direction from a central wooden stake 1.5 m above the ground. Four aerial monitoring stations were positioned in the study plot, one in each cardinal section of the orchard. Each week, sticky cards were removed, placed in clear plastic bags and returned to the laboratory. New sticky cards replaced those that were removed. In the laboratory, a central area (10 cm x 10 cm) of each sticky card was examined under a dissecting microscope and the average number of *O. perseae* caught in the center of sticky cards was calculated for each week of the trial. We assumed that *O. perseae* captured in the center of the sticky cards arrived there after aerial dispersal and did not walk into the central area of the card.

***Neoseiulus californicus* releases and phytoseiid population monitoring** - *Neoseiulus californicus* was purchased from Biotactics, Riverside California, USA, and released within 24 hrs of receipt. *Neoseiulus californicus* was delivered in plastic 50 ml vials containing 1000 predators (adults and immatures) mixed with approximately 45 ml of corn grits as a carrier. Before each release we verified predator species and numbers received. With each predator shipment, three extra vials of *N. californicus* were ordered; from each of these three vials, five 1.25 ml (i.e., ¼ tsp) aliquots of predators and corn grits were taken after vials were gently agitated to ensure even distribution of predators. Corn grits containing predators were gently sprinkled onto a white card covered with adhesive which trapped *N. californicus*. Cards with grits and *N. californicus* were placed in clear plastic bags, and the number of predators trapped on each card was recorded. The average number of *N. californicus* per 1.25 ml was calculated and used to estimate the average number of predators per vial. *Neoseiulus californicus* voucher specimens from each shipment were slide mounted in Hoyer's solution and verified as the species ordered.

