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***OLIGONYCHUS PERSEAE* (ACARI: TETRANYCHIDAE)
POPULATION RESPONSES TO CULTURAL CONTROL ATTEMPTS
IN AN AVOCADO ORCHARD**

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ABSTRACT

Populations of *Oligonychus perseae* Tuttle, Baker and Abbatiello (Acari: Tetranychidae) were monitored for 37 weeks in an avocado (*Persea americana* Miller) orchard in Fallbrook California, USA. Three cultural control methods were tested to reduce vertical recolonization of avocado trees by *O. perseae*. Control methods examined were: (1) Tanglefoot® barriers on tree trunks. (2) Removal of ground cover and leaf litter under tree canopies, and (3) Tanglefoot® barriers combined with ground cover removal. All treatments were compared to control trees that were not subjected to any of the preceding cultural practices. No significant differences in *O. perseae* populations or *O. perseae*-induced leaf damage were found among trees receiving different treatments. However, aerial dispersal activity of *O. perseae* was found to increase as *O. perseae* populations on monitored avocado trees increased, suggesting that populations could have been augmented as new immigrants arrived from unmonitored avocado trees or other miscellaneous host plants. The phytoseiids *Galendromus helveolus* (Chant) and *G. annectens* (De Leon), *Amblyseius similoides* Buchelos and Pritchard, *Euseius hibisci* (Chant), and *Neoseiulus californicus* (McGregor) were also monitored during this study. Natural enemy numbers were not adversely affected by cultural control attempts targeting *O. perseae*. Aerial applications of abamectin with NR 415 oil for *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) had an adverse effect on *Galendromus* spp., which are important predators of *O. perseae* in avocado orchards.

Key Words: *Oligonychus perseae*, cultural control, avocado, *Persea americana*, Phytoseiidae, Tetranychidae, *Galendromus helveolus*, *Galendromus annectens*, *Amblyseius similoides*, *Euseius hibisci*, *Neoseiulus californicus*

RESUMEN

Poblaciones de *Oligonychus perseae* Tuttle, Baker y Abbatiello (Acari: Tetranychidae) fueron monitoreadas durante 37 semanas en un cultivo de aguacate (*Persea americana* Miller) en Fallbrook, California, USA. Tres métodos de control cultural fueron probados para reducir la recolonización vertical de árboles de aguacates por *O. perseae*. Los métodos de control examinados fueron: (1) Barreras de Tanglefoot® en los troncos de los árboles. (2) Eliminación de la cobertura del suelo y la hojarasca presente directamente debajo del área foliar de los árboles, y (3) Barreras de Tanglefoot® en combinación con la remoción de la cobertura del suelo. Todos los tratamientos fueron comparados con árboles utilizados como controles, los cuales no fueron sometidos a ninguna de las prácticas culturales anteriores. No se obtuvieron diferencias significativas entre los árboles a los que se le aplicaron los diferentes tratamientos, con respecto a las poblaciones de *O. perseae* o a los daños foliares inducidos por *O. perseae*. Sin embargo, la dispersión en la actividad aérea de *O. perseae* aumento a medida que las poblaciones de *O. perseae* aumentaron en los árboles monitoreados, sugiriendo que las poblaciones pudieron haber aumentando al provenir, como nuevos inmigrantes, de árboles de aguacates no monitoreados o de otras plantas hospederas variadas. Los fitoseidos *Galendromus helveolus* (chant) y *G. annectens* (De Leon), *Amblyseius similoides* Buchelos y Pritchard, *Euseius hibisci* (chant), y *Neoseiulus californicus* (McGregor) fueron también monitoreados este estudio. El número de enemigos naturales no fue desfavorablemente afectado por los intentos de control cultural dirigidos a *O. perseae*. Aplicaciones aéreas de abamectin con el aceite NR 415 para *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae) tuvieron un efecto adverso sobre *Galendromus* spp., el cual es un importante depredador de *O. perseae* en cultivos de aguacate.

Oligonychus perseae Tuttle, Baker, and Abbatiello (Acari: Tetranychidae) has been a serious pest of economic importance in southern California avocado orchards since 1990 (Bender 1993). This pest inhabits undersides of leaves, where

motile stages take refuge within webbed nests where they feed and reproduce. Feeding damage to leaves within nests results in localized necrosis, which manifests itself as characteristic circular brown spots (Aponte & McMurtry 1997).

Avocado trees naturally defoliate in the spring months, and leaves bearing overwintering *O. perseae* drop to the orchard floor. Leaves are not shed simultaneously and defoliation occurs gradually over a period of 3-4 weeks, during which new leaves begin to grow (Lovatt 1990, Liu et al. 1999). As the growing season progresses and temperatures increase, so do *O. perseae* populations, which tend to peak during mid to late summer months (July-September) (Kerguelen & Hoddle 1999a; Hoddle et al. 1999, 2000).

Defoliation of avocado leaves can also occur when high infestations (>500 mites/leaf) of *O. perseae* cause 7.5-10.0% leaf area damage (Hoddle et al. 2000, Kerguelen & Hoddle 1999a), and *O. perseae* will fall to the ground on leaves during defoliation events (Kerguelen & Hoddle, unpublished). *Oligonychus perseae* have been trapped climbing on avocado tree trunks and vertical support stakes presumably in attempts to locate viable host plants after abandoning leaf material on the orchard floor (Kerguelen & Hoddle, unpublished). Following mite-induced defoliation, the ensuing new leaf "flush" may attract other pests, such as *Scirtothrips perseae* Nakahara (Thysanoptera: Thripidae), which utilizes young leaves for feeding and reproduction. In addition, trees defoliated by *O. perseae* are at greater risk of sunburn and scalding as trunks and fruit are exposed to sun, and premature fruit drop and subsequent economic losses may result (Bender 1993).

