Correct Project Number: 79-J3

Project Report 79-C3B

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Project: Control of Mites on Almonds

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Contents

Interpretive Summary

The objectives of the project were to: (a) evaluate the possibility of establishing permethrin-resistant (Ambush or Pounce) Metaseiulus occidentalis in almond orchards; (b) evaluate the possibility of establishing Sevin-resistant (carbaryl) M. occidentalis in almond orchards; (c) evaluate the Australian mite predator, Stethorus loxtoni, for establishment in California almond orchards. In addition, an evaluation of reduced rates of Omite for mite control was begun. Evaluation of mite sampling data was begun in an effort to improve sampling efficiency.

Plots were set up in 5 almond orchards during 1979 located near Davis, Chowchilla, Visalia, Bakersfield and Blackwell's Corners. Releases of pesticide-resistant M. occidentalis were made in all orchards but the Chowchilla orchard, where only Stethorus releases were made.

We have no evidence the permethrin-resistant M. occidentalis established or survived in the almond orchards, but establishment and survival of this strain did occur in an apple orchard near Sebastopol. Releases next season with this predator should be conducted in almonds using methods comparable to those used in the apple orchard.

The carbaryl-resistant strain of M. occidentalis established in the Visalia and Blackwell's Corner orchard, survived field rates of carbaryl and controlled the spider mites in those orchards. This strain is highly resistant to Guthion as well. We will try to determine if it overwinters in these orchards. We hope it is permanently established in these orchards. It is the first time anyone has selected a predator in the laboratory and demonstrated its effectiveness in the field.

The lady beetle predator (*Stethorus loxtoni*) was released in 5 orchards in 1979. Recoveries were made several weeks after several of the releases, but no evidence of permanent establishment was obtained. Overwintering of *Stethorus* in California should be possible, however, based on our laboratory and field cage evaluations. The potential value of this predator, especially in unsprayed orchards, warrants additional releases in 1980.

The phytoseiid predator, *M. occidentalis*, has been found well established in several almond orchards. Its effectiveness as a predator of spider mites (especially of twospotted spider mite, Pacific mite and Turkestani spider mites) has been documented for both the 1978 and 1979 field seasons. During 1978, it was shoen an effective predator in the Bakersfield and Blackwell's Corner IPM orchards. During 1979, it was shown to be effective again in these 2 orchards and in an orchard near Visalia. The value of *M. occidentalis* as a control agent of spider mites in almonds may be documented for other almond orchards. (The Manteca IPM orchard appears to be one according to personal communications from W. Reil.) Reasons for *M. occidentalis*' poor rating as a predator in almonds are unknown but at least 3 possibilities exist: (1) *M. occidentalis* is not an effective predator of European red mite, especially if it *predominates* in an orchard. Many almond orchards fall in this category. (2) *M. occidentalis* is not a good competitor in unsprayed orchards. It may be outcompeted in orchards by general predators such as thrips, lacewings, Stethorus species, etc. Apparently, some almond orchards especially those in milder climatic areas, have relatively few NOW or mite problems, and pesticide applications are minimal. (3) Finally, in many orchards, especially in the hotter, drier southern San Joaquin Valley where the more damaging Pacific and two spotted spider mites predominate, heavy, repeated applications of acaricides are made. Omite and Plictran can be selective acaricides, controlling spider mites and allowing M. occidentalis to survive, but survival is not possible for M. occidentalis at high rates of Omite (more than 5 lbs) due to direct mortality and to starvation. Accordingly, I suggest that use of appropriate insecticide and acaricide rates may allow us to manage mites more effectively. I suggest that M. occidentalis, if already present, can be allowed to exert its control if lower rates of acaricide are used (perhaps in the range of 1-2 lbs/acre formulated). I also suggest that M. occidentalis could be established in almond orchards where it is not currently present, if adjustments in acaricide (and insecticide) rates are made. Preliminary work in 1979 in the Bakersfield IPM orchard suggested that effective control of mites may be achieved using 1 - 2 lbs of Omite/acre. More trials should be initiated in 1980 in other areas with different spider mite densities, with and without releases of M. occidentalis. If it were possible to reduce acaricide rates, a considerable reduction in costs would occur, as well as allowing M. occidentalis to play its role more effectively.

Sampling of spider mites during the 1977, 1978 and 1979 field seasons has left me with a profound awareness of the diversity of spider mite species and composition in California almond orchards. Extremely high tree to tree variability usually exists. Within orchard "hot spots" make sampling difficult. The sampling scheme we are developing is aimed at providing a rapid assessment of the potential for _M. occidentalis_ to control mites in that almond orchard. Considerable work needs to be done yet with this subject.

Finally, observations of improper and proper water management's apparent effects on spider mites lead me to conclude that NOW management by early harvest and early water turn off in the orchard could exacerbate spider mite problems. Perhaps this should be considered as a joint effort with the IPM project for 1980.

Introduction

The objectives of the project are contained in the previous section. The report is organized into chapters, and each chapter is numbered individually. Chapter IV is a draft of a manuscript that has been accepted by California Agriculture for the January/February 1980 issue.

Releases of Permethrin-Resistant *Metaseiulus occidentalis*

Metaseiulus occidentalis is an effective control agent for spider mites in deciduous fruits and vineyards in western North America. Organophosphate insecticide resistance (especially azinphosmethyl) developed in field populations as noted by Hoyt in 1969, and this has been exploited by others, including Croft, who successfully transferred this OP-resistant predator into a southern California apple orchard. Others have since established it in Australia, New Zealand and Europe.

Limits to *M. occidentalis*' field effectiveness are its susceptibility to other insecticides such as the carbamates and synthetic pyrethroid insecticides.

We began selecting with the synthetic pyrethroid permethrin in the fall of 1977. The necessity of that selection is represented by permethrin's lethal effect on *M. occidentalis*. If we compare LC_{50} values for Pacific mite and *M. occidentalis*, we find the Pacific mite is unlikely to be affected by field rates of permethrin (Pounce/Ambush) while *M. occidentalis* is very susceptible to it (Fig III-1).

Any selection project requires genetic variability for that attribute or selection will be a failure. Accordingly, a large number of California populations from pears, and vineyards were screened for their responses to permethrin. The results were disappointing. However, S. C. Hoyt shipped us a conony of *M. occidentalis* from apples in the fall of 1977 which gave a positive response to selection.

Since then, selection has progressed using the Washington apple colony, using a colony from a British Columbia apple orchard and one from California, and using two different selection methods. All strains and both selection methods have given positive results, although we have progressed farther with the Washington apple colony.

The Washington apple colony was selected using adult gravid females, which are placed on leaf discs dipped into formulated permethrin and air dried. After 48 hrs, the surviving females are removed and placed on paraffin discs to produce the females for the next round of selection. The disadvantages of the method are that sperm from susceptible males may be carried over; and, selection is for adult resistance only; it is conceivable that the resistance mechanism may be different in adults and immatures. Therefore, we have been selecting also using immatures, using the method developed by R. T. Roush in which immatures are placed on damp filter paper, sprayed with permethrin, air dried, and survivors must walk off the filter paper to the surrounding substrate to found the next generation.

Results of the adult selection with the Washington apple colony will be presented for the last 5 founds (12 - 16) (Table III-1). We may have hit a plateau of response, although this is not certain due to the complications of a previously-undescribed (bacterial/rickettsial) disease which is adding an unknown amount of mortality to the selection treatments. We hope to assess this in January. LC_{50} values were obtained for this strain every third selection round also.

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Results with the immature selection method are also promising (Table III-2). Initial selection began with a colony in which females had been selected with permethrin for 10 rounds. Yet, when immatures were treated with 2 grams, only 16% of 1425 larvae, protonymphs, deutonymphs or males survived. That jumped to 30%, 35%, 38% and 48%. A doubling in rate to 4 grams yielded 34%, 39% and 40% survivorship. The two rounds with 21% survival are probably due to the influence of disease. We may be stuck at 41% survival (round 12). Inheritance studies and mechanisms of resistance are unknown for this line at present.

The level of resistance in the Washington apple colony last June was sufficiently high to allow us to do preliminary field releases in 1979 into 3 almond orchards and one apple orchard using predators from the 8th round of selection. The results in the almond orchards were disappointing -- we obtained no evidence that the resistant predators established or survived the permethrin sprays. In 2 orchards, low prey densities could have been a factor in the failure to establish. In one orchard prey was abundant, but there were also abundant native _M. occidentalis_ to interbreed with, thus diluting the resistance levels. A partial genetic analysis of this 8th selection round (Table III-3) indicated that F_1 progeny were more resistant than the susceptible parents, but resistance is not as high as would have been desirable. (F_2 and BC progeny were not obtained as this was planned to be a preliminary analysis only since the colony was not yet a pure line.)

TABLE III-1. RESPONSE OF THE WASHINGTON APPLE COLONY OF M. OCCIDENTALIS TO SELECTION WITH PERMETHRIN.

SELECTION NO.	DOSE G/ 100 LITERS	NO. FEMALES TREATED	% SURVIVAL @ 48 HRS
12	8	1200	18.8
13	8	1400	18.4
14	8	1050	19.9*
15	8	1500	21.9*
16	8	1000	26.2*

* Colonies have a disease which may affect their survival.

