

Project Report 82-C5

Correct Project Number: 82-C6

Control of Mites on Almonds

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I. INTERPRETIVE SUMMARY

Pesticide-resistant Metaseiulus occidentalis were mass reared during 1982 using a greenhouse technique and a soybean field plot system. Efficiency of the greenhouse method was improved and a sustainable yield throughout the field season is possible. The soybean field plot, located at the Kearney Horticultural Field Station near Parlier, produced predators by mid-August, although not at the same rate as in the 1981 plot due to contamination by the six-spotted thrips which caused substantial losses of spider mites. Predator releases in mid to late August allow little time for predator multiplication and spread and so improved field rearing to obtain predators in late June or early July should be evaluated in 1983.

Sevin-OP resistant predators released into orchards in 1981 were monitored during 1982. They successfully overwintered and survived early season applications of Sevin. Spider mite control was better in these orchards during 1982 than in 1981, even though a May spray of Sevin was applied. The use of low rates of Omite and Plictran was again a useful mite management tool. It reduced spider mite populations without killing all spider mites, thereby providing food for the predators. Since this predator requires mites to maintain itself in the orchard, low levels of prey should be kept. The predators have spread from release trees to adjacent nonrelease trees and resistance levels of predators recovered from the release sites indicate that the predators have established well.

During 1982, predators were released into additional orchards after Sevin applications were made. Establishment and substantial control of spider mites occurred in the site where predators were released in June.

The pesticide-resistant strains of M. occidentalis are maintained through periodic selection with pesticides. Keeping the strains pure requires regular effort.

Aerial dispersal of both spider mites and predators was documented in two almond blocks. Spider mites dispersed in large numbers all season, while predators did not disperse until late July or early August. The dispersal of massive numbers of spider mites through the air indicates that movements within and without almond orchards are extensive. The resistant predators are moving from tree to tree through the air, and explain the rapid spread of the resistant predators. We hope to discover next season how far these resistant predators can disperse away from the orchard.

A cooperative project with Frank Zalom and Bill Barnett to develop simple sampling methods for spider mites and predators continues.

Large scale implementation of these pesticide-resistant predators may be possible in the 1984 field season, if: a) orchards can be sprayed only with nondisruptive pesticides such as Guthion, diazinon, Imidan, or Sevin. The permethrin (Ambush/Pounce) resistant predator is not particularly useful as the permethrin resistance level is only moderate, and the resistance is polygenically determined. Thus, permethrin applications would be disruptive to the predators' control of spider mites. b) Low rates of selective acaricides (such as Omite/Plictran) can be used to manage spider mite densities; high rates give too much control and the predators may starve. c) The orchards can be monitored so that ratios and distribution patterns of spider mites and predators are known to be adequate. Such monitoring is

time consuming and requires knowledge of spider mite-predator population dynamics that takes some experience to acquire. I.e., it is simpler to apply acaricides than it is to go through the one or two year transition period when the predators are establishing in the orchard. d) We have too little experience yet to know whether the predator-spider mite system settles down and acaricide usage is no longer required. Our field experiences with commercial almond orchards are only for two seasons; we hope that the 1983 field season will answer that question.

The benefits of applying this system are that acaricide costs should be reduced; predators should be permanently established; and resistance to acaricides in spider mites should be delayed or prevented. The availability of trained personnel to rear, release, monitor, and evaluate predator releases in almond orchards will be an important factor in implementation.

A Sevin-OP resistant predator (Typhlodromus pyri) was imported from New Zealand and is being reared in the laboratory. It is particularly effective as a predator of European red mite, and releases into almond orchards where that spider mite predominates are planned for 1983.

II. Introduction

The Project objectives for 1982-83 were: 1) release a new strain of M. occidentalis that is Sevin-permethrin-OP resistant into almond orchards to determine if it establishes, survives sprays, overwinters and disperses. 2). Monitor efficacy of Sevin-OP and permethrin-OP strains released in 1981; evaluated control of spider mites and dispersal of predators. 3). Continue to evaluate low rates of Omite and Plictran to control spider mites. 4). Mass rear M. occidentalis. 5). Import a carbaryl-OP resistant strain of Typhlodromus pyri colonies for release into orchards where European red mite dominates. This predator is known to be effective against the European red mite whereas M. occidentalis is not a very good European red mite predator.

This report includes data in manuscript or galley form that has been, or is being, published.

Mass-rearing Pesticide Resistant Predators

During 1981, about 62 million carbaryl-OP resistant M. occidentalis were reared in a 0.5 acre soybean plot at Westside Field Station near Five Points. This rearing was repeated during 1982 at the Kearney Field Station near Parlier to provide additional predators for field releases, to allow several Farm Advisors the opportunity to observe the rearing method, and to document that such rearing could be repeated.

The plot consisted of 60 225-foot rows, spaced 32 inches apart. The soil was prepared on April 27, and 3 pints of Lasso herbicide and 640 lbs of 12-12-12 fertilizer were incorporated into the soil. Soybean seed (cv. Williams) was planted on May 12 at about 5 seeds/foot. Irrigation was provided on May 6, June 4, June 18 and July 21.

On June 9 the plants were 3-4 inches high and 15 flats of pinto beans infested with two spotted spider mites from the U.C. Berkeley greenhouse were cut and placed on the small plants. (The plants contained an estimated 750,000 to 1,500,000 active stages of spider mites.) On July 1, approximately 185,000 adult female predators (plus an unknown number of males and immatures) were distributed throughout the plot by placing cut pinto bean plants on the soybeans. These predators are resistant to carbaryl-OP-sulfur pesticides. The soybean plants were about 12 inches tall with 4-6 trifoliolate leaves on that date. To reduce contamination by foreign predators and to keep resistance levels high, carbaryl (Sevin) was applied on June 28 and July 30 (1 lb. a.i./acre). Diazinon (1 lb a.i./acre) was applied on August 18, as well.

Leaf samples were taken periodically by Bill Barnett to monitor predator population growth (Table 1). In addition, a sample was taken on August 25 to estimate the total production in the plot. On that date there were an average of 3.53 plants/row foot with an average of 68.5 leaflets/plant. Counts of predators gave the following estimates/leaflet: eggs (1.6), males and immatures (1.7) and adult females (5.2). Because there were 225 row feet X 60 rows X 3.53/foot there were an estimated 47,655 plants in the plot. Each plant had an average of 109.6 predator eggs, 116.5 immatures/males, and 356.3 adult females: this would suggest that there were ca. 17 million adult females; 5,600,000 immatures or males, and 5,200,000 predator eggs. This represents a 90-fold increase in the 7-week interval since infestation.

The predator production during 1982 was lower than it was during 1981. The reasons for this are several: the plot was heavily infested with the six spotted thrips, and on August 25 it is likely that there were about 10,000,000 thrips present in the plot. Such abundant thrips populations exerted substantial predation upon the spider mites and M. occidentalis was not able to multiply at an optimal rate due to this low prey population. The failure to control the thrips with diazinon and carbaryl is disappointing and may have been due to the difficulty to obtain good coverage of the plants with the spray equipment rather than to resistance/tolerance to these two materials by the thrips. Due to the rapid growth of the plants, a large proportion of the foliage was unprotected by insecticides in the intervals between sprays, as well.