Control of *O. perseae* populations is usually achieved through acaricides (e.g., refined narrow-range petroleum oils) or through augmentative releases of biological control agents. Two commercially available phytoseiids, *Neoseiulus californicus* (McGregor) and *Galendromus helveolus* (Chant) have demonstrated an ability to reduce *O. perseae* densities to levels comparable to those produced by acaricidal oils (Kerguelen & Hoddle, 1999a; Hoddle et al. 2000). However, an unexplored control option is the use of cultural practices to mitigate vertical recolonization of trees by *O. perseae* from dropped leaves on the ground during periods of defoliation.

During the winter, *O. perseae* densities on leaves are at almost undetectable levels (Kerguelen & Hoddle, 1999; Hoddle et al. 2000) and potential overwintering sites utilized by *O. perseae* on avocados other than leaves might occur in leaf duff under trees, cracks and crevices of branches, and bark cover on trunks. However, Berlese funnel extractions of material collected over winter have not provided evidence that *O. perseae* overwinters on woody twigs, bark, or ground cover (Takano-Lee, unpublished).

Therefore, we decided to investigate the efficacy of cultural control measures that were designed to eliminate possible routes of tree recolonization by *O. perseae* from the orchard floor

from fallen leaves. Treatments investigated to reduce vertical recolonization rates and subsequent pest population growth were: (1) placement of sticky barriers on tree trunks to trap motile *O. perseae* that abandon dropped leaves under trees and walk up vertical structures (e.g., tree trunks and support stakes) to locate suitable host plants. (2) Removal of all defoliated leaves and weeds from under trees thereby removing sources of ambulatory mites. (3) Combining treatments 1 and 2, and (4) monitoring *O. perseae* densities on control trees that received no cultural management. In addition to monitoring *O. perseae* on experimental trees, we also investigated the impact of these cultural practices on resident phytoseiid populations.

MATERIALS AND METHODS

Study Site and Experimental Design

A commercial 40 ha 'Hass' avocado orchard, located in Bonsall, California, USA served as the study site. *Oligonychus perseae* surveys began on April 4, 2000 (wk 0), when spring defoliation began. Thirty trees 3 m high were selected and 10 randomly selected leaves were removed from each tree and returned to the laboratory. The number of motile *O. perseae* was recorded by leaf for each tree.

Following these pre-counts, 24 trees were blocked into 6 trees per treatment, to produce comparable mean *O. perseae* densities per leaf across treatments. On April 10 (wk 1), four treatments were applied to study trees: (1) Tanglefoot® (The Tanglefoot Company, Grand Rapids, Michigan USA) was applied to both sides of a strip of double-sided sticky carpet tape (Manco Inc., Avon, Ohio, USA) that was wrapped around the trunk approximately 20 cm above soil. Leaf material was left on the orchard floor beneath trees (n = 6). (2) Ground cover (i.e., weeds, leaf litter, branches, etc.) was raked away from under experimental trees so that the ground beneath the canopy was bare dirt (n = 6). (3) Tanglefoot® on carpet tape was applied in conjunction with ground cover removal (n = 6), and (4) control trees were those to which no treatments were applied (n = 6). *Oligonychus perseae* populations on all experimental trees were quantified weekly for each treatment by counting the number of motile stages on each of 10 randomly chosen leaves that were returned to the laboratory. Sticky carpet tape barriers with Tanglefoot® were checked periodically to ensure adhesive properties existed and every week leaf duff was raked and removed from beneath trees in treatments 2 and 3 for the entire duration of the 37 week experimental period. Weekly removal of leaf duff was deemed acceptable because the number of leaves falling post-defoliation were few (range = 0-30).

Sampling *Oligonychus perseae* on Dropped Leaves

Commencing weekly from May 8, 2000 ten dropped leaves from spring defoliation from under six randomly selected trees at the study plot were removed from the ground and the percentage of leaves infested and the mean number (\pm SEM) of occupied nests, eggs, and motile *O. perseae* for 60 leaves were calculated. Seven consecutive samples were made with the last being June 12, 2000.

Statistical Analysis of *O. perseae* Densities

The average total number of mite days (M-D) for each treatment (i.e., the cumulative area beneath population trends graphs) was determined as:

$$M-D = \sum_{n=1}^i (M_n \cdot d)$$

with

i = number of sampling intervals

d = sampling interval in days

M_n = mean number of mites per leaf at sampling period n

and calculated for each treatment group and compared by ANOVA. Tukey's Studentized Range Test was conducted at 0.05 level of significance to separate means to determine treatment effects.

Assessment of Leaf Damage

To determine the previous season's feeding damage to leaves by *O. perseae*, recently excised avocado leaves ($n = 27$) were randomly collected from all 30 trees at the study plot on April 10, 2000 (wk 1). Percentage leaf area damage caused by *O. perseae* feeding was measured by using automated image analysis techniques (Kerguelen & Hoddle 1999b).

From October 9, 2000 (wk 27) until monitoring ceased (December 17, 2000 wk = 37), 15 defoliated leaves per treatment were collected and percentage surface area damaged by *O. perseae* feeding was calculated using automated image analysis. At the conclusion of the field season, all leaves collected directly from trees in each experimental treatment were assessed for percentage leaf area damaged levels ($n = 240$). Percentage damage across treatments was analyzed with a fully nested ANOVA after arcsine-square root transformation. Significance was determined at the 0.05 level with Tukey's Studentized Range test.

Aerial Dispersal

Aerial dispersal of *O. perseae* was monitored in the study plot. Four wooden stakes (1.5 m high with two 1.5 m cross-arms) were established at

the north, south, east, and west directions of the experimental plot. Each cross-arm held four white sticky cards (19.5 \times 16 cm) facing in each cardinal direction for a total of 16 sticky cards in the study plot. Every sampling interval, cards were removed from cross-arms, placed in clear plastic bags, and returned to the laboratory and the number of *O. perseae* within a central square (10 cm \times 10 cm) of each sticky card was counted. Sticky cards were replaced each sampling period. The directional tendencies of *O. perseae* dispersal were calculated by square root ($x + 1$) transforming *O. perseae* counts on cards. Transformed data by cardinal direction were compared with ANOVA and Tukey's Studentized Range test for means separation at the 0.05 level.

