Project No. 80-J4
(Continuation of Project No. 79-J3)

Cooperator:
University of California
Department of Entomological Sciences
201 Wellman Hall
Berkeley, California 94720

Project Leader: Dr. Marjorie A. Hoy Phone (415) 642-3989

Personnel: Kathy B. Smith

Project: Navel Orangeworm Research
Control of Mites on Almonds

Objectives: (1) To evaluate further the possibility of establishing permethrin (Ambush/Pounce) -resistant Metaseiulus occidentalis in almond orchards; (2) to continue to evaluate the possibility of establishing Sevin[R] (carbaryl)-resistant M. occidentalis in almond orchards; (3) to continue evaluation of the Australian mite predator, Stethorus loxtoni for California almond orchards; (4) to test reduced rates of Omite[R] for spider mite management; (5) to act as an advisor on mite problems for IPM personnel and assist them in monitoring test plots for mites.

Progress: Work during 1979 indicated that the carbaryl-resistant strain selected by R. T. Roush established, survived field applications and controlled spider mites in the Visalia and Blackwells Corner almond orchards. Additional releases should determine how widespread this success could be; also samples of overwintering populations will indicate how long the carbaryl resistance ought to persist in the field. The permethrin-resistant strain was released but did not do well in almond orchards, probably due to improper release strategy. Results in an apple orchard were favorable, and new releases will incorporate that information. Also, a genetic analysis will have been completed of the mode of inheritance of the resistance and a more resistant strain will be released.

Releases of Stethorus loxtoni suggested establishment ought to occur; laboratory and field cage information indicate S. loxtoni ought to be able to overwinter in California. The most limiting factor will probably be its sensitivity to pesticides.

Reduced rates (one or two pounds) of Omite were compared to a normal rate (five pounds) applied to an orchard near Bakersfield and indicated that the two pound rate gave better mite control and may be less disruptive to predator populations. Additional tests may show that mite management is more effective with lower rates of acaracide without causing disruption of predators such as M. occidentalis, thus saving costs for materials as well as giving improved control.

Plans: (1) To evaluate a permethrin-resistant strain (Ambush/Pounce) of Metaseiulus occidentalis in almond orchards, using a more resistant strain than in 1978 and using different release strategies; (2) to release the carbaryl-resistant strain into additional almond orchards; field tests during 1979 were very successful with this strain; (3) to release the Australian mite predator, Stethorus loxtoni, into additional almond orchards; (4) to conduct tests with reduced rates of Omite for spider mite management.

Almond Industry Participation $15,231

UNIVERSITY OF CALIFORNIA, BERKELEY

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College of Natural Resources
Agricultural Experiment Station
Division of Entomology and Parasitology

Berkeley, California 94720

December 18, 1980

Dr. Dale Morrison
Almond Board of California
P.O. Box 15920
Sacramento, CA 95813

Dear Dale:

Enclosed are 2 copies of my 1980 report. I have sent a copy to M. Barnes, D. Rice, F. Zalom, C. Davis, B. Barnett, W. Bentley, N. Ross and D. Rough.

If you or Bob have questions, please contact me at (415) 642-3989.

Thank you very much for your assistance. Our request for funds for 1981-82 is on its way.

Sincerely,

Marjorie

Marjorie A. Hoy,
Associate Professor

MAH:fk
Encl

P.S. I enclose a copy of a letter a plant pathologist might find useful.

RECEIVED
DEC 29 1980
ALMOND BOARD

CONTROL OF MITES ON ALMONDS

Project 80-J4
Project Leader: Marjorie A. Hoy, U.C., Berkeley December 1980

Objectives for 1980 were: 1) to evaluate the possibility of establishing Guthion-Sevin and Guthion-Ambush/Pounce resistant spider mite predators (Metaseiulus occidentalis) in almond orchards; 2) To release the spider mite predator Stethorus loxtoni for establishment in California almonds; 3) To evaluate the use of low rates of Omite to manage spider mites in collaboration with the IPM group headed by Clancy Davis and Wilbur Reil.

During the 1980 field season we tested the selected strains of M. occidentalis in almonds, apples and pears. The Sevin-Guthion strain overwintered in 3 almond orchards where it had been released in 1979. In the Bakersfield IPM orchard, we documented that predators released into a few trees along a road in August 1979 have spread throughout 25 acres of the orchard and probably are in the entire 80 acre block. They survived a Sevin application in July 1980 and substantially helped to control spider mites, along with low rates of Omite (1, 2 or 5 lbs/acre). We are thus optimistic that this Sevin-Guthion resistant predator can be released, established, and survive in commercial almond orchards, and larger scale releases should be made in 1981. (We want to try releasing the predators from a helicopter.)

The permethrin (Ambush/Pounce)-Guthion resistant predator strain also performed well in 1980. It successfully overwintered in a Sebastopol apple orchard where it had been released in June 1979. Releases in 1980 into almond, apple and pear orchards showed we can establish this strain and that it can survive low commercial rates of Ambush/Pounce (0.05, 0.1 or 0.2 lbs AI/acre). The resistance is determined by several genes, so can be lost if the predators interbreed with native (susceptible) M. occidentalis. However, if releases are made after permethrin is applied, we have obtained successful establishments. This strain also will be tested on a larger scale in 1980.

Stethorus loxtoni, the small lady beetle predator of spider mites, was released in 1980 for the third year. No evidence of establishment was obtained and this project will be discontinued. Our best guess is that this beetle's sensitivity to pesticides is a critical factor in its failure to establish in commercial almond orchards. It is possible that it has established in the San Joaquin Valley in unsprayed areas.

During 1980, we tested the use of low rates of Omite to manage mites. We tested 1, 2, and 5 lbs Omite/acre at the Bakersfield IPM plot (where the Sevin-Guthion resistant predator helped control mites) and in the Manteca IPM plot, where the native predators are susceptible to Sevin. These rates were put on by ground; we also compared 10 and 2 lbs Omite at the Bakersfield IPM orchard applied by helicopter. All plots were treated with Sevin in July. The results indicate that reduced rates of Omite, applied at the proper time, can give good control of spider mites. This work should be continued in 1981 on a much larger scale. However, it appears that combining low rates of Omite with resistant predators (M. occidentalis) may offer a useful spider mite management system that should substantially reduce acaricide costs. Even in the Manteca orchard, where M. occidentalis' effectiveness was reduced by Sevin applications, the 5 and 2 lb rates gave promising results.

CIBA-GEIGY

Agricultural Division
CIBA-GEIGY Corporation
925 N. Grand Avenue
Covina, California 91724
Telephone (213) 331 0077

November 21, 1980

This material will be selective & Bayleton is also selective & and appears not to harm H. o.

Dr. Marjorie A. Hoy
Division of Entomology
201 Wellman
University of California
Berkeley, CA 94720

Dear Dr. Hoy:

Thank you for your report on the tolerance of Metaseiulus occidentalis to CGA-64251. This will be valuable to us in understanding how to fit this compound into the marketplace with respect to IPM programs.

For your information, we have recently received an Experimental Use Permit and temporary tolerance for CGA-64251 on almonds, peaches, cherries, prunes, plums and apples. We should have a few large trials out this year on these crops and may be able to get a pretty good idea of how this compound may affect mite and predator mite populations under field conditions. If you would like to observe or monitor any of these trials or cooperatively establish a trial for this purpose, please let me know.

For grapes, we will be pursuing only the 0.345% Dust formulation. Another compound, CGA-71818, is looking very promising as a spray for control of powdery mildew on grapes.

Your research in this area is very much appreciated. If we can assist you in any way, please do not hesitate to contact me.

Sincerely,

M. Dale Christensen

M. Dale Christensen
Research and Development
Representative

MDC:mmm

Project Report 80 - J4

From: Dr. Marjorie A. Hoy

Department of Entomological Sciences

201 Wellman Hall

University of California

Berkeley, CA 94720

(415) 642-3989

Project: Control of Mites on Almonds

Date: December 1980

Personnel: Dan Cahn

Cooperators: Wilbur Reil and Clancy Davis, Team - IPM Almond Project

Contents

I Interpretive Summary

During the 1980 field season we tested the selected strains of M. occidentalis in almonds, apples and pears. The Sevin-Guthion strain overwintered in 3 almond orchards where it had been released in 1979. In the Bakersfield IPM orchard, we documented that predators released into a few trees along a road in August 1979 have spread throughout 25 acres of the orchard and probably are in the entire 80 acre block. They survived a Sevin application in July 1980 and substantially helped to control spider mites, along with low rates of Omite (1, 2 or 5 lbs/acre). We are thus optimistic that this Sevin-Guthion resistant predator can be released, established, and survive in commercial almond orchards, and larger scale releases should be made in 1981. (We want to try releasing the predators from a helicopter.)

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II Introduction

The project objectives for 1980-81 are to: 1) Evaluate the establishment of permethrin-resistant Metaseiulus occidentalis in almond orchards; 2) To continue evaluation of the Sevin^R-resistant strain of M. occidentalis; 3) Evaluate Stethorus loxtoni; 4) Act as an advisor on mite problems for IPM personnel; 5) Test reduced rates of Omite for spider mite management.

In addition, Wilbur Reil and I began evaluation of a potential parasite of the southern red fire ant, which can damage almond nuts in the southern San Joaquin Valley.

Furthermore, I include a copy of a manuscript on work with M. occidentalis which was designed to learn if M. occidentalis searched for different species of spider mites on almonds in a similar manner. This would help us to understand why M. occidentalis is a more effective predator of two-spotted and Pacific spider mites than of European and citrus red spider mites, or Bryobia.

III Releases of Permethrin-Resistant M. occidentalis

Permethrin-resistant (which are also organophosphate-resistant) M. occidentalis were released into A) one almond orchard, B) 4 apple orchards and C) one pear orchard in 1980. D) In addition, we monitored the overwintering success of the 1979 releases into the Sebastopol apple orchard.

The permethrin-resistant strain of M. occidentalis established in all 6 orchards where it was released in 1980 and survived sprays at field rates of 0.05 to 0.2 lb AI/acre. The predators generally had a visible impact on spider mite populations. A complete analysis of all predator-prey data is not yet available.

The ability of the permethrin-resistant strain to survive the 1980-81 winter was crucial in our evaluation of this strain. Because it did so well in 1980, we hope to release into larger almond acreage in 1981. If permethrin has a Section 18 use permit in almonds for 1981, we want to release into at least one 10-20 acre block (and more, if possible) under"grower" conditions, using our "large-scale release" methods.

A) Visalia Almond Orchard - Permethrin-resistant M. occidentalis (ca. 750 ♀♀/tree) were released on 9 July 1980 into 10 almond trees at the ICI, Visalia orchard. These trees, and 10 check trees, had been treated by Dennis Culver with 0.2 lb permethrin AI/acre on 19 May to remove susceptible native predators. Few spider mites were collected on 12 June, so 1/2 flat of beans with the 2-spotted spider mite, Tetranychus urticae, were released into the 20 trees. On 3 July, spider mites averaged 96.8/leaf. However, an additional 1/2 flat of T. urticae was released on 3 July, which was a serious error as spider mites were already too abundant. On 9 July the predators were finally released. Samples were taken on 17 July and showed the predators were present, but not yet dispersed. On 28 July the trees were partially defoliated, and predators were present in low numbers. Permethrin was applied (0.05 lb AI/acre) on 29 July. On 4 August, the trees were nearly 70% defoliated. Predators were recovered from 5 of the 10 release trees; predators were recovered from 7 of 10 release trees on 18 August and on 3 September. By September the trees had defoliated but resistant predators were present on new growth on 17 September at the tops of the release trees. Another permethrin application at 0.05 lb AI/acre was applied on 23 September. The trees were banded to trap overwintering M. occidentalis so that we can determine if they successfully overwinter in the spring of 1981.

Colonies of predators from the release trees were made on Sept 3, 1980 and Sept 29, 1980 (before and after the second sprays) and they were treated with a 2 gram AI/100 l water challenge dose in the laboratory to determine if the predators collected were progeny of the released predators or had migrated in from adjacent areas. The results indicated that the permethrin-resistant strain was present on Sept 3, 1980 (% survival = 22%, N = 140) and that resistance levels of predators collected on Sept 29 was improved after the spray was applied on Sept. 23, 1980 (survival = 46%, N = 180). Survival of predators collected from individual trees in the first test ranged from 5 - 40% and from 30 - 70% in the second sample. Colonies tested as controls had survival rates of: 55% for a selected resistant laboratory colony and 3% for a susceptible lab colony. Thus, the permethrin-resistant strain established and survived sprays at the Visalia almond orchard. Because we released far too many spider mites we can't rate the effectiveness of the predator, but these data support our conclusion that further tests are warranted with this strain.

B) (1) Apple Orchard Releases: Releases of the predator also were made into 4 apple orchards in 1980: 1) into 7 release trees in Wenatchee, WA with S. C. Hoyt. See attached letter for a summary of the results, 2) into 2 orchards near Watsonville with C. Pickel, and 3) into 10 trees in the Sebastopol apple orchard where we had also worked in 1979, with J. Joos. The results of the 1979 Sebastopol releases are given in the Nov - Dec. 1980 issue of California Agriculture (attached).

B) (2) Watsonville apple orchards: Small numbers of permethrin-resistant predators (ca. 400/tree) were released in April and June 1980 into 2 orchards near Watsonville - into 10 trees in the Silva orchard and into 8 trees in the Rider orchard. Four trees in the Rider orchard were sprayed with 0.1 lb AI/acre and 4 with 0.2 lb AI/acre. Trees in the Silva orchard were treated with 0.01 lb AI/acre. The orchards in Watsonville do not have native *M. occidentalis* (C. Pickel and S. Hoying, pers. comm.). The native phytoseiid species present is *Typhlodromus arboreus*, which is a pollen feeder and ineffective against spider mites. Most orchards in the area have European red mite (ERM) as the dominant spider mite, with few 2-spotted spider mites and almost no rust mites. The permethrin strain established in these 2 orchards and survived sprays of permethrin in July, but little multiplication was evident in the trees and no control of ERM was evident.

We will probably sample 2 more times this year. Next spring we will treat the block with permethrin before bloom, and then a reading of resistance levels should probably be made as populations increase.

Perhaps by the time of the national meeting in Atlanta I will have this summarized.

Sincerely yours,

TREE FRUIT RESEARCH CENTER

Stan

Stanley C. Hoyt
Entomologist

SCH:le

TREE FRUIT RESEARCH CENTER
WASHINGTON STATE UNIVERSITY
WENATCHEE, WASHINGTON 98801

1100 NORTH WESTERN AVENUE
(509) 663-8181

III-4
B-1

September 4, 1980

Dr. Marjorie Hoy
Department of Entomology
University of California
Berkeley, CA 94720

Dear Marjorie:

Thank you for sending the copy of your manuscript for California Agriculture.

I thought I should bring you up to date on the permethrin resistant predator studies.

→ July 11 - 0.05 lb. AI per acre permethrin applied to the entire block.
July 16 - 5 of the 7 release trees had predator populations of .2 to 1 predator per leaf. One check tree had predators.
July 24 - 4 of the 7 release trees and 2 of the 7 check trees had predators.
July 30 - All 7 release trees and 1 check tree had predators.
Aug 6 - All 7 release trees and 2 check trees had predators with predator numbers increasing.
Aug 14 - 6 release trees and 2 check trees with predators.
Aug 19 - 5 release trees and 7 check trees with predators (0-3.4 per leaf on release trees and .2-1.6 per leaf on check trees).
→ Aug 21 - .05 lb. AI per acre permethrin on entire block.
Aug 26 - 6 release trees and 3 check trees with predators. Populations reduced substantially.

The buildup of predators on the check trees is not too surprising since we have observed a similar buildup on 6 other blocks treated with permethrin. In a few of these samples predators were present 8 days after the permethrin applications suggesting the possibility these field populations survived the treatment.

At least this is a substantial change from former years when predators were rarely seen for 6 to 8 weeks after an application.

Peak populations of <u>Tetranychus urticae</u> were substantially higher on the check trees in 3 pairs and about equal on the other 4 pairs. I have not had time to determine the average per sample for mites or predators as yet. This could be more meaningful than peak populations.

M. occidentalis were recovered from the Rider orchard in September 1980 and tested for resistance to permethrin. Survival was 66% at 2 gr AI/ 100 l, on one date (N = 50) and 67% on another (N = 90). Thus, resistance was well maintained in this orchard.

However, until we can manage apple sprays effectively so as to increase rust mite populations I am not ready to do large-scale releases of M. occidentalis into Watsonville apple orchards, where ERM prevail as the prey. Thus, we plan to monitor the overwintering success of the permethrin strain there in 1981 but do not plan additional releases in 1981. S. C. Hoyt has found in Washington that M. occidentalis can do an effective job against ERM if rust mites are abundant early in the season.

B) (3) Sebastopol Apple Orchard - Permethrin-resistant predators (ca. 500/tree) were released on June 9, 1980 into 10 trees that had been treated with 0.2 lb AI/acre permethrin May 7. A few permethrin-resistant M. occidentalis (ca 300/tree) were also released on June 9 into 10 check trees. Spider mites were released into the trees on June 24. A few more predators were released on July 8 and July 16.

The trees were treated on July 29 with 0.05 lb AI/acre permethrin. Predators from the release trees were colonized as a group on Sept. 2 and from individual trees on Sept 18 and tested with 2 gr AI/100 l water. Trees were banded on September 18 to help monitor overwintering populations.

This orchard has mixed populations of European red mite, two-spotted spider mite and rust mites which serve as prey for M. occidentalis. Other phytoseiids present in the orchard are susceptible to permethrin and recovered only late in August from treatment in July (Fig.III-1).

M. occidentalis established in the release trees. The spray applied on 29 July did not have a noticeable negative impact on the M. occidentalis numbers (Fig.III-1) and in late September, M. occidentalis numbers increased substantially. We hope to show overwintering in spring 1981 and to monitor the trees to see if the predators can control mites effectively in 1981, without additional releases.

The predators recovered in the September 1980 samples were tested in the laboratory for levels of permethrin resistance. All tested were resistant to permethrin (59% survival at 2 grams). Survival of predators collected from the 1980 check trees was also high (50% survived at 2 grams), a contrast to our results in 1979. Apparently there were few native M. occidentalis in the 1980 check trees and the resistant strain was able to establish and survive in these unsprayed check trees (Fig. III-2).

Predators collected on 9 September 1980 from the 1979 permethrin release were still resistant to permethrin (68% survival at 2 grams). These predators had been released in June 1979, treated with permethrin in July 1979, overwintered, and were treated with permethrin in July 1980. Thus, this strain has persisted for more than a year and retained a good level of resistance. We will monitor them in spring 1981 to see if they survive a second winter in this orchard.