Other factors contributing to the relatively lower production are: the weather was relatively cool early in the season and because of late rains inoculation with the predators was delayed until early July. In addition, the seeding rate was low and there were only 3.53 plants/row foot rather than 8.9 as there was in 1981 at Westside Field Station plot. Thus, the number of predators produced per row foot was lower in 1982. However, the 1982 results do confirm that large numbers of pesticide resistant predators can be reared in soybean plots although we believe that there are several improvements that could/should be made in the rearing scheme.

It is desirable to harvest the predators in early July to mid August so that the predators have time to multiply and distribute themselves in the orchards where they are released. To achieve that early harvest date (ideally beginning in early July), soybeans should be planted earlier, infested with spider mites and predators earlier, and kept protected from such predators as six-spotted thrips.

Earlier planting is dependent upon the ability of farm machinery to enter the plot to work the soil. Also the seeds must germinate and grow early in the season, spider mites must grow and reproduce well (they prefer hot, dry weather), and more frequent use of selective insecticides to control predaceous thrips must be made. Accordingly, different soybean varieties should be evaluated during 1983 so that the effect of different genetic backgrounds can be evaluated for growth early in the season, as well as ability of spider mites to reproduce on them.

Plastic tunnel type greenhouses are being used to achieve rapid early

season growth of vegetable crops; the possibility exists that soybean varieties could be grown under them very early in the season which might allow substantially earlier production of predators, perhaps as early as late June. During 1983, we would like to test 6-8 varieties of soybeans with early, mid, and late harvest dates at the Oxford Tract in Berkeley. The climate there is temperate and if the soybeans and spider mites can be grown effectively under these conditions using plastic tunnel greenhouses, then they should be grown successfully anywhere.

Table 1. Leaflet Samples from Kearney Soybean Plot, 1982 - B. Barnett.

Sample date	Mean mites/leaflet ^{*/}		
	Spider mites	<u>M. occidentalis</u>	
		actives	eggs
July 1	6.0	0.01	
13	39.7	0.01	
22	61.0	0.06	
30	314.0	0.36	
Aug. 6	422.2	2.28	0.6
16 ^{**/}	439.9	9.36	4.8

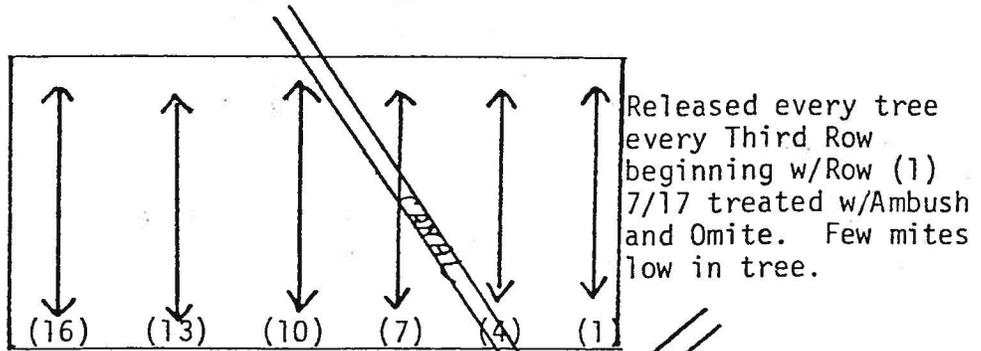
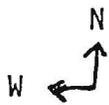
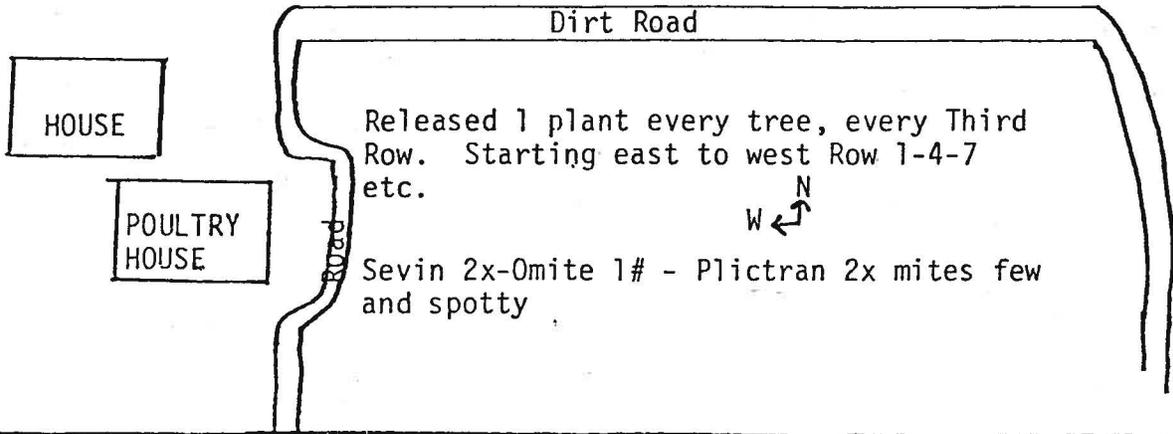
*/ 100 leaflets were sampled, brushed, and counted.

**/ On August 16 there were an average of 5.5 six-spotted thrips larvae/leaflet.

MITE RELEASES

August 18, 1982 - One soybean plant/tree
average 12/leaves per plant (36 leaflets)
9.3 adults *M. occidentalis* + 4.8 *M. occidentalis*
eggs per leaflet

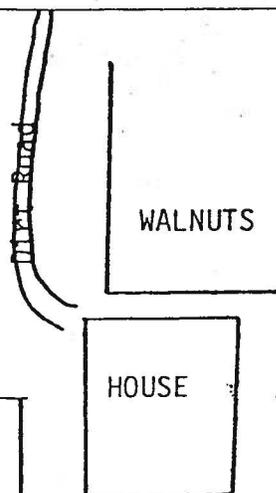
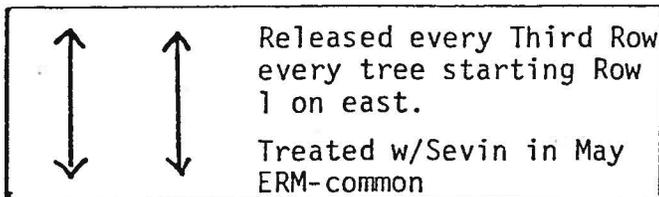
C.V. HORTON



Magnolia Avenue

Peach Avenue

FRANK DUR JARA - GROWER



PASTURE

The predators reared at the Kearney Field Station were released in the following almond orchards:

Livingston, Horton IV - area near house - by B. Barnett in every 3rd tree every 3rd row, August 18. (see map).

Livingston, Magnolia Avenue block, Mr. Horton, ca. 20 acres previously treated with permethrin, every 3rd tree every 3rd row by Bill Barnett, August 18. (see map).

Livingston, Peach Avenue, Mr. Dur Jara, ca. 20 acres, every 3rd tree every 3rd row by Bill Barnett, August 18. (see map).

Butte County - predators delivered by Rich Coviello to release into 20 acres of almonds.

Kern County - Walt Beltley collected for releases into every tree every third row in 120 acres.

Other Releases: San Luis Obispo - 320 acres of almonds, by grower, pattern unknown at this time.