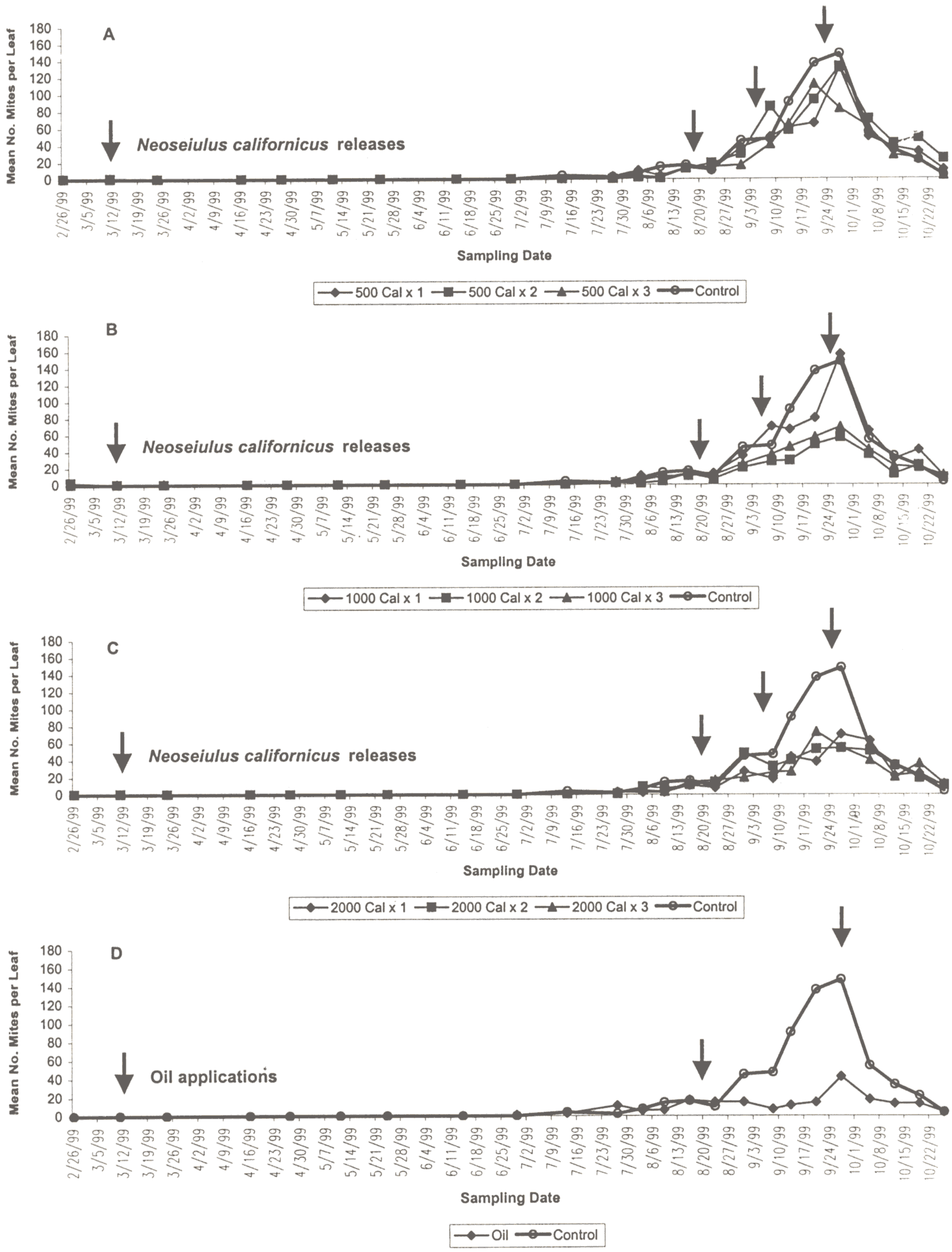

Fig. 2. Average weekly numbers of motile *Oligonychus perseae* per leaf (n= 60) on trees treated with (A) 1-3 releases of 500 *Neoseiulus californicus*, (B) 1-3 releases of 1000 *N. californicus*, (C) 1-3 releases of 2000 *N. californicus*, and (D) NR 415 oil. All treatments are compared to control trees (i.e., no treatments).

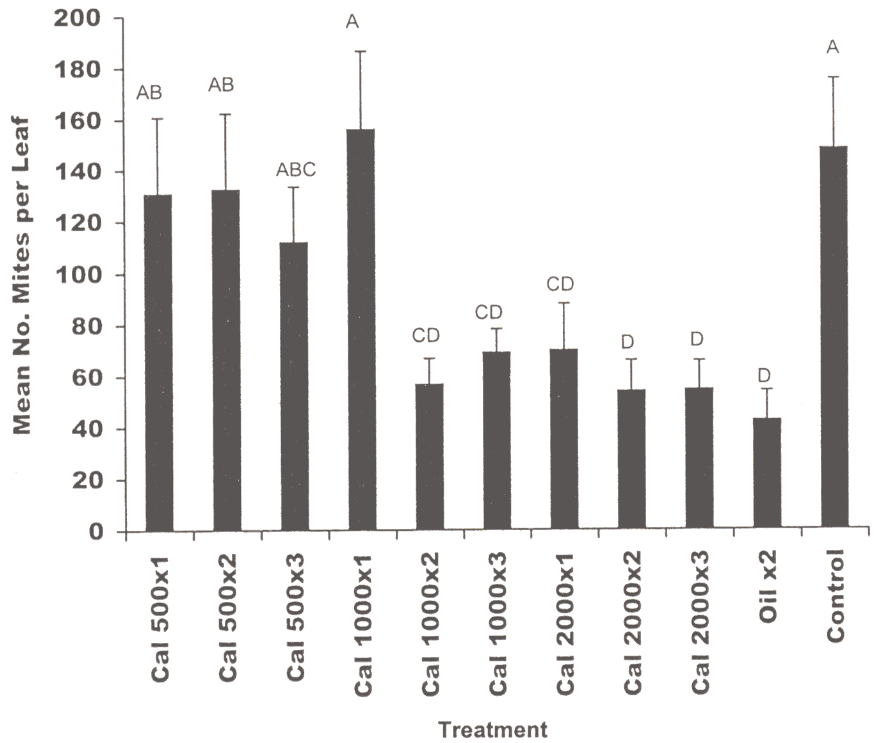

Fig. 3. Comparison of mean (± SE) maximum *Oligonychus perseae* densities per leaf across treatments. Means followed by the same letters are not significantly different from each other at the 0.05 level.

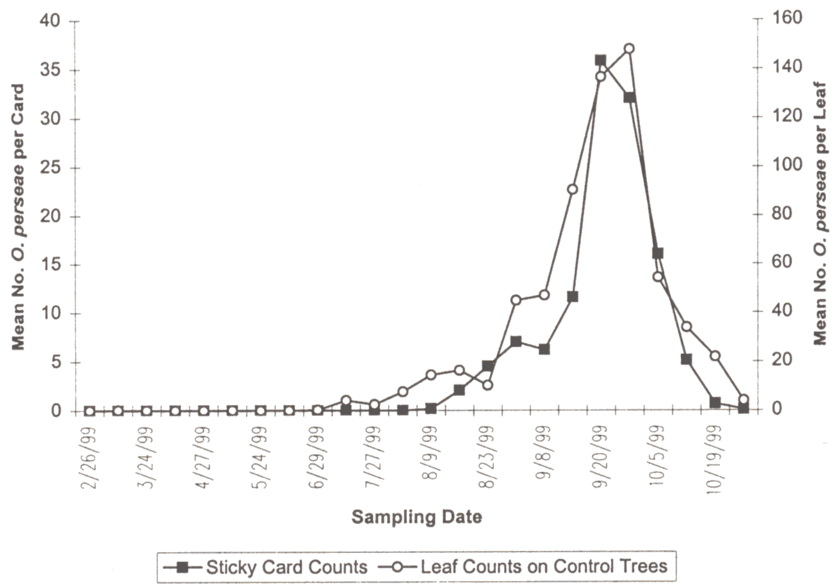

Fig. 4. Comparison of mean weekly *Oligonychus perseae* caught per sticky card with mean weekly *O. perseae* densities recorded on the leaves of control trees.