Fig. III-1. Mean mites per leaf (all stages) in the Sebastopol apple orchard - 1980. (ERM eggs are graphed separately from actives. M. occidentalis

Fig. III 1

SUMMARY DATA FROM 1980 PERMETHRIN TREES
— SEBASTOPOL —
HAVEN BEST

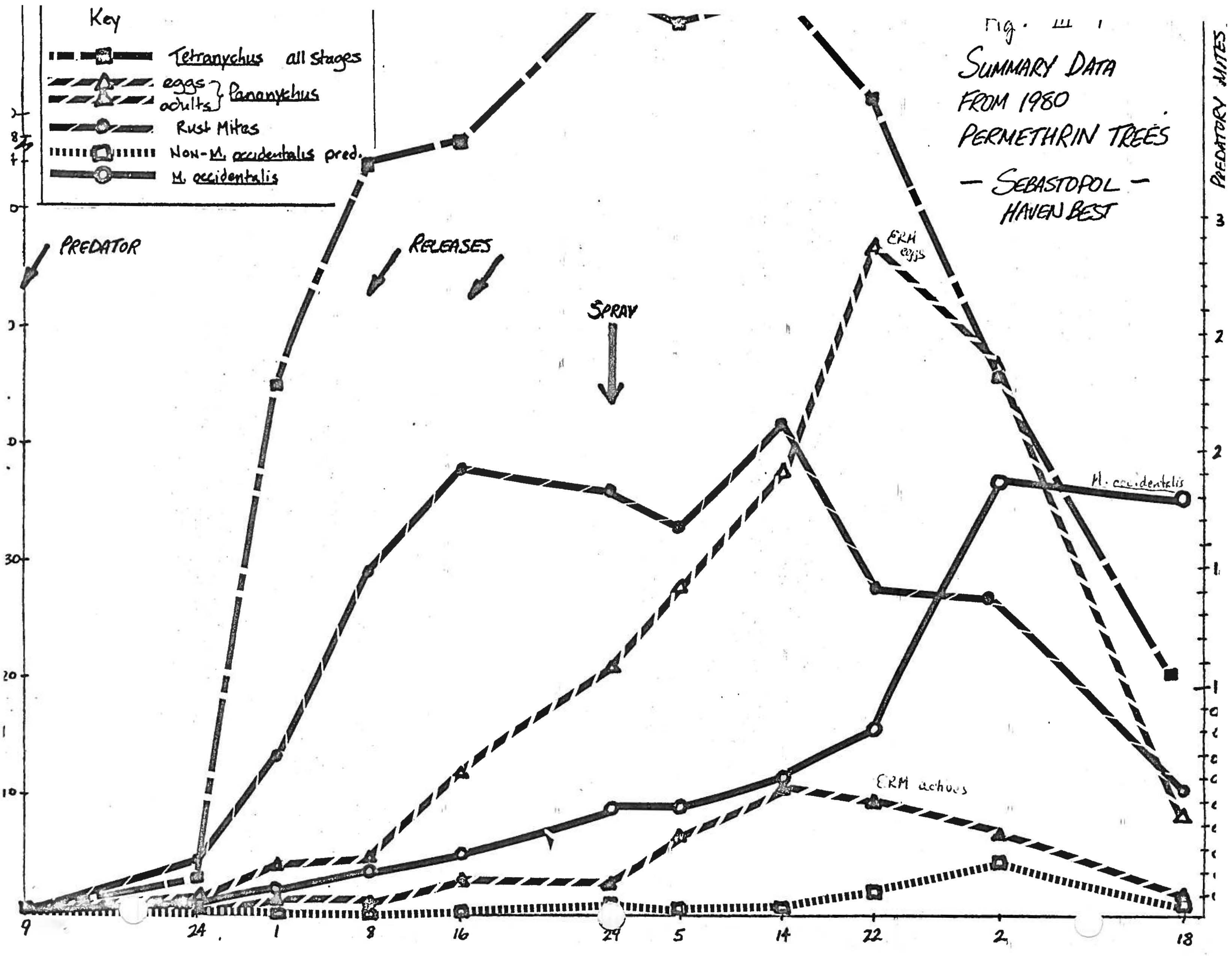
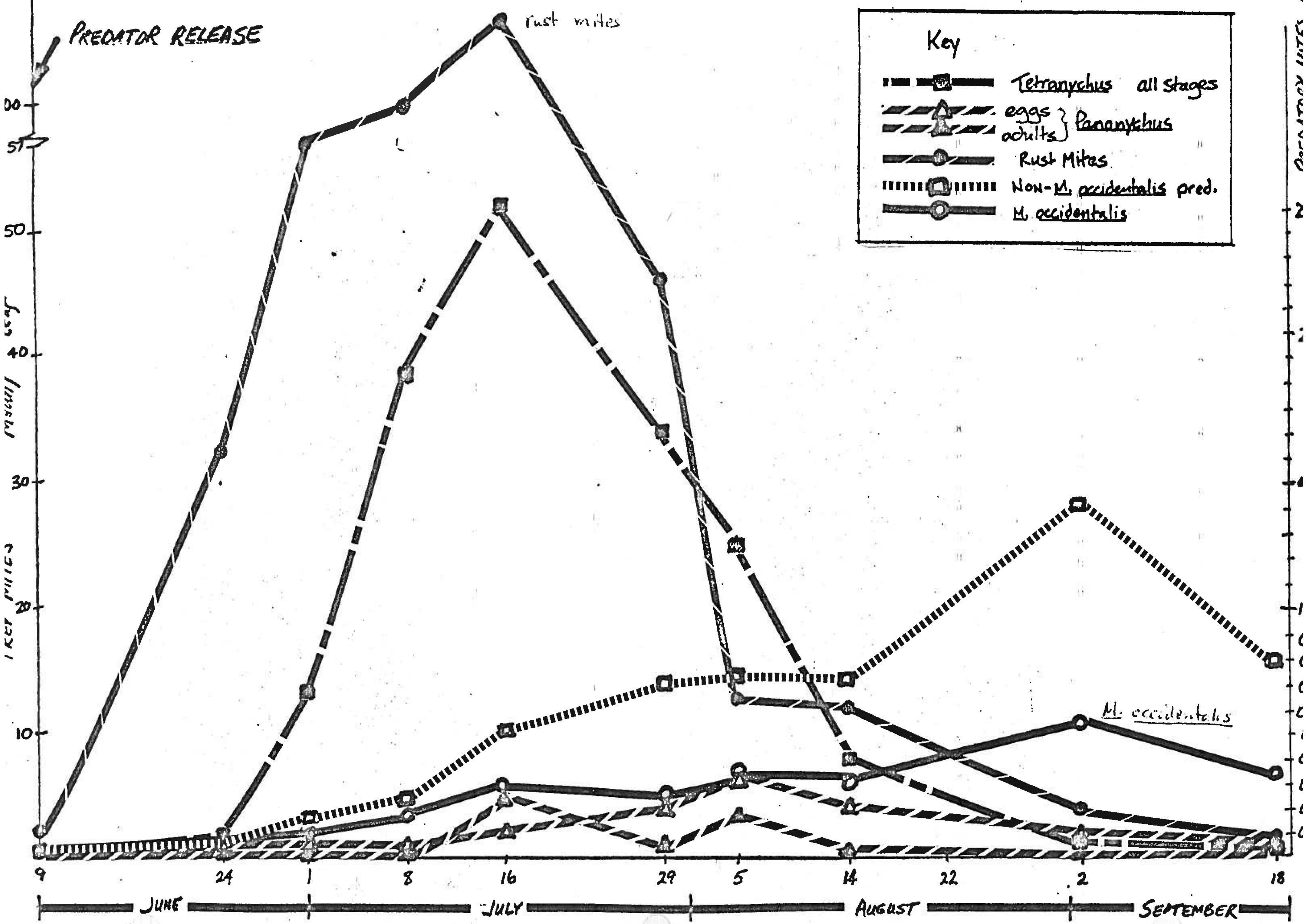


Fig. III-2



SUMMARY DATA FOR CHECK 1980 TREES

HAVEN BEST ORCHARD

rarely feeds successfully on eggs.) Trees were sprayed May 7 with 0.2 lb AI/acre and with 0.05 lb AI/acre on July 29, 1980. Tetranychus urticae were released in the trees June 24.

Fig. III-2. Mean mites per leaf (all stages) in the Sebastopol apple orchard - 1980. (ERM eggs are separate from actives). No permethrin was applied in 1980. M. occidentalis collected in September were resistant to permethrin. Few T. urticae were released into the trees.

B) c) Dr. P. H. Westigard released the permethrin-resistant strain into 3 pear trees in Medford, Oregon on June 16, 1980. The trees had been treated with 0.1 lb AI/acre on May 7 and were treated with the same rate on July 22. The predators were well established in 2 trees but due to low prey they were recovered only once in the 3rd tree (Table 1). Dr. Westigard noted that visible differences were evident in the quality of foliage on trees with and without predators.

Overwintering of predators and spread in the pear orchard will be monitored in 1981. A colony of M. occidentalis was sent to us in September 1980 from this pear orchard. Survival averaged 55% (N = 140) at 2 grams AI/100 l. This is strong evidence that the M. occidentalis released were still in the plot in September.

Table 1. Population trends of the two-spotted mite (2-Spot) and released M. occidentalis (M. o.) in permethrin-treated pear trees. Permethrin treated (0.1 lb AI/acre) May 7 and July 22. Predator release June 16. Bosc variety. Dr. P. H. Westigard, Cooperator

			No. mites/leaf									
Treatment	Replicate	Species	7/2	7/14	7/29	8/6	8/14	8/26	9/4	9/10	9/24	10/1
Predator release	A	2-spot	12.7	11.7	34.9	22.1	45.4	119.6	89.2	45.6	8.3	7.1
		M. o.	0.4	1.07	0.05	0	0.4	1.28	1.4	1.7	0.53	0.72
	B	2-spot	2.0	0.4	0.15	2.8	1.3	not	2.16	39.6	---	14.5
		M. o	0.13	0.13	0	0	0	sampled	0	0	---	0
	C	2-spot	0.40	0	0.15	0.1	0.26	---	0.52	5.84	---	13.5
		M. o	0.27	0	0	0	0	---	0	0	---	0
Non-predator release	A	2-spot	2.7	0.3	0.5	9.8	5.3	---	7.4	20.0	---	4.4
		M.o.	0	0	0	0	0	---	0	0	---	0
	B	2-spot	6.7	3.9	5.2	44.9	21.9	---	56.8	85.2	---	111.7
		M. o.	0	0	0	0	0	---	0	0	---	0
	C	2-spot	40.1	31.1	30.1	50.6	26.2	31.8	16.9	37.5	16.5	15.5
		M. o.	0	0	0	0	0	0	0	0	0	0

IV Releases of Carbaryl-Resistant *M. occidentalis*

New releases of carbaryl-resistant *M. occidentalis* were made into the Sebastopol apple orchard and into 3 Watsonville apple orchards in 1980. The predators established, survived field applications of carbaryl, and had a substantial impact on spider mites in one apple orchard in Watsonville and in the Sebastopol apple orchard. In 2 Watsonville apple orchards, where very few *T. urticae* were present, control of European red mite was not achieved.

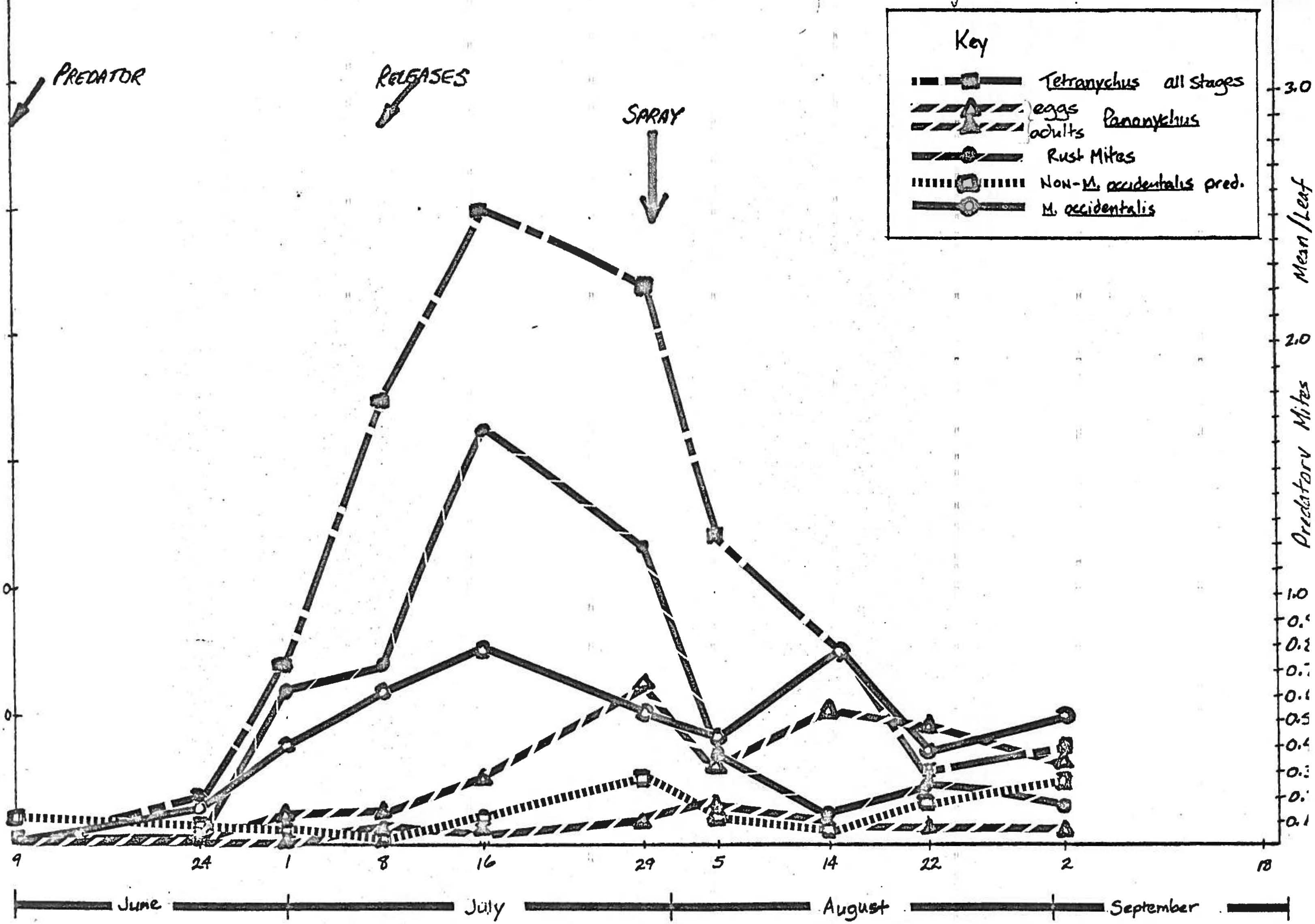
In one Watsonville orchard (Kleins) the predators ate all their prey and spread throughout the 10 acre orchard by September. These predators had been released into apple trees along with *ca.*1/2 flat of pinto beans containing *T. urticae* prey. Thus, the predators had lots of preferred food and they controlled these mites (and ERM in these trees) very well. There was no defoliation or obvious damage in the 20 release trees, (Half (10) were sprayed with carbaryl; half were left unsprayed).

At Sebastopol, the predators established in the 8 release trees, survived the Sevin application (4 lbs AI/acre) and controlled the spider mites (mixed population of ERM and *T. urticae*) and rust mites (Fig IV-1). The predators ran out of food in some trees in August, so additional *T. urticae* were released into a few trees so we could be sure to have sufficient prey to get the predators into diapause and thus be able to evaluate their overwintering ability. The carbaryl- (and Guthion-) resistant *M. occidentalis* performed very well here. Predators recovered in September had a high survival rate at the field dose (86%) - cf. 12% of a susceptible lab colony.

The carbaryl-resistant predators released into the ICI, Visalia and Blackwell's Corner almond orchards in 1979 successfully overwintered.

Fig. IV-1   Mean mites per leaf in the Sebastopol apple orchard - 1980, Carbaryl was applied (4 lbs AI/acre) on July 29 to 8 trees.

Fig. IV - 1



SUMMARY DATA : CARBARYL TREES PBO — HAVEN BEST ORCHARD — SEBASTOPOL —

Samples of predators from the 1979 release trees had fair to good survival rates in lab tests. The lab colony resistant to carbaryl averaged 66% survival at 2.4 g AI/liter (n = 80). Predators from ICI, Visalia trees 1 - 7 had survival rates of 15, 10, 13, 10, 19, 25 and 35% each (n = 40 each tree). These trees were not treated with carbaryl until Sept. 1980. Predators from the Blackwell Corner orchard averaged 43% survival and from Bidart they averaged 55% survival. Predators from susceptible lab colonies had 0% and 3.8% survival rates. It appears the carbaryl colony has interbred with susceptible natives at the ICI, Visalia almond orchard. Survival of predators collected from Blackwell's Corner and Bidart almond orchards is very close to that of the lab colony, suggesting that the resistant colonies are not interbreeding with susceptible predators, or have responded to 1980 Sevin treatments. The carbaryl-release trees at the Visalia almond orchard were sprayed with carbaryl in Sept. 1980. Overwintering and resistance levels will be monitored in spring 1981.

The most interesting results were obtained from some releases made by R. Roush in August 1979 into the Bakersfield IPM almond orchard. Rick released the Sevin-resistant strain into a few trees along a dirt road (see map). This year we conducted Omite tests in that area, and all trees were treated with Sevin in July at hull split. High numbers of M. occidentalis were evident in these trees in August, so we sampled twice to document whether the M. occidentalis present were resistant to Sevin or not. The map indicates the high survival of adult females treated with the field rate of Sevin on leaf discs in the laboratory. Clearly, the few predators released into the trees (marked by X's) along the road had spread throughout the 25-acre test block.

Fig IV-2 Map of the Bakersfield IPM almond orchard plot where 0, 1, 2, or 5 lbs (formulated) Omite were applied. M. occidentalis from 7 blocks were tested for their resistance to carbaryl. All tested were resistant, as indicated by (R) in the block.

Dialart Almonds 1980

COFFEE RD.

	25 rows		7 rows	6 rows	6 rows	7 rows	13 rows	12 rows	12 rows	13 rows
		I	0-FP Ⓡ	1-B	5-Y	2-P	2-FG	5-Or.	2 FG	5-Or.
		II	5-Y	2-P Ⓡ	0-FP	1-B				
		III	1-B Ⓡ	0-FP Ⓡ	2-P	5-Y				
		IV	5-Y	2-P	1-B	0-FP				
		V	0-FP Ⓡ	1-B	5-Y	2-P				
	RES.	VI	2-P	0-FP Ⓡ	5-Y	1-B Ⓡ				
			Ground spray area				Helicopter spray area			

Ground spray area - to be sprayed by U.C.

Rate	Ribbon	Treatment
0	F. Pink	Check
1	Blue	1 lb./A Omite 30W
2	Pink	2 lb./A Omite 30W
5	Yellow	5 lb./A Omite 30W

Helicopter spray area - sprayed commercial

Rate	Ribbon	Treatment
2	Fl. Green	2 lbs/A Omite 30W
5	Orange	5 lbs/A Omite 30W

We strongly suspect they are throughout the 80-acre orchard because the M. occidentalis in the helicopter-Omite plot also survived the July Sevin spray well (see section V). This spectacular spread in an almond orchard is important because it supports our hope that we can release a few predators (100-200/tree on bean plants) into orchards (i.e, every 5th tree each 5th row) as is done in Australia, and achieve establishment and efficacious predator numbers within the next 1 or 2 field seasons.