GREENHOUSE PRODUCTION

The greenhouse rearing system was refined and efficiency was increased during 1982. Using 40% less space, 50% more pesticide predators were produced in 1982 than in 1981 during a similar period (March 3 - July 1) (Table 3). Labor inputs were reduced by an estimated 25% because watering was done with an automatic system. Because rearing was relatively trouble free, sampling frequency was cut from 4 times a month to 3, or even 2, times a month (cf. Tables 2 and 3).

During 1982, ca. 588,000 carbaryl-OP-sulfur resistant predator females were produced by July 1 on 112 square feet of greenhouse bench space (5,150 females/sq. ft.) (Table 3). During 1981, 383,700 sulfur-OP predator females were produced during the same interval on 190 square feet of bench space (2,014 females/sq. ft.) (Table 2); thus we produced 2.6 times as many females/sq. ft. in 1982 as in 1981. During 1981, we required 3 greenhouse benches (1-19 X 4' and 2-19 X 3' in size) plus about 1/4 of a bench for spider mites to add to the system as prey. During 1982, we produced the carbaryl-OP-sulfur resistant predators in 2-14 X 4' benches and required another bench for spider mites to add to the predator flats.

The enhanced efficiency was due primarily to keeping denser predator populations on the pinto bean plants (Table 3); this meant that spider mite populations rarely were so dense that the plants were in danger of severe foliage damage and thus the selective acaricide Omite was applied less often (cf. Table 2 & 3). The average ratio of spider mites:predators during the March 4 to May 1, 1981 interval was 330 spider mites: 1 predator on the pinto bean leaflets. During the same period in 1982 the average ratio was 14:1 and no acaricides were applied in 1982 in contrast to 4 applications in 1981.

Because spider mite densities were lower, unlimited food for predators was not always present so it was necessary to add spider mites to the system. During the March 4 to May 1 interval in 1981 spider mites were added only once; during the same interval in 1982 spider mites were added four times (Table 3). This meant that pinto bean flats with spider mites had to be available throughout the period and such rearing was done in another greenhouse section to prevent contamination with predators.

The greenhouse system is efficient and capable of producing large numbers of predators every week throughout the field season. If several hundreds of acres are to be inoculated at any one time, the greenhouse system is adequate for this purpose, and the predator yield can be sustained.

Table 2.

1981 Predator Production

Two methods for large scale production of pesticide-resistant strains of *M. occidentalis*

Table 2. Actual production schedule of the sulfur-OP-resistant *M. occidentalis* strain in the University of California, Berkeley greenhouse - 1981

No. flats on each bench	Date infested	Prey: predator ratio (all stages) on each sample date ¹				Date flats harvested	Mean <i>M.o.</i> ♀♀/flat	Total no. <i>M.o.</i> ♀♀ kept for infesting	Total no. <i>M.o.</i> ♀♀ send to field
		1	2	3	4				
4	stock	-	-	-	25	Mar. 4	840	3,360	0
12	Mar. 4	(S)10(Tu)	(S)17	358(P)	189	Apr. 1	440	5,280	0
39	Apr. 1	(S)316(P)	790(P)	297(P)	(S)32	May 18	4,160	128,960	0
13	May 18	(S) -	(S)24(D)	23	12	June 10	4,740	23,700	37,920
24	May 18	(S) -	(S)64(D)	13	17	June 10	5,870	0	70,440
						June 16	4,300	51,600	0
13	May 18	(S) -	(S)35(D)	14	21	June 16	17,200	223,600	0
17	June 10, 16	(S,D,Tu)3	20(S,D)	0.6	-	July 2	2,900	20,300	29,000
24	June 10, 16	(S,D)98	13(S,D)	1.5	-	June 30	5,200	0	83,200
						July 2	- ?	41,600	0
7	June 10, 16	(Tu,S,D) 3	21(S,D)	0.5	-	June 30	2,900	0	11,600
						July 2	0	0	8,700
24	July 2	(Tu,S) 31	4(Tu)	25	12	July 14	3,800	22,800	0
						July 20	- ?	0	68,400
24	July 14	(Tu,S,D)59	2	-	-	Aug. 4	3,800	30,400	0
						Aug. 10	8,000	0	128,000
24	Aug. 4	(S,Tu)12	(S,Tu)2	4	-	Aug. 24	2,600	15,600	46,800

¹ (Tu) indicates addition of *T. urticae* to system either before or after leaf sampling depending upon the placement of the letters. (P), (D) and (S) indicate propargite, diazinon or sulfur, respectively, were sprayed on the flats before or after the leaf sample to reduce mite densities (P), remove contaminating phytoseiids such as *A. californicus* (D), or maintain the pure sulfur-OP resistant strains (S). Samples were taken approximately 1 week apart once the bean plants were infested with *T. urticae* and *M. occidentalis*.

from: Hoy et al. 1982.
Zeitsch. Angew. Entomol.

Table 3. 1982 Production of Carbaryl-OP-Sulfur Resistant M. occidentalis in the U.C. Berkeley Greenhouse.

No.flats/ bench	Date in- festad	Prey:pred.ratio (all stages) on each sampling date				Date of harvest	Mean MO/ flat ††	Total †† sent	
		1	2	3	4			kept	to field
2	stock	-	-	-	6	2/16	6150	12300	
4	2/16	Tu(C)-	14	Tu - (S)27		3/18	3500	14000	
8	3/18	Tu(C)- (S) 4	Tu8.8	Tu -		4/16	6900	55700	
26	4/16	Tu(C)-	23	(C)8	Tu 6	5/10	13800	358000	
50	5/10	Tu(S)-	10	Tu -	2	5/28	7300	64500	300000
24	6/4	Tu(C)-	28	(S)18	Tu10	7/1	12000	60000	192000
									36000
5	-								

Tu indicates addition of T. urticae to system either before or after leaf sampling depending upon the placement of the letters. (S) (C) indicates carbaryl or sulfur was sprayed on the flats.

IV. Releases and Evaluations of Pesticide Resistant Predators

During 1981, carbaryl-OP and permethrin-OP resistant M. occidentalis were released into 9 San Joaquin Valley almond orchards (Table 1 and Fig. 1). These releases were made for establishment purposes and spider mite control was not expected during the first season. Despite this, good first season spider mite suppression was achieved in several orchards where releases were made early in the season so that the predators had time to multiply and spread from the release trees throughout the orchard.

During 1982, we monitored spider mites and predators in as many as possible of those release sites and made additional releases of a new strain resistant to carbaryl-OP-sulfur pesticides. (See Section III for list of release sites.)

The permethrin-OP-carbaryl resistant strain was reared in the Berkeley greenhouse and was available for release into almond orchards during 1982. However, we did not find appropriate cooperators who wished to apply permethrin and no releases with this strain into almonds were made. Releases into pear and apple orchards were made during 1982 so the strain is being evaluated in the field. The carbaryl-OP-sulfur and carbaryl-OP resistant strains are clearly superior to the permethrin-OP-carbaryl strain because these resistances are determined by dominant genes and they are therefore easier to work with. It is difficult to recommend use of the permethrin resistant strain in almonds when both OPs and carbaryl are nearly as effective navel orangeworm control materials and are less disruptive to biological control than is permethrin. (Native M. occidentalis are susceptible to carbaryl.)