Table III-2. *M. OCCIDENTALIS* IMMATURE SELECTION WITH PERMETHRIN.

SELECTION NO.	DOSE G AI/100 LITERS	TREATED	% SURVIVAL
1	2	1425	16
2	2	850	30
3	2	1000	20*
4	2	700	35
5	2	700	38
6	2	630	49
7	4	630	34
8	4	810	39
9	4	700	40
10	4	400	21**
11	4	850	24**
12	4	675	41

** Survival may have been reduced due to disease.

TABLE III-3. PARTIAL ANALYSIS OF 8TH SELECTION FOR PERMETHRIN RESISTANCE IN _M. OCCIDENTALIS_ PRIOR TO ORCHARD RELEASES IN 1979.

CROSS ♀ X ♂	NO. ♀♀ TESTED	LC_{50}	95% C.I.
WA X WA-resistant	276	6.02	3.7-9.9
CA X CA-susceptible	419	1.21	0.6-2.6
WA X CA reciprocal F_1 progeny	435	2.22	1.3-3.9
CA X WA	419	2.43	1.2-5.1

However, we obtained evidence which indicates that this permethrin-resistant strain did establish and survive permethrin sprays in an apple orchard, located near Sebastopol. About 1000 gravid female M. occidentalis were released into 6 trees each on 11 June 1979 and treated by J. Joos with 0.05, 0.01 and 0.2 lb AI/acre Pounce (permethrin). Permethrin sprays had been applied before predators were released; applications were made on 14 May in the 0.2 lb and 0.1 lb trees and on 1 June for the 0.05 trees. A second application of permethrin (but the FIRST post-predator release application) was made on 12 July. On 14 September and 25 September, M. occidentalis were collected from these trees and from nearby, permethrin-untreated trees. Colonies were reared and comparative assays conducted using 2 g permethrin AI/100 liters on bean leaf discs (TABLE III-4). Mortality of the "native" M. occidentalis was at a rate of 67 and 75% after 48 hours, whereas M. occidentalis recovered from the trees where resistant M. occidentalis were released had a higher survivorship (only 21, 17 or 19% mortality).

Considerable work remains to be done with these "genetically-improved" strains of M. occidentalis, including an analysis of the mode of inheritance, persistence of the resistance in unselected populations, laboratory and field evaluations of interbreeding potential of the resistant and wild type strains, the ability of the resistant strain to retain OP resistance, or for crosses to combine OP, CARB and Permethrin resistances within a single strain.

TABLE III-4. MORTALITY (%) OF *M. OCCIDENTALIS* RECOVERED FROM THE SEBASTOPOL APPLE ORCHARD IN SEPTEMBER 1979*

MORTALITY OF *M. OCCIDENTALIS* RECOVERED FROM TREES WHERE RESISTANT PREDATORS WERE RELEASED AND TREATED WITH			MORTALITY OF *M. OCCIDENTALIS* RECOVERED FROM TREES WHERE NO PREDATORS WERE RELEASED. TREES TREATED WITH	
POUNCE .1 LB/ACRE	POUNCE .2 LB/ACRE	POUNCE .05 LB/ACRE	IMIDAN	DIMILAN
21	18	19	67	75
N=(130)	(105)	(78)	(59)	(24)

* Tested with 2 grams permethrin AI/100 liters water on leaf discs. Mortality of adult females was assessed after 48 hours.

Acknowledgments

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Carbaryl Resistance Developed for a Spider Mite Predator: Genetic Improvement of a Biological Control Agent

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Spider mites have become increasingly important agricultural pests in the last 25 years. California growers lost an estimated $60,328,102 to mites in 1977 due to yield losses as well as money spent on pest control, making mites the second most important agricultural pests in the state. The ability of spider mites to tolerate or develop resistance to pesticides which destroy their predators is a major factor contributing to their economic significance.

Some spider mite predators, the phytoseiid mites, have developed resistance to some insecticides in nature. One such predator, *Metaseiulus* (= *Typhlodromus*) *occidentalis* (Nesbitt), has developed widespread resistance to organophosphorus insecticides such as azinphosmethyl (Guthion®). This resistance is a central component of apple and pear pest management programs in Washington and California.

Unfortunately, *M. occidentalis* has not developed resistance to all pesticides used in those crops where *M. occidentalis* can be effective in minimizing spider mite outbreaks. Carbaryl (Sevin®) is one example. Some of its uses include blossom thinning in apples and navel orangeworm (*Paramyelois transitella* (Walker)) control in almonds.

Genetic selection program

A genetic selection program to develop a carbaryl-resistant strain of *M. occidentalis* was begun in December 1977. The first step involved mass hybridization of *M. occidentalis* colonies collected from 18 locations in California and Washington in order to provide adequate genetic variability. None of these colonies were detectably resistant to carbaryl. Two genetic selection methods were used. One method involved rearing predators and prey on pinto bean plants and spraying them with increasing doses of formulated carbaryl. The other method involved treating just the immature, motile stages and adult males on pieces of moistened filter paper. About 500 - 1000 predators were treated in each round of selection to give about 70-90% mortality.

A "leaf flood method" was adopted to quantify M. occidentalis' responses to carbaryl: bean leaf discs are placed on moist cotton and flooded with a 2 lb AI/100 gallon "challenge" dose of carbaryl (80% WP). Gravid adult female predators are then floated in the pesticide which is allowed to dry. Tetranychus urticae Koch, the two-spotted spider mite, are added to the leaflets after the carbaryl dries as prey, and the leaf discs are held at 28°C for 48 hours when the number of survivors is recorded. Ten females are tested on each of ten leaf discs (100 predators total) for each assay.

A high level of resistance developed in M. occidentalis strains selected by both methods. After 15 - 19 rounds of selection, about 83% of the selected strains survived compared to about 2% in the unselected strains. Genetic crosses indicated that the carbaryl resistance is inherited as a single incompletely dominant gene. The F_1 hybrids (offspring resulting from the mating of resistant and susceptible parents) survive the "challenge" dose nearly as well (72%) as their resistant parents.

Laboratory and greenhouse tests

Laboratory and greenhouse tests were conducted to examine the vigor of these laboratory-selected predators in the absence of carbaryl treatments. Traits evaluated included: reproductive rate, development rate, sex ratio, mating preferences and compatibilities, diapause capacity (ability to enter their overwintering state), azinphosmethyl resistance, and capacity to control spider mite populations. Pesticide resistant strains of insects and mites often develop slowly and/or produce fewer eggs than do susceptible (wild type) strains, but these strains do not. In fact, based on one greenhouse experiment, a population of these resistant predators may increase faster than those of the susceptible predator strains tested. The sex ratio may have increased so that more females are produced than normal.

The carbaryl-resistant predators mate freely and seem reproductively compatible with California M. occidentalis populations. Their diapause capacity seems normal and, although it was never used during the course of the selection program, their resistance to azinphosmethyl increased. Two greenhouse tests demonstrated that the carbaryl-resistant predators could survive a normal application of carbaryl and control two-spotted spider mites on pinto beans.

The carbaryl-resistance in these predator strains doesn't appear to break down over time. M. occidentalis populations with equal numbers of resistant and susceptible genes (i.e. F_1 hybrid progeny of resistant X susceptible parents) retained the expected level of resistance (51% survival at the 2 lb challenge dose) for eight months (about 16 - 24 generations) when maintained on pinto bean plants in the greenhouse which were not treated with carbaryl.

Field releases

These laboratory and greenhouse assessments of this genetically-selected strain indicated that it should perform well in the field. In order to assess their effectiveness in the field, the resistant predators were reared on the two-spotted spider mite on pinto beans, released into two almond orchards, and sprayed with carbaryl applied for navel orangeworm control during 1979. There were three objectives in these experiments: 1) to determine if the predators could survive the carbaryl applications; 2) determine if the surviving predators could control spider mite populations in these almond trees and 3) determine if the resistance characteristic could persist for more than one season.

The almond orchards used were a research orchard near Visalia, California, and a commercial orchard near Blackwell's Corner, Kern County, California. The trees in the Visalia orchard are planted closely together; in some places there is less than one foot distance between the foliage of different trees. The trees had also been radically pruned and therefore produced leaves about 4 times larger than those at the Blackwell's corner orchard. Seven trees in each orchard were randomly assigned to one of three treatments: 1) no releases (NR); 2) release susceptible (unselected) laboratory-reared predators (SR); and 3) release resistant (selected) laboratory-reared predators (RR). All 21 trees in a given orchard were contiguous in one or two rows, i.e., there were no "guard" trees between experimental trees. Untreated check trees were within 3 rows of both test plots.

Azinphosmethyl (4 lbs 50% WP/acre) was applied with a speed sprayer on May 17 at the Visalia orchard to precipitate a spider mite outbreak.

A total of 3500 M. occidentalis were then released per tree between June 6 and June 20. A dilute spray of carbaryl (10 lbs/acre, 80% WP) was applied with a handgun on July 6. One thousand predators were released per tree on June 14 in the Blackwell's Corner orchard. Carbaryl (7 lbs/acre, 80% WP) was applied in a concentrate spray by helicopter on July 13. Thirty leaves were randomly sampled per tree and counted by a leaf brushing method. The mean totals of all stages are given in the figures.