Monitoring Phytoseiid Populations

All phytoseiid predators on sampled leaves were removed, mounted in Hoyer's medium, and identified to species. Cumulative mean predator days by treatment at each sampling interval were calculated (see mite days calculations) and compared with ANOVA and Tukey's Studentized Range test was used for means separation at the 0.05 level.

Scirtothrips perseae Management

On April 15, 2000, the entire orchard was helicopter-sprayed with abamectin (Agri-Mek, 0.15 EC, Novartis Crop Protection, Inc., Greensboro, North Carolina, USA) to control *S. perseae*. Abamectin was applied at 0.25 l/ha, delivered with 2% Leffingwell Supreme 415 Oil (Pace International, Seattle, Washington, USA) and 0.02-0.1% CMR Silicone Surfactant (Monterey Chemical Company, Fresno, California, USA) with water at a rate of 153 l/ha.

Temperature and Humidity Monitoring

Temperature and relative humidities in the orchard were recorded during the 37 wk of the experiment. Measurements were made at 30 min intervals with a HOBO data logger (Onset®, Bourne, Massachusetts, USA) attached to a wooden stake 1.5 m above the ground and positioned in the center of the experimental plot. Mean weekly maximum and minimum temperatures ($^{\circ}$ C) and maximum and minimum weekly percentage relative humidities were calculated for the duration of the experiment.

RESULTS

Oligonychus perseae on Dropped Leaves

All life stages of *O. perseae* were found on spring defoliated leaves. Percentage of defoliated

leaves with either occupied nests, eggs, or motile mites, ranged 0-28.33%, 0-23.33%, and 0-26.67% respectively. The mean number of nests, eggs, and motiles per leaf ranged from 0-19.01 ± 7.65, 0-41.20 ± 23.33, 0-39.1 ± 21.65, respectively.

Assessment of Treatment Efficacy

Oligonychus perseae populations began to increase 12 wk after the study was initiated and densities peaked in October before declining steadily thereafter (Fig. 1A). Mean weekly population counts were consistently lower for ground cover removal trees (Treatment 2), than other treatments (Fig. 1A). Percentage leaf infestation began to increase steadily after June 19 (wk 11) and by September 4 (wk 22), 100% of collected leaves across all treatments were infested with ≥1 motile *O. perseae* (Fig. 1B). Percentage of leaf infestation did not begin to decline until December 4 (wk 35) and remained high (≈85%) until the conclusion of the experiment and no differences among treatments were discernible. Comparison of mean cumulative mite days across treatments did not reveal significant differences between treatments ($F = 0.62$; $df = 3, 20$; $P = 0.61$) indicating that the use of Tanglefoot® barriers, ground cover removal, and a combination of both these tactics had no effect on *O. perseae* population dynamics on trees receiving these treatments (Fig. 2).

Mean Percentage Leaf Area Damaged

Mean percentage leaf area damaged by *O. perseae* feeding for leaves remaining on all 30 experimental trees at the end of the previous season (1999) before this experiment was initiated was 30.87 ± 3.28%. In contrast, leaf damage at the end of the 2000 season was only 6.68 ± 0.03% for leaves remaining on trees and 9.04 ± 0.37% for defoliated leaves collected off the orchard floor. There were no significant differences between treatment groups at any time interval for leaves collected from the orchard floor that were analyzed for percentage area leaf damage ($F = 1.237$, $df = 18$, $P = 0.229$) (Fig. 3). *Oligonychus perseae* feeding damage differed significantly between sampling dates ($F = 10.283$, $df = 5$, $P < 0.005$), a probable reflection of population trends. However, for leaves collected directly from trees at the conclusion of the experiment, there were no significant differences in mean percentage area leaf damaged across treatments ($F = 0.226$, $df = 3$, $P = 0.878$) (data not shown).

Aerial Dispersal

Aerial dispersal by *O. perseae* peaked during the week of November 6 (wk 31), which corresponded with peak *O. perseae* populations on

leaves (Fig. 4). Aerial movement by *O. perseae* tended to be northerly, but no significant differences between cardinal directions were detected ($F = 0.72$; $df = 3, 60$; $P = 0.55$) (Fig. 5). Mite life stage and gender were not determined, due to the difficulty of removing intact specimens from the sticky medium, for purposes of microscopic examination.

Monitoring of Phytoseiid Populations

Four different species of phytoseiid predators were recovered from experimental trees. *Euseius hibisci* (Chant) dominated the fauna comprising 79.66% ($n = 1731$) of predators recovered. *Galendromus* spp. (19.88%) ($n = 432$), *Neoseiulus californicus* (0.28%) ($n = 6$), and *Amblyseius similoides* Buchelos and Pritchard (0.18%) ($n = 4$) were all recovered with lesser frequency, and 0.8% ($n = 17$) of phytoseiids were found within *O. perseae* nests. Of these 17 phytoseiids, 6% ($n = 1$) were *E. hibisci*, 6% ($n = 1$) were *N. californicus*, and 88% ($n = 15$) were *Galendromus* spp.

Galendromus spp. were immediately reduced in number after the abamectin application for *S. perseae* control. *Galendromus* spp. densities began to increase after September 18 in response to increasing *O. perseae* densities (Fig. 6A). *Euseius hibisci* populations did not appear to be affected by the abamectin application as abrupt declines in predator density were not observed (Fig. 6B). There was no significant difference in the overall total number of phytoseiids recovered when pooled by treatment group ($F = 0.19$; $df = 3, 112$; $P = 0.90$).

Comparison of predator densities across treatments over time using predator days did not yield significant differences for either *Galendromus* spp. ($F = 0.52$, $df = 3, 20$, $P = 0.6706$) or *E. hibisci* ($F = 0.10$, $df = 3, 20$, $P = 0.9575$) (Fig. 7).

Temperature and Humidity Monitoring

Maximum weekly temperatures peaked during the first two weeks of September (Fig. 8). Temperature peaks did not coincide with peak *O. perseae* populations but did coincide with *O. perseae* dispersal activity. Maximum weekly relative humidities were consistently 100% until late October (Fig. 8).