In the field, *N. californicus* was released onto experimental trees by pouring the contents of vials into four 104 ml paper cups that were evenly distributed around the tree and attached to branches with binder clips at shoulder height. The amount of material dispensed into each release cup was dependent on the release rate assigned to each experimental tree and our estimates of the numbers of predators per vial. Predator releases were made on Aug. 8 (50% sampled leaves infested with *O. perseae*), Sept. 7 (75% leaf infestation), and Sept. 27, 1999 (95% leaf infestation).

For each sampling period, phytoseiids found foraging on sampled leaves were slide mounted in Hoyer's solution and identified to species. The average number of *N. californicus* collected per 10 leaf sample for each treatment was calculated. The average number of *E. hibisci* per 10 leaf sample across all biological control treatments and control trees was calculated and compared to trees that were treated with oil.

Leaf damage estimates - Visible leaf damage was quantified on experimental trees on October 26, 1999 at the end of the experiment. Ten randomly selected leaves per tree were returned to the laboratory in labeled bags and the abaxial surface was scanned on a flatbed scanner to obtain a color image. Automated image analysis software was used to calculate the percentage of leaf area damaged by *O. perseae* and to count the number of necrotic spots per leaf which resulted from mite feeding (Kerguelen and Hoddle, 1999b). Average percentage leaf area damaged (arcsin transformed) and mean number of necrotic spots were compared across treatments with a nested ANOVA and means were separated with Tukey's Studentized Range Test at 0.05 level of significance (SAS, 1989).

Additionally, during periods of defoliation, 308 leaves were collected from the orchard floor beneath non-experimental trees and returned to the laboratory. Mean percentage leaf area damaged and numbers of necrotic spots per leaf were calculated to determine the amount of *O. perseae* feeding damage needed to induce leaf drop in this study plot.

Temperature and humidity monitoring - Temperature and relative humidity were recorded at 30 min. intervals in an exposed area on the orchard floor in the center of the study plot and in the canopy of an adjacent avocado tree. Data loggers (Onset®, Bourne, Massachusetts, USA) were either attached to a stake (orchard floor measurements) or to a support stake adjacent the trunk (canopy measurements) 1.5-1.75 m above the ground. Weekly average daily maximum and minimum temperatures and humidities were calculated both for the orchard floor and avocado canopy.

RESULTS

Monitoring *Oligonychus perseae* densities and aerial dispersal - Percentage leaf infestation on all experimental trees began to increase steadily in July, with all experimental trees (except those treated with petroleum oil) reaching near 100% leaf infestation in September. Percentage leaf infestation began to decline on all experimental trees in October (Fig. 1). The average density of *O. perseae* per leaf remained at very low levels at the trial site until July. After this time, numbers of *O. perseae* per leaf increased rapidly to peak in density across all treatments in early October (Fig. 2). Population densities on experimental trees treated with 1500 *N. californicus* (i.e., three sequential releases of 500 predators [Fig. 2A]), 2000 *N. californicus* (i.e., either two releases of 1000 predators [Fig. 2B], or one release of 2000 predators [Fig. 2C]), 3000 *N. californicus* (i.e., three sequential releases of 1000 *N. californicus* [Fig. 2B]), 4000 *N. californicus* (i.e., two releases of 2000 predators [Fig. 2C]), 6000 *N. californicus* (i.e., three releases of 2000 predators [Fig. 2C]), or oil applications (Fig. 2D) were substantially lower when compared to *O. perseae* densities on control trees.

Comparisons of mean peak *O. perseae* densities per leaf across treatments were significantly different ($F = 8.46$; $df = 10, 55$; $p = 0.0001$) (Fig. 3). Substantial reduction of *O. perseae* densities with *N. californicus* was obtained once a minimum release of 2000 phytoseiids per tree had been made. Levels of control with *N. californicus* at release rates of 2000 predators per tree or higher were similar to suppression obtained with insecticidal oil (Fig. 3).

Oligonychus perseae was first detected on white sticky cards in mid-August and mean numbers of *O. perseae* caught per card steadily increased until mid-September before declining. Ballooning activity of *O. perseae* closely followed trends in mite densities on control tree leaves, suggesting that the likelihood to engage in aerial dispersal was correlated with increasing *O. perseae* densities on leaves (Fig. 4).

Monitoring *Neoseiulus californicus* densities and other phytoseiids - *Neoseiulus californicus* was recovered from all predator release trees (Fig. 5A-C). In general, increased release frequency of *N. californicus* at each release rate resulted in higher recovery rates of predators as cumulatively more natural enemies were released onto trees. However, this trend was not observed for releases of 500 *N. californicus* where two predator releases resulted in highest recovery at this release rate (Fig. 5A). *Neoseiulus californicus* numbers peaked in density across all release trees between Sept. 20-27, 1999 before declining with the *O. perseae* population. This time period of peak predator densities closely coincided with the third predator release and peak *O. perseae* numbers (both of which occurred Sept. 27, 1999) in each treatment grouping.