To document that the predators found on the trees after the carbaryl application were resistant, a sample of predators collected on August 1 was colonized in the laboratory and tested for carbaryl resistance. A colony collected before the predator releases were made was tested for comparison. This was necessary because it is possible that the M. occidentalis found on a tree after a carbaryl application may have survived due to incomplete coverage or they may have migrated to the tree after the carbaryl application. These predators need not be resistant.

Results of field releases

None of the predator releases caused any statistically significant increases in the predator populations before the carbaryl treatments at either orchard.

In both orchards, the resistant predators survived the carbaryl application and controlled the spider mite populations whereas the susceptible predators did not. The principal mite species in the Visalia orchard was the two-spotted spider mite. The May azinphosmethyl application produced a spider mite population greater than that desired. Some defoliation and considerable webbing were evident before the carbaryl application on July 6. The carbaryl application appeared to cause a slight decrease in the *M. occidentalis* populations in the RR trees (where resistant predators were released) (Fig. 1A), but this decrease was not statistically significant and is probably due to mortality of a large proportion of the native susceptible predators also present on the trees (as illustrated by the insignificant impact of 3500 released predators per tree). There was a significant decrease in predator populations in the other (SR and NR) trees ($P < .008$, signed rank test, Figs. 1B, C). Although there were no significant differences in *M. occidentalis* or spider mite populations before the carbaryl application, there were more predators ($P < .001$) and fewer spider mites ($P < .01$, Mann-Whitney U test) in the RR trees (Fig. 1A) on July 17 (after the application). In spite of decreases in predator populations on the non-release (NR) and susceptible release (SR) trees (July 17, Figs. 1B, C), there were no great increases in spider mite populations as are often observed after a carbaryl application. This is probably due to the poor nutritional quality of the almond leaves at that time. The differences in *T. urticae* populations persisted through August 1, even though the differences in predator numbers became insignificant because of predator reproduction. The proportion of defoliation was much less in the RR trees (Fig. 2A) than in the other trees (Fig. 2B).

The resistant predators successfully colonized the Blackwell's Corner orchard, even though the spider mite populations were very low, and kept the spider mites in low numbers. The principal spider mite species in this orchard was the Pacific spider mite, *Tetranychus pacificus* McGregor. There were no significant differences in the predator and prey population densities at the Blackwell's Corner orchard until the August 1 sample when the trees containing resistant predators (Fig. 3A) had significantly lower Pacific mite densities than the other trees (Mann-Whitney U test, $P < .05$). There were, however, no statistically significant differences in M. occidentalis populations. Apparently, as in the Visalia orchard, the predators on the RR trees survived the carbaryl application in sufficient numbers to control the spider mite populations (Fig. 3A), but the trees with the susceptible predators (SR and NR) suffered a Pacific spider mite population increase (Figs 3B, 3C). Unfortunately, the initial populations of the predators were too low and the samples taken at an inappropriate time to show statistical differences in the numbers of M. occidentalis in the first post-application sample (as was possible in the Visalia orchard). No Pacific spider mites could be found in this plot on August 17, probably due to their depletion by the M. occidentalis populations. There was no defoliation in any of these trees.

The results of the 2 lb AI/100 gal leaf flood tests on the predators recovered from the test plots on August 1 show that the released resistant predators were responsible for controlling the spider mites. The predators recovered from the RR trees at the Visalia orchard on August 1 are more resistant to carbaryl (survival: 71%) than are those collected from the SR and NR trees (34%, $P < .001$). But even the predators from the NR and SR trees are more resistant than the native (pre-release) population (2%, $P < .01$), which suggests that some of the resistant predators have dispersed among these closely spaced trees.

The predators on the resistant release trees are significantly more resistant (63% survival) than are those collected from the SR and NR trees (7%, $P < .001$). The resistances on these trees are unchanged from their pre-release levels. The trees in this orchard are more widely spaced, so dispersal among these trees was probably lower than at the Visalia orchard.

The levels of resistance exhibited by the _M. occidentalis_ collected from the RR trees in these two orchards are well within the ranges expected from the resistance levels of the laboratory strains (Table 1) because some susceptible genes would undoubtedly "survive" the carbaryl application in heterozygotes (F_1 predators). Some susceptible (homozygote) predators would be produced as the predators continued to mate randomly.

The work described up to this point documents two of the objectives of this genetic improvement project: predator survival after field applications of carbaryl and prey regulation. That the resistant predators could be established even at very low prey densities and survive to control the spider mites in the Blackwell's Corner orchard is particularly impressive.

The third objective was to show that the resistance trait can persist in these predator populations from year to year. This phase of the project will require further study, and because of a variety of environmental vagaries, full documentation of this aspect may take some time. However, as a preliminary test of overwintering ability and persistence, a strain less resistant than the one used in this project (from the ninth selection) was released in the Blackwell's Corner orchard in August 1978. This strain did successfully persist through June 1979. The predators were difficult to find in June 1979 because of the low Pacific spider mite populations (Fig. 3), but 3 M. occidentalis were collected from a resistant release tree and one was collected from a susceptible release tree. A laboratory colony formed from the 3 predators from the RR tree had a challenge dose survivorship of 21% which was significantly greater (P = .05) than of the colony founded by the predator from the NR tree. Unfortunately, the colonies tested are from small samples and the data are suggestive rather than conclusive.

Full acceptance of the value of these resistant predators for pest management will require larger field plots and longer trials. We expect that resistance levels will increase as additional carbaryl applications cull the susceptible predators in the orchards. Tests of predator efficacy will require study sites where high rates of acaricides are not routinely used. Although acaricides such as propargite (Omite®) and cyhexatin (Plictran®) kill few M. occidentalis directly, some spider mites must survive the acaricide application or all the predators will starve in about 10 days. If that happens, wind-blown spider mites can return to the orchard and rapidly build up in the absence of predators.

Entomologists have noted the successes of plant and animal breeders and have discussed selective breeding of improved strains of natural enemies for over 60 years. Honeybees, silkworms, and other domesticated or semi-domesticated insects have been "improved" by selection, but no one has documented genetic improvement of a biological control agent's field effectiveness until now. We believe that this is the first successful field demonstration of its kind. We also believe that genetic improvement projects will eventually be successful for other species of biological control agents and can involve attributes other than pesticide resistance.

Table 1. Survivorship of gravid females from M. occidentalis colonies treated with a 2 lb AI/100 gal carbaryl challenge dose.

	Survival (%)[1]
Visalia Orchard	
Colony collected before predators were released	2 c
Colony collected on August 1 from trees where resistant predators were released(RR)	71 a
Combined colony collected on August 1 from trees where susceptible predators were released and where no predators were released (SR & NR)	34 b
Blackwell's Corner Orchard	
Colony collected before predators were released	7 bb
Colony collected on August 1 from trees where resistant predators were released (RR)	63 aa
Combined colony collected on August 1 from trees where susceptible predators were released and where no predators were released (SR & NR)	7 bb
Laboratory strains	
Resistant strain	83
Susceptible strain	2
F_1 progeny	72
F_2 progeny	51

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[1] The survivorships of the predator colonies from each orchard followed by different letters differ significantly ($P < .01$, Mann-Whitney U test with multiple comparisons based on percentage survivorship in replicates after Abbott's correction for mortality in water controls). No comparisons between orchards are made or are appropriate.

Figure Legends

Figure 1. Visalia Almond Orchard - 1979. A: trees where resistant predators were released (RR). B: trees where susceptible predators were released (SR). C: trees where no releases were made (NR).

Figure 2. Closeup of foliage at the Visalia orchard showing the relative conditions of trees where (A) resistant predators were released (RR) and (B) susceptible predators were released (SR).

Figure 3. Blackwell's Corner Orchard. A, B, and C are the same as in Fig. 1.

R. T. Roush is a graduate student and Marjorie A. Hoy is Assistant Professor and Assistant Entomologist at the University of California, Berkeley.