Discussion

Removing leaf litter and blocking entry to the tree canopy via the trunks with Tanglefoot® on carpet tape did not significantly reduce subsequent *O. perseae* population development following defoliation of leaves in spring in comparison to control trees not subjected to cultural management. This suggests that the main route of reinfestation of trees by *O. perseae* may occur in ways

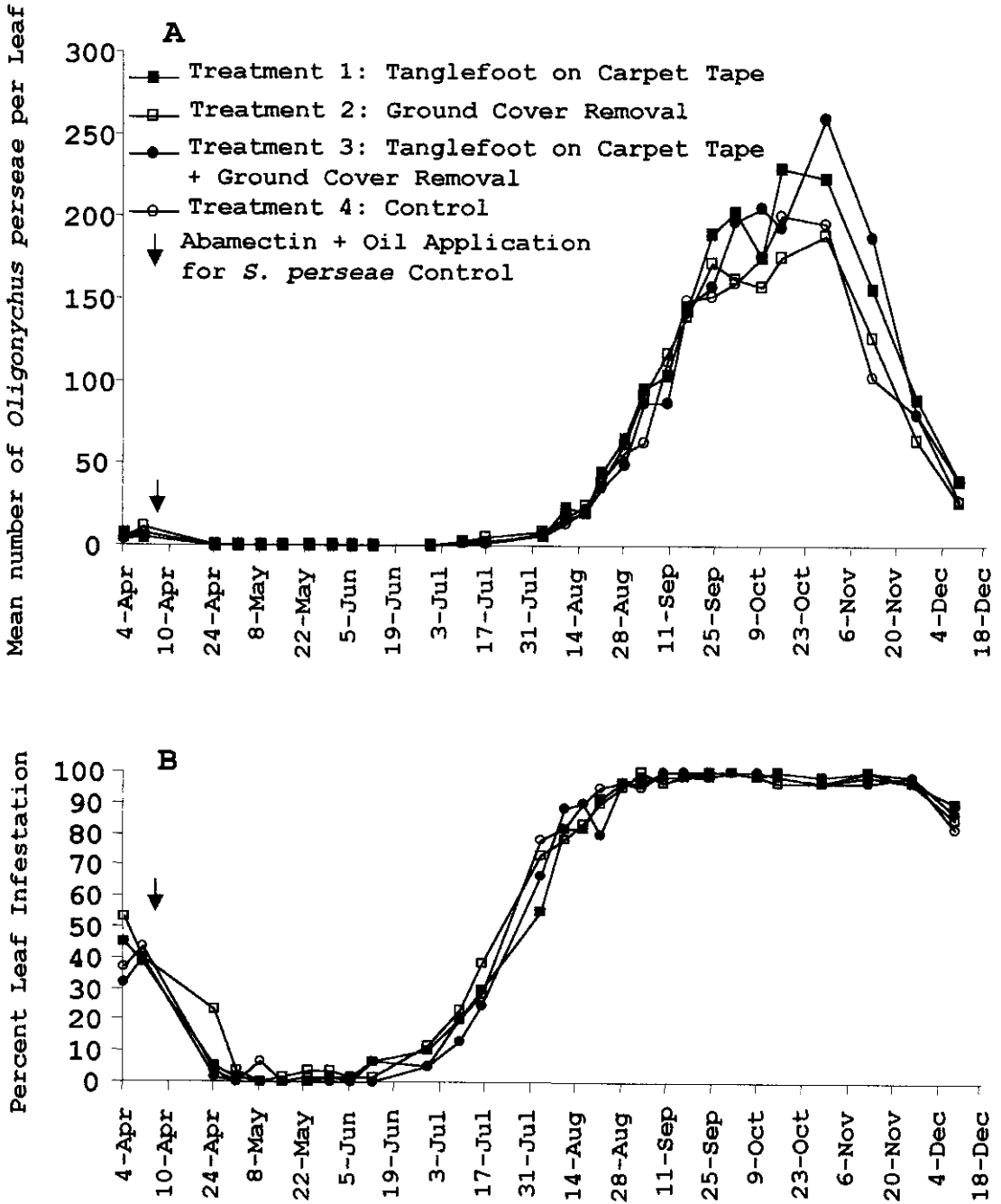


Fig. 1. Mean number of *Oligonychus perseae* collected per leaf from April-December, 2000 (A) and percentage of collected leaves infested with *Oligonychus perseae* from April-December, 2000 (B).

other than vertical recolonization from the ground after leaf drop. Possible recolonization mechanisms of new leaves in late spring could be: (1) *O. perseae* motiles are not dropping from trees on senescent leaves in sufficient numbers during periods of spring defoliation to permit effective

recolonization from the ground, and the majority of the population remains on trees. Consequently, overwintering by *O. perseae* may take place within cracks and fissures on twigs or bark on trunks or large branches. However, Berlese funnel extractions of these substrates for *O. perseae* have

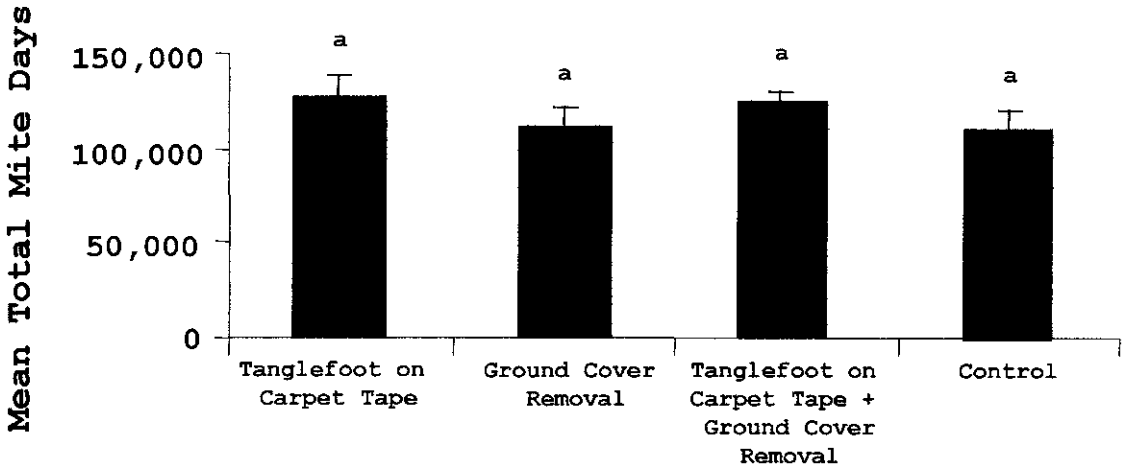


Fig. 2. Average total mite days for each treatment calculated over 37 weeks of observation. Means with same letters were not significantly different at the 0.05 level (ANOVA).