We don't know precisely how the predators spread throughout this almond orchard. It is thought that the predators are spread by wind currents in the orchard. We would like to study this movement if we make large-scale releases in 1981-1982. We can use the carbaryl resistance as a genetic marker.

This Sevin-resistant colony did so well in laboratory, glasshouse and orchard tests in 1979 and 1980 that it seems justified to implement its use in California almond orchards where Tetranychus spider mite species are abundant. It is not likely to be effective in orchards where ERM predominates unless alternate prey are present on which they can build up. We hope to rear large numbers of this predator strain to allow releases on the scale of hundreds of acres rather than into single experimental trees. A full evaluation of this strain now should take place under grower conditions.

V Spider Mite Management with Reduced Rates of Omite

During 1979 a plot was set up at the Bakersfield IPM (Bidart) orchard to test the efficacy of low rates of 30 WP Omite (0, 1, 2, or 5 lbs formulated) as a tool for managing spider mites. The results were presented in our 1979 report. They are summarized here in Table V-1 so that comparisons with 1980 data can be made.

During 1980 we repeated this work at the same Bakersfield almond orchard with the help of W. Reil. W. Reil and his group conducted a comparable test in the Manteca IPM almond orchard in 1979 and 1980. Their results should be consulted as well. I include only a summary of their 1980 data (Table V-4).

Fig. V-1a shows the plot map for the Bakersfield plot in 1980. Fig. V-1b shows the plot map for the 1979 tests, and the insecticide treatment history for 1979. The 1980 helicopter plot (= 50 acres) was treated July 15, 1980 with 30 WP Omite at 40 gal/acre and with 80 S Sevin. The ground rig plot (= 24 acres) was sprayed with Sevin on 15 July by helicopter also, but the Omite was not applied until 29 July (100 gal/acre).

Fig. V-1. Mean spider mites/leaf (all stages) in almond trees treated with 0, 1, 2 or 5 lbs (formulated)Omite/acre by concentrate sprayer July 29, 1980. Sevin was applied to all trees by helicopter on July 15.

V-2. Mean _M. occidentalis_/leaf (all stages) in the trees treated by concentrate sprayer in 1980. Sevin did not kill these resistant predators.

V-3. Mean spider mites/leaf all stages in the blocks treated with 2 and 10 lbs (formulated) Omite and Sevin applied by helicopter on July 15, 1980.

Leaf samples (30 leaves/tree) were brushed and all stadia of spider mites and _M. occidentalis_ recorded. Data were analyzed by Games and Howell

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

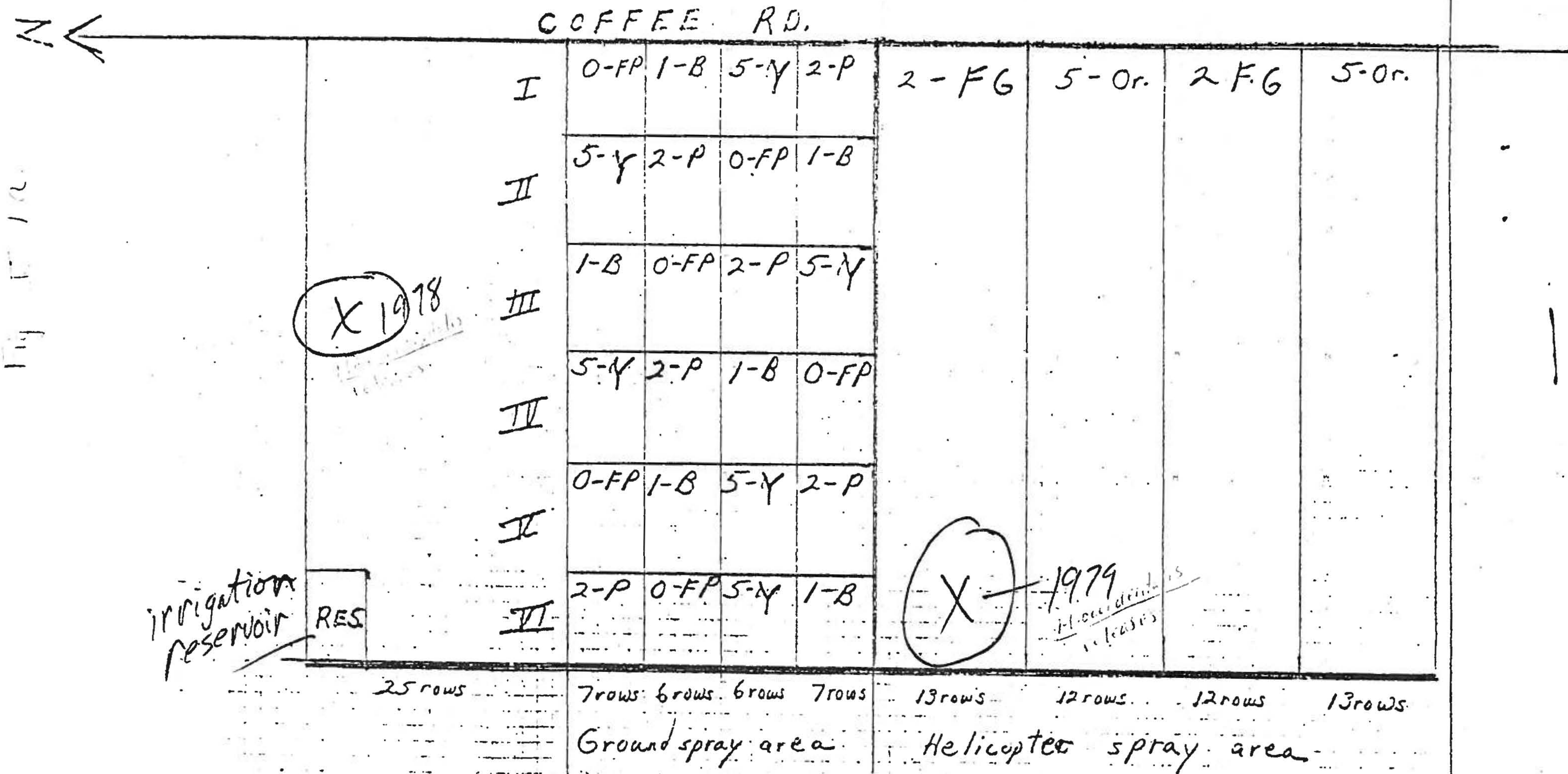
	Mean numbers per leaf on 6 trees treated with							
	5 lb[b/]		2 lb[c/]		1 lb[c/]		Check	
Sample dates	Spider mites	M. occ.	Spider mites	M. occ.	Spider mites	M. occ.	Spider mites	M. occ.
6 June	-	-	0	0	0.01	0	0.01	0
5 July	0	0	0.2	0.01	1.5	0	0.5	0
16 July	2.2	0.03	9.2	0.01	3.5	0.02	0.4	0.02
	Treatment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

d/ Numbers of mites significantly different ($P \leq 0.05$) from the check using Games and Howell + modification for paired multiple comparisons with unequal variances.

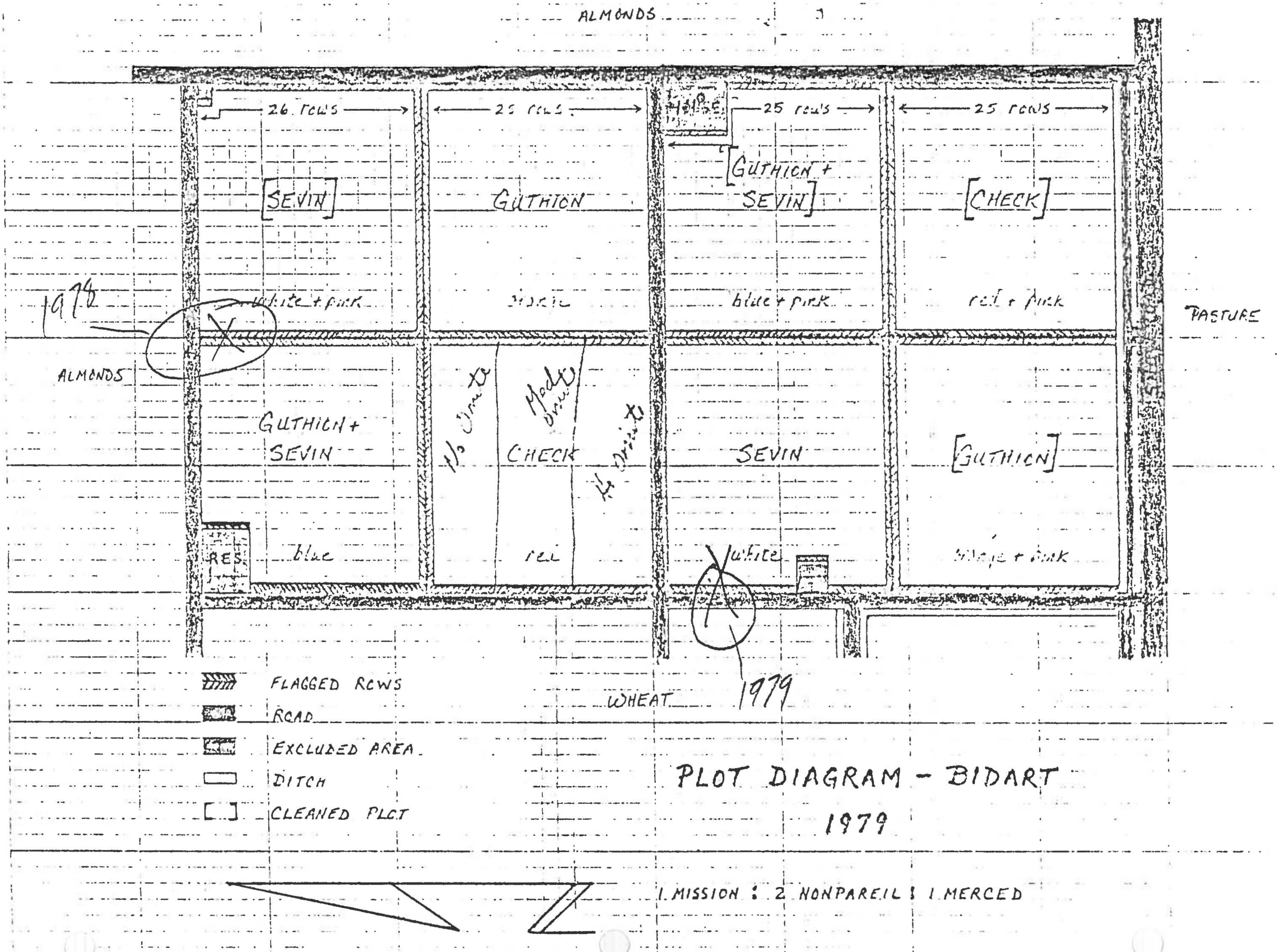


Ground spray area - to be sprayed by U.C.

Rate	Ribbon	Treatment
0	F. Pink	Check
1	Blue	1 lb./A Omite 30W
2	Pink	2 lb./A Omite 30W
5	Yellow	5 lb./A Omite 30W

Helicopter spray area - sprayed commercial

Rate	Ribbon	Treatment
2	Fl. Green	2 lbs/A Omite 30W
5	Orange	5 lbs/A Omite 30W



PLOT DIAGRAM - BIDART
1979

1 MISSION : 2 NONPAREIL : 1 MERCED

Fig. IV-1

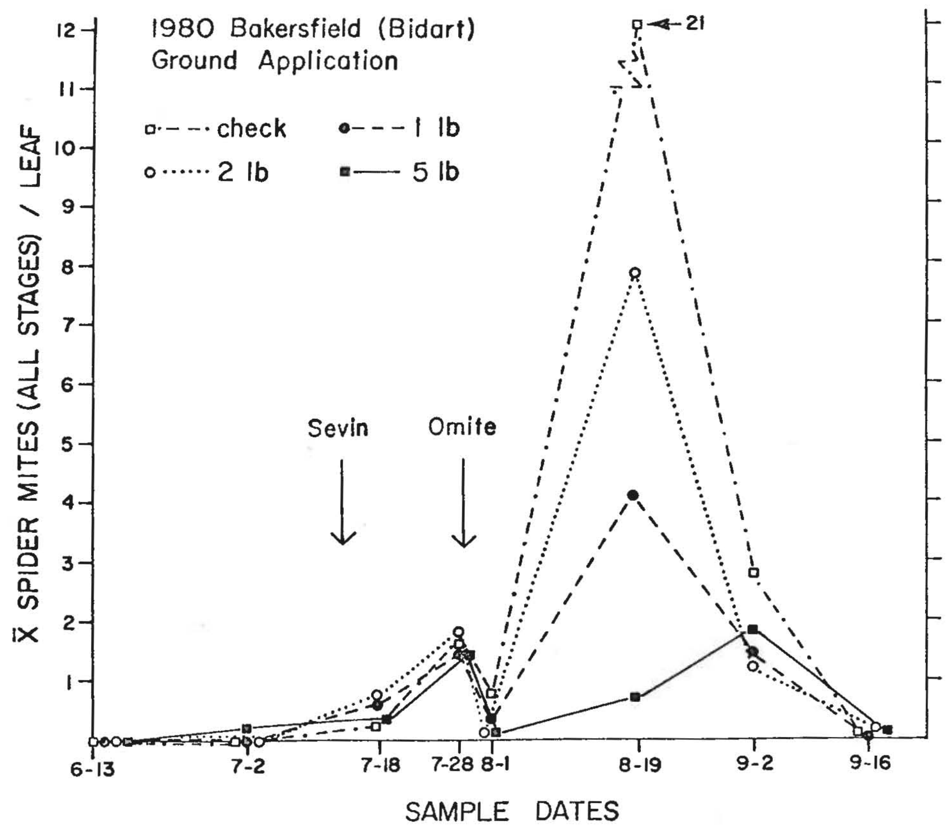


Fig. IV-2

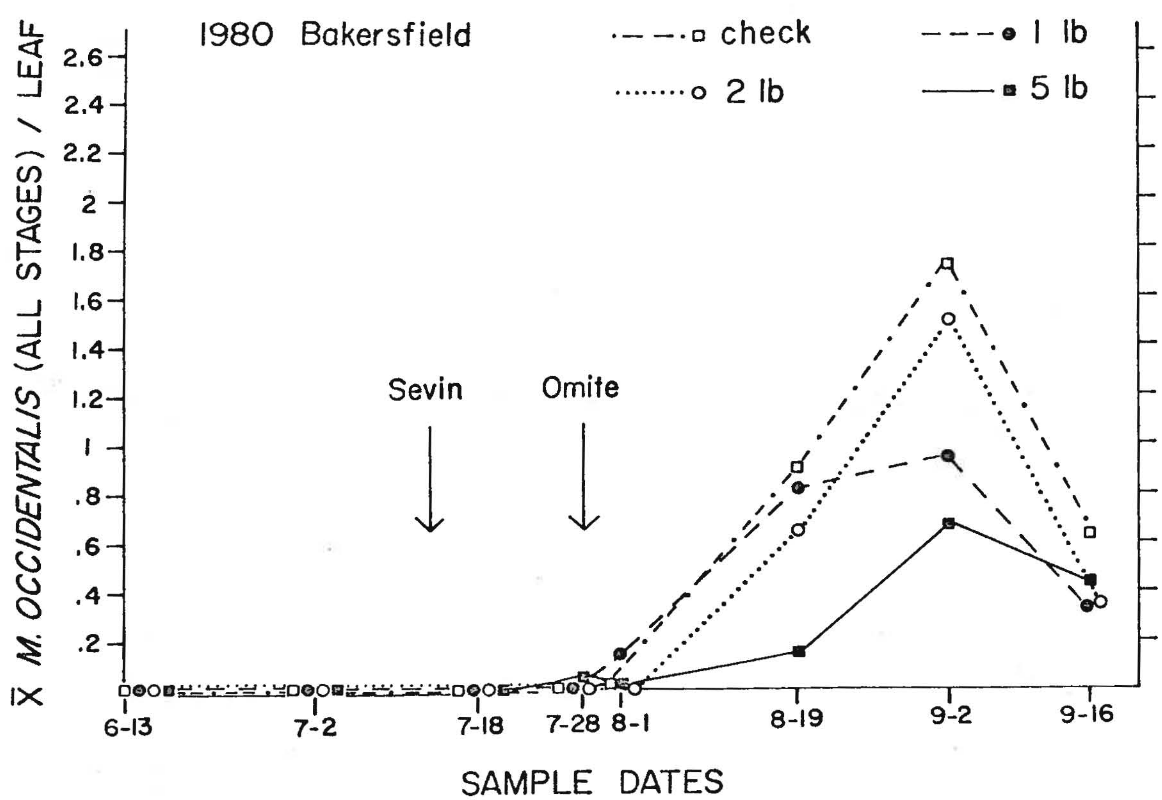
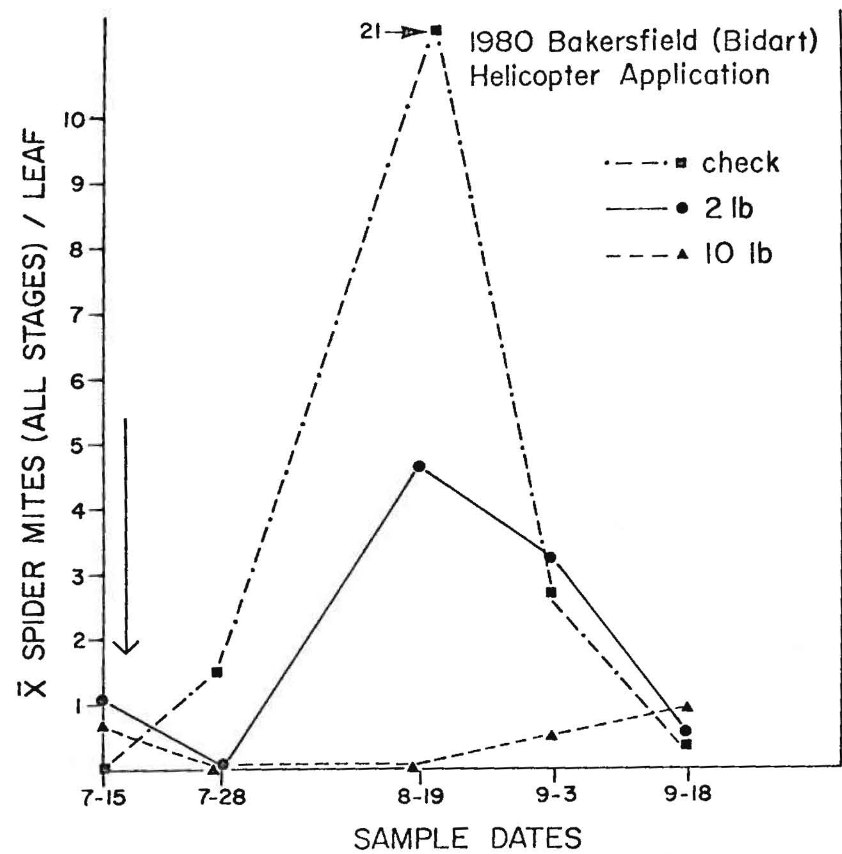


Fig. V-3



21
1980 Bakersfield (Bidart)
Helicopter Application
check
2 lb
10 lb
X̄ SPIDER MITES (ALL STAGES) / LEAF
10
9
8
7
6
5
4
3
2
1
7-15
7-28
8-19
9-3
9-18
SAMPLE DATES

Table 2. Average number of spider mites[a] and *M. occidentalis* per leaf (all stages) in the Bakersfield IPM orchard treated with Omite by ground - 1980.