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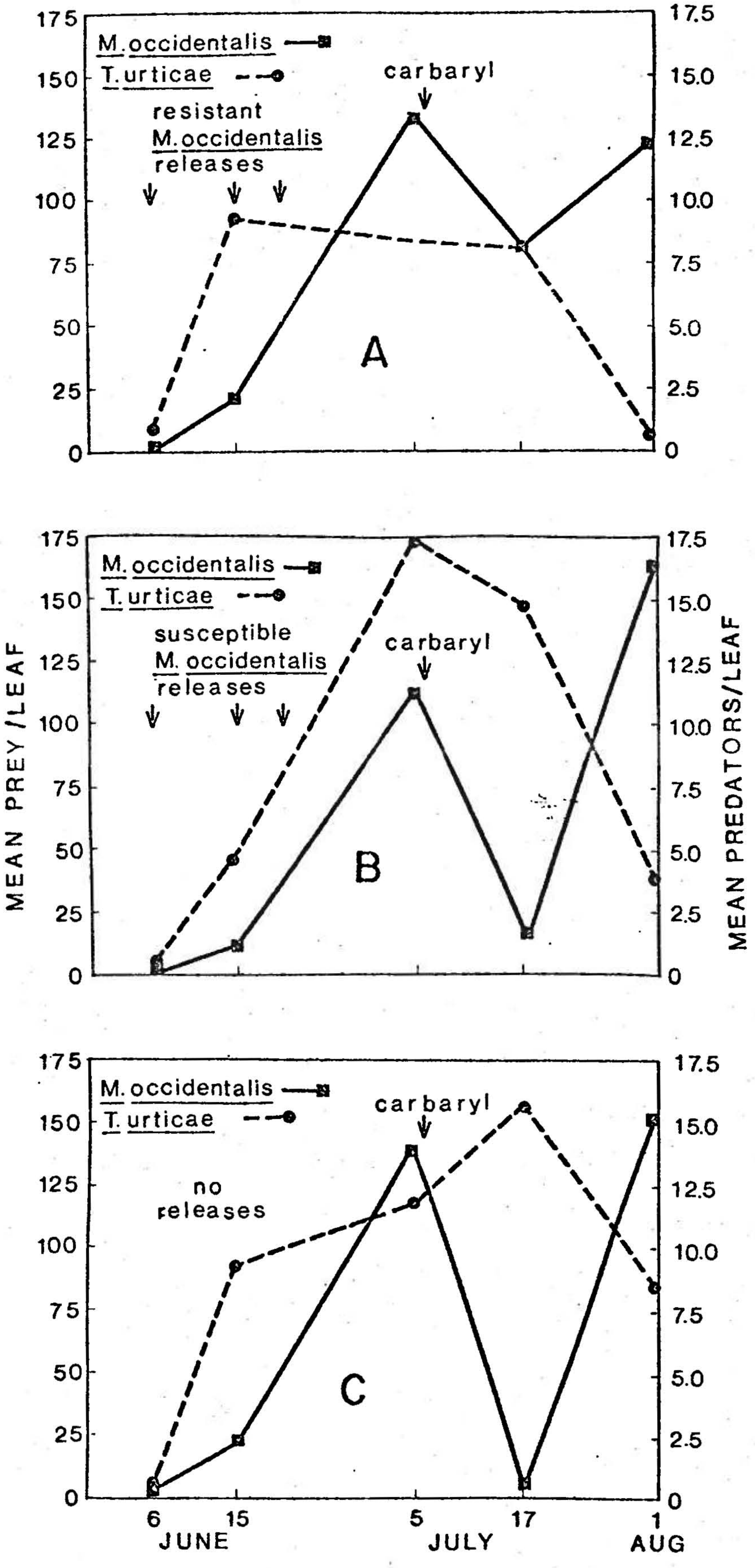
M. occidentalis
T. urticae
resistant M. occidentalis releases
carbaryl
A
susceptible M. occidentalis releases
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no releases
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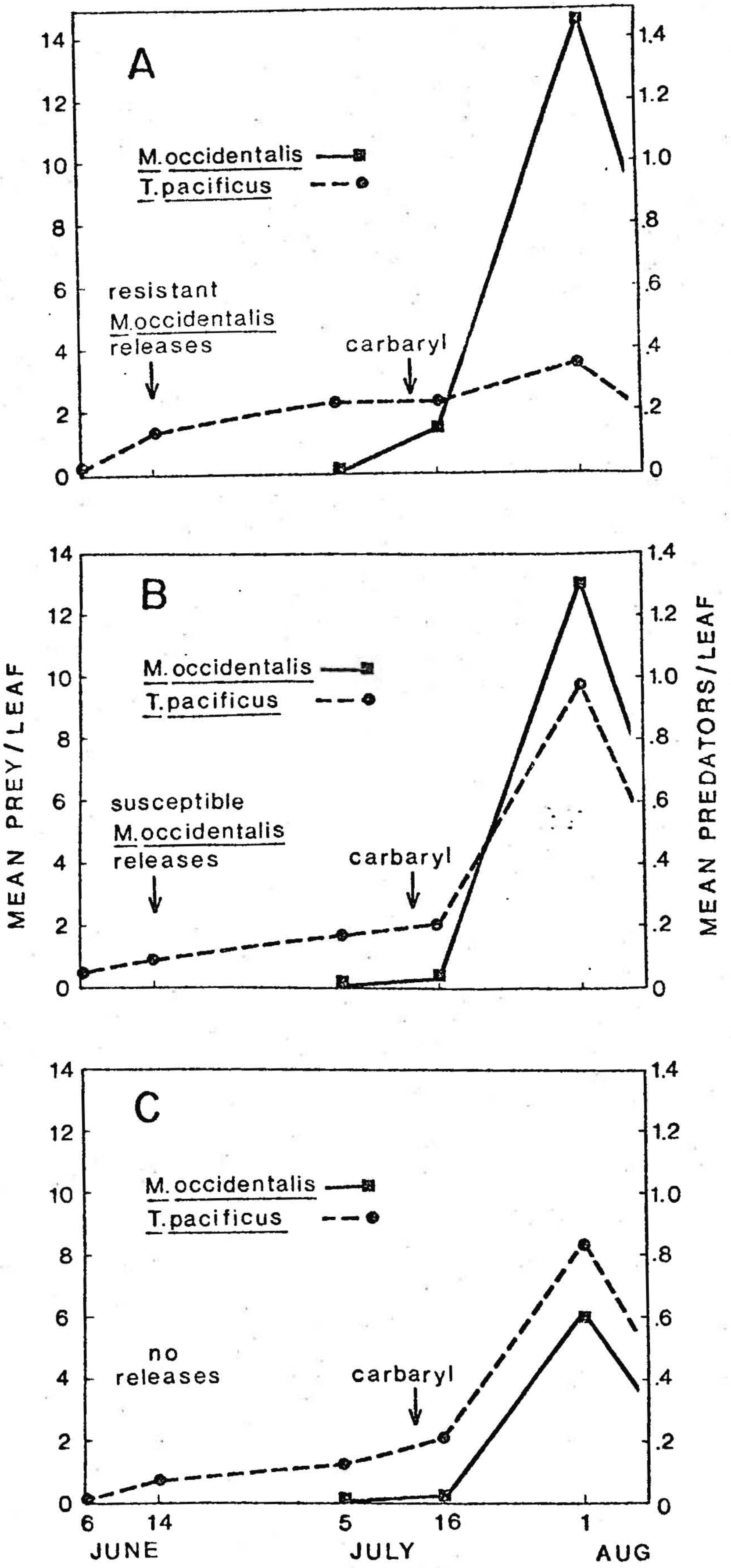
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T. pacificus
resistant M. occidentalis releases
carbaryl
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M. occidentalis
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susceptible M. occidentalis releases
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Spider Mite Management with Reduced Rates of Omite

An experiment was conducted during 1979 to determine if reduced application rates of Omite^R could be used to manage mites in San Joaquin Valley almond orchards. Our goals were to determine if reduced rates of Omite^R gave adequate control, and to determine if the phytoseiid predator, _Metaseiulus_ _occidentalis_ (Nesbitt) is affected by these different application rates.

This report gives the results of one field test which was conducted in the Bakersfield IPM orchard (Bidart). Four treatments were applied to blocks of trees within the red and pink check block. Six Nonpariel almond trees in each treatment were flagged and 30 leaves/tree were sampled on June 6, July 5, July 16, Aug. 1, Aug. 17 and Aug. 28. All stages of spider mites and _M_. _occidentalis_ were counted and the results are reported as mites per leaf.

Spider mite species present in this orchard included: _Tetranychus_ _urticae_ _T_. _pacificus_, _T_. _turkestani_, and _P_. _citri_. The _Tetranychus_ species predominated, comprising > 80% of the spider mite population, with _T_. _urticae_ and _T_. _pacificus_ predominating over _T_. _turkestani_, based on species determinations using slide-mounted male spider mites.

Visual observations on 5 June indicated numerous hemerobiids (both eggs and adults) were present in this block whereas spider mites were sparse (less than 0.01/leaf). No phytoseiids were observed in this block and none were present in the leaf samples (Table 1).

On 5 and 16 July, all blocks had low numbers of spider mites and predators (_M_. _occidentalis_) (Table 1). Omite treatments were applied on 19 July by a

Table 1. Average numbers of spider mites[a] and M. occidentalis per leaf in the Bakersfield pest management orchard treated with Omite® - 1979.

	Mean numbers per leaf on 6 trees treated with							
	5 lb[b]		2 lb[c]		1 lb[c]		Check	
Sample dates	Spider mites	*M. occ.*	Spider mites	*M. occ.*	Spider mites	*M. occ.*	Spider mites	*M. occ.*
6 June	-	-	0	0	0.01	0	0.01	0
5 July	0	0	0.2	0.01	1.5	0	0.5	0
16 July	2.2	0.03	9.2	0.01	3.5	0.02	0.4	0.02
	Treatment 19 July							
1 August	3.5	0.11	0.09	0	18.3	1.04	42.8	0.33
17 August	48.9	1.42	5.6	1.37	36.7	4.37	76.2	5.62
28 August	14.3	2.94	0.2	0.41	0.02	0.12	0.06	0.33

[a] Spider mites present included: *T. urticae*, *T. pacificus*, *T. turkestani* and *P. citri*.