yielded negative results and an alternative sampling technique (e.g., alcohol washes) may be required to detect overwintering *O. perseae* motiles. (2) *Oligonychus perseae* populations are initiated in spring by resident mite populations on leaves bearing *O. perseae* that do not defoliate. Retention

rates of previous season's leaves have not been determined and this potential route of reinfestation requires further investigation. (3) Resident *O. perseae* populations on avocado leaves are eliminated when defoliation occurs and mites die on the orchard floor as leaf quality deteriorates or

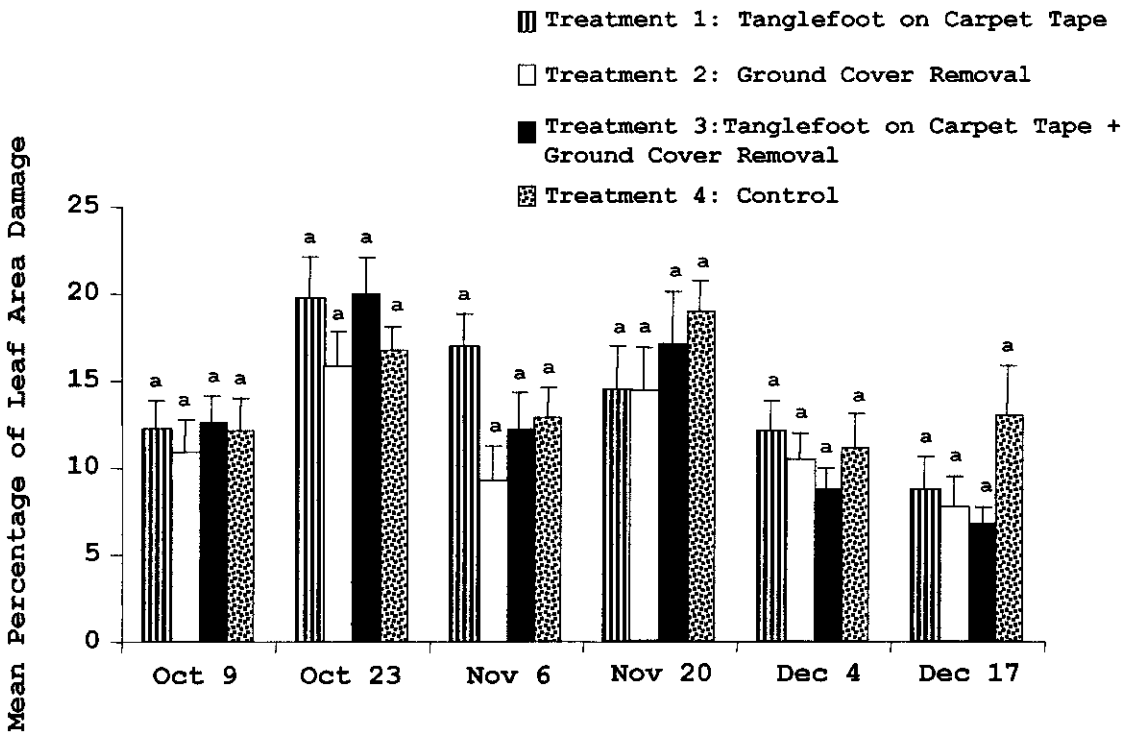


Fig. 3. Mean percentage of leaf area damaged by *Oligonychus perseae* feeding activity across treatments at six different sampling intervals on defoliated leaves. Means with same letters were not significantly different at the 0.05 level (ANOVA).

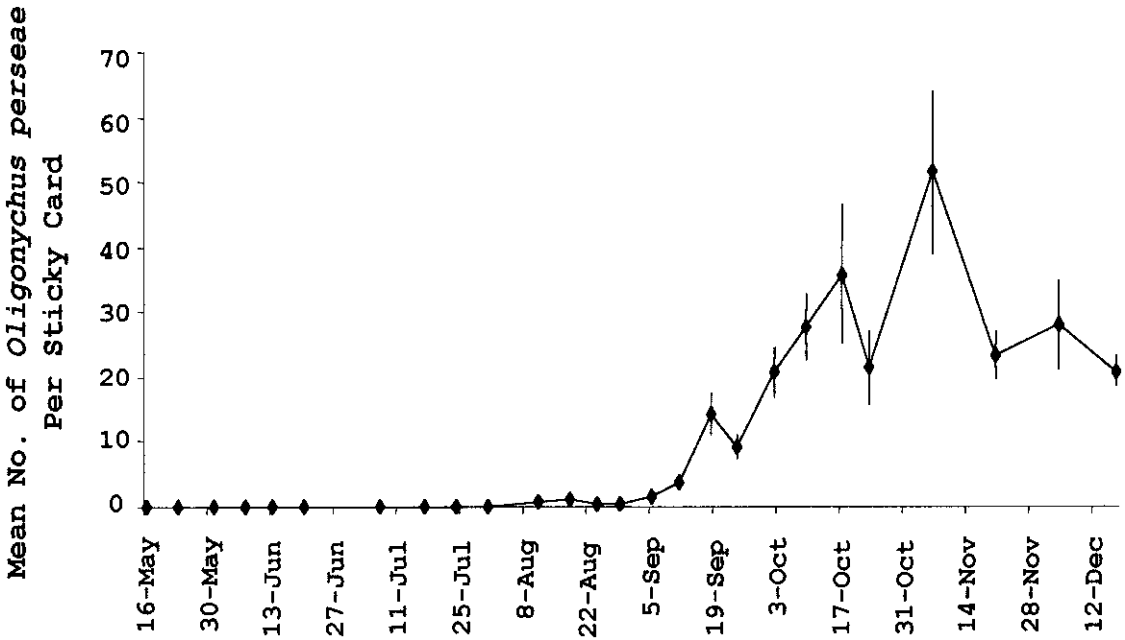


Fig. 4. Mean number (\pm SEM) of *Oligonychus perseae* caught per white sticky card at each sampling interval.