Euseius hibisci was recovered from all experimental trees. Densities were highest over the period May-July, 1999 (Fig. 5D) and may have been a response by *E. hibisci* to available pollen which is readily utilized as a food source by this predator (McMurtry and Johnson, 1965). There were no obvious differences in *E. hibisci* densities on trees treated with *N. californicus* and control trees suggesting intra-guild predation was not significant enough to be detected if it was occurring (Rosenheim,

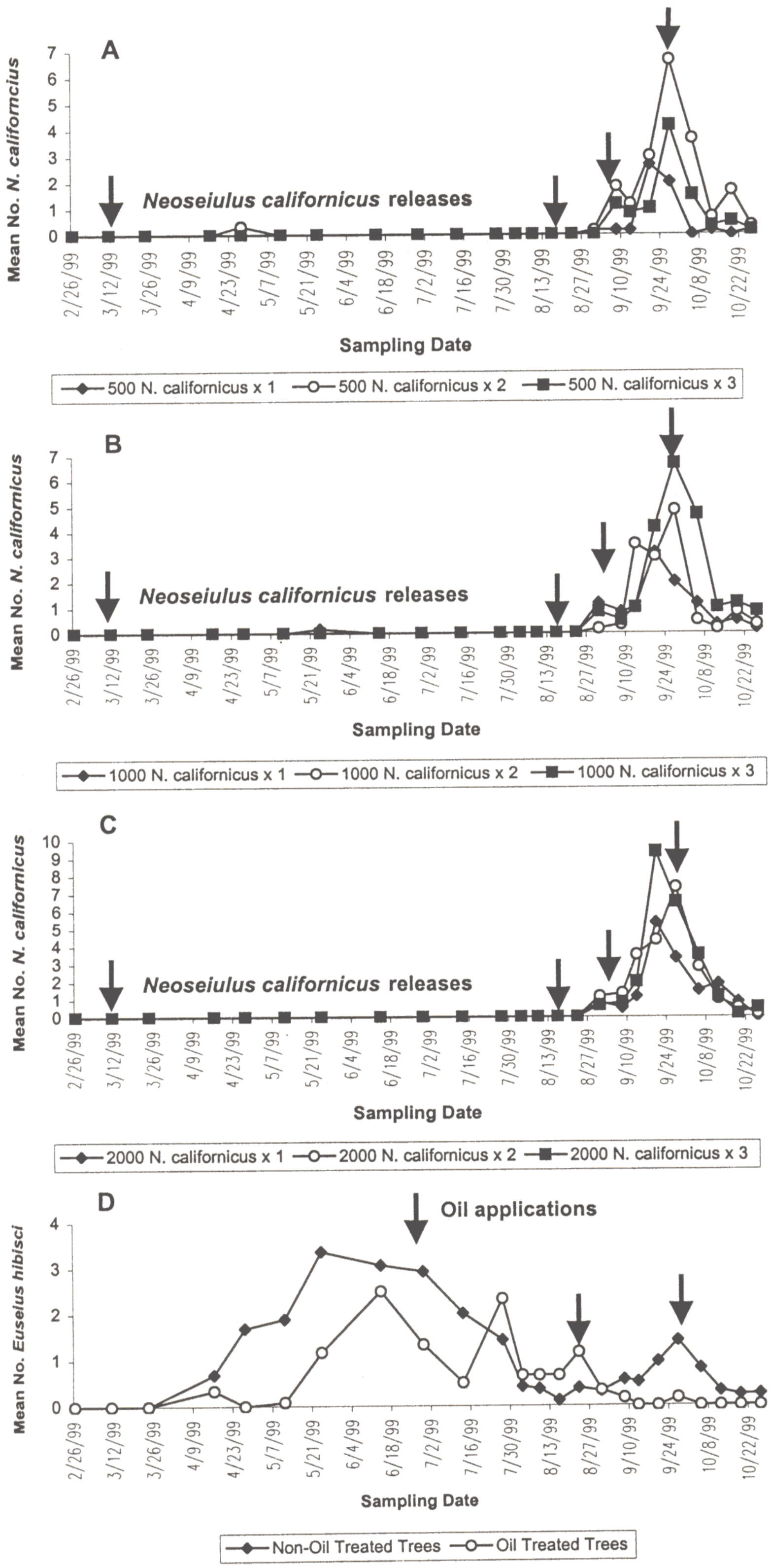

Fig. 5. Mean number of *Neoseiulus californicus* recovered per 10 leaf samples on trees treated with (A) 1-3 releases of 500 *Neoseiulus californicus*, (B) 1-3 releases of 1000 *N. californicus*, and (C) 1-3 releases of 2000 *N. californicus*. (D) Mean number of *Euseius hibisci* recorded on all non-oil treated trees and NR 415 oil treated trees. Arrows indicate time of predator releases or oil applications.