Table 1. Resistant *Metaseiulus occidentalis* releases in almonds during 1981

Orchard location	Acreage	Strain released	Release date	Release pattern	No. females released/tree*	Total females released	No. bands†
N. Palm & North Ave. Turlock—I	3	Carbaryl-OP	July 31	2nd tree 3rd row	500	50,000	40
N. Palm & North Ave. Turlock—II	6	Permethrin-OP	July 31	3rd tree 3rd row	1,000	34,300	80
Washington & Westside Rd. Livingston—I	14	Carbaryl-OP	June 9	3rd tree 3rd row	350	61,600	100
Washington & Westside Rd. Livingston—II	10	Carbaryl-OP	Aug. 15	3rd tree 3rd row	350	60,000	40
Ave. 18 & Rd. 20 Madera	6	Carbaryl-OP	July 21	every tree	300	180,000	74
Hwy. 33 & Mountain View Three Rocks	80	Carbaryl-OP	July 10	3rd tree 3rd row	350	555,400	240
Merced & Palm Ave. Wasco	20	Permethrin-OP	Sept. 15	3rd tree edges only	200	8,600	30
Hwy. 46 & Palm Ave. Wasco	15	Carbaryl-OP	May 28	5th tree 5th row	2,900	175,000	40
Hwy. 46 & 43, Block 32-4 Blackwell Corners	60	Permethrin-OP	Aug. 5	3rd tree 3rd row	350	165,000	100

*Based on prerelease counts of bean plants.

†Trees were banded on Sept. 15, 16, or 17 to monitor overwintering success and resistance levels of *M. occidentalis*.

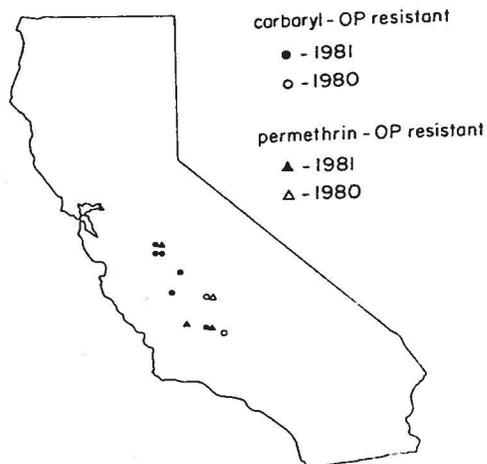


Fig. 1. Dispersal of two resistant *M. occidentalis* strains from almond orchards where releases were made in 1980 and 1981.

LIVINGSTON - I

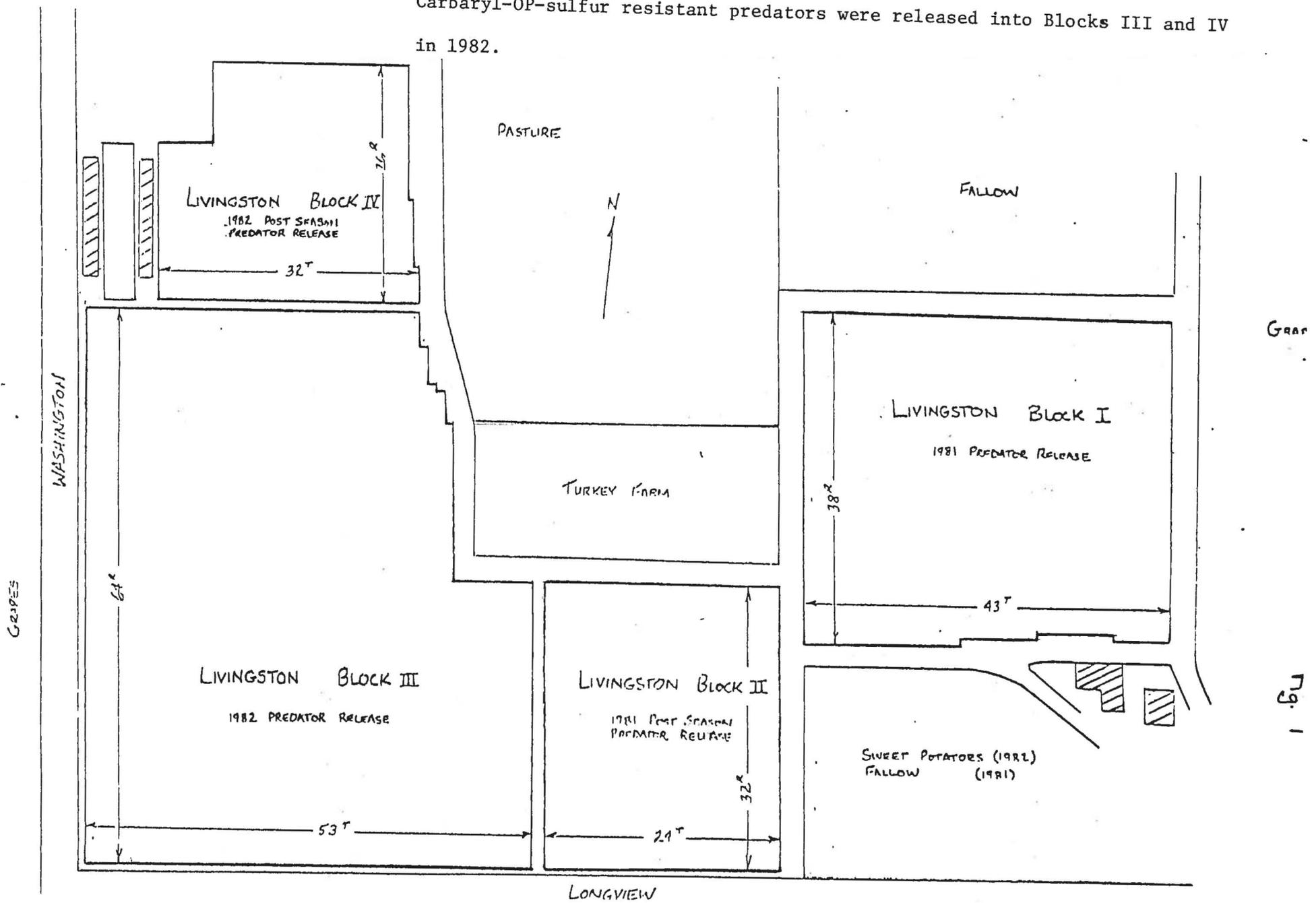
This 14 acre block is comprised of Mono, Yosemite, and Mission varieties. Trees are spaced 15 X 25 ft. apart. Orchard dimensions are 38 rows and 43 trees/row. Ca. 350 predator females were released on June 9, 1981 into every third tree in every third row. A total of 61,600 females were released. The predators established in the trees and spread from the release to adjacent nonrelease trees and gave good control of spider mites in the block during 1981 (Fig. 2) with 2 applications of lower than label rates of acaricides to assist the predators. The trees were banded and overwintering M. occidentalis were collected in December 1981 from the block, reared in the laboratory, and tested with carbaryl to indicate whether the resistant predators were overwintering. A colony collected from the east side (near 2 towers) had a 34% survival rate while a colony collected only from release trees had 68% survival rate. Predators from bands on nonrelease trees had a 26% survival rate. (Survival rates of nonresistant M. occidentalis usually are 0 - 5% while the pure lab strains of resistant predators usually exhibit an 80% survival rate.) These data suggest that carbaryl-OP resistant predators were overwintering in the orchard, but that carbaryl-susceptible natives were also present and/or interbreeding with the released strain.