ambulatory mites that abandoned leaves are unable to locate nutritive resources. Consequently, subsequent recolonization of avocado trees could occur via aerial dispersal of motiles from other host plants in or around orchards. In California, *O. perseae* has been recorded from a variety of al-

ternate host plants such as acacia (*Acacia senegal* L.), annatto (*Bixa orellana* L.), apricot (*Prunus armeniaca* L.), camphor (*Cinnamomum camphora* T. Nees & C. Eberm.), carob (*Ceratonia siliqua* L.), citrus (*Citrus* spp.), sow-thistle (*Sonchus* spp.), grapes (*Vitis* spp.), lamb's quarters (*Chenopodium*

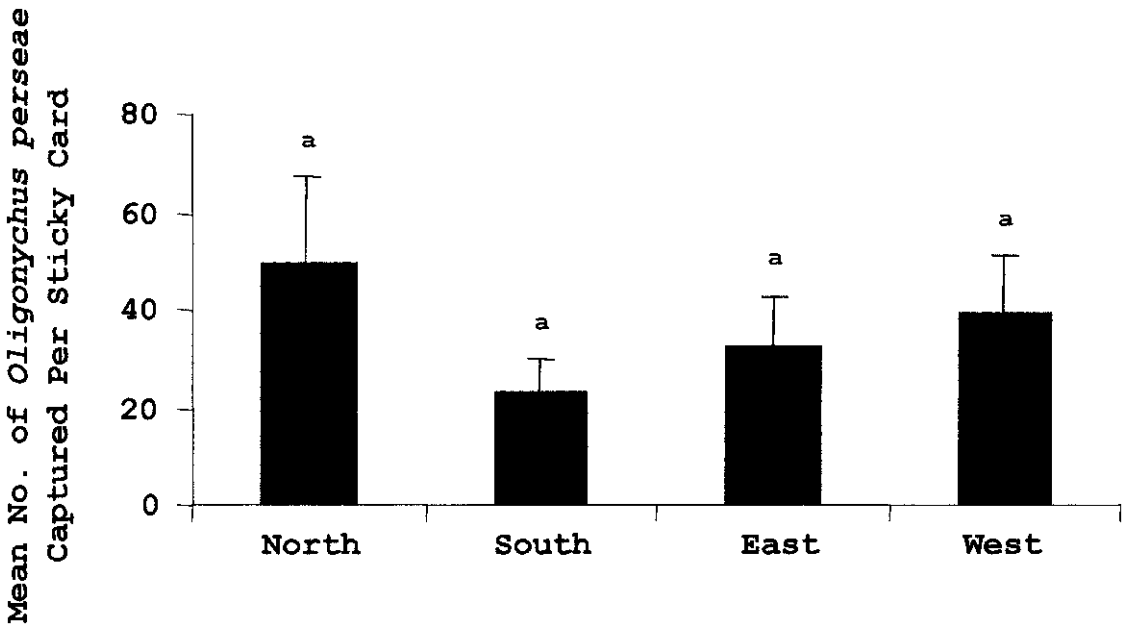


Fig. 5. Mean (\pm SEM) total number of *Oligonychus perseae* captured per sticky card in each cardinal direction. Means with same letters were not significantly different at the 0.05 level (ANOVA).