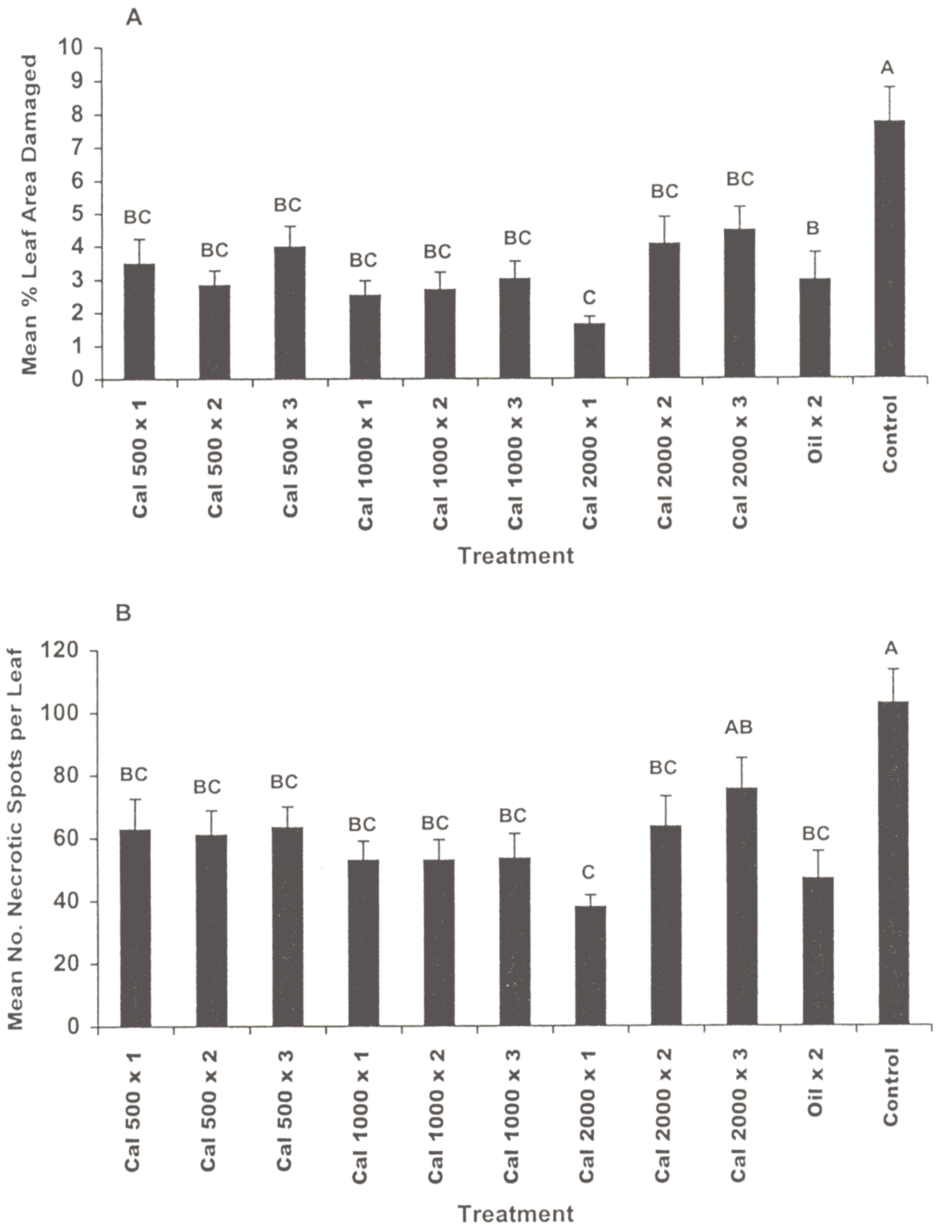

Fig. 6. (A) Mean (± SE) percentage leaf area damaged by *Oligonychus perseae* feeding across treatments and (B) mean (± SE) number of necrotic spots per leaf for each treatment.

1998). On oil-treated trees, *E. hibisci* numbers were reduced to non-detectable levels for the remainder of the trial following the first oil application on Aug. 24, 1999 (Fig. 5D). *Galendromus annectens* and *G. helveolus* were found at low densities on experimental trees. Neither of these two predators exhibited obvious population growth in response to increasing *O. perseae* densities.

Leaf damage estimates - Percentage area leaf damage varied significantly across treatments when measurements were made in October at the end of the trial ($F= 6.73$; $df= 10,55$; $p= 0.0001$) (Fig. 6A). The most heavily damaged leaves were those on control trees, and the least damaged leaves were from trees treated with a single release of 2000 *N. californicus*. Intermediate levels of damage were recorded on the remaining biological control trees and those treated with insecticidal oil (Fig. 6A).

The mean number of necrotic spots per leaf followed similar trends to percentage leaf area damage with significant differences being detected across treatments ($F= 6.44$; $df= 10,55$; $p= 0.0001$) (Fig. 6B). The highest average number of necrotic spots was counted on control trees and the lowest was observed on trees treated with a single release of 2000 *N. californicus*. The remaining biological control treatments and oil-treated trees had mean numbers of necrotic spots per leaf of intermediate values (Fig. 6B).