Carbaryl was applied in May 1982 and M. occidentalis survived in all areas of the orchard (Figs. 4-10) and gave substantial control of spider mites. Two applications of lower than label rates of selective acaricides were made. The first application of Omite was made in June (Figs. 4-10) by air blast sprayer. This spray did not reach the top quarter of the trees.

Because our leaf samples were taken from the lower half of the tree, the graphs (Figs. 4-10) probably overestimate spider mite densities in the orchard early in the season and somewhat underestimate the numbers of spider mites on the foliage later in the season. Therefore, as a result of poor coverage with Omite and higher spider mite densities as a result in the top quarter of the trees, particularly in sample areas 2, 3, and 5 (Figs. 6, 7, and 9), an aerial application of Plictran was made in August to assist the predators. This spray was only necessary in about half of the orchard. Figs. 5-10 also document that M. occidentalis was present in the entire orchard.

The orchard looked visibly better in 1982 than it did in 1981, and the reduction in acaricide costs over the previous spray program are substantial. We would like to determine if the predators can control the mites in this block in 1983 without the need for any acaricides at all. Clearly, these predators are doing an excellent job despite the application of carbaryl, which is considered to be a very disruptive material, and the fact that this orchard is quite dusty from the adjacent turkey pens. If the first acaricide had been applied so that coverage was good, it is likely that the second would not have been needed.

Fig. 1. Map of the Livingston I, II, III, & IV almond blocks 1982.
 Carbaryl-OP resistant predators were released in 1981 into Blocks I and II.
 Carbaryl-OP-sulfur resistant predators were released into Blocks III and IV
 in 1982.



GRAP

Fig. 1

Fig. 2. Spider mites and *M. occidentalis* on foliage in the Livingston I block in 1981. Carbaryl-OP resistant predators were released in June 1981 (ca. 350 females into every third tree in every third row) after carbaryl had been applied in May. Carbaryl was applied again in July and low rates of Omite were applied twice. The resistant predators had a substantial control impact. The dashed line represents *M. occidentalis* counts; the solid line represents spider mites (mostly *Tetranychus* species).

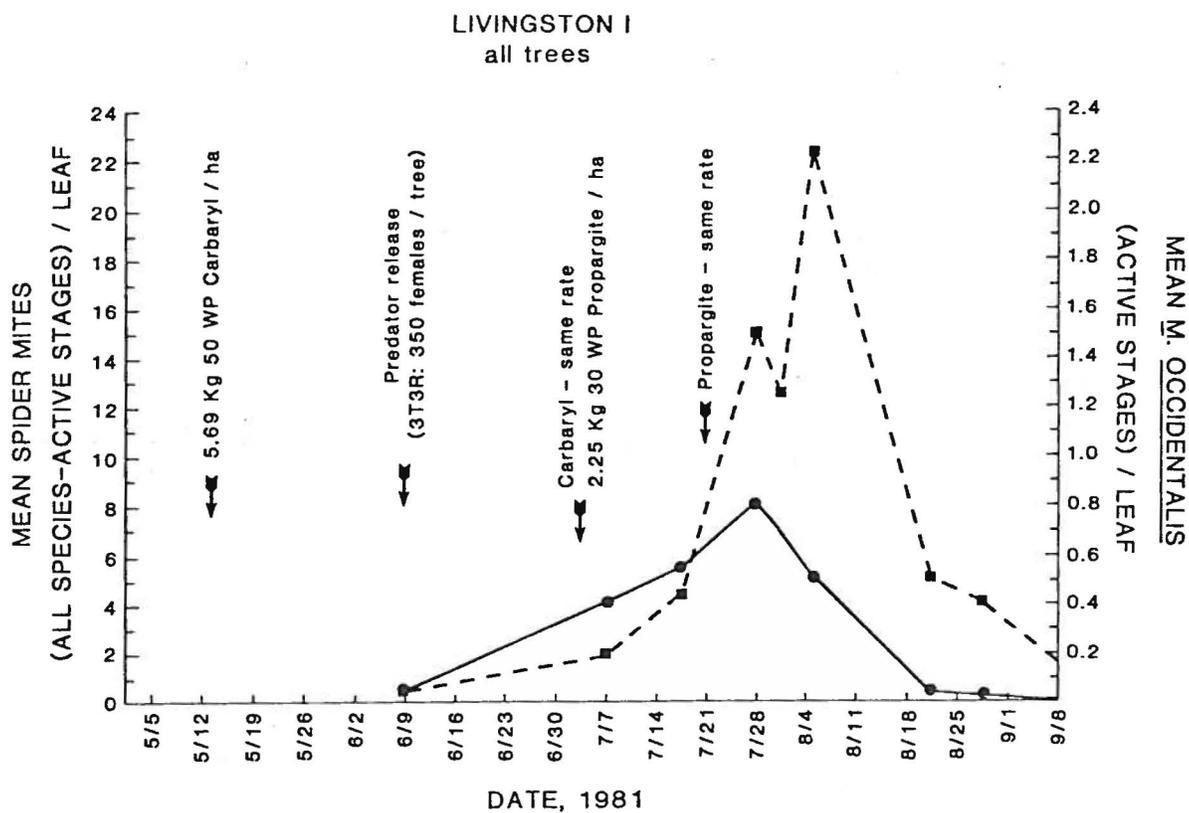


Fig. 3. Spider mites and M. occidentalis on foliage in the Livingston I block during the second season -- 1982. Spider mite densities were substantially lower than in 1981 and M. occidentalis survived the early May application of carbaryl. Two applications of low rates of acaricide were applied. Counts from the 6 sample sites are pooled in this graph.