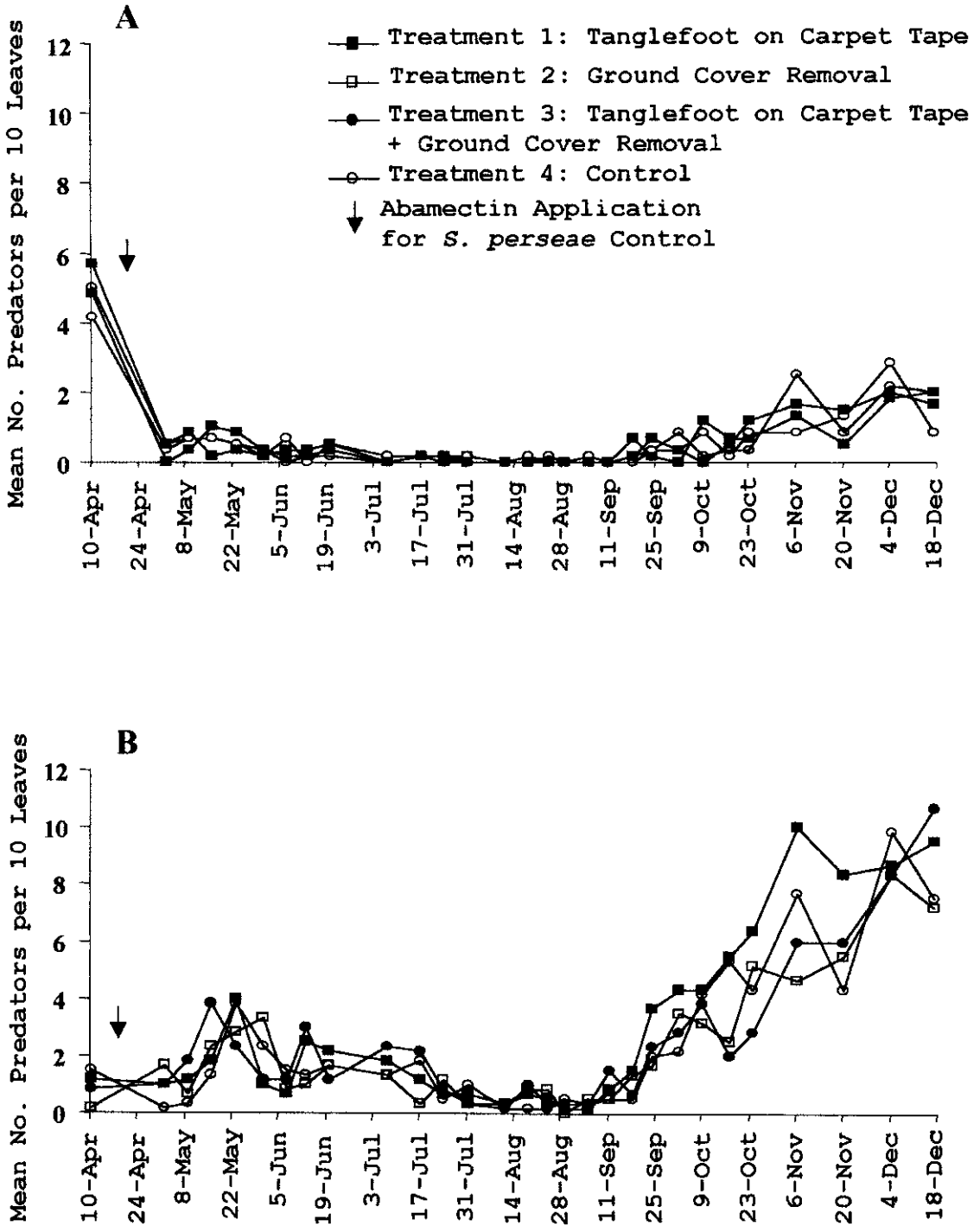


Fig. 6. Mean number of phytoseiids recovered for each 10 leaf sample by treatment over time; *Galendromus* spp. (A), *Euseius hibisci* (B)

album L.), liquidambar (*Liquidambar* spp.), milkweed (*Asclepias* spp.), nectarine and peach (*Prunus persica* L. Batsch.), persimmon (*Diospyros*

spp.), plum (*Prunus* spp.), rose (*Rosa* spp.), sumac (*Rhus* spp.), and willow (*Salix* spp.) (Baker & Tuttle 1994, Bender 1993, Aponte & McMurtry 1997).

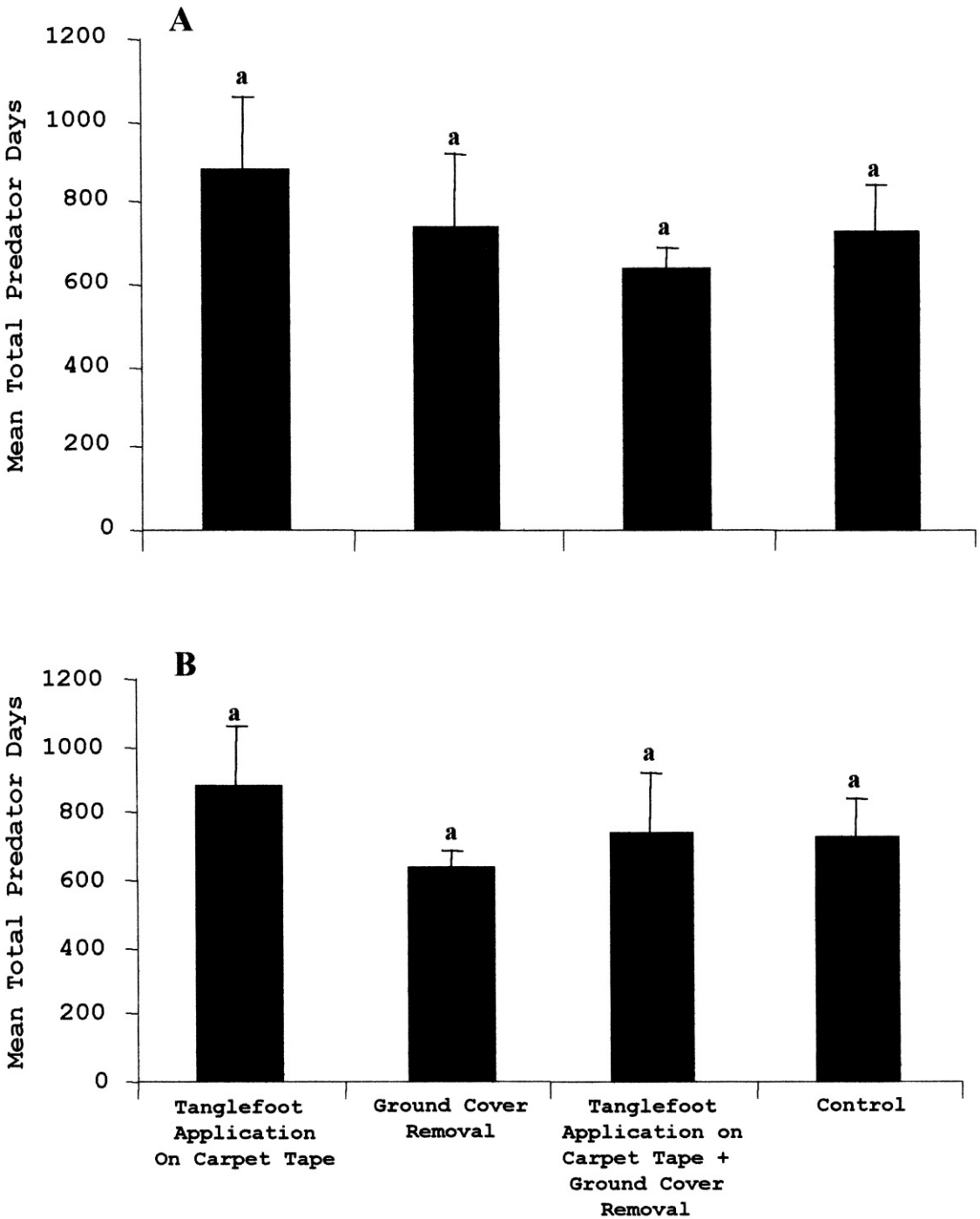


Fig. 7. Average total predator mite days for each treatment calculated over 37 weeks of observation for *Galendromus* spp. (A) and *Euseius hibisci* (B). Means with same letters were not significantly different at the 0.05 level (ANOVA).