	Mean mites per leaf on 24 trees treated with Omite at							
	5 lb.[b]		2 lb.[b]		1 lb.[b]		Check[b]	
Sample dates	Spider mites	*M. occ.*	Spider mites	*M. occ.*	Spider mites	*M. occ.*	Spider mites	*M. occ.*
June 13	0.01	0	0.02	0	0.01	0	0	0
July 2	0.24	0	0.03	0.006	0.02	0.02	0	0
	July 15 Sevin applied to all trees							
July 18	0.26	0.17	0.63	0	0.49	0.01	0.22	0
July 28	1.23	0.15	1.73	0.03	1.39	0.05	1.47	0.07
	July 29 Omite applied							
August 1	0.09	0.02	0.09	0	0.26	0.16	0.70	0.03
August 19	0.76[c]	0.16	7.66	0.65	4.06	0.82	21.33	0.89
September 2	1.75	0.68	1.15	1.50	1.13	0.95	2.80	1.71
September 16	0.10	0.44	0.10	0.35	0	0.34	0.10	0.63

a/ Spider mites present predominately were *T. urticae* and *T. pacificus*.

b/ Six replicates of 4 trees each were sampled.

c/ Numbers of mites significantly different from the check ($P \leq 0.05$) on this sample date. Data analyzed by Games and Howell t - modification for paired multiple comparisons with unequal variances.

t-modification for paired multiple comparisons, with unequal variances. This is a conservative statistical test.

Spider mites were low in the plot until the mid-August sample date (table V-2). Peak spider mites in the check averaged 21.3 on Aug. 19. Abundant Sevin-resistant M. occidentalis were present and probably helped keep spider mite numbers down (Figs, V-1 and 2).

Statistically-significant differences in spider mite numbers occurred only on Aug. 19 in the 5 lb. rate. Thus, 5 lb gave good control in this plot; some growers might be satisfied with the control achieved in the 2 and 1 lb rates (peak mites = 7.7 and 4.1/leaf, respectively). This grower had previously used 8-10 lbs Omite/acre.

Good control was also achieved with 2 lbs Omite applied by helicopter (Table V-3 and Fig V-3). There were fewer mites in the trees treated with 10 lbs of Omite, but the peak numbers of spider mites averaged only 4.7 on August 19 in the 2 lb rate. Here, too, M. occidentalis were present, except on July 28. It is more likely the M. occidentalis were starved out by lack of prey than that they were killed by the effects of Sevin. I suspect the Sevin-resistant strain is well-established in these 50 acres, although we conducted no toxicity tests to prove this. If so, the Sevin-Guthion-resistant predators have spread throughout the 80 acre orchard in ca 1 year.

The results of the 1980 trials in the Manteca IPM almond orchard conducted by W. Reil and his group are summarized in Table 4. I analyzed their data in the same way as our Bakersfield data. This orchard has Sevin-susceptible

Table 3. Average number of spider mites[a] and M. occidentalis per leaf (all stages) in the Bakersfield IPM orchard treated with Omite by helicopter - 1980.

	Mean mites per leaf on 16 trees treated with Omite at					
	2 lb.[b]		10 lb.[b]		Check[c]	
Sample dates	Spider mites	M. occ.	Spider mites	M. occ.	Spider mites	M. occ.
July 15-pretreatment	1.09	0.03	0.67	0.02	0.22	0
	15 July Omite and Sevin applied to trees				Sevin only applied	
July 28	0[d]	0	0[d]	0	1.47	0.07
August 19	4.69	0.12	0.02[d]	0	21.33	0.89
September 3	3.26	0.38	0.50	0.02	2.80	1.71
September 18	0.56	0.20	0.97	0.15	0.10	0.63

a/ Spider mites present predominately were Tetranychus urticae and T. pacificus.

b/ Four replicates of 4 trees each were sampled.

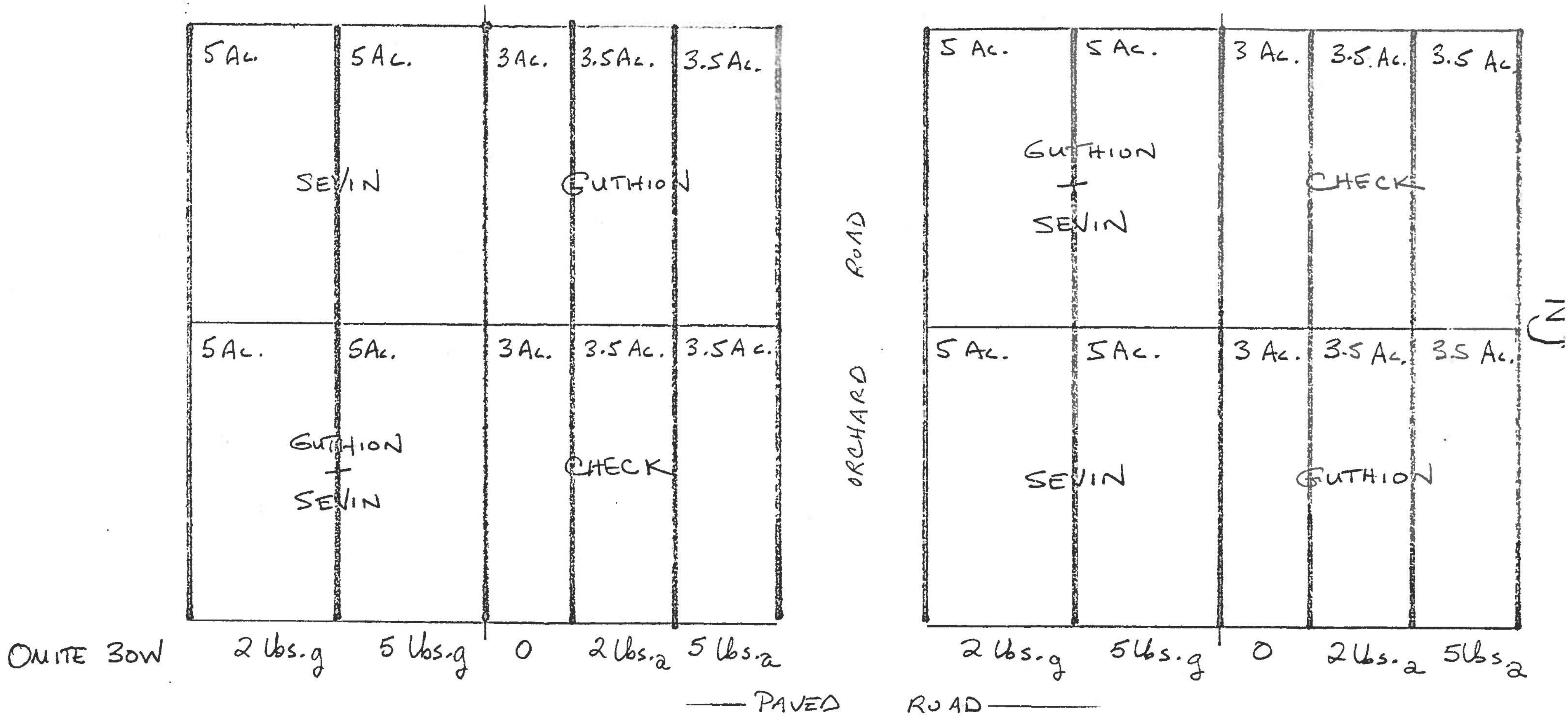
c/ Six replicates of 4 trees each were sampled.

d/ Numbers of mites significantly different from the check ($P \leq 0.05$) on this sample date. Date analyzed by Games and Howell t - modification for paired multiple comparisons with unequal variances.

MANTECA IPM ALMOND ORCHARD - 2X40 Ac = 80 Acres Total

1979 SEASON

VARIETIES: NONPAREIL, MERCED, THOMPSON



GUTHION applied 5/2,3 ; 5 lbs. (2.5 lbs. AI) 50W

SEVIN applied 7/18,19,20 ; 7 lbs. (5.6 lbs. AI) 80S

OMITE applied by ground (g) 7/18,19,20 ; Variable rates @ 200 GPA

OMITE applied by air (a) 8/10 ; Variable rates @ 20 GPA

- leaf samples Collected @ biweekly intervals, 10 lvs. from 10 trees at random within each treatment area (3-5 Acres) -

M. occidentalis, however, and the spider mite peaks probably reflect that difference. In this orchard average numbers of ERM peaked at 53.9 in the 2 checks on Aug. 25 and Sept. 8. Peak ERM in the 5, 2 and 1 lb rates occurred on Sept. 22 with 26.8, 48.8 and 54.0 mites/leaf (all stages). Thus the Omite delayed ERM population peaks by nearly a month. Tetranychus species peaked at 19.7 and 22.6 in the checks on Sept. 22. Averages on that date for the 1, 2 and 5 lb Omite rates were 25.7, 29.7 and 9.8.

The delays in all spider mite population peaks appear to be due to the Omite applications. It is likely that late populations of spider mites exert less effect on almond tree productivity than do early populations, although I know of no data to support this.

General Conclusions

Omite is highly toxic to spider mites. In a lab test with 0.125, 0.25, 0.5 and 1 lb formulated Omite/100 gal water, mortality of field-collected Pacific mites was 90, 90, 100, and 100%. An LC_{50} developed for Pacific mites from a vineyard near Visalia was 0.2 lb formulated Omite/100 gal water. We have no evidence to date in California that there is any resistance to Omite in spider mites in almonds. However, resistance to Plictran has been documented by Dr. P. Westigard in spider mites in an Oregon pear orchard, and it is clear that resistance to Plictran or Omite could develop unless we manage spider mites in almonds effectively.

It is my opinion that we can manage spider mites in almonds (especially two spotted and Pacific spider mites) by combining two tactics. One involves the use of the lowest doses and numbers of acaricide applications possible to delay onset of resistance. It is my opinion that use of high doses,

n red mite = ERM, T. pacificus and T. urticae = Tet. spp.) and M. occidentalis per leaf
ted with Omite.

Mean mites per leaf on 16 trees[a] treated with

2 lb.			1 lb.			Check-Sevin S			Check-Sevin sprayable liquid		
	Tet. spp.	M. occ.	ERM	Tet. spp.	M. occ.	ERM	Tet. spp.	M. occ.	ERM	Tet. spp.	M. occ.
	.013	.016	1.914	0	.026	1.834	.004	.012	1.195	0	0
	.012	.009	.914	.004	.013	.945	.008	.026	.890	0	.008
	.004	.012	.501	.025	.004	.485	.055	.004	.601	.017	0
	0	0	.139	0	0	.855	0	0	1.511	0	0
b/	.004	0	.233[b]	.017	0	8.800	.955	.004	17.300	.899	0
bc/	.270	0	3.840[bc]	.300	0	40.430	4.804	.008	53.900	5.700	.008
bc/	2.940	.038	31.500[c]	2.360	.008	53.880	14.470	.006	32.760	11.457	.044
b/	29.720	.310	54.00 [b]	25.72	.300	9.618	22.596	.572	8.21	19.650	.640
c/	21.440	.830	5.700[c]	22.080	.560	2.780	7.940	.620	2.583	7.350	1.00
	6.680	.659	2.038[c]	12.030	.696	.963	1,880	.739	1.160	2.160	.603

he test trees and one check received Sevin S ; one check received Sevin sprayable liquid.
< .0.05) from the check treated with Sevin WP on this sample date. Data analyzed using
multiple comparisons with unequal variances.
lb. rate.

frequently applied, will lead most rapidly to acaricide resistance determined by a single gene. If lower selection pressures are used, resistance can be swamped out by interbreeding with susceptible survivors, and resistance is less likely to be due to a single gene. The second strategy involves the use of natural enemies such as M. occidentalis. Pesticide-resistant M. occidentalis will eat acaricide-resistant or - susceptible spider mites indiscriminately.

If M. occidentalis can, in combination with low rates of acaricides, keep spider mites in check, it is my opinion that we will substantially delay (or prevent) onset of acaricide resistance.

At this point, we have tested low Omite rates 2 years in 2 orchards: 1979, 1980 in the Bakersfield and Manteca IPM orchards. It will be important to get good coverage; it will be important to time applications properly. If we wait until defoliation is imminent, we can't control spider mites with 5 or 10 lbs Omite. It is clear that M. occidentalis is an important component; control in the Manteca orchard was not good with any rates tested (1, 2, 5) in 1980 because Sevin effectively removed the native M. occidentalis from the system.

If we can get the Guthion-Sevin resistant strain of M. occidentalis established in orchards where Tetranychus spider mites prevail, it should be possible to control NOW and to reduce acaricide costs - perhaps by half or more. This will require a training program to allow monitoring of orchards so that PCO's or growers know if the predators are present. We will need to get acaricides applied in a timely fashion. It may be that a hull split application of low rates of Omite will be a useful tool if Sevin is used.

If Sevin-Guthion-resistant _M. occidentalis_ are released into large blocks of almonds in 1981, we hope to further test the combined use of predators and low rates of Omite for spider mite management in almonds.

VI *Stethorus loxtoni* Releases

Orchards where releases were made in 1979 did not yield recoveries of *S. loxtoni*.

New releases were made in August 1980, when spider mites finally become abundant in several San Joaquin Valley almond orchards.

Beetles (ca 200) were released in the ICI untreated check trees on 4 August and at the Chowchilla IPM orchard (ca 200). Within a week the Chowchilla plot was treated with an acaricide, and the beetles were never recovered.

On August 20, ca. 200 beetles were released at the Bakersfield IPM (Bidart) orchard into a check block. No information is available yet as to the persistance of these beetles.

We are terminating these releases, as we have no evidence that the beetles have established in almonds, although they could be picked up at some future date. Since they are highly mobile, it is possible they have established somewhere and will be found in untreated orchards in the future. If they have failed to establish, it is probably because they are sensitive to most pesticides.

VII A Test for Resistance to Omite in an Almond Orchard Population of *Tetranychus pacificus*

Bill Barnett, Fresno County Farm Advisor, contacted me regarding 2 trees in the DeFreitas almond orchard near Caruthers, Fresno County. These trees were treated about 1 July 1980 with Omite 30W at 6 lbs/acre and Guthion 50W at 2 1/2 lbs/acre. The 2 trees (20 N-8W and 9 N-6W) had abundant *T. pacificus* populations on 2 Sept. 1980. He wondered if they were resistant to Omite.

We conducted a laboratory test with progeny of these mites reared on pinto beans (*Phaseolus vulgaris*). They were compared to a laboratory colony of Pacific mites, reared on grape leaves for 2 years, originally collected from a San Joaquin Valley vineyard and to *T. urticae*, reared on pinto beans in the UC-Berkeley greenhouses for an unknown period of time. Bean leaf discs were dipped into water, 0.625, and 1 lb/100 gal of 30W Omite. The results (see table VII-1) indicate resistance to Omite is not obvious in this population. However, rumors of Omite resistance in spider mites recurs. It is thus important to monitor such resistance regularly. It is likely that use of low rates of Omite *combined* with the use of predators should delay, and possibly prevent, the onset of Omite resistance.

Table VII-1 Omite Resistance Test

Colony	% survival of adult ♀♀ after 48 hours on 0.0625 lbs[a/]	1 lb.[a/]	water[b/]
DeFreitas Pacific mites	33	11	95
Vineyard Pacific mites	44	2	85
T. urticae	33	26	90
		after 72 hours	
DeFreitas Pacific mites	24	4	95
Vineyard Pacific mites	20	0	85
T. urticae	26	17	90

a/ 45 adult females were tested, 9 replicates of 5 ♀♀.

b/ 20 " " " " , 4 replicates of 5 ♀♀.

VIII Effect of KNO_3 on Spider Mites

Growers have noted, and we have also observed, that spider mite numbers are often substantially reduced after applications of KNO_3 as a foliar spray in the spring. To test in the laboratory whether KNO_3 residues have a toxic effect on spider mites on almond leaves, a leaf dip test was conducted using 0, 15 lb/150 gal or 30 lb/150 gal rates. Adult gravid *Tetranychus urticae* females and larvae from almond trees in the UC-Berkeley glasshouse were placed on almond leaf discs resting on water-soaked cotton at 27 - 29°C under an 18 hr daylength. Mortality was assessed after 48 hours.

Treatment	% survival (no. tested)			
	adult females		larvae	
water	100	(30)	87	(30)
15 lb.	94	(80)	76	(80)
30 lb.	79	(80)	90	(80)

T. urticae eggs deposited on the residues were then monitored to determine their success in developing to adulthood on the KNO_3 residues. Survival to adulthood on the water-treated checks was 69% (120 tested), 80% (371 tested) on the 15 lb/150 gal rate and 80% (329 tested) on the 30 lb/150 gal rate.

Thus, there is no evidence that KNO_3 exhibits a direct toxic effect on *T. urticae* on almond leaf discs in the laboratory. We did not test the effects of KNO_3 on *T. pacificus*, *P. ulmi*, etc. but do not expect substantial differences. Possibly, the reduction in spider mites is due to the physical effect of applying sprays at a time when spider mites are at very low densities.

IX Kairomones of Spider Mites and Predator Prey-Location Behavior

This work was conducted to determine how well *M. occidentalis* is cued into its various spider mite prey species on almonds and grapes. The results support field observations that *M. occidentalis* is a better predator of *Tetranychus* species than of *Panonychus* species or of *Bryobia*.

The use to which we can put this information awaits chemical determination of the nature of the kairomone(s), and the determination of whether we can use the kairomone to enhance *M. occidentalis*' effectiveness against European red mites.