[b] Applied commercially by helicopter.

[c] Applied with a concentrate sprayer (50 gal/acre) using Omite 30W.

concentrate spray rig and by helicopter. In the first post treatment sample on 1 August the check block had significantly more spider mites than did the 1, 2 or 5 lb rates. The 1 lb rate gave the poorest control, as an average of 18 spider mites per leaf were present compared to 0.09 for the 2 lb rate or 3.5 mites/leaf for the 5 lb rate. Predators were undetected in the 2 lb rate block on that date, probably because so few spider mites (0.09/leaf) were present to sustain them. Predators recovered in that 2 lb block by the 17 August sample date, however. A peak of 37 spider mites/leaf was found in the 1 lb Omite block compared to 76 spider mites/leaf in the check (Table 1), so even the 1 lb rate gave some, possibly adequate, control. By contrast, peak number of spider mites/leaf in the 5 lb rate applied by helicopter was 49.

By August 28 all mite populations had declined. On this date, there were more predators/leaf than there were spider mites/leaf in the check, 1 and 2 lb rates!

The best spider mite control was achieved using the 2 lb rate applied with a concentrate sprayer. The 5 lb rate applied by helicopter gave less effective spider mite control than the 2 lb rate applied by ground rig, presumably because more complete coverage was achieved with the ground rig.

The 1 lb rate allowed more spider mites to survive than did the 2 lb rate, but the peak spider mite density/leaf (36.7) was lower than in the check (76.3) or in the 5 lb rate (48.9), suggesting that under these conditions of relatively few spider mites, 1 lb rates of Omite^{R} might give adequate mite control. Economic injury levels of spider mites are not yet determined, however.

These results indicate that further work with reduced rates of Omite^R would be worth while. Additional field tests in diverse orchards with different spider mite densities should be conducted to determine if reduced application rates of Omite^R would be a useful almond pest management technique. The potential advantages of reduced application rates would include 1) the possibility of reducing costs if less material is applied/acre, and 2) the preservation of predators (especially M. occidentalis). At the very effective 2 lb application rate, predators were reduced to zero on the first post-treatment date, possibly because there were no spider mites present so that they starved. Higher rates, such as are common (5 - 22 lbs/acre), would possibly prevent adequate predator-prey retention in these orchards. Also, while Omite is selectively toxic to spider mites, it does have some lethal effect on M. occidentalis and so direct mortality as well as starvation could have been a factor in reducing predator populations at the higher rates of Omite.

Studies with Stethorus loxtoni from Australia

Stethorus loxtoni was released for the second field season by us. A few recoveries were made in almond orchards, but we have no evidence of establishment to date (Table V-1). Applications of acaricides in the Chowchilla plot destroyed a promising Stethorus population (due to loss of prey). Recoveries in the Blackwells Corner orchard seemed likely in late July but spider mites had abruptly declined and the Stethorus left. The potential value of this predator, especially in orchards with few pesticide applications, warrants additional releases in 1980.

The following draft of a manuscript describes the results of experiments designed to determine if S. loxtoni can overwinter successfully in California. We believe it can, and thus these data support our conclusion to continue releases in 1980.

TABLE V. RELEASES OF S. LOXTONI DURING 1979 IN THE SAN JOAQUIN VALLEY AND SOUTHERN CALIFORNIA.

SITE AND CROP	DATE(S) RELEASED	NOS. RELEASED	DATE(S) RECOVERY
PARLIER - ALFALFA	8 May	150	16 July
VISALIA - ALMONDS	15 June	400	none
CHOWCHILLA - ALMONDS	25 June	600	eggs and larvae on 7 July but sprayed out
BLACKWELLS CORNERS - ALMONDS	16 July	1500	1 adult Aug. 1 prey declined
CHOWCHILLA - ALMONDS	31 July	900	--
CHULA VISTA - PEACHES	27 August	1000+	--

EFFECT OF DECREASING TEMPERATURES AND DAYLENGTHS UPON OVIPOSITION BY THE SPIDER MITE PREDATOR *Stethorus loxtoni* (COLEOPTERA: COCCINELLIDAE)

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Abstract

Stethorus loxtoni Britton and Lee was first imported from Australia into California in 1974 and released in 1974 and 1976. A new colony was imported from Australia in 1978 and released in 1978 and 1979. *S. loxtoni*'s apparent lack of a diapause was considered a possible limitation to its overwintering ability which could prevent its establishment in California. Efforts to induce diapause in *S. loxtoni* reared at 10 h daylengths at 19°C temperatures failed. Several generations were reared in growth chambers programmed with diurnally cyclic, decreasing temperatures and declining daylengths to mimic conditions in the San Joaquin Valley of California in the fall and winter. Under these conditions, and in field cages at Berkeley, California, adult female *S. loxtoni* became dormant during the winter. Establishment of *S. loxtoni* may be difficult due to its sensitivity to pesticides rather than its overwintering ability.

Introduction

All known *Stethorus* species are predators of spider mites (McMurtry *et al.* 1970) and several species have been demonstrated to be highly efficient predators of spider mites in agricultural crops (for example, Hull *et al.* 1976; Readshaw 1971; McMurtry & Johnson 1966). While the phytoseiid predator *Metaseiulus* (=*Typhlodromus*) *occidentalis* (Nesbitt) control spider mites in a number of California deciduous fruit crops (Flaherty and Huffaker 1970; Hoy *et al.* 1970), the addition of a predator that could move more rapidly to spider mite "hot spots" would be useful. If it were an effective predator of the European red mite (*Panonychus ulmi* Koch) and the citrus red mite (*P. citri* (McGregor)), spider mite species not preferred by *M. occidentalis* (Hoy and Smilanick, In prep.), an added benefit would accrue.

S. loxtoni Britton and Lee was first introduced into California by the University of California Division of Biological Control, Albany, in 1974 (Richardson 1977). About 300 and 19,000 *S. loxtoni* were released in California in 1974 and 1976, respectively (Richardson 1977). No evidence of permanent establishment was obtained after these releases, but the documented value of this species in Australia (Richardson 1977; Field 1977; and Readshaw 1971) indicated additional evaluation and release efforts were justified.

This paper reports attempts to induce diapause in *S. loxtoni* by rearing it for two generations under constant short daylengths and cool temperatures and for 3 generations under the declining temperatures and daylengths occurring in Berkeley and in the San Joaquin Valley of California in the fall and winter. Observations of S. loxtoni's feeding preferences are included as well as its responses to the synthetic pyrethroid insecticide, permethrin.

MATERIALS AND METHODS

Colony Source--Colonies of S. loxtoni were initiated from the progeny of adults collected on February 14 and 28, 1978 in Waikerie, South Australia by N.L. Richardson. The experimental colonies were begun in early March from about 230 F_1 progeny of the adults held in quarantine. Most F_1 progeny were used to start a laboratory colony; the remainder (ca. 50) were used to start an outdoor colony kept continuously in a field cage in Berkeley, California so that inadvertent selection against diapause would not occur.

Development Under Constant Short Daylength at 19°C--S. loxtoni were reared at 19°C under a 10 h daylength to see how a short, cool day affects reproduction and development. About 100 females were placed into 0.47 liter cardboard containers for 3 days to oviposit and then removed. The F_1 generation was reared with abundant Tetranychus urticae Koch as prey and the adults left together for one week for mating and the pre-oviposition period. Each adult was isolated in a plastic petri dish (50 X 9 mm) for one week with a blackeyed pea (Vigna unguiculata subsp. unguiculata) infested with T. urticae. The number of beetles that oviposited was recorded at the end of a week. Since males are morphologically indistinguishable from females (Britton and Lee 1971; Richardson 1977), a 50% oviposition rate was interpreted to mean that all females were ovipositing; dissections of nonovipositing beetles were conducted to confirm this assumption. A group of F_2 progeny was reared under the same conditions and the number that oviposited was recorded to determine if diapause might be induced in the maternal generation.

Oviposition and Development Under Cyclic Temperatures and Decreasing Daylengths--The population of beetles reared continuously in the Berkeley field cage since March 1978 was tested on a monthly basis from September 1978 to March 1979 to determine their reproductive status. Eighty adults were individually isolated each month with abundant *T. urticae* prey and held for one week to determine the number ovipositing under these field cage conditions. Temperature was recorded on a hygrothermograph in a nearby standard weather shelter during the course of the tests (Table 1).