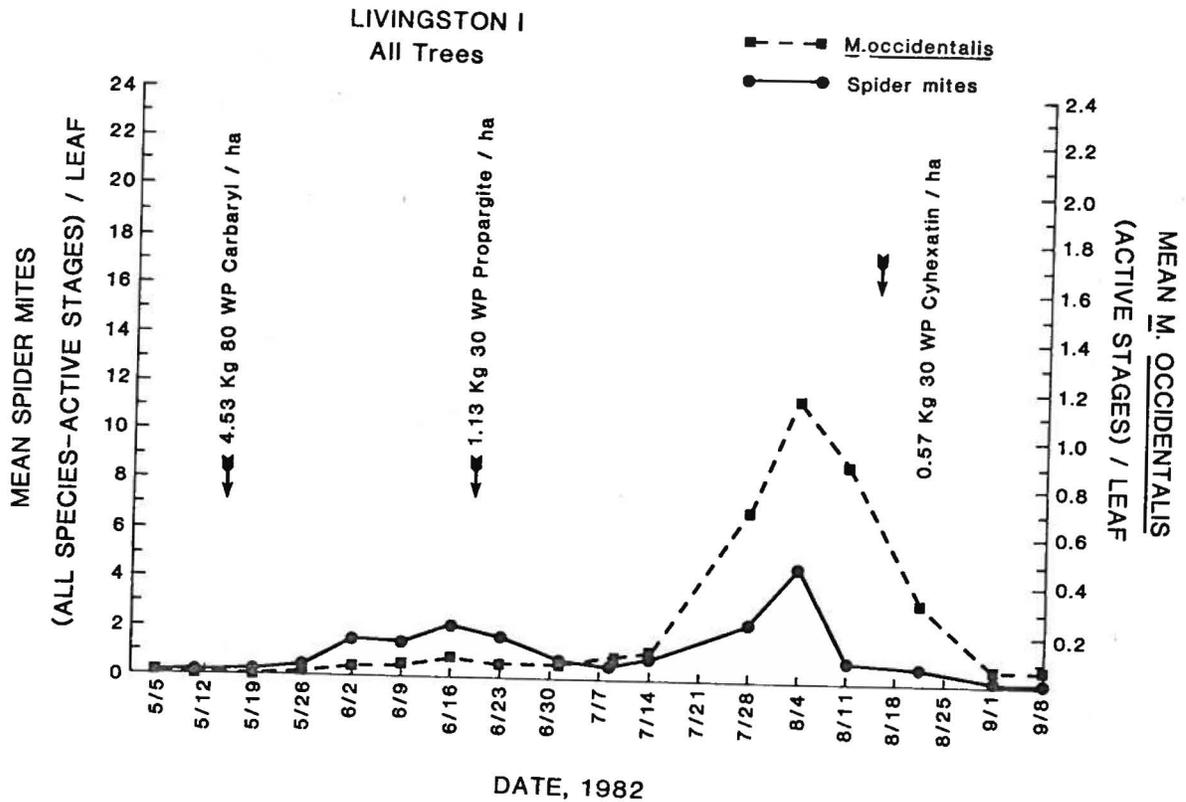
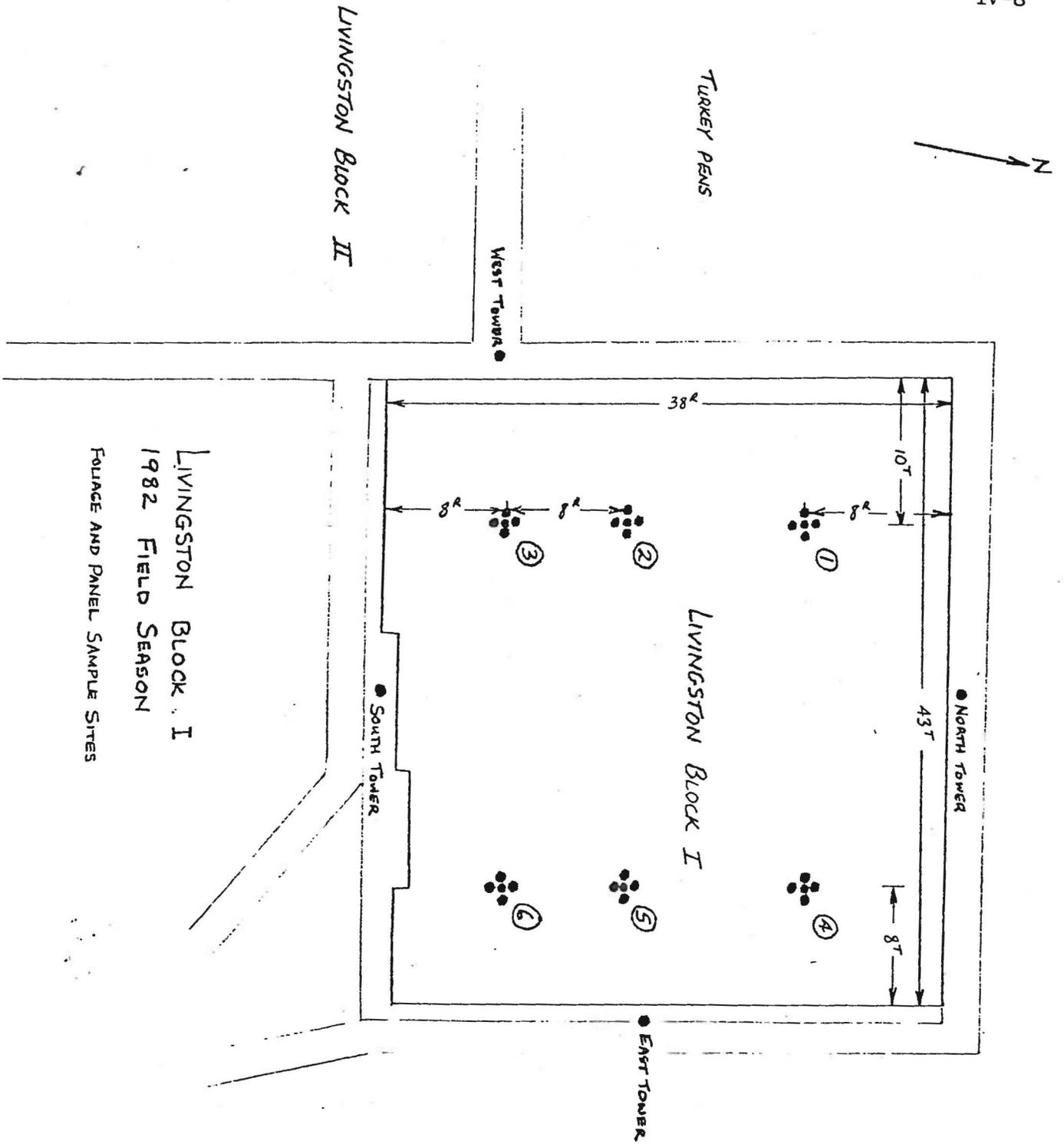


Fig. 4.



5 trees at each of the 6
sample sites were sampled.

(6) Sample Sites, foliage
and aerial dispersal panels
(4) Tower Sites -
emigration and immigration
through aerial transport

Fig. 5. This graph illustrates the spider mite and M. occidentalis densities on 5 trees at one of the six different sample sites of Livingston I during 1982.