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In press - 1981 IX-

NON-RANDOM PREY LOCATION BY THE

PHYTOSEIID PREDATOR *METASEIULUS OCCIDENTALIS*:

DIFFERENTIAL RESPONSES TO SEVERAL SPIDER MITE SPECIES

By

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ABSTRACT

Metaseiulus (= Typhlodromus) occidentalis (Nesbitt) is an effective predator of the spider mites Tetranychus urticae (Koch) and T. pacificus McGregor in vineyards and almond orchards in the San Joaquin Valley of California. It is less effective against the Willamette mite (Eotetranychus willamettei (McGregor)), the European red mite (Panonychus ulmi (Koch)), the citrus red mite (P. citri (McGregor)) and the brown mite (Bryobia rubrioculus (Scheuten)) in these crops. Behavioral observations and experiments documented that M. occidentalis detects cues deposited on leaves by several prey species, including T. urticae, T. pacificus and E. willamettei but weakly detects or responds to cues (silk and other residues) deposited by B. rubrioculus, P. citri, and P. ulmi. The cues continue to elicit a specialized "search" behavior by M. occidentalis for several days, but the cues can be removed partially by ageing or by washing the discs with water. Therefore, prey location is not due only to random encounters but is influenced by cues deposited by spider mites on leaf surfaces. We suggest that M. occidentalis' prey finding behavior is enhanced by silk and kairomonal cues which act as a releaser to switch a hungry predator into a special search mode, thereby increasing the likelihood that the predator will encounter prey.

INTRODUCTION

The phytoseiid mite, *Metaseiulus* (= *Typhlodromus*) *occidentalis* (Nesbitt) is an important predator of spider mites in agricultural crops in the western United States (Huffaker *et al*., 1970). It was introduced into Australia, New Zealand and Europe to control spider mites in deciduous fruit orchards, because it was documented to be an effective predator of spider mites and because it developed resistance to organophosphorus insecticides (Penman *et al*., 1979; Readshaw, 1975). *M. occidentalis* is effective in controlling the Pacific spider mite, *Tetranychus pacificus* McGregor, in vineyards of the San Joaquin Valley of California (Flaherty & Huffaker, 1970). Recently, it was demonstrated to be an effective spider mite predator in some almond orchards in the same area (Hoy *et al*., 1979; Roush & Hoy, 1980), controlling *T. pacificus* and *T. urticae* (Koch).

However, *M. occidentalis*' ineffectiveness against several spider mite species in California vineyards and almond orchards also was demonstrated (Hoy *et al*., 1978, 1979). In several almond orchards, *M. occidentalis* populations were present and well established but never responded numerically to the European spider mite, *Panonychus ulmi* (Koch), the brown mite, *Bryobia rubrioculus* (Scheuten), or the citrus red mite, *P. citri* (McGregor). Flaherty and Huffaker (1970) note that *M. occidentalis* is an ineffective predator of the Willamette spider mite, *Eotetranychus willamettei* McGregor, in vineyards. Thus, orchard or vineyard studies suggested that *M. occidentalis* is a more effective predator of spider mites in the genus *Tetranychus* than of spider mites in the genera Panonychus, Bryobia or Eotetranychus. There may be several reasons for these apparent differences in efficacy. For example, Huffaker & Flaherty (1970) suggested that T. pacificus produced more webbing and is more colonial than E. willamettei, implying that M. occidentalis is a more efficient predator of colonial prey. However, M. occidentalis can feed upon and develop on prey in these 3 genera (Hoy, unpubl.). This suggested to us that M. occidentalis might exhibit different prey location behavior in response to these prey species. Detailed life table studies also might document that fecundity and development rate are affected by these other prey species, which could influence predator efficacy.

This paper focusses on comparisons of M. occidentalis' prey location behavior using laboratory assays. M. occidentalis' behavior is described when it is in contact with silk and other residues of T. urticae and P. ulmi on prey-free almond leaf discs. Also, two-choice assays with hungry M. occidentalis females were conducted witn silk and other residues deposited by T. urticae, T. pacificus, P. ulmi, P. citri and B. rubrioculus on almond leaf discs, and with T. pacificus and E. willamettei on grape leaf discs. We present evidence suggesting that silk and a soluble kairomone(s) of T. urticae influence prey location by M. occidentalis.

MATERIALS AND METHODS

Colony sources. M. occidentalis were collected from almond orchards or vineyards in the San Joaquin Valley of California. All M. occidentalis colonies were fed all stages of T. urticae reared on Phaseolus vulgaris L. unless otherwise noted. All colonies and all experiments or observations were held at 24-27^{o} under an 18 hr daylength. Predators collected from vineyards were used in tests involving vineyard spider mite species and those collected from almonds were used for tests with spider mites collected from almonds. We assumed that the host plant might affect the cues deposited by spider mites, so all spider mites were collected from and tested on their respective host plant, i.e. grapes, almonds, or beans.

Behavioral Observations.

Gravid females were removed from the stock colonies and held without prey for 24 hr on paraffin-coated paper discs resting on water-soaked cotton. About one-third of the females ran off the disc, but all of the remaining "hungry" females actively searched for prey when placed upon test arenas.

Predator behavior was observed on several 18 mm diameter leaf disc substrates: clean almond leaf discs, previously-infested almond leaf discs, and leaf discs that were half clean and half previously-infested with *T. urticae* or *P. ulmi*. Previously-infested leaf discs were prepared by placing 10 adult female spider mites on clean leaf discs. After 22-24 hr, the spider mite females and their eggs were removed, leaving a residue of silk and excreta. If a 2-choice leaf disc were desired, a razor blade was used to divide a clean and a previously-infested leaf disc into two pieces along the central midvein. The two different halves were sealed together with melted paraffin applied with a camel's hair brush. One "hungry" predator was placed on the midline of the disc and its movements observed continuously under a dissecting microscope illuminated with a cool white fluorescent light source for 30 min. Tracings of the predator's path during 5-min intervals were made on a 127 mm diameter paper disc, for a total of 6 patterns/female. A transverse mark was made on the path each 15 sec during the observation so that the distance traveled during 15 sec could be estimated by a map measuring wheel. Initially, predators were followed on discs that were clean or had only P. ulmi or T. urticae residues. Later 2-choice leaf discs were used as well. Then, the mean distance traveled per 15 sec, the number of 15 sec intervals spent resting, and the number of intervals spent on each side of the 2-choice discs were recorded. All test leaf discs were used once and then discarded.

Predator Interference.

To test for indirect influences of several predators on a test arena, 2-choice leaf discs were prepared with one-half clean and the other half previously-infested with 50 M. occidentalis females held on the disc for 24 hr without prey. Predator females and their eggs were removed and five hungry M. occidentalis females added to each 2-choice leaf disc. Their locations after 1/2 and 1 hr were recorded.

Conditioning by Prey Species.

Most M. occidentalis females used in these tests were fed T. urticae reared on pinto beans. To determine if the prey species used to feed the stock predator colonies influenced the behavior of the test predators, M. occidentalis were reared under identical conditions but using either P. ulmi or T. urticae as prey. Newly-hatched M. occidentalis larvae were placed on almond leaf discs containing eggs and 2 adult females of either T. urticae or P. ulmi. The adult females reared on both prey species were tested using

2-choice leaf discs with T. urticae or P. ulmi residues. Three "hungry" predator females were transferred to each test arena and their locations were recorded after 1/2 hour.

Behavior on Grape Leaves.

M. occidentalis' behavior when in contact with residues deposited by the 2 spider mite species from grapes was determined using 2-choice grape leaf discs. Five hungry M. occidentalis females were placed on each test arena and their location was recorded after 1/2 and 1 hr. Tests with smooth-leaved Thompson Seedless variety included 2-choice discs with: T. pacificus vs. clean; E. willamettei vs. clean; E. willamettei vs. T. pacificus. The effect of ageing the spider mites' residues for 72 hrs on Thompson Seedless leaves was also tested: T. pacificus (aged 72 hrs prior to test) vs. clean; T. pacificus (aged 72 hr) vs. T. pacificus (0-24 hr old residues). Tests using E. willamettei vs. T. pacificus and E. willamettei vs. clean disc halves were conducted on the hairy-leaved Chenin Blanc variety, as well.

Behavior on Almond Leaves.

M. occidentalis' behavior when in contact with residues of the 5 spider mite species collected from almonds was determined using 2-choice almond leaf discs. Five hungry females were placed on Nonpareil variety almond leaf discs and their location recorded after 1/2 and 1 hr, comparing T. urticae, vs. clean; T. pacificus vs. clean; P. citri vs. clean; P. ulmi vs. clean; B. rubrioculus vs. clean; B. rubrioculus (density of prey, 50 rather than 10 females/disc) vs. clean; T. urticae vs. T. pacificus; P. ulmi vs. P. citri; T. urticae vs. P. ulmi; T. urticae vs. P. citri.

Comparisons of Washed and Unwashed Leaf Discs.

To determine if a chemical cue (kairomone) could be removed from the leaf discs with spider mite silk and excreta residues, almond and bean leaf discs that had been infested with 10 or 30 *T. urticae* females for 24 hr were gently washed 5 times with 150 ml of distilled water and air-dried. The silk on the washed discs did not appear different from unwashed discs with silk. These prey-free washed discs were cut into halves which were joined to previously-infested unwashed or clean disc halves. Five predator females were tested for 1/2 and 1 hr.

Comparisons of Aged and Fresh Residues

To determine if spider mite silk and other residues lost their effect after ageing, bean leaf discs that had been infested with 10 *T. urticae* females for 24 hr were held for 48 or 72 hr before testing. Clean discs were set up simultaneously and aged an equivalent time for comparison. Comparisons were also made with discs prepared in the standard manner (24 hrs).

Contingency table analysis (Steel and Torrie 1960) was used to determine whether there were significant differences in the numbers of predators located on each disc half. The tests were conducted at $P \leq 0.05$ level. Discrepancies between the total tested and the numbers on each half recorded in the results section are because any predators located on the midline at the time of the recordings were excluded from the analysis.

RESULTS AND DISCUSSION

Behavior on Leaf Discs Previously-Infested with Spider Mites and on Clean Leaf Discs.

M. occidentalis moves more rapidly and turns less often on clean leaf discs than on leaf discs previously-infested with spider mites (Fig. Ia,b,d). Females exhibited different behavior when they moved over the midline of discs which were half clean and half previously-infested with *T. urticae* (Fig. Id). *M. occidentalis* did not exhibit such distinctive behavior on leaves with *P. ulmi* residues (Fig. Ic,e,f). Hungry females also travel greater distances on clean discs than on leaf discs previously infested with *T. urticae* or *P. ulmi* (Table I).

Hungry *M. occidentalis* females spend about 3/4 of the 30-minute test time on the disc half with *T. urticae* residues (Table II, test 1). At the end of the 30-minute test, all females were on the *T. urticae* leaf disc half (Table II tests 1, 3). Females spent more time searching on the *T. urticae* half, as indicated by number of 15 second intervals where the predators were active (55 vs. 16). They also spent more time resting on the *T. urticae* halves (16.7 vs. 5.2) (Table II, test 1). The preference for *P. ulmi* residues was less obvious (Table II test 2). Slightly more than half of the time was spent on *P. ulmi* residues; only 3 females were on the *P. ulmi* halves, one was on the midline, and one was on the clean disc half at the end of the test. The *T. urticae* disc half was occupied by all 5 females tested on the *T. urticae*-*P. ulmi* arenas by the end of the test (Table II, test 3).

Table I

Movement of hungry *M. occidentalis* females on clean almond leaf discs or with *T. urticae* or *P. ulmi* residues.

Interval (Minutes)	Mean distance traveled in mm (S.D.) on		
	Leaf discs with *T. urticae* residues	Leaf discs with *P. ulmi* residues	Clean leaf discs
0-5	60.2 (12.9)	62.6 (16.1)	162.0 (67.2) *
10-15	79.5 (34.2)	78.9 (14.2)	100.7 (77.8)
15-20	80.9 (18.8)	84.6 (25.8)	160.9 (104.3) *
25-30	76.4 (27.8)	87.1 (10.2) 1	159.4 (75.2) *
Combined	297.0 (64.0)	313.2 (31.7)	583.1 (240.7) *

*indicates a value significantly different from other row values ($P \leq 0.05$).

N = 3 each treatment.

Fig. I. Behavior of hungry M. occidentalis females on clean almond leaf discs or with T. urticae and/or P. ulmi residues. Distance traveled on disc within 15 seconds indicated by distance between 2 transverse lines. Each pattern is a record of movement during 5 minutes.

Table II

Behavior of hungry *M. occidentalis* females on 2-choice almond leaf discs with no residues or *T. urticae* or *P. ulmi* residues.

Treatments	No. tested	No. observed on each half after 30 min*	Mean no. 15-sec intervals on disc half	Mean no. 15-sec intervals spent resting	Mean no. times over mid-line
1)					
T. urticae vs. Clean	6	6 : 0	55.0 : 16.0	16.7 : 5.2	4.5
2)					
P. ulmi vs. Clean	5	3 : 1	43.4 : 32.8	6.2 : 15.2	4.6
3)					
T. urticae vs. *P. ulmi*	6**	5 : 0	49.4 : 27.2	19.6 : 3.8	3.4

* Discrepancies in the number of females tested and the numbers on tested halves are because test females located on the midline were excluded.

** One female of 6 tested did not cross the midline after it moved on to the *T. urticae* half, so was excluded.

Predator Interference.

Hungry M. occidentalis females placed on 2-choice leaf discs consisting of halves previously-infested with 50 M. occidentalis females for 24 hrs and halves never infested with M. occidentalis distributed themselves equally. Thus, if chemical cues were deposited by the 50 M. occidentalis females, their (indirect) effects on other female M. occidentalis were not detected by this test. The subsequent use of 5 rather than one predator female per test arena seemed reasonable. No direct interference was observed in the subsequent tests using 5 females.

Influence of Prey Species During Development

The prey species provided the stock cultures of M. occidentalis do not appear to affect M. occidentalis' behavior on leaf disc test arenas. M. occidentalis reared on P. ulmi prey spend more time on leaf discs with T. urticae residues, as do predators reared on T. urticae (Table III). Thus, differences in M. occidentalis' responses to P. ulmi and T. urticae cues appear to be inherent rather than influenced by previous exposures to prey residues during development and young adulthood.

Response of M. occidentalis to Cues Deposited by Spider Mites from Vineyards.

Hungry M. occidentalis responded positively to cues deposited by the Pacific spider mite (Table IV, test 1). More predator females were located on leaf disc halves previously infested with Pacific mites than on clean leaf disc halves after 1/2 and 1 hr. Pacific mite residues aged for 72 hr still elicited a positive response (Table IV, tests 2, 3). Predators did not exhibit a preference between Willamette and Pacific mite residues (Table IV, test 4). However, predators did not discriminate between Willamette mite residues vs. clean halves (Table IV, test 5). This may have been due to the smoothness of the young leaves used in this test. In subsequent tests, using hairy Chenin Blanc leaf discs, predators strongly discriminated between clean halves and Willamette mite residues (Table IV, test 6). M. occidentalis appears to respond equally to cues from both of these native North American spider mite species. This suggests that differences in this predator's ability to control these spider mite species in vineyards are not due to an inability of M. occidentalis to perceive cues deposited by Willamette mites. We noted that the Pacific spider mite females deposited more webbing within 24 hours than do an equivalent number of Willamette mite females and yet M. occidentalis did not exhibit a preference for the more profusely-webbed disc half containing Pacific mites during these tests (Table IV, tests 4, 7). Perhaps the quality and quantity of chemical cues deposited are more important than the amount of silk deposited. Differences in M. occidentalis' vineyard effectiveness thus may be due to other factors such as their location on the vine (i.e. top vs. sides) and dispersion patterns (Flaherty & Huffaker, 1970).

Table IV

Response of M. occidentalis to Cues Deposited by Spider Mites from Almonds.

Hungry M. occidentalis females responded positively to cues deposited by 10 T. urticae, T. pacificus, P. ulmi, or P. citri females reared on almonds, but not to 10 B. rubrioculus females (Table V, tests 1-5). However, when 50 B. rubrioculus females rather than 10 females were left on an almond disc to deposit residues, more M. occidentalis females were located on these disc halves than on clean disc halves (Table V, test 6).

Table V

M. occidentalis exhibited no preferences between leaf disc halves containing T. urticae and T. pacificus, and only slight differences in its responses to those with P. ulmi and P. citri residues (Table V, tests 7, 8). However, M. occidentalis always preferred leaf disc halves with T. urticae cues to those deposited by a Panonychus species (Table V, tests 9, 10). Although M. occidentalis prefers Tetranychus residues, it spends more time on Panonychus residues than on clean leaf discs (tests 3, 4). A hierarchy of M. occidentalis' preferences appears to be: Tetranychus spp. > Panonychus spp. > Bryobia sp.

Comparisons of Behavior on Washed and Unwashed Leaf Discs.

Water washes removed something from the leaf discs with spider mite residues. M. occidentalis females preferred unwashed leaf disc halves previously infested with 10 or 30 T. urticae females for 24 hr to infested leaf disc halves that were washed in water and air dried (Table VI, tests 2, 4). However, washed leaf disc halves arrested more M. occidentalis than did clean leaf disc halves (tests 2, 3). We suggest that washing removed a kairomone(s) from the leaf surface or from the silk which decreased the response of hungry M. occidentalis females, since spider mite silk is not water soluble. Since the washed disc retained all or most of the silk and it was preferred over the clean disc half, we conclude that silk alone may have some ability to arrest M. occidentalis although we can't be certain we removed all traces of the kairomone(s) from the washed disc. However we believe that silk is only part of the cues deposited by these spider mites that elicits a response by M. occidentalis.

Table IV

Location of hungry *M. occidentalis* females after transfer to Thompson Seedless or Chenin Blanc grape leaf discs with residues deposited by 10 adult *T. pacificus* or *E. willamettei* females.

Treatments	Total no. tested	No. *M. occidentalis* females on each leaf disc half after 1/2 hr	and 1 hr
Thompson Seedless Variety Leaves (Smooth)			
1. *T. pacificus* vs. Clean	100	63 : 22*	54 : 35*
2. *T. pacificus* (72 hr) vs. Clean	95	56* : 26*	52* : 33*
3. *T. pacificus* vs. *T. pacificus* (72 hr)	100	44 : 50	36 : 56*
4. *E. willamettei* vs. *T. pacificus*	90	48 : 36	41 : 37
5. *E. willamettei* vs. Clean	60	32 : 26	33 : 19
Chenin Blanc Variety Leaves (Hairy)			
6. *E. willamettei* vs. Clean	35	31 : 4*	26 : 9*
7. *E. willamettei* vs. *T. pacificus*	40	19 : 21	21 : 18

* Numbers of females on disc halves are significantly different from 1 : 1 at $P \leq 5\%$.

Table V

Location of hungry *M. occidentalis* females after transfer to almond leaf discs with residues of 10 adult *T. urticae*, *T. pacificus*, *P. citri*, *P. ulmi* and 10 or 50 *B. rubrioculus* females.

Treatments	Total no. tested	No. *M. occidentalis* females on each leaf disc half after 1/2 hr	and 1 hr
1. *T. urticae* vs. Clean	225	155 : 44*	143 : 51*
2. *T. pacificus* vs. Clean	100	60 : 21*	55 : 20*
3. *P. citri* vs. Clean	150	79 : 44*	82: 49*
4. *P. ulmi* vs. Clean	105	59 : 24*	49 : 35
5. *B. rubrioculus* vs. Clean	100	50 : 35	43 : 41
6. *B. rubrioculus* (50) vs. Clean	100	52 : 31*	62 : 31*
7. *T. urticae* vs. *T. pacificus*	100	42 : 53	-
8. *P. ulmi* vs. *P. citri*	100	45 : 40	51 : 27*
9. *T. urticae* vs. *P. ulmi*	100	69 : 26*	72 : 15*
10. *T. urticae* vs. *P. citri*	150	81 : 38*	73 : 49*

* Number of females on disc halves are significantly different from 1 : 1 at $P \leq 5\%$.