Table 1

TEMPERATURE CONDITIONS (^{o}C) RECORDED AT BERKELEY, CALIFORNIA FIELD CAGE, 1978-1979 DURING OVIPOSITION TESTS WITH *S. LOXTONI*

Test Date	Mean	Maximum	Minimum
Sept. 6-12	23	37	14
Sept. 30-Oct. 2	20	31	13
Oct. 31-Nov. 7	15	26	9
Nov. 30-Dec. 7	9	15	1
Jan. 6-13	11	13	7
Feb. 5-13	12	18	6
Mar. 2-9	14	23	6

TABLE 2

TEMPERATURES AND DAYLENGTHS PROGRAMMED FOR KHFS TEST WITH *S. LOXTONI*

TEMPERATURES				DAYLENGTH	
Date Set	Minimum	Mean	Maximum	Date Set	Photophase
Aug. 30	14.4	24.0	35.0	Aug. 30	13:00
Sept. 16	9.5	18.9	31.1	Sept. 6	12:45
Oct. 1	8.3	17.3	29.4	Sept. 14	12:15
Oct. 17	5.0	13.9	26.1	Sept. 20	12:00
Nov. 1	4.4	10.8	25.0	Sept. 26	11:45
Nov. 16	2.8	8.3	17.2	Oct. 2	11:30
Dec. 1	0.6	4.5	16.1	Oct. 10	11:15
Dec. 17	0.0	6.3	17.2	Oct. 17	11:00
Jan. 1	2.2	6.9	14.4	Oct. 24	10:45
Jan. 17	3.3	9.3	16.1	Oct. 31	10:30
Feb. 1	5.0	9.2	17.8	Nov. 7	10:15
Feb. 15	6.7	12.9	21.7	Nov. 15	10:00
				Nov. 26	9:45
				Dec. 13	10:00
				Jan. 17	10:15
				Jan. 26	10:30
				Feb. 3	10:45
				Feb. 18	11:00

A growth chamber (Percival Mfg., Model E-30B) was programmed with a temperature regime to approximate the average conditions at the Kearney Horticultural Field Station (KHFS) located near Parlier in the San Joaquin Valley of California. Temperatures were regulated by plastic cams cut so that temperatures cycled daily between maximum and minimum values calculated by averaging 3 years of hygrothermograph data from the KHFS. Maximum and minimum values were changed twice a month by replacing the plastic cams (Table 2). Lighting was provided by 20-w cool white fluorescent bulbs and day-length was decreased or increased by 15 min intervals on appropriate dates (Table 2).

On August 30 (simulated date) about 500 adult S. loxtoni were allowed to oviposit for 40 hr on blackeyed pea leaves infested with T. urticae (all stages) in 0.47 liter cardboard cartons. The resulting 200-300 eggs were labeled the F_1 generation. Throughout the experiment beetles wre given excess prey. When the F_1 adult beetles completed development in the third week of September, they were allowed to mate and oviposit. Each month a group of 60 F_1 adults were isolated, and the number of beetles that oviposited was recorded until the experiment was terminated in February. The beetles were transferred to new cartons every 2-3 weeks and their mortality was estimated then. The F_2 generation completed development by the last week of October and its oviposition rate and mortality were estimated in the same manner as for the F_1 generation. Only 23 F_3 eggs deposited in late October completed development by the end of February. These F_3 adults were held a week to determine if they were ovipositing.

Since the beetles reared in the previous experiment were always provided with excess food, another experiment was conducted to determine the effects of reduced or alternate food on adult longevity. Beetles were reared from egg to adulthood under conditions approximating the late November temperature and daylength at KHFS (Table 2). At maturity, they were isolated in petri dishes. One group (31 beetles) was given no food or water; a second group (25) was given only water on a small wad of cotton; a third group (24) was given diluted honey on filter paper. Nine control adults were fed excess *T. urticae*. The amount of mortality was assessed every 1 or 2 days.

Feeding Preference

S. loxtoni adults and larvae were starved 24 h and placed on leaf discs with *Panonychus citri*, which were confined to the disc by a water moat. Beetles were observed up to 55 minutes and their feeding success was recorded.

Pesticide Testing

The effect of permethrin (2EC) on *S. loxtoni* adults was assessed using groups of twenty adults which were confined on filter paper or leaf discs in a covered 9 x 50 mm petri dish. The filter paper or leaf disc was dipped in pesticide solution and allowed to dry before beetles were placed on the substrate. The mortality of beetles was recorded after 48 hours. Doses tested include 0.1, 0.5, 0.75, 1.0, 1.5, 2.0 gm A.I./100 liters water.

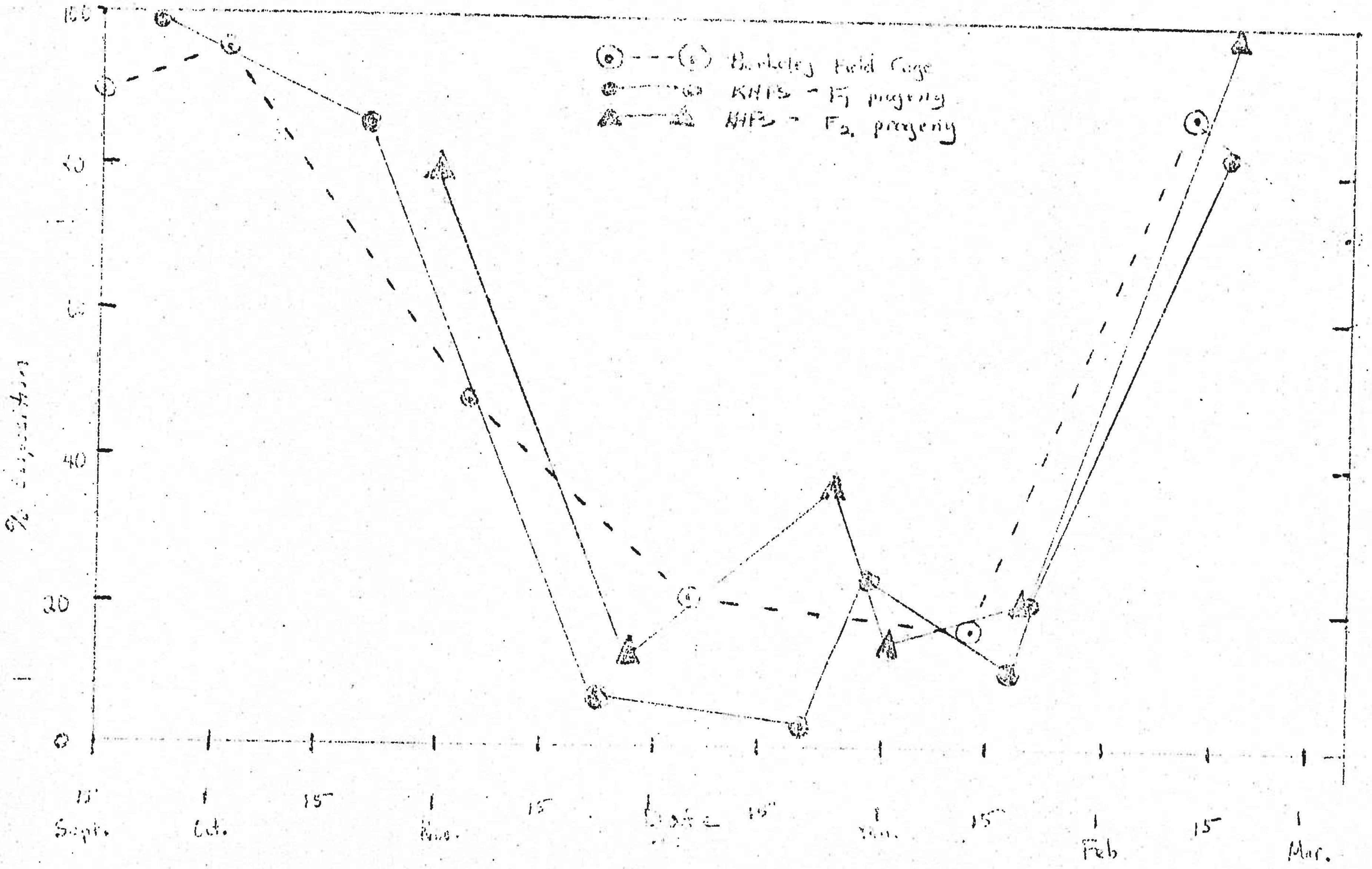
Results and Discussion

Development Under a Constant 19° and 10 H Day--Of 178 S. loxtoni reared from egg to adulthood at a constant 19° under a 10 h day, 62 oviposited (35%), indicating lack of an adult reproductive diapause. Dissection of 102 of these beetles indicated that 39% were females, a skew from the normal 1:1 sex ratio of this species (Richardson 1977). Therefore, we assume that most of the females were reproductively active. Their daughters were reared under the same conditions and also oviposited; 37% of all F_2 beetles tested oviposited. Since 43% of the F_2 progeny dissected were fmales, we concluded that most F_2 daughters oviposited which indicated the lack of maternal influence on diapause induction in this species. Development of S. loxtoni to adulthood rquired about 6 weeks at 19°, indicating that larval or pupal diapause did not occur.

Development under Cyclic Decreasing Temperatures and Daylengths--S. loxtoni reared with abundant T. urticae prey in field cages at Berkeley, California oviposited in September (fall) but by late October the oviposition rate had dropped to 48% of 50 females tested (Fig. 1). Only 21% of 33 females tested during the November 30-December 7 interval oviposited, and 17% of 35 females oviposited in the January interval. By February 5, 88% of 41 females oviposited and by March 9, 70% of 37. Thus, oviposition was arrested in the majority of S. loxtoni females tested throughout November, December and January in the Berkeley field cages.