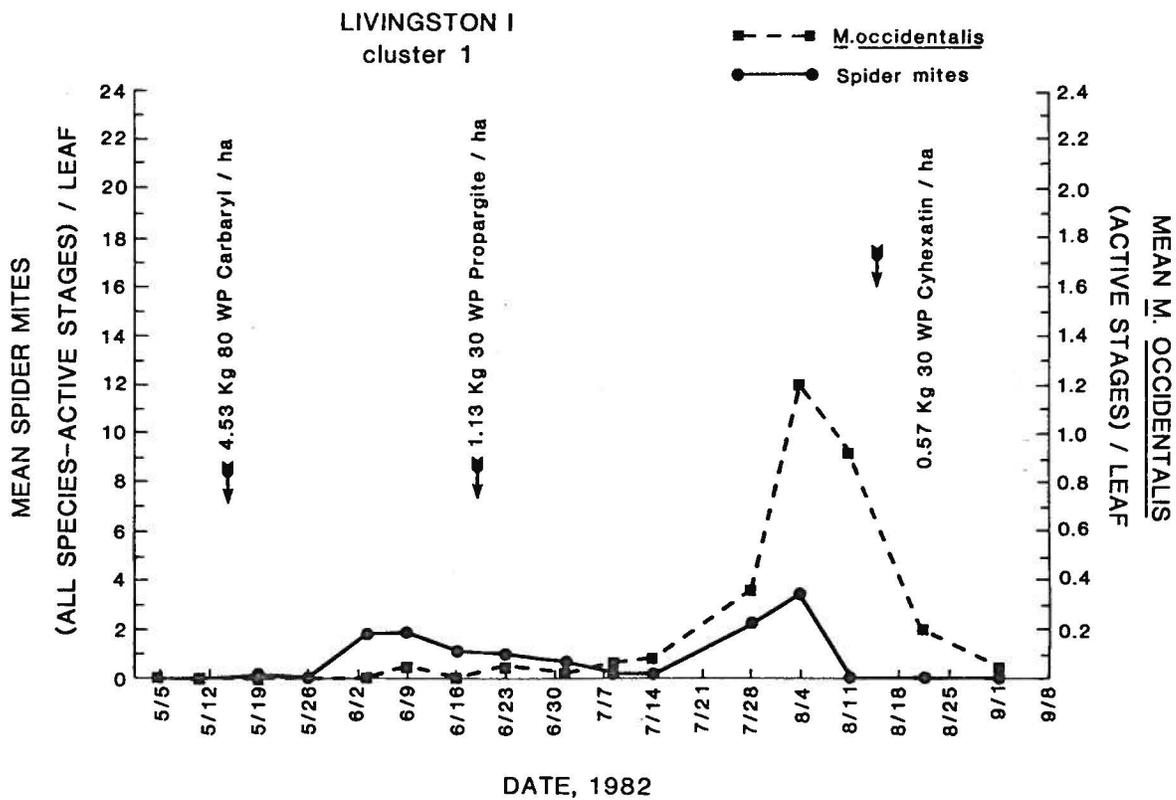


Fig. 6. This graph illustrates the spider mite and *M. occidentalis* densities on 5 trees at one of the six different sample sites of Livingston I during 1982.

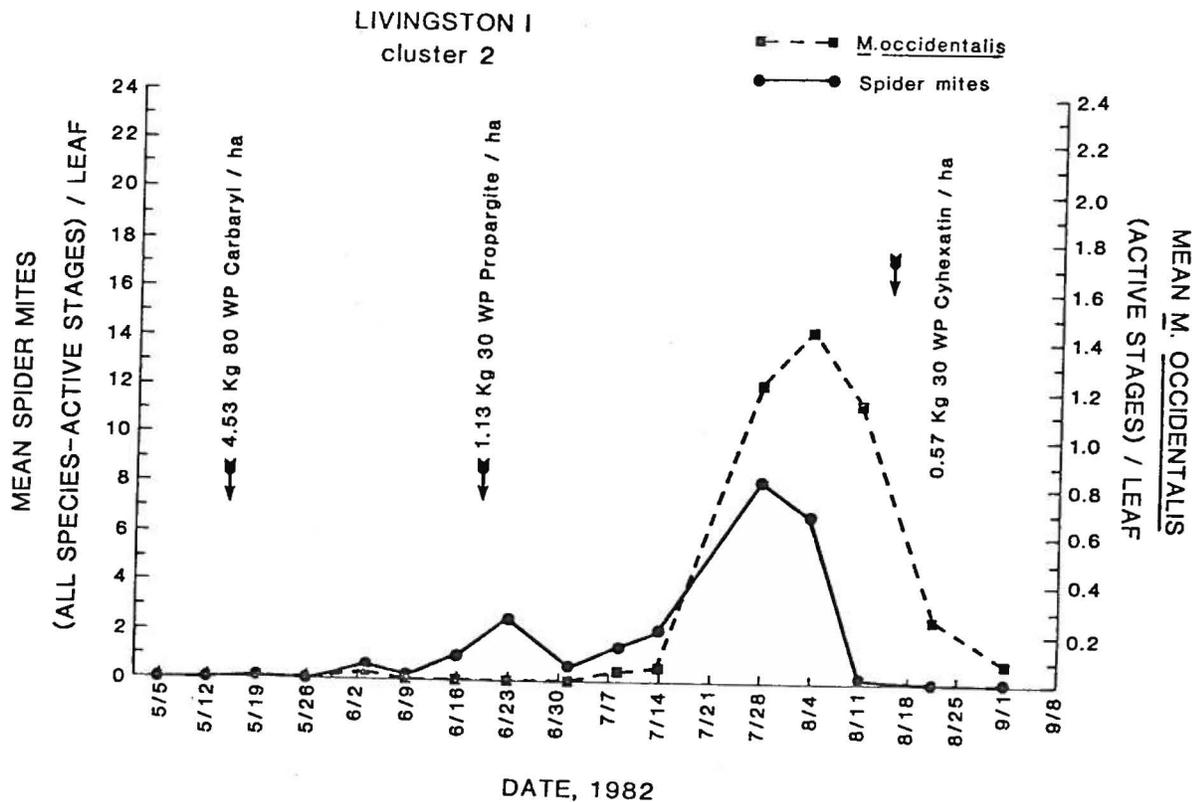


Fig. 7. This graph illustrates the spider mite and *M. occidentalis* densities on 5 trees at one of the six different sample sites of Livingston I during 1982

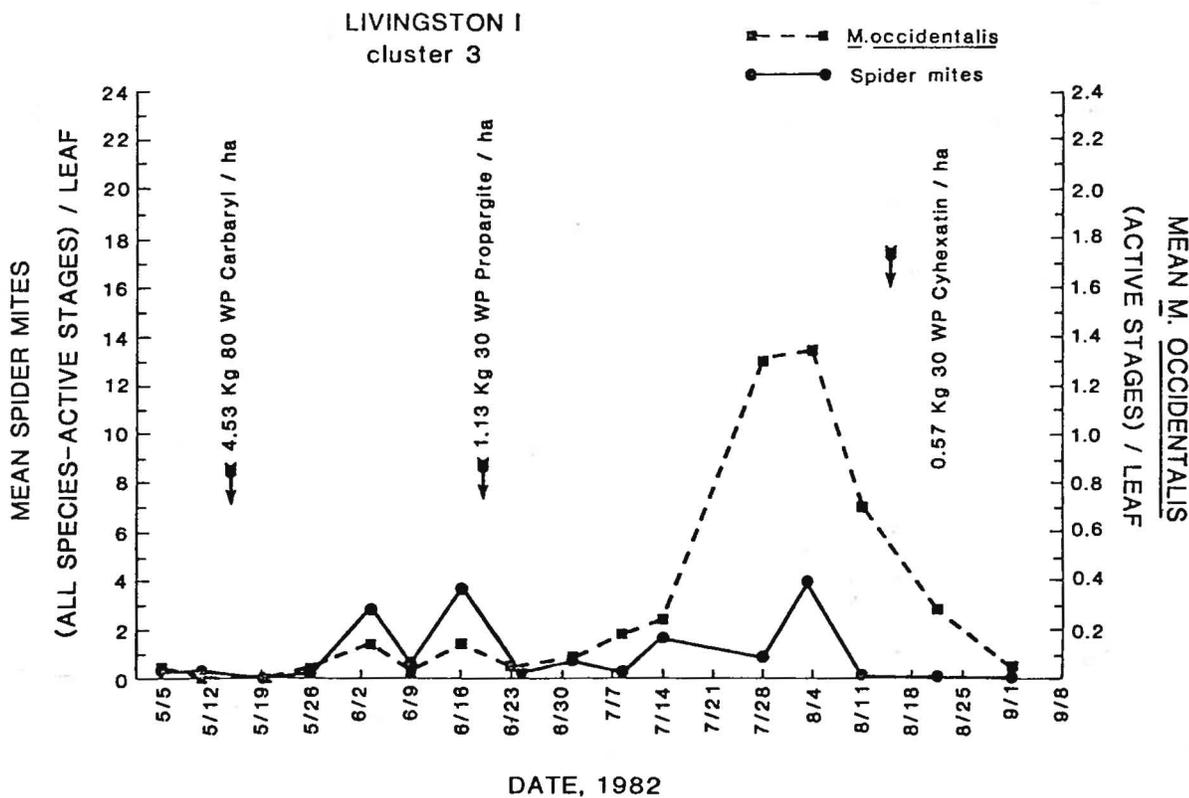


Fig. 8. This graph illustrates the spider mite and *M. occidentalis* densities on 5 trees at one of the six different sample sites of Livingston I during 1982.