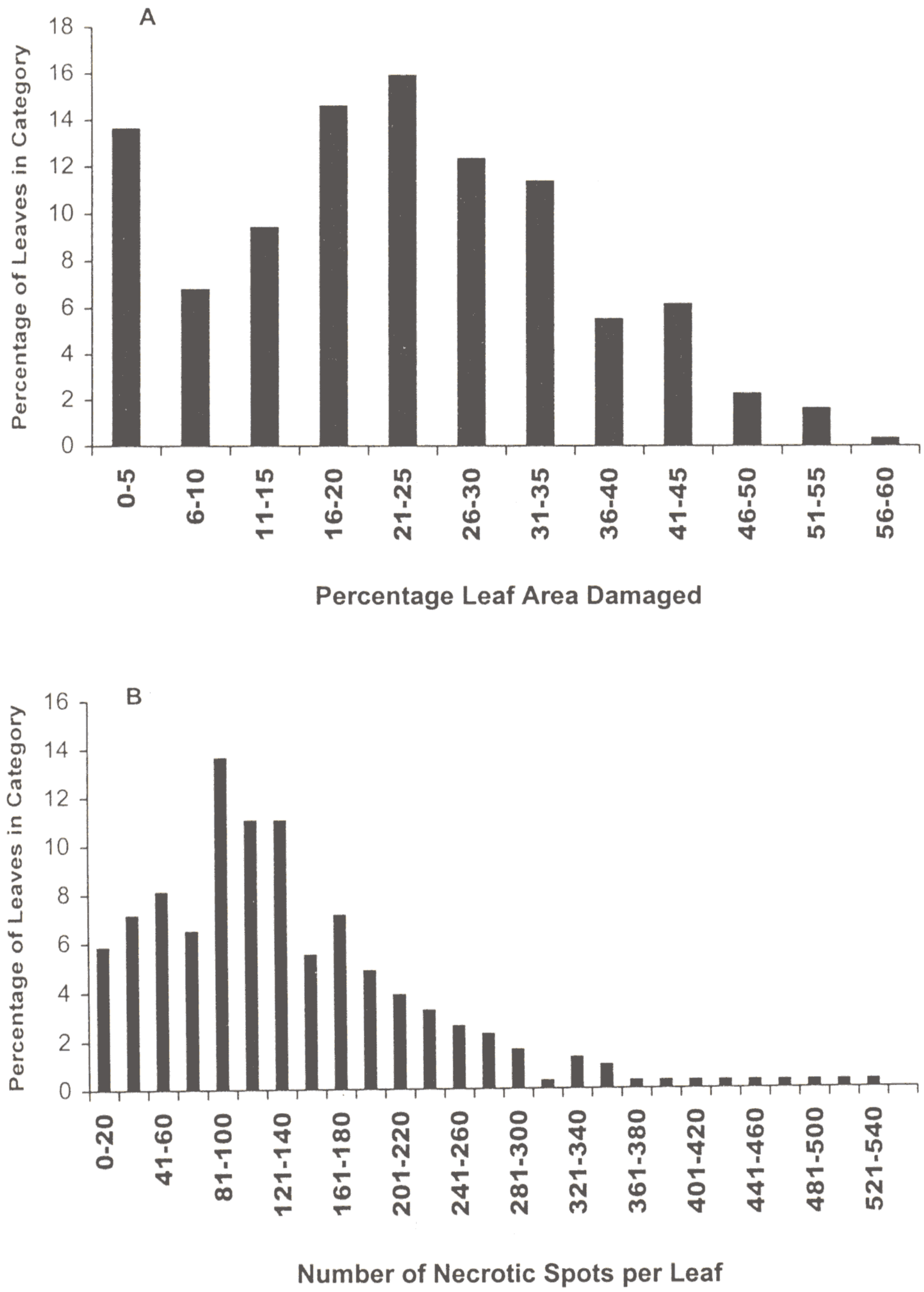

Fig. 7. (A) Percentage of defoliated avocado leaves collected from the orchard floor in each percentage leaf area damage category and (B) the percentage of collected leaves exhibiting the number of necrotic feeding spots as indicated by category.

The mean percentage leaf area damage measured on defoliated leaves collected from the ground was 21.96% ± 0.75% (SE) (median = 22.53%; range = 0-55.96% damage) (Fig. 7A). The mean number of necrotic spots counted per defoliated leaf was 134.38 ± 5.36 (SE) (median = 116.5; range = 0-539 spots) (Fig. 7B).

Temperature and humidity - Weekly average minimum temperatures were almost identical in the open orchard and tree canopy (Fig. 8A). Average weekly maximum temperatures were consistently 2-4^{o}C lower when measured in the canopy. Weekly average maximum relative humidities were close to 100% throughout the entire trial in both the open orchard and canopy. Average minimum relative humidities were consistently lower when measured in the open orchard when compared to canopy measurements (Fig. 8B).