The same pattern of arrested reproduction was observed for most S. loxtoni females reared under the growth chamber conditions mim-

Fig. 1. The proportion of S. loxtoni females ovipositing in conditions of decreasing daylength and decreasing cyclic temperatures in the Berkeley field cages and in the KHFS growth chamber. See tables 1 and 2 for details of temperature and daylength conditions.


Berkeley Field Cage
KHPS - F_1 progeny
NHPS - F_2 progeny
100
80
60
40
20
0
%
15 Sept.
1 Oct.
15
1 Nov.
15
1 Dec.
15
1 Jan.
15
1 Feb
15
1 Mar.

icking the KHFS temperatures and daylengths. Eighty beetles of unknown sex were isolated monthly the number of ovipositing females was low and remained low in the November assay period until the February 17 assay date, when 41% of 80 adults of unknown sex oviposited.

Survival of the F_1 and F_2 beetles in the KHFS growth chamber was good. Total mortality of the F_1 beetles held from October 28 until February 17 was ca. 12%. Mortality of F_2 beetles was ca. 13% from November 18 until February 13.

When adult beetles held under the fall-winter KHFS conditions were given nothing, water only, or honey in water, their survival rate declined from that observed when the beetles were provided abundant prey. Beetles given nothing lived an average of 10.8 days (S.D. = 3.6); beetles provided water only lived an average of 10.1 days (S.D. = 4.6), an insignificant difference. Beetles provided honey lived an average of 20.7 days (S.D. = 11.5), which is a significant improvement, but significantly less than for beetles provided abundant _T. urticae_, prey which lived throughout the winter with only 12-13% mortality. It thus appears that these beetles require food during this overwintering period. Putman (1955) found _S. punctillum_ Weise behaved similarly with these alternative foods in his studies in Canada. Permethrin was very toxic to _S. loxtoni_. Survivorship of _S. loxtoni_ was low. An LC_{50} of 0.48 g AI/100 liters (95% confidence interval = 0.29-0.79) was obtained. Walters (1976) had demonstrated that _S. loxtoni_ is susceptible to Guthion, Sevin and DDT.

General Discussion

Richardson (1977) evaluated the effects of short daylengths (10 h) and cool temperatures (15-20°C); short days and high temperatures (30-35°C); long days (15 h) and cool temperatures; and long days and high temperatures on *S. loxtoni*. He found that neither daylength or temperatures significantly affected *S. loxtoni*'s oviposition rate, although he did not determine the effects of these conditions for more than one generation. Richardson (1977) and Field (1977) reported that *S. loxtoni* eggs, larvae, and adults could be found associated with hibernating *T. urticae* in Australia in tree bands throughout the winter months and concluded that there was no obligatory diapause. We confirmed their findings with constant temperatures when we reared *S. loxtoni* for two generations at 19° under a 10 h day; no obligatory diapause was detected.

S. loxtoni females reared under conditions of cool temperatures and declining daylengths do not all oviposit. This arrested reproductive state could be due to a facultative diapause or to simple dormancy. It would not be considered a "strong" type of diapause as is expressed by other species which inhabit less moderate climates, but involves suspension of reproduction by only some females. We indirectly confirm Richardson's (1977) and Field's (1977) observations that immature S. loxtoni can be found under tree bands during the winter. It appears from our field cage and growth chamber experiments that eggs deposited in September or October (fall in California) would be able to develop slowly throughout the winter, but few new eggs would be deposited in late November, December, or January. This appears to be an effective strategy for S. loxtoni, allowing part of the population to overwinter as the presumably more resistant adult stadium.

Lack of oviposition by S. loxtoni could be because experimental temperatures were below the threshold for oviposition. The threshold temperature for development of all stages of S. loxtoni except the 2nd and 3rd instars was determined by Richardson (1977) to be between 11 and 12° using a linear model, but was 9° using a sigmoid model. That for the second and third instars was between 6 and 6.5°. The threshold for development of the egg is 11.5° and Richardson (1977) found S. loxtoni eggs could tolerate at least 7 consecutive days at 8°, although mortality was complete after 2 days at 8° Apparently Richardson did not determine the threshold for oviposition. These temperatures are in the range of those S.

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loxtoni experienced in the Berkeley field cage (Table 1) and in the KHFS growth chamber (Table 2). Diapause has been defined variously, and usually with the paradigm of species which inhabit a climate with colder winters than those found in the San Joaquin Valley of California. Definitions usually include the notion that it is a genetically determined state of suppressed development which typically begins before the onset of unfavorable conditions and may not be terminated until after the disappearance of such conditions (Beck 1968). Simple dormancy differs from diapause in that the dormant state is a direct response to deleterious physical conditions, and may occur at several different growth stages of the insect, whereas diapause typically occurs only at a specific stage (Beck 1968). These experiments were designed to determine if *S. loxtoni* could overwinter successfully in California, but were not designed to discriminate between dormancy and a subtle form of diapause. Either most *S. loxtoni* females enter a facultative reproductive diapause under conditions of declining temperatures and daylengths, but not under constant cool days or constant short daylengths, or these females have a different threshold for oviposition than the 17-21% that continued to oviposit. *I.e.*, the failure of most *S. loxtoni* females to oviposit could be because the temperature is below their threshold of oviposition rather than due to a diapause which is induced by the combined cues of decreasing tem- perature and daylength.

McMurty *et al.* (1974) found that adult females of *Stethorus picipes* Casey may enter a facultative reproductive diapause under short day conditions in southern California, which has even milder winters. S. picipes females were sensitive to photoperiod and diapause induction occurred in the adult beetles, in contrast to the situation normally observed in regions with colder winters. McMurtry et al. (1974) noted that all stages of this species were found even in midwinter where spider mite infestations occurred. Diapause was not diagnosed easily in S. picipes, particularly since only a portion of the S. picipes population enters diapause.

Examples of other insects which do not readily enter diapause under constant conditions are becoming increasingly common. For example, Anderson et al. (1977) reared the braconid Rogas indiscretus Reardon in field cages in Connecticut, U.S.A. and induced a diapause in the fall under decreasing daylengths and temperatures. They were unable to induce diapause under constant short days and constant cool temperatures in growth chambers in the laboratory. Later Wallner (1979) reported R. indiscretus entered diapause in response to short daylengths coupled with cooler temperatures during the scotophase under laboratory conditions.

The ability of S. loxtoni to overwinter in the Berkeley field cage and in the KHFS growth chamber programmed to mimic San Joaquin Valley conditions indicates that establishment of S. loxtoni in California ought not be limited by climatic factors; rather this species' sensitivity to insecticides used in agricultural systems may be a more serious factor in its establishment.

Acknowledgements

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Sampling Mite Populations in California Almond Orchards - Progress Toward an "Economic" Threshold and Treatment Criteria

The potential of various species of tetranychid mites to cause damage to California almond orchards has attracted considerable interest (e.g., Barnes and Andrews 1978). A sampling program is needed as a preliminary step in assessing the damage potential of these species and the need for mite control practices. This report summarizes work designed to facilitate sampling programs for spider mites and a phytoseiid predator, *Metaseiulus occidentalis* (Nesbitt).

Preliminary studies of 8 almond orchards had shown that species compositions and abundances varied greatly in northern and southern San Joaquin Valley orchards, and even between orchards which were close geographically (Hoy *et al*. 1979). These studies also showed *M. occidentalis* to be an important and effective predator in southern San Joaquin Valley orchards where *Tetranychus* spider mite species predominate, but not in northern orchards where *Panonychus* and *Bryobia* species predominate. This is consistent with the experiences of other workers (e.g. Westigard and Calvin 1971) that *M. occidentalis* is not an effective predator on *Panonychus* spp.

We had 3 objectives: 1) assess the sources of variation within the orchard and the trees throughout the growing season; 2) estimate the number of leaves needed for reliable estimates of population densities for any given tree; 3) develop practical methods to assess *M. occidentalis* and spider mite populations for decision-making purposes.

Materials and Methods

Four almond orchards, chosen for their diversity of locations and mite fauna, were sampled in this study. The 1st, near Yuba City, was dominated by the brown almond mite, *Bryobia rubioculus* (Scheuten) (found only in the early season) and the European red mite, *Panonychus ulmi* Koch (later in the season). The 2nd, near Stockton, was dominated by the two-spotted mite, *Tetranychus urticae* Koch. The last 2, one near Bakersfield and one near Blackwell's Corner (western Kern County), were dominated by the Pacific spider mite, *Tetranychus pacificus* McGregor, but the Bakersfield orchard also had some Atlantic spider mites, *T. turkestani* (Ugarov and Nikolski). All orchards were flood irrigated except for the Blackwell's Corner orchard, which was sprinkler irrigated. Four trees were sampled in each of the northern (Yuba City and Stockton) orchards; 6 were sampled in the southern orchards. All of the trees were adjacent to each other, i.e., in small blocks, and of the Nonpareil variety.

Each orchard was sampled by 2 methods, one intensive and one rapid, so that comparisons of the methods could be made. For the rapid method, each orchard was sampled every 2 weeks from late April through September by randomly pulling 30 leaves from the lower half of each tree, except that the Blackwell's Corner orchard was sampled by climbing up into the tree to sample above the area washed by the sprinklers. These leaves were cooled for transport and mite densities (all stages) were counted by direct examination under a microscope.