Table VI

Location of hungry *M. occidentalis* females after transfer to 2-choice washed or unwashed leaf discs.

Treatments	Total no. tested	No. *M. occidentalis* females on each leaf disc half after 1/2 hr	and	1 hr
Residues of 30 *T. urticae* females				
1. Clean vs. Washed	80	25 : 53*		33 : 40
2. Washed vs. Unwashed	20	1 : 19*		4 : 14
Residues of 10 *T. urticae* females				
3. Clean vs. Washed	80	24 : 46*		34 : 43
4. Washed vs. Unwashed	51	7 : 44*		11 : 34*

* Number of females on disc halves are significantly different from 1 : 1 at $P \leq 5\%$.

Comparisons of Aged Residues and Fresh Residues

Leaf discs aged for 72 or 48 hr arrested fewer hungry predators than fresh (24 hr) leaf discs (Table VII). All test discs were always the same age; only the age of the spider mite silk and other residues changed. This suggests either that a volatile component(s) of the silk or other residues declines in amount or that some other type of degradation had occurred. Since the silk was undisturbed, this data further suggests that the silk is only one part of the cues *M. occidentalis* uses in its prey location behavior.

The physical and chemical nature of the cues deposited by these spider mite species is currently unknown, so we do not know if *M. occidentalis* is responding to qualitative or quantitative differences in the cues deposited by the different spider mites or to both. The responses of *M. occidentalis* to cues deposited by 50 *B. rubrioculus* females within 24 hours but not to 10 females suggests, however, that *M. occidentalis* responds to increased quantities of at least one residue (Table V). The location of the tactile and chemoreceptors involved in perception of these cues is unknown for *M. occidentalis* but the many sensory receptors located on legs I and the palps of phytoseiids are good candidates (Jackson 1974).

M. occidentalis' behavior changes after it encounters silk and other cues deposited by spider mites of the genus *Tetranychus*; the predator slows its rate of walking, increases its rate of turning, and enters a specialized "search mode" (Fig. 1, Tables I, II). This behavior seems to be optimal for increasing the likelihood that a hungry predator will encounter prey, and decreases the amount of time spent on leaf surfaces that are unlikely to yield prey since they lack silk or other residues. Its behavior is less

Table VII

Location of hungry M. *occidentalis* females on 2-choice bean leaf discs with different aged residues of 10 T. *urticae* females.

Treatments	Total no. tested	No. M. *occidentalis* females on each leaf disc half after 1/2 hr	and	1 hr
1. 72 vs. 24 hr residues	65	13 : 45*		10 : 48*
2. 72 hr residue vs. Clean	65	48 : 10*		47 : 7*
3. 48 vs. 24 hr residues	45	15 : 21		12 : 22
4. 48 hr residue vs. Clean	45	27 : 8*		22 : 12

* Numbers of females are significantly different from 1:1 at $P \leq 5\%$.

distinctive on *Panonychus* residues, which suggests that this predator would spend less time searching for prey. Thus, prey location is not entirely a matter of chance encounter by this predator. Vision is not involved, however, as phytoseiid predators do not have eyes. *M. occidentalis* probably uses tactile and chemical cues to initiate its search of an area which is more likely to yield prey, especially *Tetranychus* prey, since both aged discs and discs with water-washed silk arrested hungry females.

Tetranychus species elicit more intense search behavior than do *Panonychus* or *Bryobia* species (Tables IV, V), which parallels the relative effectiveness of this predator in the field. This suggests that the "choice" arenas used in these tests may be an effective way to evaluate prey preferences in exotic species of phytoseiids being imported for biological control projects. This bioassay technique might determine which spider mite genus a phytoseiid "prefers" so that releases for establishment are more likely to be successful. Thus, while *M. occidentalis* will feed on all the prey species we tested in the laboratory, it is most successful in the field with *Tetranychus* species, as would be predicted by these 2-choice tests.

Other mites utilize both chemical (Egan, 1976) and tactile cues to find hosts or mates. Penman & Cone (1972, 1974) determined that spider mite males (*T. urticae*) respond to a sex pheromone produced by quiescent *T. urticae* female deutonymphs. They also showed that silk webbing deposited by the deutonymph before she becomes quiescent, in combination with the sex pheromone, comprised a 2-component system that the male uses to locate female deutonymphs. Other roles have been ascribed to silk (See Gerson for a review (1979)), including the protection of spider mite eggs and immatures. That this protective function could have been subverted by natural enemies was suggested by Gerson (1979). He reviewed Schmidt's (1976) work and noted that "silken threads apparently led P. persimilis to Tetranychus, possibly by a tactile sense. Such observations suggest that certain predators have adapted to this defense mechanism and are, in fact, using it for their own purposes." Our data support Gerson's hypothesis; we believe that M. occidentalis uses cues associated with spider mite silk and other residues to their advantage -- namely, as an aid in prey location.

Behavior of other natural enemies is influenced by chemical cues and silk. Weseloh (1976, 1977) demonstrated that host selection behavior is elicited in the braconid Apanteles melanosceles (Ratzeburg) by a combination of silk and a water-soluble kairomone of the gypsy moth (Lymantria dispar (L)). His work triggered our hypothesis that M. occidentalis might respond to silk and kairomone cues deposited by spider mites. Hislop et al. (1978) reported briefly that another phytoseiid, Amblyseius fallacis Garman, responds to kairomonal cues deposited by T. urticae but less well to cues left by P. ulmi.

Prey location by phytoseiid mites has long been considered to be entirely a matter of chance (Putman, 1962; Mori & Chant, 1966). There was no evidence that phytoseiids responded to distant olfactory prey stimuli and it was assumed that the predator detected its prey only after actual chance contact with their tarsi (Jackson & Ford, 1973). We suggest that M, occidentalis' prey location behavior can be divided into components parallel to those proposed for insect parasites (Vinson, 1976), i.e., prey habitat location, prey location, prey acceptance, and prey suitability, and that prey location is not a completely random event. Research on the host-finding behavior of parasites has been a fertile area of research for the past few years (Vinson, 1976). Less work has been done with prey location and selection behavior by predatory arthropods (for a review see Greany & Hagen, in press). However, the role(s) that chemical and physical cues play in prey location should receive more attention as entomologists, and especially biological control workers, become increasingly aware of the economic importance of predators.

SUMMARY

Metaseiulus occidentalis (Nesbitt) is an effective predator of spider mites in deciduous crops. In the San Joaquin Valley of California (U.S.A.), this predator can control Tetranychus urticae (Koch) and T. pacificus (McGregor), but it is less effective against the Willamette mite (Eotetranychus willamettei (McGregor)), the European red mite (Panonychus ulmi (Koch)), the citrus mite (P. citri (McGregor)), and the brown mite (Bryobia rubrioculus (Scheuten)) in almond orchards and vineyards.

We observed M. occidentalis' behavior on clean grape or almond leaf discs and on discs with silk and other cues deposited by these spider mite species. Gravid adult females held 24 hours without prey (= "hungry") moved more slowly and turned more often on leaf discs previously infested with T. urticae than on clean leaf discs. Two-choice tests were conducted on prey-free discs with spider mite silk and residues and the location of hungry

<u>M. occidentalis</u> females was recorded after 1/2 and 1 hour. These tests showed that <u>M. occidentalis</u> does not locate prey entirely at random, but searches leaf areas more intensively if they contain silk and other cues deposited by spider mites. This behavior should improve their chances of encountering prey. <u>M. occidentalis</u> spends more time searching <u>Tetranychus</u> residues than <u>Panonychus</u> or <u>Bryobia</u> residues, which parallels the relative efficiency of this predator in the field.

The cues used by <u>M. occidentalis</u> are partially removed by water and by ageing the leaf discs; we propose that spider mite (especially <u>Tetranychus</u>) silk and other (kairomonal) cues release an efficient search behavior in <u>M. occidentalis</u>. The chemical nature of the kairomone(s) are unknown at at present.

REFERENCES

EGAN, M. E. (1976) The chemosensory basis of host discrimination in a parasitic mite. J. Comp. Physiol. 109: 69-89.

FLAHERTY, D. L. & HUFFAKER, C. B. (1970) Biological control of Pacific mites and Willamette Mites in San Joaquin Valley Vineyards. I. Role of Metaseiulus occidentalis. Hilgardia 40(10): 267-330.

GERSON, U. (1979) Silk production in Tetranychus (Acari: Tetranychidae). Recent Adv. Acar. I: 177-188.

GREANY, P. D. & HAGEN, K. S. (In press) Role and significance of allelochemics and prey selection. IN: Semiochemicals: Their Role in Pest Control, D. Nordlund, R. Jones and W. Lewis, Eds.

HISLOP, R. G., ALVES, N. & PROKOPY, R. J. (1978) Spider mite substances influencing searching behavior of the mite predator, Amblyseius fallacis, on apple. Fruit Notes 43(6): 8-11.

HOY, M. A., ROSS, N. W. & ROUGH, D. (1978) Impact of NOW insecticides on mites in northern California almonds. Calif. Agr. 32(5): 10-12.

HOY, M. A., ROUSH, R. T., SMITH, K. S. & BARCLAY, L. W. (1979) Spider mites and predators in San Joaquin Valley almond orchards. Calif. Agr. 33: 11-13.

HUFFAKER, C. B., VAN DE VRIE, M. & MCMURTRY, J. A. (1970) Ecology of tetranychid mites and their natural enemies: A review. II. Tetranychid populations and their possible control by predators: An evaluation. Hilgardia 40(11): 391-458.

JACKSON, G. J. (1974) Chaetotaxy and setal morphology or the palp and first tarsi of Phytoseiulus persimilis A.-H. (Acarina: Phytoseiidae). Acarologia 16: 583-594.

JACKSON, G. J. & FORD. J. B. (1973) The feeding behaviour of Phytoseiulus persimilis (Acarina: Phytoseiidae), particularly as affected by certain pesticides. Ann. Appl. Biol. 75: 165-171.

MORI, H. & CHANT, D. A. (1966) The influence of prey density, relative humidity, and starvation on the predaceous behavior of Phytoseiulus persimilis Athias - Henriot (Acarina: Phytoseiidae). Can. J. Zool. 44: 383-491.

PENMAN, D. R. & CONE, W. W. (1972) Behavior of male two-spotted spider mites in response to quiescent female deutonymphs and to web. Ann. Entomol. Soc. Amer. 65: 1289-1293.

PENMAN, D. R. & CONE, W. W. (1974) Role of web, tactile stimuli, and female sex pheromone in attraction of male two-spotted spider mites to quiescent female deutonymphs. Ann. Entomol. Soc. Amer. 67: 179-182.

PENMAN, D. R., WEARING, C. H., COLLYER, E. & THOMAS, W. P. (1979) The role of insecticide-resistant phytoseiids in integrated mite control in New Zealand. Recent Adv. Acar. Vol. I: 59-69.

PUTMAN, W. L. (1962) Life-history and behavior of the predaceous mite Typhlodromus (T.) caudiglans Schuster (Acarina: Phytoseiidae) in Ontario, with notes on the prey of related species. Canad. Entomol. 94: 163-177.

READSHAW, J. L. (1975) Biological control of orchard mites in Australia with an insecticide-resistant predator. J. Aust. Inst. Agric. Sci. 41: 213-214.

ROUSH, R. T. & HOY, M. A. (1980) Selection improves Sevin resistance in spider mite predator. Calif. Agr. 34: 11-14.

SCHMIDT, G. (1976) Der Einfluss der von den Beutetieren hinterlassenen Spuren auf Suchverhalten und Sucherfolg von *Phytoseiulus persimilis* A. & H. (Acarina). Z. ang. Ent. 82: 216-218.

STEEL, R. G. D. & TORRIE, J. H. (1960) Principles and Procedures of Statistics. McGraw-Hill Book Company, New York, 481 pp.

VINSON, S. B. (1976) Host selection by insect parasitoids. Annu. Rev. Entomol. 21: 109-133.

WESELOH, R. M. (1976) Behavioral responses of the parasite, *Apanteles melanoscelus*, to gypsy moth silk. Environ. Entomol. 5: 1128-1132.

WESELOH, R. M. (1977) Effects on behavior of *Apanteles melanoscelus* females caused by modifications in extraction, storage, and presentation of gypsy moth silk kairomone. J. Chem. Ecol. 3: 723-735.

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This project was sponsored in part by funds from California Agricultural Experiment Station Project 3522-H, The California Almond Advisory Board, and the California Table Grape Commission. We thank W. Allen, M. Liebman, L. Barclay, and R. Roush for assistance in obtaining spider mite species, and R. Weseloh and D. Wood for reviews.

X A Mite Parasite for Ants that are Pests of Almonds in the Southern San Joaquin Valley

During 1980, W. Reil contacted me regarding ant damage in almonds and the potential for biological control of ants since there are no pesticides currently registered for use on ants in California.

Wilbur had heard rumors of a mite parasite of ants and asked me about it. Dr. Bill Bruce, in Georgia, has been studying a mite, *Pyemotes tritici*, that shows potential for biological control of imported fire ant mounds in Georgia. The ant species in California doing damage apparently is the southern fire ant, *Solenopsis xyloni*.

We have received permission to import Dr. Bruce's strain for tests and received a shipment on Nov. 1, 1980. Others are planned. If *P. tritici* can parasitize *S. xyloni* successfully, Wilbur and I would like to conduct limited releases in the 1981 field season.

Mass rearing of these parasitic mites will have to be worked out first; however, we are now rearing small colonies successfully.

X-2

UNIVERSITY OF CALIFORNIA, BERKELEY

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College of Agricultural Sciences
Agricultural Experiment Station
Division of Entomology and Parasitology

201 Wellman Hall
Berkeley, California 94720

27 June 1980

MEMO TO: State and Federal Officials

FROM: Marjorie A. Hoy *Marjorie A. Hoy*

RE: Impact of Pyemotes tritici

Pyemotes tritici (Acarina: Pyemotidae) is a parasite of insects. It has been found effective in the control of the imported fire ant in Georgia (Bruce and LeCato 1979 and Dr. Bill Bruce, personal communication). This species is ubiquitous, and no doubt occurs in California; however, the strain studied by Dr. Bruce is especially desirable as it is effective as a parasite of ants.

We want to obtain specimens of this mite from Dr. Bruce to evaluate its potential as a control agent of the southern fire ant, Solenopsis xyloni, which can be a pest of almond nuts in California orchards (W. Reil, personal communication and Davis et al., 1979).

Our goal in 1980 is to determine if P. tritici will paralyze and kill S. xyloni in the laboratory. If so, we will continue with evaluations of P. tritici for possible releases in one or more almond orchards in 1981.

P. tritici (= P. ventricosis) can be irritating to humans and can be a pest of insectaries. We will rear this mite in containers with a water-filled moat. Dr. Bruce assured me by telephone that this species has caused no problems to himself or technical staff in several years of rearing it. Since this species is already in California, we do not believe any environmental or health problems are likely to occur.

Bruce, W.A. and LeCato, G.L. (1979) Pyemotes tritici: potential biological control agent of stored-product insects. Recent Adv. Acar. I: 213-220. (See enclosed).

Davis, C. et al. (1979) Summary of 1979 Almond Integrated Pest Management Trials. Report to The Almond Board of California.

MAH/klb

Acknowledgments

W. Reil, T. Johnson, C. Davis, J. Profita provided valued assistance in these projects. We also thank Dennis Culver of ICI, America for the use of almond trees in Visalia, and the growers who allowed us use of their almond orchards.

Publications

Roush, R. T. and M. A. Hoy (1980). Selection improves Sevin resistance in spider mite predator. Calif. Agr. 34(1):11-14 (Attached).

Hoy, M. A., N. F. Knop and J. I.Joos (1980). Pyrethroid resistance selected in a spider mite predator. Calif. Agr. 34:11-12 (Attached).

In Press

Roush, R. T. and M. A. Hoy (1981) Genetic improvement of *Metaseiulus occidentalis*: Selection with methomyl, dimethoate, and carbaryl and genetic analysis of carbaryl resistance. J. Econ. Ent.

Roush, R. T. and M. A. Hoy (1981) Laboratory, glasshouse and field studies of artificially selected carbaryl resistance in *Metaseiulus occidentalis*. J. Econ. Ent.

Hoy, M. A. and N. F. Knop (1981) Genetic improvement of a biological control agent: Selection for and genetic analysis of permethrin resistance in *Metaseiulus occidentalis* (Acarina: Phytoseiidae) Entomologia Exp. et Appl.

PYEMOTES TRITICI: A POTENTIAL NEW AGENT FOR BIOLOGICAL CONTROL OF THE RED IMPORTED FIRE ANT, *SOLENOPSIS INVICTA* (ACARI: PYEMOTIDAE)

W. A. Bruce and G. L. LeCato[1]

----- ABSTRACT—In laboratory and field tests the straw itch mite, *Pyemotes tritici*, a parasite of stored-product insects, acted as a biological control agent against the red imported fire ant when the mite was placed on the nest and taken beneath the soil surface by the ants. All stages of the ant, including the queen, are capable of being parasitized by the mite. -----

The straw itch mite, *Pyemotes tritici*, has frequently been regarded as a past species (Moser, 1975), but it has also been known for a long time as an effective parasite of stored-product insects. The effectiveness results primarily from the short (five to seven days) developmental cycle, ovoviviparity that gives rise to adult progeny, high reproductive potential (ca. 250 adult offspring/gravid female), no intermediate hosts or food sources required, females represent 95% of the population, females mate immediately after birth and begin host-seeking activity, cosmopolitan distribution, and populations can be easily reared and synchronized in the laboratory. These characteristics are uniquely appropriate for biological control investigations.

Our study of the control of stored-product insects (Bruce and Lecato, 1979) achieved with this mite led us to speculate about its possible efficacy as a biological control agent against the red imported fire ant, *Solenopsis invicta*. This insect is generally recognized to be a significant agricultural pest in this country (Lofgren et al., 1975; Adkins, 1970) but it is credited also with the reduction of pests such as ticks (Harris and Burns, 1972) and weevils (Sterling, 1978) common to pasturelands and cotton fields. Although eradication probably is neither possible nor necessary, we believe some form of control is desirable.

In the laboratory when adult female mites were placed in petri dishes together with larvae, pupae, or adult ants, all ants, including queens, were parasitized within several hours. We therefore conducted limited field tests with naturally-occurring nests. The results indicate that *P. tritici* has potential as a biological control agent of the fire ant.