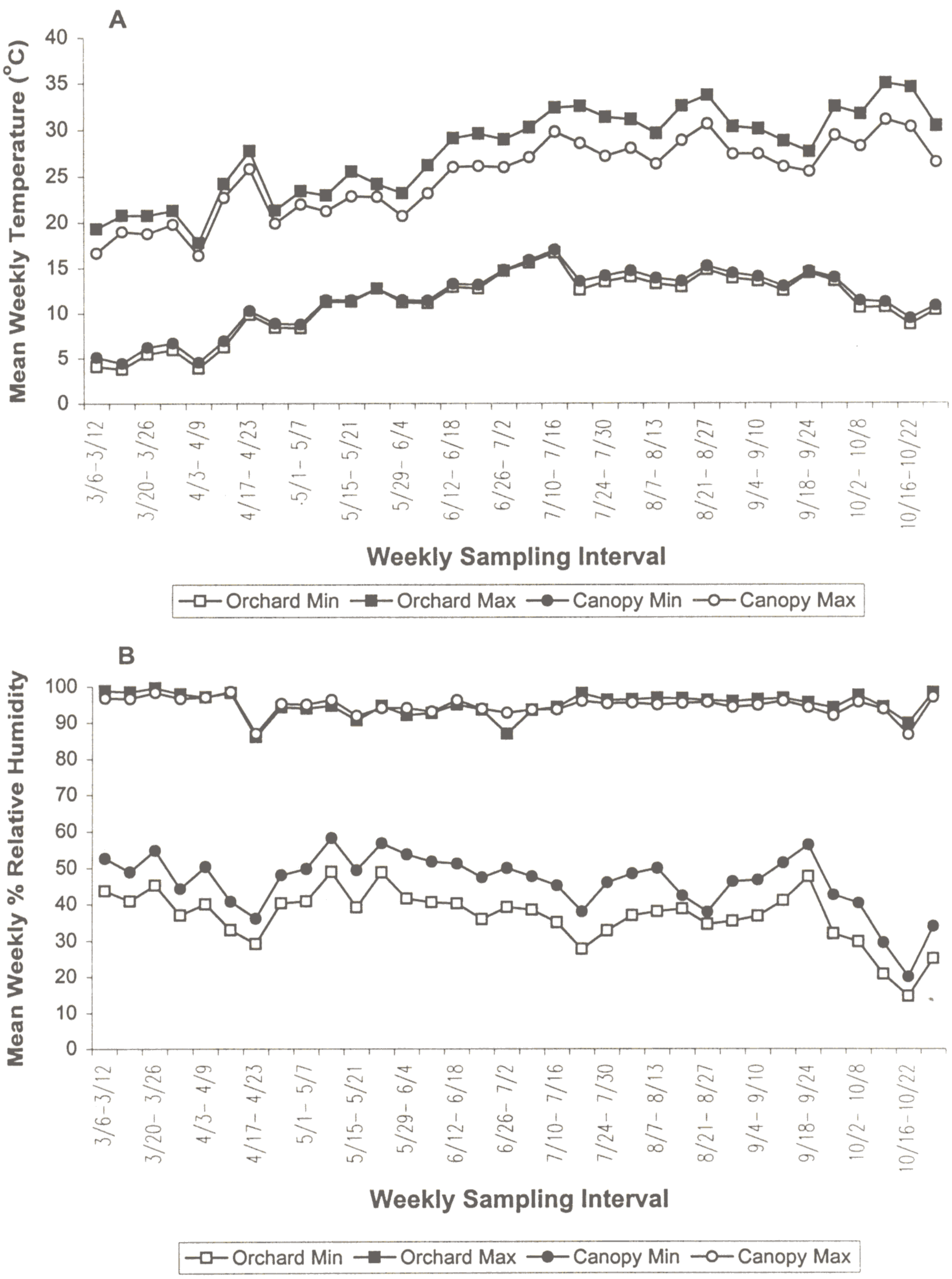

Fig. 8. Weekly average minimum (Min) and maximum (Max) temperatures (A) and relative humidities (B) in the open avocado orchard and within the canopy of the tree.

DISCUSSION

Releases of *N. californicus* controlled *O. perseae* as effectively as two petroleum oil applications when total numbers of predators released per tree equaled or exceeded 2000. Total releases of 1500 or fewer *N. californicus* per tree did not reduce *O. perseae* densities significantly in comparison to control trees. A single release of 2000 *N. californicus* or two releases of 1000 *N. californicus* provided similar levels of control, suggesting release frequency was unimportant for attaining control of this pest but total numbers of predators released per tree was important. Releases exceeding 2000 predators per tree did not provide an appreciable increase in control regardless of release rate and timing when compared to trees receiving a cumulative total of 2000 *N. californicus*.

Predator releases significantly reduced *O. perseae* feeding damage to leaves in comparison to control trees and average percentage leaf area damage estimates on all trees treated with *N. californicus* were similar to damage measured on trees treated with petroleum oil. The average number of necrotic spots per leaf resulting from *O. perseae* feeding were significantly reduced on biological control trees and oil treated trees when compared to control trees. However, average percentage leaf area damage measurements were similar for all predator release treatments. Significantly lower levels of damage to leaves remaining on trees at the end of the season were not observed for the *N. californicus* (= 2000 predators released per tree) and oil-treated trees that were most effective at reducing *O. perseae* densities.