For the intensive method, the orchards were sampled using a quadrant system similar to that of Westigard and Calvin (1971). Each tree was divided into upper and lower halves (except at Blackwell's Corner, where only the upper half was sampled because of the sprinklers) and in each half a 25 leaf sample was taken from the center area of the tree and from the north, east, south and west quadrants aound the periphery (250 leaves total, except that only 125 leaves were taken at Blackwell's Corner). These samples were taken every 2 weeks from late April through late September in the northern orchards, but only twice between June and August in the southern orchards (because spider mite densities were very low during most of the season). The leaves from these samples were cooled for transport and all stages counted with a leaf brushing method (Henderson and McBurnie 1943). Preliminary comparisons showed that mite counts obtained by direct examination and by the mite brushing machine were very similar.

The data was analyzed with the aid of a computer packaged program (SPSS) for analysis of variance (using the actual data and using data transformed by $\log_{10}$ N+1) and regression as is described more completely in the next section.

Results

The various mite species seem to be fairly evenly distributed throughout each tree throughout the season, i.e., the mites are not especially abundant in any particular area of the tree. The only consistent source of variation in mite populations is tree-to-tree variation (generally $p < .001$). The results are very similar for both transformed data and are similar to those of Westigard and Calvin (1971). They worked on pear orchards with populations of P. ulmi, T. urticae and M. occidentalis and found significant between tree variation but no significant variance among different quadrants of the tree.

In order to assess the number of leaves needed for a representative sample of spider mite densities in any given tree, we correlated the mean densities of 5-30 randomly chosen leaves from the 30 leaf samples against the mean densities of the 250 (or 125) leaf samples which we assumed to be the best available estimate of the actual population densities of each tree. The correlation of 30 against 250 leaves for the Yuba City orchard, where Bryobia and Panonychus dominated, was only ca. 0.1. The 30 to 250 (or 125) correlations ranged from 0.05 to 0.74 ($p > 0.09$) for Tetranychus spp. in the other 3 orchards. Correlations of Tetranychus from 5 against 250 leaves in these latter 3 orchards were worse (0.05 to 0.64, $p > 0.18$). Correlations of mean M. occidentalis densities were somewhat better than those of the tetranychids: 30 against 250 leaf correlations ranged from 0.63 to 0.97 ($p = 0.01$ to 0.18). After spider mite populations reached moderate densities (ca. 10 mites of all stages/leaf), the correlations were even better; as few as 5 leaves against 250 (or 125) gave correlations of greater than .9 ($p > .05$).

Dr. D.L. Flaherty has begun to develop a spider mite and predator assessment approach for San Joaquin Valley vineyards that relates M. occidentalis distributions to their potential for spider mite (particularly T. pacificus) control. His approach is based on his experience that the distribution of predators in terms of number of leaves with at least one predator is more important than the density of predators throughout the whole vine. A similar approach was adopted by Field and Webster (1978) for M. occidentalis in apples and peaches in Australia. In order to test if this approach might be extrapolated to almonds, we correlated numbers of leaves with M. occidentalis and M. occidentalis population densities in the 30 leaf samples. The correlations are very good, greater than 0.8 ($p < .001$).

Discussion

Selection of an adequate sampling approach for mite populations in almonds is a difficult problem. The variation of their densities is so large that a statistically adequate sampling approach (large number of samples) is not very practical. Westigard and Calvin (1971) used a coefficient of variation approach to assess the size of an adequate sample, but this requires some prior notion of variance in order to be helpful in deciding how many samples to take on a given day. We have found (unpublished), as have Westigard and Calvin (1971), that variance changes with mite density. Such densities will change throughout the season. Even when the variation is known, the number of samples that need to be taken for even ±40% accuracy may be quite large (Westigard and Calvin 1971). A sampling system for Bryobia developed by Summers and Baker (1952) would require 2 man-hours per block. Few growers would be willing to spend that much time sampling.

Our correlations don't give estimates of how many leaf samples should be taken, but they do show that even samples of 30 randomly selected leaves don't produce very good estimates of spider mite populations in a given tree, and we doubt that many growers could be persuaded to take samples that large. Furthermore, the greatest source of variation is that between trees. Our studies were conducted on small blocks of trees, and our results should come as no surprise to field workers familiar with spider mites. Growers and researchers (e.g., Flaherty and Huffaker 1970) are often aware of spider mite "hot spots" that recur year after year in a particular spot of an orchard or vineyard, often without readily apparent cause. This between tree variation justifies the use of spot acaricide treatments to control "hot spots".

Assessment of spider mite populations is discouragingly difficult. Determination of economic thresholds is dependent on adequate and practical sampling, but even if such a sampling program were available, economic thresholds would be difficult to assess. Spider mite populations don't affect almond tree productivity during the year in which they occur, but can affect productivity in the next year (Barnes and Andrews 1978). Economic thresholds for mites in almonds are therefore affected by varying economic conditions (Barnes and Andrews 1978) and potentially cumulative long term effects on productivity and decline of the trees. These would be difficult to assess and may also depend on soil and water conditions in particular areas, differential effects of different species on yields, and on economic considerations such a replanting with new varieties or new crops.

Actual economic thresholds are, in summary, practically impossible to assess. Many growers apparently operate on a perceived economic threshold which seems reasonable to us. They treat early enough to avoid "webbing over" of the foliage. Once webbing has occurred, it is impossible to obtain adequate coverage with acaricides, and defoliation may be imminent. Webbing over appears to begin at ca. 10 mites (motile stages) per leaf for *Tetranychus* spp. (our unpublished observations), which is less than the densities causing 2nd year reductions in yield (Barnes and Andrews 1978). Since the greatest source of variation is that among trees, a prudent grower might best examine all areas of his orchard for early signs of webbing over (the spider mite sampling scheme) and treat when necessary to prevent webbing over (the economic threshold).

Leaf-to-leaf variation in *M. occidentalis* populations is not as great as that for spider mites, and the number of leaves with predators ishighly correlated with predator densities. These observations suggest that sampling for predators may be far more efficient than sampling for their prey, and that predator densities can be incorporated into the decision-making process. When examining his orchard, if a grower encounters trees with early signs of webbing over, he could count the number of leaves where predators are found to assess the need for treatment. If predators were found on a large enough sample of leaves, there would be no need to treat with acaricides, or perhaps a lower treatment rate could be used.

Unfortunately, we cannot yet estimate what the critical proportion of leaves-with-predators might be. We worked extensively in only 2 southern orchards for 2 years. Both had abundant *M. occidentalis* populations and never had spider mite populations which met the economic threshold criterion (webbing over) described above. Although other researchers have rarely seen *M. occidentalis* in southern almond orchards, this may be because of extensive acaricide use. For example, Barnes and Andrews (1978) specifically chose orchards with past history of acaricide use. When they eliminated the acaricides for yield studies, the only common predator was the six-spotted thrips (*Scolothrips sexmaculatus* Pergande), a predator which appears to have better dispersal and more rapid recolonization potential than *M. occidentalis*. Removal of acaricides, which had kept prey, and, probably, predator populations in low numbers allowed a rapid buildup of endemic and migrating spider mites. *M. occidentalis* was not present in sufficient numbers to respond to this buildup, but the six-spotted thrips could migrate in. Flaherty and Huffaker (1970) found that spider mite and *M. occidentalis* populations in vineyards would not get back into balance (the re-establishment of predator-prey interactions with minimal mite damage) for up to 4 yearsafter the removal of pesticide applications. Releases of *M. occidentalis* accelerated the balancing process in vineyards. We suspect that the same principles will apply in almond orchards, that *M. occidentalis* can be an important predator where it is not disrupted by pesticides.

The orchards we studied did not have a history of heavy acaricide use. Six-spotted thrips were uncommon and generally found only in the early part of the season, whereas *M. occidentalis* were common whenever spider mites could be found. If acaricides are applied only when needed, only in the hot spots of the orchard, and at rates low enough to preserve some prey so that *M. occidentalis* populations don't die from starvation, spider mite control costs can probably be significantly reduced in the southern San Joaquin Valley.

Further development of a spider mite sampling and management program, as outlined in this report, depends on two kinds of research: 1) The use of spot treatments and reduced rates of acaricides to preserve some spider mite prey for the maintenance of *M. occidentalis* populations while controlling potentially damaging mite populations. We already have strains of *M. occidentalis* resistant to azinphosmethyl and carbaryl, two key insecticides used in the IPM program. 2) Field trials of a leaf sampling system for M. occidentalis populations. Data should be gathered on the proportions of leaves with predators in several orchards, with a wide range of spider mite and predator populations, to develop an index of what proportions give adequate spider mite control and which do not. Records should also be kept on the proportions of leaves with spider mites in order to develop a predictive early-warning index for webbing over. Our tentative idea is that when predators can be found on half the leaves, spider mite control (without damage to the trees) will occur within two weeks.

The development of a management program which reduces acaricide treatments may not only reduce costs; it should also reduce the potential for acaricide resistance problems in spider mites.

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