First we rear the mites in the laboratory on pupae of the cigarette beetle (*Lasioderma serricorne*) (CBP) as follows: Approximately 30-35 ml of washed CBP are placed in each of three containers. Then several thousand one- to four-day-old adult female mites are brushed on the CBP, a procedure that tends to synchronize the succeeding generation. Within less than an hour the mites, characteristically, find a suitable place to attach, insert their stylet-like chelicerae, and secrete a neuromuscular toxin that paralyzes the insect. Because the female is physogastric, the opisthosoma becomes enormously distended with developing embryos beginning several hours after attachment, and this distention may continue until the sac is several times the length of the mite body (Fig. 1). At ca. 22°C and 60% RH, the first adult progeny begin to emerge from the gravid females after 7 days of attachment.

Now the CBP with the gravid female mites attached are ready to be applied to fire ant nests nests in the field. Application is simple. The top of the nest that is to be treated is scraped to expose interior tunnels and to induce the ants to the surface. Then an arbitrarily selected volume (ca. 100ml) of CBP with *P. tritici* attached is sprinkled over the surface of the nest. The response of the ants to this material contributes greatly to the success of the treatment. Almost immediately they transfer the CBP and mites to the interior of the nest. This action would seem

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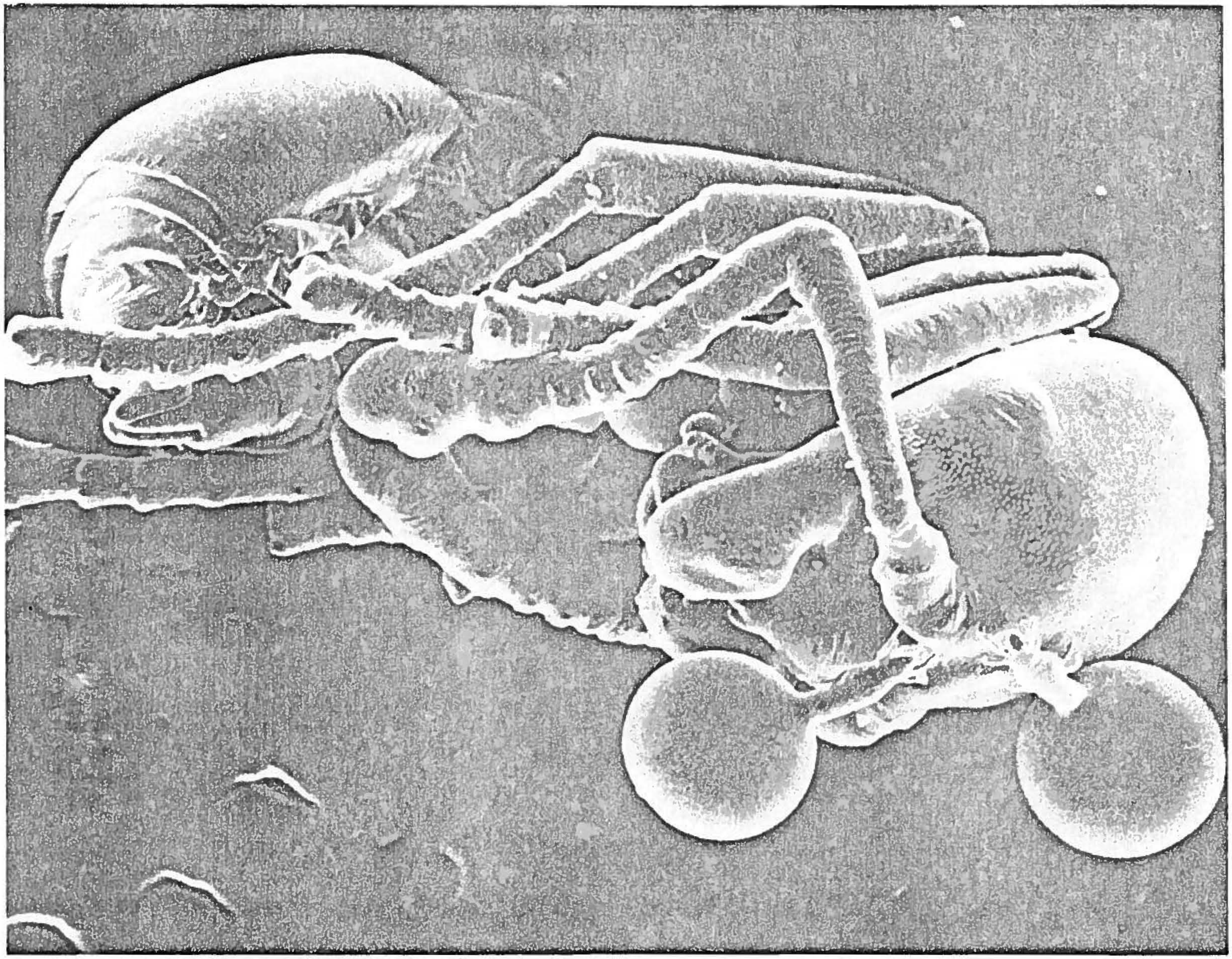


Fig. 1: Scanning electron micrograph of two female *Pyemotes tritici* attached near the base of the antenna of a pupa of the red imported fire ant. Note the distension of the mite opisthosoma after 48 hours (X 50).

to preclude any contact with man or his domesticated animals. Once in the nest the mite progeny continue to emerge from the gravid females for several days and begin to parasitize the ants, presumably including the queen (s), thereby destroying the colony.

Eleven ant nests on the grounds of our laboratory were treated in this manner (1976-77), and were inactivated (Table 1). In view of these results we established another test site located near Middleburg, FL, in an old pecan grove now used as a pasture. There we treated 17 fire ant nests in a 2-ha area on June 7, 1978, in the manner described; the remaining nests were tagged as controls. Treatments were applied three times at ca. 2-week intervals. As of August 30, 1978, and January 17, 1979, 12 of the 17 treated nests were inactive.

Still another test area was established near Savannah, GA, in a 2-ha unshaded pasture. Each nest was numbered and a total of 233 nests was tagged. Ten nests in the center of the field were treated every 1-3 weeks until they were inactive or had received a maximum of ten treatments. Also, nine other nests were treated three times during the summer and early fall of 1978. Presently, ten of the 19 nests treated remain inactive.

Control was less successful at each successive test site though the percentage of nests inactivated never dropped below 50. However, no attempt was made to determine an LD_{50}. In addition, predetermined numbers of treatments were used because it would be difficult to ascertain precisely when the queen had been parasitized in relation to continued worker activity. If a mound was noticeably inactive prior to the next treatment a decision was made as to whether or not to continue treatments (e. g. Savannah farm) (Table 1). At the Savannah laboratory all nests except one were small (ca. 20 cm diameter), and the treatments were applied primarily in the fall or spring. The brood at this time of year tends to be near the surface on warm days and is therefore more readily accessible to the mites. Also additional stress due to winter weather may have enhanced the effect of the mites. In the Florida test, the ground moisture was high, and most of the field was shaded much of the time, which again tended to keep the ants and brood near the surface. On the other hand, we used the same quantity of CBP + mites as in the first test though the nests were much larger (50 cm diameter). In the third test, at the Savannah farm test site, the nest sizes were similar to those in Florida (but the treatment was not increased), there was no shade, and treatments were made during the hot summer months (35+^{o}C) so it was more difficult to induce the ants to come to and remain on the nest surface. In addition it is not known what effect, if any, the mild winter temperatures of 1978-1979 may have had.

Further studies are required to examine the full potential of this strategy. However, our primary purpose in the study reported here was to determine whether *P. tritici* could effect any degree of biological control of *S. invicta* in the field. A total of 47 nests was treated at various times of the year from late 1976 through 1978 and 33 of the 47 were rendered inactive. Thus some degree of biological control may be possible with the technique used. In fact, *Pyemotes* spp. may be parasitic on other species of ants as well. *Pyemotes* spp. from Brazilian leaf-cutter ant nests (identified by P. Hunter, Department of Entomology, University of Georgia, Athens, 1972) were thought to be responsible for the death of several ant colonies. It is conceivable that pyemotid mites may also be associated with fire ants in South America. Also, if *P. tritici*, like many species of this group, is phoretic (Moser and Cross, 1975) or cannot parasitize a particular stage or species of arthropod associated with *S. invicta* then inter-nest movement of mites could be enhanced. Such a mechanism could explain why some of our control nests located near treated nests eventually became inactive. This relationship would provide one strategy for establishing natural control along the lines proposed by Buren et al. (1979).

ACKNOWLEDGEMENT

We thank D. Jouvenaz, USDA-SEA-AR, for field advice; T. McCray, J. M. Collins, M. A. Schweikert, R. A. Myers, G. F. Haussmann, and S. D. Bruce for laboratory and field assistance; R. V. Byrd for photomicrography and especially E. H. Zipperer for the use of pastureland.

TABLE 1.—Results of treating fire ant nests with *Pyemotes tritici*.

Location	Treated nests: Total no.	No. times treated	Active	Inactivated	Controls: Active	Inactive
Savannah Laboratory	11	3*	0	11	5	2
Middleburg, Florida	17	3 ‡	5	12	23	3
Savannah farm	19	1-10‡	9	170§	10	0

*Since all nests within a test area were tagged, any formation of an adjacent nest subsequent to treatment would be noted immediately. Inactivity was determined by the lack of loose soil buildup on the nest surface and increased growth of grass over and around the nest and by scraping or digging into the nest to observe living ants. No attempt was made to excavate an entire nest, which might extend downward into the soil 0.5-1.5 m, to collect dead ants and mites. One large nest (ca. 50 cm diameter) treated 5 times. ‡ Ten nests scheduled for ten treatments: four nests inactive after three treatments; six nests active after ten treatments. Nine nests scheduled for three treatments. Nine nests scheduled for three treatments: four nests inactive after one treatment; two nests inactive after two treatments; three nests active after three treatments. § Total of 233 nests was tagged of which 44 were old-inactive before test, 19 were treated, and 170 served as controls.

REFERENCES

Adkins, H. G. (1970). The imported fire ant in the southern United States. Assoc. Am. Geogr., 60: 578-592.

Bruce, W. A. and G. L. LeCato. (1979). *Pyemotes tritici*: Potential biological control agent of stored-product insects. In Recent Advances in Acarol. (ed. Rodriguez, J. G.) 213-220. Academic Press, New York.

Buren, W. F., G. E. Allen and R. N. Williams. (1979). Approaches toward possible pest management of the imported fire ants. Bull. Entomol. Soc. Amer., 68: 418-421.

Harris, W. G. and E. C. Burns. (1972). Predation on the lone star tick by the imported fire ant. Environ. Entomol., 1: 362-365.

Lofgren, W. A., W. A. Banks and B. M. Glancey. (1975). Biology and control of imported fire ants. Annu Rev. Entomol., 20: 1-30.

Moser, J. C. (1975). Biosystematics of the straw itch mite with special reference to nomenclature and dermatology. Trans. R. ent. Soc. London., 127: 185-191.

Moser, J. C. and E. A. Cross. (1975). Phoretomorph: A new phoretic phase unique to the Pyemotidae (Acarina: Tarsonemoidea). Ann. Entomol. Soc. Am., 68: 820-822.

Sterling, W. L. (1978). Fortuitous biological suppression of the boll weevil by the red imported fire ant. Environ. Entomol., 1: 564-568.

Pyrethroid resistance persists in spider mite predator

Marjorie A. Hoy ☐ Nancy F. Knop ☐ John L. Joos

Spider mite predators laboratory-selected for pyrethroid resistance successfully overwintered in a northern California apple orchard.

The phytoseiid mite *Metaseiulus (= Typhlodromus) occidentalis* (Nesbitt), a predator of spider mites, has developed a low to moderate level of resistance to organophosphorus insecticides, such as azinphosmethyl, diazinon, and dimethoate, in the field. Since it can survive low rates of these insecticides applied to control insect pests, the predator is effective against spider mites in many of California's deciduous orchards and vineyards.

Other pesticides are sometimes necessary, because pest insects have developed resistance to many organophosphorus insecticides, and biological control agents are not always available. The pyrethroid insecticides are of potential value for IPM programs, because they have low mammalian toxicity, are very toxic to many insects, and are applied at very low rates. We report here the results of a laboratory project with *M. occidentalis* in which we selected a strain resistant to the pyrethroid permethrin and analyzed the genetic basis of the resistance so that field releases could be conducted most effectively. In addition, we report the successful establishment and overwintering of the permethrin-resistant strain in a Sebastopol apple orchard during 1979-80.

Initially, we tested about 40 populations of *M. occidentalis* from California orchards and vineyards to learn if resistance to permethrin was already present. We screened over 10,000 adult females, using several doses of permethrin during 1977 and 1978. No consistent increase in survival was evident in their progeny. We also screened predator populations from Washington and British Columbia apple orchards. Progeny of three of these populations survived increasing doses of permethrin, and this report concerns our work with one colony sent to us from Washington by S.C. Hoyt.

This colony responded gradually to laboratory selection during the two-year project, yielding a modest level of permethrin resistance (fig. 1). After 18 selections, a genetic analysis of the resistance (fig. 2) indicated that no single dominant or recessive gene was involved. We found no evidence of sex linkage or maternal effects in the F_1 progeny (progeny produced by crossing resistant and susceptible parents), and the F_2 progeny (those produced by intercrossing F_1 individuals) and backcross progeny (produced by crossing the F_1 females to susceptible males) were very susceptible to permethrin. This indicates that this permethrin resistance is inherited as a polygenic character; that is, it is the result of the cumulative action of multiple sets of independently transmitted genes, each of which produces only a small effect. The permethrin-resistant strain thus should be released into orchards or vineyards where native *M. occidentalis* are absent, or are not abundant because of previous permethrin treatments, so that resistance will not be lost through interbreeding with the susceptible natives.

Significantly, this laboratory-selected predator strain retained its original resistance to azinphosmethyl (table 1), even though it was not treated with the insecticide during two years of selection with permethrin. The strain also exhibits some cross-resistance to other pyrethroid insecticides, such as fenvalerate and an experimental pyrethroid (Shell 57706) (table 2), which may increase the predator's usefulness in IPM programs.

Field trials with a permethrin-resistant strain selected 18 times are under way during 1980-81 in California almond and apple orchards and in Washington apple and Oregon pear orchards.

A predator colony that had undergone only nine selections with permethrin was field tested during 1979-80 in a California apple orchard and an almond orchard. The predators failed to retain their permethrin resistance in the almond orchard, which had abundant susceptible *M. occidentalis* with which to interbreed. This failure supported our conclusion that permethrin resistance is polygenically inherited.

This predator strain did become established successfully in an apple orchard near Sebastopol where permethrin had been applied before predator releases. Four trees each had been treated on 14 May 1979 at rates of 0.05, 0.1, or 0.2 pound active ingredient permethrin per acre, which had reduced native *M. occidentalis* populations to nil. Predators were released on 11 June, and the first post-release sprays of 0.05, 0.1, or

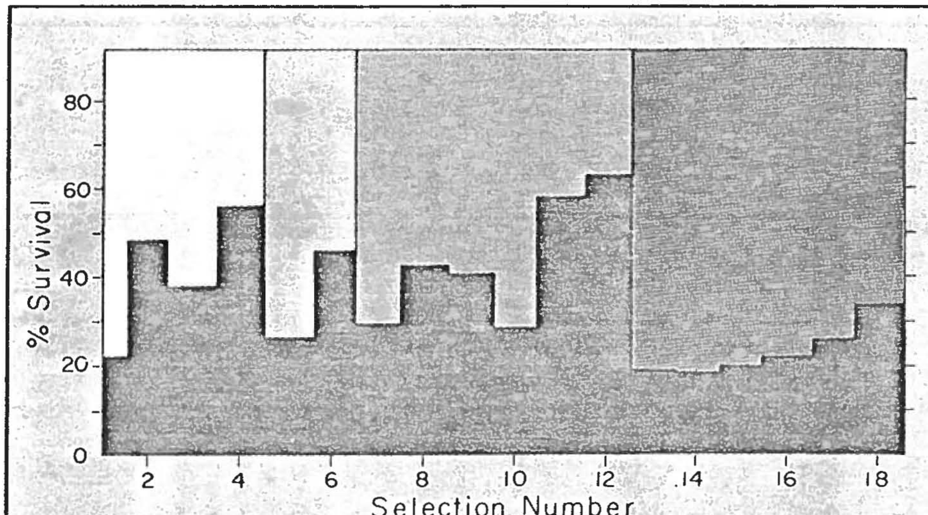


Fig. 1. *M. occidentalis* survival in 18 selections with increasingly higher permethrin rates: four at 0.008 lb active ingredient per 100 gal (unshaded section); two at 0.02 (lightest shading); six at 0.03 (medium); six at 0.07 (darkest).

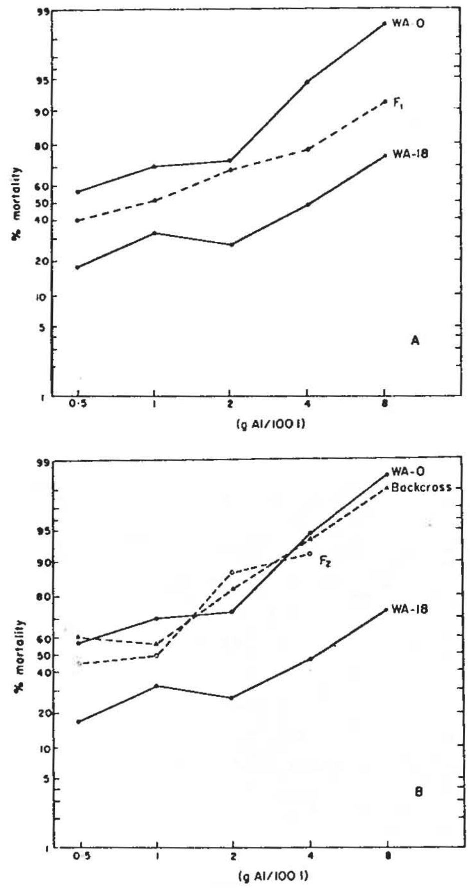


Fig. 2. Genetic analysis: (A) concentration response lines (logit-log scales) for permethrin-resistant (WA-18) and susceptible (WA-0) predators and their F_1 progeny; (B) F_2 and backcross progeny (to susceptible parent) are nearly as susceptible as susceptible colony.

0.2 pound active ingredient per acre were applied on 12 July to each of the four trees. Permethrin-resistant predators were released also into eight unsprayed (check) trees. Predator counts on leaves sampled periodically throughout the season indicated that the permethrin-resistant predators had become established in the twelve sprayed trees and survived the three different rates of permethrin treatment.

Samples of *M. occidentalis* were taken on 25 September 1979 from each of the three permethrin treatments and colonized to determine if they had retained their resistance over the summer. In addition, two colonies of native *M. occidentalis* were initiated from nonrelease trees never treated with permethrin from a different area in the same orchard. Adult females from these five colonies were assayed using 0.02 pound active ingredient per 100 gallons water on bean leaf discs. The native *M. occidentalis* collected from unsprayed trees had survival rates of 25 and 33 percent after 48 hours on treated discs, whereas the three colonies collected from sprayed release trees had survival rates of 79, 82, and 81 percent. This indicated that the resistant strain released in June 1979 had become established in the orchard and survived the three rates of permethrin applied on 12 July.