These host plants may act as reservoirs for *O. perseae* during periods of leaf drop in or around avocado orchards and low density aerial movement

via ballooning by *O. perseae* from alternate host plants may be a route of re-infestation of avocados. In this study, *O. perseae* ballooning activity

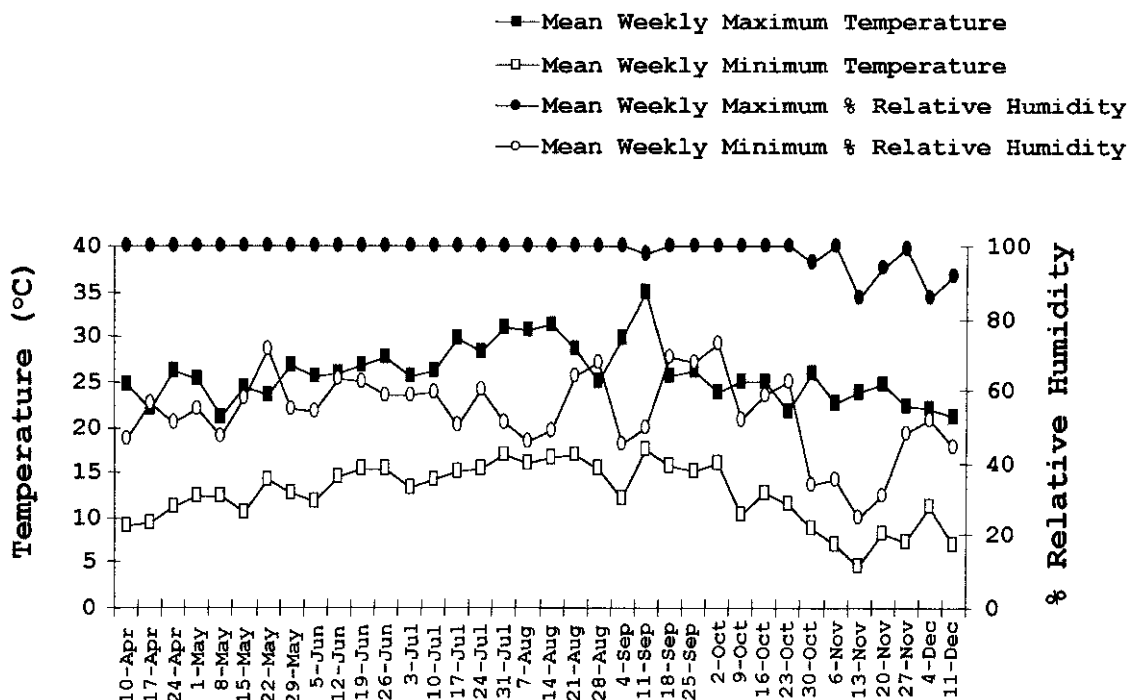


Fig. 8. Mean weekly maximum and minimum temperature ($^{\circ}\text{C}$) and percentage relative humidities recorded in the study plot at Bonsall, California over April-December, 2000.

increased as avocado leaf infestation approached 100%, suggesting that aerial dispersal occurred as a function of population density and deteriorating resource quality. Such behavior may be initiated by *O. perseae* on non-avocado host plants also. To better understand the overwintering and recolonization ecology of *O. perseae* in avocado orchards, points 1-3 need further investigation.

The abrupt decline of *Galendromus* spp. populations following abamectin applications for *S. perseae* may have been due to the fact that these predators are Type II phytoseiids (McMurtry & Croft 1997) that attack tetranychids inhabiting webbed nests. Abamectin has known toxicity to *O. perseae* (J. Morse, pers. comm., 2001) and *Galendromus* spp. population declines could have resulted because of direct contact toxicity, poisoning through ingestion of toxic *O. perseae* that acquired either a lethal or sublethal dose of abamectin, or starvation because of the absence of prey. *Euseius hibisci*, a Type IV phytoseiid, can subsist on a diet consisting primarily of pollen, and it did not appear to be adversely affected by the abamectin application. Despite a long-term low density population of *O. perseae*, *E. hibisci* densities remained relatively high as this predator was probably able to survive on pollen and non-mite prey.

The use of abamectin for controlling *S. perseae*, a serious thrips pest in California avocado or-

chards, is the most efficacious management tool used by growers to prevent damage to fruit by feeding larvae and adults (Yee et al. 1999). The impact of abamectin applications on *S. perseae* and *O. perseae* natural enemies have not been thoroughly studied. However, Zhang and Sanderson (1990) observed that abamectin was less toxic to *Phytoseiulus persimilis* Anthias-Henriot (Acari: Phytoseiidae) than its prey, *Tetranychus urticae* Koch (Acari: Tetranychidae). Likewise, Ibrahim and Yee (2000) found that although abamectin deleteriously affected *Neoseiulus longipinosus* (Evans) (Acari: Phytoseiidae), this predator did not suffer the same toxic effects as *T. urticae*, based on comparison of growth and reproduction estimates. Earlier studies demonstrated that survivability and female fecundity were compromised among predatory mite species such as *Metaseiulus occidentalis* (Nesbitt), *Phytoseiulus finitimus* Ribaga, and *Amblyseius gossipi* E-Badry (Grafton-Cardwell and Hoy 1983, El-Banhawy and El-Bagoury 1985, Reda and El-Banhawy, 1988). Development and implementation of integrated pest management programs for *O. perseae* and *S. perseae* that combine selective insecticides (e.g., abamectin) and natural enemies will require a thorough understanding of the non-target effects of these insecticides and the field ecology of target pests.

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