We speculate that feeding damage by *O. perseae* on predator release and oil-treated trees probably caused defoliation and leaves with similar low levels of damage (i.e., 5% leaf area damaged) were retained on experimental trees and harvested at the end of the season. Shedding of heavily damaged leaves and retention of leaves with minimal damage would result in uniform damage estimates across natural enemy and oil treated trees. Damage (7.72% leaf area damaged) to leaves retained on control trees was significantly higher than treatment trees, indicating that trees can retain leaves with this amount of damage as seen previously (Kerguelen and Hoddle, 1999a). In this study, 86% of leaves collected from the ground had damage greater than 10% of the surface area indicating that *O. perseae* feeding damage needs to be maintained below this level to minimize the probability of leaf drop. This 10% damage threshold for leaf drop is close to the 7.5% leaf damage threshold caused by *O. perseae* in a previous study (Kerguelen and Hoddle, 1999a). The relationship between *O. perseae* densities and end of season damage levels on retained leaves may be better understood by quantifying leaf drop rates below trees and combining this information with leaf damage measurements and *O. perseae* densities on leaves for experimental treatments.

Neoseiulus californicus managed to establish and increase in density on all experimental trees on which releases were made. Predator population growth closely followed *O. perseae* density increase and decline. Densities of predators tended to be highest on experimental trees that received the largest cumulative releases. However, numbers of *N. californicus* recovered were not substantially different across high and low release treatments. Releases of predators when 95% of sampled leaves (i.e., the third release at each release rate) were infested with *O. perseae* coincided exactly or within one week of peak predator and prey densities. *Neoseiulus californicus* densities declined rapidly across all treatments after this third release as did *O. perseae* densities. The decline in numbers of predators recovered immediately after the third release, coupled with no significant reduction in *O. perseae* numbers on trees receiving three predator treatments, indicated that there was no benefit from releasing *N. californicus* a third time. Lack of impact from the third release probably resulted because densities of *O. perseae* began to decrease at this time and could not sustain predator population growth.

Oligonychus perseae populations declined across all treatments during the period Sept. 27 – Oct. 5, 1999. It has been proposed that population declines of *O. perseae* occur when mean weekly temperatures exceed 32°C during summer (Aponte *et al.*, 1997). In this study and work by Kerguelen and Hoddle (1999a), the amplitude of variation of maximum weekly temperatures was minimal and there was no obvious correlation between temperature and *O. perseae* population increase and decline. Previous work monitoring *O. perseae* field populations recorded late season increases in mite numbers, demonstrating that declines in population densities were not driven by decreasing day length and the induction of an overwintering diapause (Kerguelen and Hoddle, 1999a). Our data suggests that *O. perseae* population declines occur because of over-exploitation of host plant material which results in abandonment of leaves by ballooning as mites disperse to locate new feeding sites. We found that *O. perseae* ballooning activity closely followed population growth and decline when compared to weekly leaf count data and ballooning activity was greatest when mite densities on leaves reached their highest levels. Similar population crashes have been observed for *O. punicae* (Hirst) on avocados. Population declines of *O. punicae* have been attributed to a deterioration in host plant quality after extensive mite feeding (McMurtry, 1970). The relationship between resource deterioration and *O. perseae* densities and subsequent population decline need to be investigated experimentally.

A minimum cumulative release of 2000 *N. californicus* per tree is 13-14 times more expensive per acre when compared to aerial applications of NR 415 oil for control of *O. perseae*. Releasing predators in paper cups is not an efficient way to evenly distribute natural enemies onto trees as predators need to disperse from these localized release points to provide canopy-wide pest suppression. Improved *O. perseae* control with lower release rates of *N. californicus* may be attained if predators could be uniformly and artificially dispersed through the canopy.

Mechanical applicators that spray metered aliquots of predators and carrier (e.g., corn grits) onto trees have the potential to improve predator distribution in the canopy thereby enhancing control (Sargent, 1998). Mechanical dispensing systems mounted on tractors have been shown to be more effective for evenly distributing *Phytoseiulus persimilis* Athias-Henriot for control of *Tetranychus urticae* Koch in strawberries than similar releases made by hand. Mechanical releases are superior to hand-releases because natural enemies are distributed at a consistent rate in the crop, time to release and subsequent labor costs are reduced (Giles *et al.*, 1995), and in some instances, natural enemy viability can be enhanced (Stocker, 1998). We are currently evaluating the efficacy of mechanical application of *N. californicus* for *O. perseae* control on avocados.

Furthermore, the use of *N. californicus* could become cost effective if a number of production factors change. These factors include the following: (1) the ability of commercial suppliers to minimize costs by making predator production as cheap and efficient as possible. (2) Increased industry demand for *N. californicus* promotes increased supply and lower prices. (3) Development of grower cooperatives that produce natural enemies for use in avocado orchards. The formation of grower "protective districts" have been very effective for mass rearing natural enemies (Graebner *et al.*, 1984) and incorporation of efficacious natural enemies into integrated pest management programs can reduce pest control costs by 80% when compared to non-cooperative growers with pesticide reliant pest management strategies (Luck, 1998). Formation of avocado protection districts in California may increase grower use of biological control technology, reduce the cost of natural enemy production for avocado pest control, and minimize grower reliance on pesticides for *O. perseae* control.

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