The trees were sampled again in July 1980 to determine if the permethrin-resistant strain had overwintered. Three colonies of predators were collected from sprayed release trees, and their resistance compared with that of predators collected from the unsprayed release (check) trees and three laboratory colonies (table 3). Predators from unsprayed release trees were susceptible to permethrin; those from the sprayed release trees were resistant. The loss of resistance in the unsprayed release trees probably was due to interbreeding with the susceptible native *M. occidentalis*, as had occurred in the almond orchard. The resistant laboratory colony (WA-18) selected 18 times had a survival rate similar to that of the orchard-collected colonies (table 3), indicating that permethrin resistance was retained in the orchard populations for over 11 months after treatment in July 1979. The moderate level of permethrin resistance developed in this strain of *M. occidentalis* (LC_{50} = 0.03 pound active ingredient per 100 gallons water; field rates = 0.05 to 0.2 pound active ingredient per 100 gallons water) means that only low rates of permethrin (or other pyrethroids) will allow this predator strain to persist in orchards or vineyards. However, the use of low application rates of azinphosmethyl to preserve *M. occidentalis* was also necessary in the pear pest management program, thus setting a precedent.

The recent success in selecting this predator for resistance to carbaryl (January 1980, *California Agriculture*) makes it likely that a strain of *M. occidentalis* can be developed that can tolerate organophosphorus, carbamate, and pyrethroid insecticides.

Marjorie A. Hoy is Associate Professor of Entomology and Associate Entomologist, University of California, Berkeley; Nancy F. Knop is a graduate student in the Department of Entomology, Berkeley; and John L. Joos is Area Research Farm Advisor for Sonoma, Lake, Marin, Mendocino, and Napa counties.

We thank FMC, ICI Americas, and Shell Development for, respectively, the permethrin, fenvalerate, and SD-57706 materials used. This project was supported in part by Pear Zone I, the Almond Board of California, the California Raisin Advisory Board, the California Table Grape Commission, and Experiment Station Project No. 3522-H. We thank S. C. Hoyt and R. Downing for providing colonies of M. occidentalis, *D. Culver for use of an almond orchard, and Haven Best for use of his Sebastopol apple orchard. K. Smith, M. Mochizucki, and D. Castro provided technical assistance.*

TABLE 1. Comparison of Azinphosmethyl Resistanc in Three Colonies of *M. occidentalis*

Colony	Mortality on leaf discs sprayed wit Water	0.5 lb azinphos-methyl ai/100 gal	1.0 lb azinpho methy ai/100 g
	%	%	%
Berkeley blackberry†	5.1	45.2	48.2
WA-O‡	10.5	4.1	2.0
WA-18§	0	5.5	0

*Forty to 60 adult females on bean leaf discs treated at each dose (ai = active ingredient).
†Susceptible to azinphosmethyl and permethrin.
‡Originally azinphosmethyl-resistant; never selected for permethri resistance.
§Originally azinphosmethyl-resistant; selected for permethrin resistance.

TABLE 2. Cross-resistance to Other Synthetic Pyrethroids in Permethrin-selected *M. occidentalis* Strain

Colony and date tested	Materials and rates	Survival of female
	lb ai/100 gal	%
Permethrin-selected WA-9 (1979)	fenvalerate, 0.008	18.8
	fenvalerate, 0.033	3.8
	permethrin, 0.008	67.5
	permethrin, 0.033	43.3
	water	93.3
Unselected California pear (1979)	fenvalerate, 0.008	0
	fenvalerate, 0.033	0
	permethrin, 0.008	15
	permethrin, 0.033	7.5
	water	97.5
Unselected WA-O (1980)	fenvalerate, 0.008	3
	fenvalerate, 0.017	0
	Shell-57706, 0.004	0
	Shell-57706, 0.008	3
	Shell-57706, 0.017	0
	water	88
Permethrin-selected WA-18 (1980)	fenvalerate, 0.008	25
	fenvalerate, 0.017	17
	fenvalerate, 0.033	5
	fenvalerate, 0.067	0
	water	100
	Shell-57706, 0.004	3
	Shell-57706, 0.008	35
	Shell-57706, 0.017	7
	water	100

*Forty to 60 adult females tested at each insecticide dose.

TABLE 3. Permethrin Resistance Retained in Overwintered *M. occidentalis* Collected from Sebastopol Apple Orchard Compared wi Resistance Levels of Three Laboratory Coloni

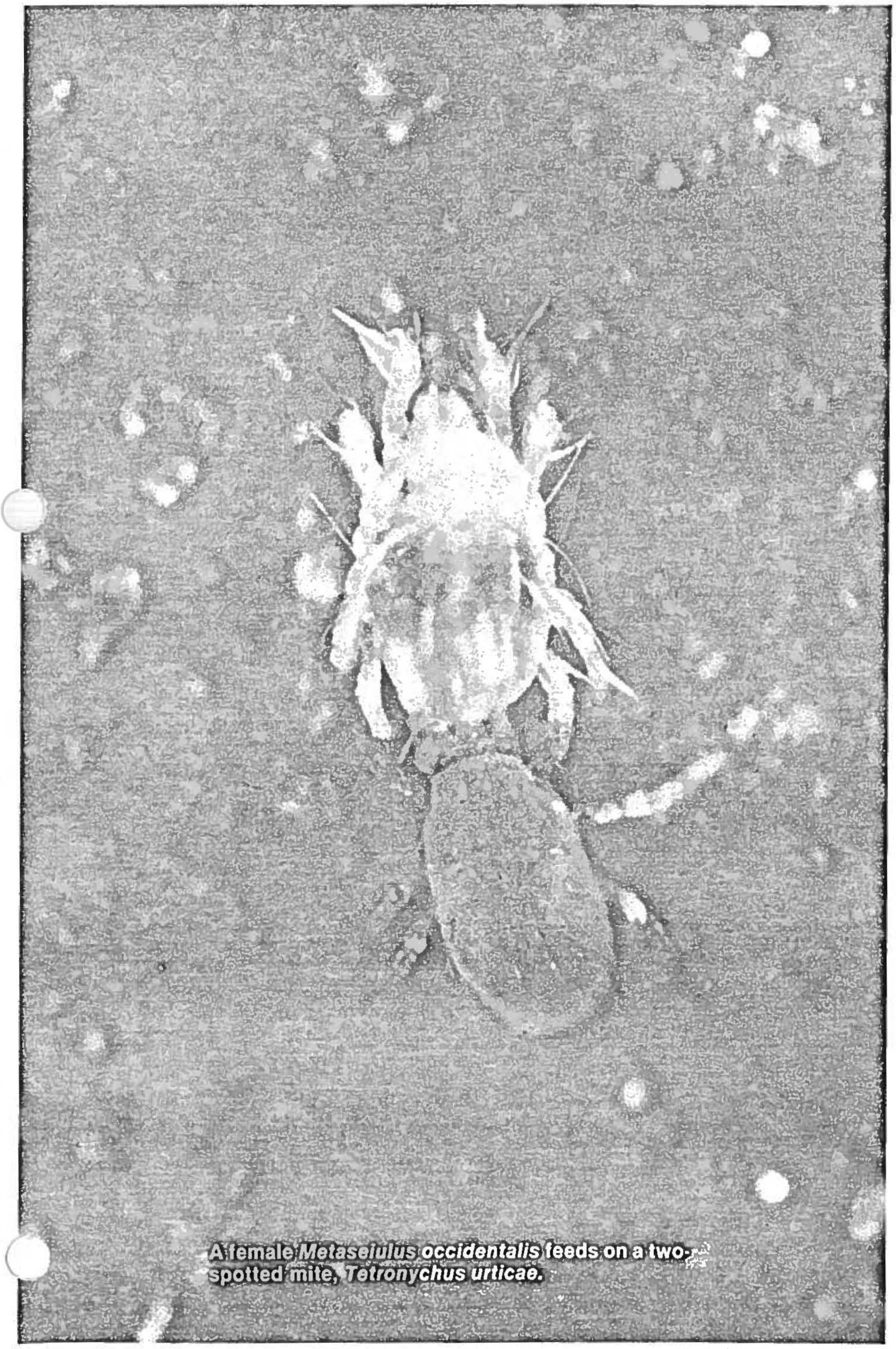
Colony and history	Sur
Colonies collected in July 1980 from 1979 release trees	
Unsprayed release trees	
Permethrin treated @ 0.05 lb ai/acre	
Permethrin treated @ 0.1 lb ai/acre	
Permethrin treated @ 0.2 lb ai/acre	
Laboratory colonies tested for comparison	
Unselected original colony	
Permethrin-resistant colony (WA-18)	
Permethrin-resistant colony selected 27 times	

*Sixty to 240 adult females of each colony tested on 2 or 3 day bean leaf discs sprayed with 0.02 lb permethrin ai/100 gal

Selection improves Sevin resistance in spider mite predator

Field trials have documented the genetic improvement of an important biological control agent in almond orchards

Richard T. Roush ☐ Marjorie A. Hoy



A female *Metaseiulus occidentalis* feeds on a two-spotted mite, *Tetronychus urticae*.

—*Photo by Jack Kelly Clark*

Spider mites cost California growers an estimated $60 million in crop losses and pest control expenditures in 1977. Their ability to tolerate or resist pesticides which destroy their predators accounts for 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), important in apple and pear pest management in Washington and California.

Unfortunately, *M. occidentalis* has not developed resistance to all pesticides used in those crops where it 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 (*Amyelois (= Paramyelois) transitella* (Walker)) control in almonds.

Genetic selection program

A genetic selection program to develop a carbaryl-resistant strain of *M. occidentalis* began in December 1977. The first step involved mass hybridization of *M. occidentalis* colonies collected from 18 locations in California and Washington to provide adequate genetic variability. None of these colonies was 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 to 1000 predators were treated in each round of selection to give about 70 to 90 percent mortality.

A "leaf flood" method was adopted to quantify *M. occidentalis'* responses to carbaryl: bean leaf discs were placed on moist cotton and flooded with a "challenge" dose of 2 pounds (active ingredient) carbaryl (80 percent wettable powder) per 100 gallons of water. Gravid adult female predators were then floated in the pesticide which was allowed to dry. *Tetranychus urticae* Koch, the two-spotted spider mite, was added to the leaflets after the carbaryl dried as prey, and the leaf discs were held at 28° C for 48 hours when the number of survivors was recorded. Ten females were 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 to 19 rounds of selection, about 83 percent of the selected strains survived compared with about 2 percent 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) survived the "challenge" dose nearly as well (72 percent) as their resistant parents.

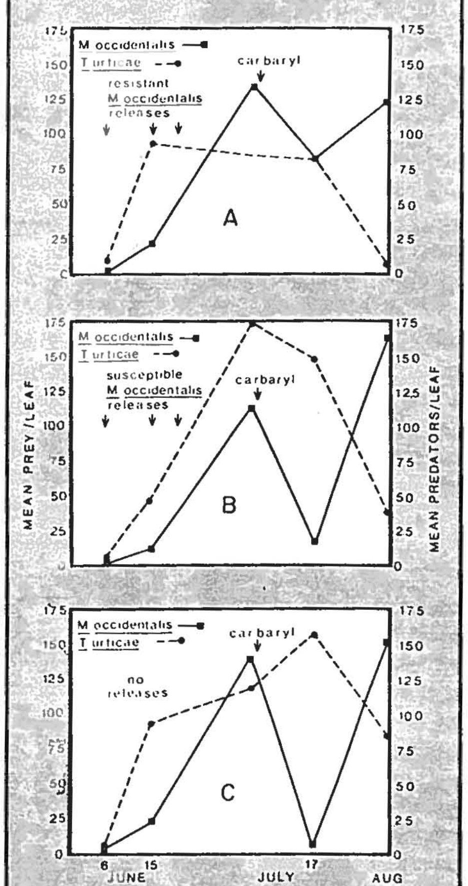


Fig. 1. Visalia Almond Orchard, 1979: (A) trees where resistant predators were released (RR); (B) rees where susceptible predators were released (SR); (C) trees where no releases were made (NR).

Laboratory and greenhouse tests examined 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 their resistance to azinphosmethyl increased, although the predators were never exposed to this insecticide during the selection program. 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 percent survival at the 2-pound challenge dose) for 8 months (about 16 to 24 generations) when maintained on pinto bean plants in the greenhouse which were not treated with carbaryl.

Field releases

Laboratory and greenhouse assessments of this genetically-selected strain indicated that it should perform well in the field. 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: (1) to determine whether the predators could survive the carbaryl applications; (2) to determine whether the surviving predators could control spider mite populations in these almond trees and (3) to determine whether the resistance characteristic could persist for more than one season.

The almond orchards used were a research orchard near Visalia and a commercial orchard near Blackwell's Corner, Kern County. The Visalia orchard is closely planted with less than one foot between the foliage of trees. The trees had also been radically pruned and therefore produced leaves about four times larger than those at the Blackwell's Corner orchard. Seven trees in each orchard were randomly assigned to each 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

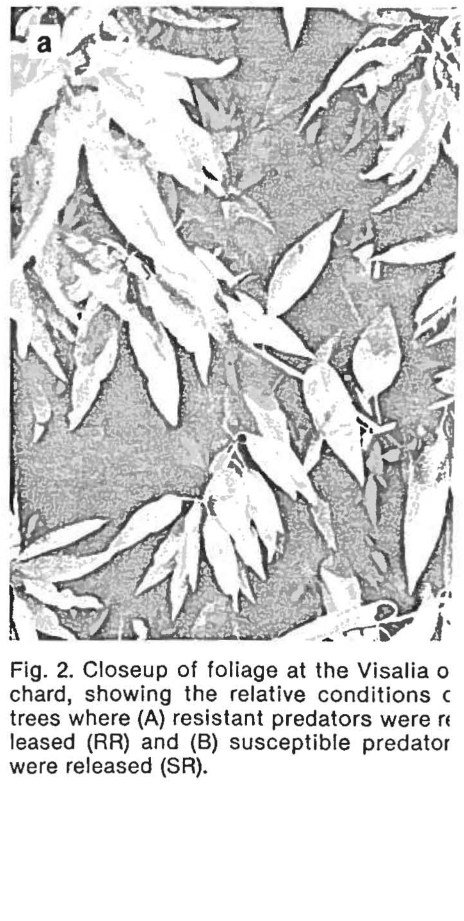


Fig. 2. Closeup of foliage at the Visalia o chard, showing the relative conditions c trees where (A) resistant predators were re leased (RR) and (B) susceptible predator were released (SR).

check trees were within three rows of both test plots.

Azinphosmethyl (4 lbs 50% WP/acre) was applied with a speed sprayer on May 7 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. On July 6 carbaryl 80 WP was applied at the rate of 10 lb/acre as a dilute spray (Ca 400 gal/acre), using a handgun. One thousand predators were released per tree on June 14 in the Blackwell's Corner orchard. On July 13 carbaryl 80 WP was applied at the rate of 7 lb/acre as a concentrate spray (approximately 35 gal/acre) by helicopter. 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 because of 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), figure 1A, but this decrease was not statistically significant and is probably because of 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, figures 1B, C).

Although there were no significant differences in *M. occidentalis* or spider mite populations in the Visalia orchard before the carbaryl application, there were more predators ($P < .001$) and fewer spider mites ($P < .01$, Mann-Whitney U test) in the RR trees (figure 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, figures 1B, C), there were no great increases in spider mite populations as are often observed after a carbaryl application. This is probably because of 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 (figure 2A) than in the other trees (figure 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 (figure 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 (figure 3A), but the trees with the susceptible predators (SR and NR) suffered a Pacific spider mite population increase (figures 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 because of 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 percent) than are those collected from the SR and NR trees (34 percent, P<.001). But even the predators from the NR and SR trees are more resistant than the native (pre-release) population (2 percent, 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 percent survival) than are those collected from the SR and NR trees (7 percent, 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 (figure 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 percent which was significantly greater (P = .05) than that of the colony founded by the predator from the NR tree. Unfortunately, the colonies tested are from smal samples and the data are suggestive rathe than conclusive.

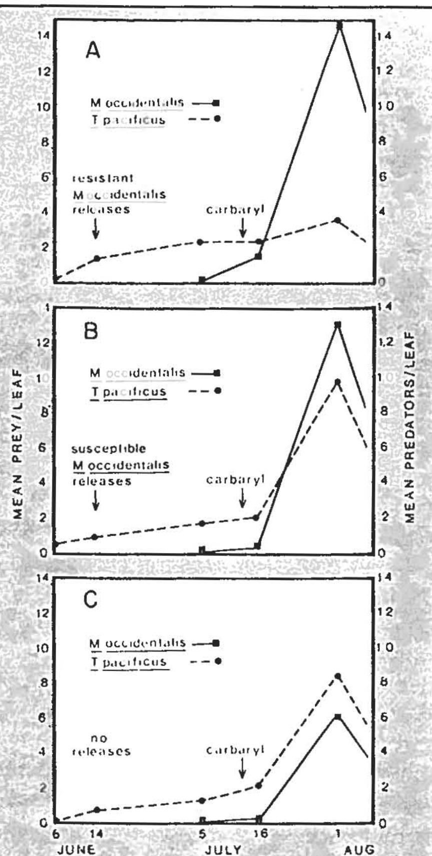


Fig. 3. Blackwell's Corner Orchard. A, B, and C are the same as in Figure 1.

Full acceptance of the value of these re sistant predators for pest management wil require larger field plots and longer trials We expect that resistance levels will in crease as additional carbaryl application cull the susceptible predators in the or chards. Tests of predator efficacy will re quire study sites where high rates of acari cides are not routinely used. Althoug acaricides such as propargite (Omite) an cyhexatin (Plictran) kill few *M. occiden talis* directly, some spider mites must sur vive the acaricide application or all th predators will starve in about 10 days. I that happens, wind-blown spider mites ca return to the orchard and rapidly build u in the absence of predators.

Entomologists have noted the successe of plant and animal breeders and have dis cussed selective breeding of improve strains of natural enemies for more than 6 years. Honeybees, silkworms, and othe domesticated or semi-domesticated insec have been "improved" by selection, but n one has documented genetic improvemen of a biological control agent's field effe tiveness until now. We believe that this the first successful field demonstration c its kind. We also believe that genet improvement projects will eventually b successful for other species of biologic control agents and can involve attribut other than pesticide resistance.

TABLE 1. Survivorship of Gravid Females from *M. occidentalis* Colonies Treated with a Carbaryl Challenge Dose (2 lb AI/100 gal).

	Survival* (percent)
Visalia orchard	
Colony collected before predators were released	2 c
Colony collected August 1 from trees where *resistant* predators were released (RR)	71 a
Combined colony collected August 1 from trees where *susceptible* predators were released and where no predators were released (SR and NR)	34 b
Blackwell's Corner orchard	
Colony collected before predators were released	7 bb
Colony collected August 1 from trees where *resistant* predators were released (RR)	63 aa
Combined colony collected August 1 from trees where *susceptible* predators were released and where no predators were released (SR and NR)	7 bb
Laboratory strains	
Resistant strain	83
Susceptible strain	2
F1 progeny	72
F2 progeny	51

*The survivorship 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.

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