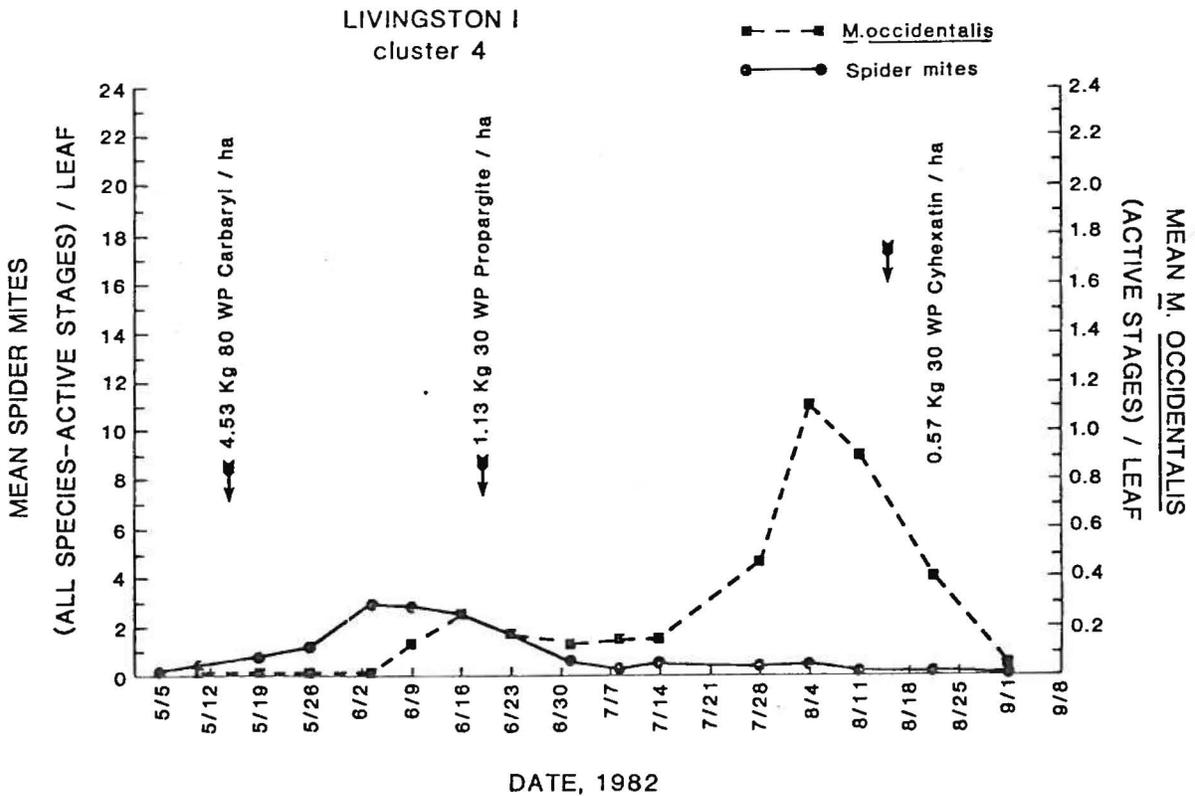


Fig. 9. This graph illustrates the spider mite and *M. occidentalis* densities on 5 trees at one of the six different sample sites of Livingston I during 1982.

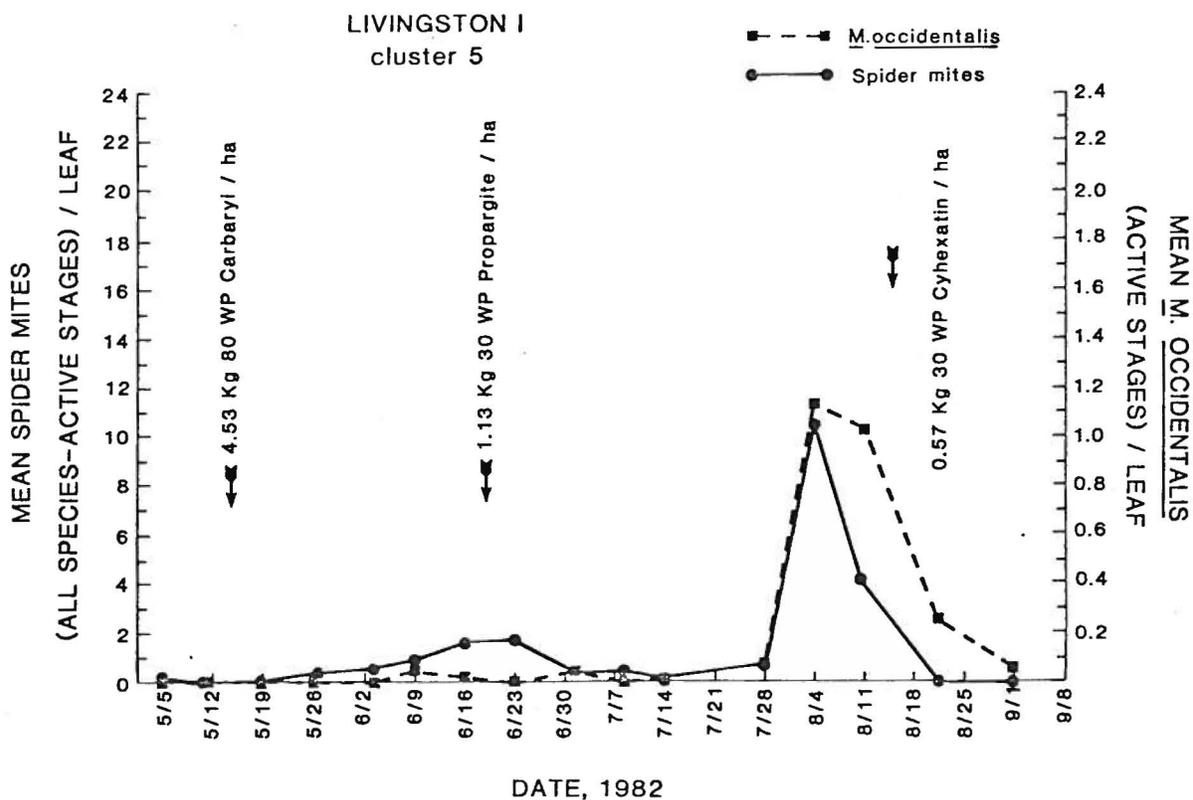
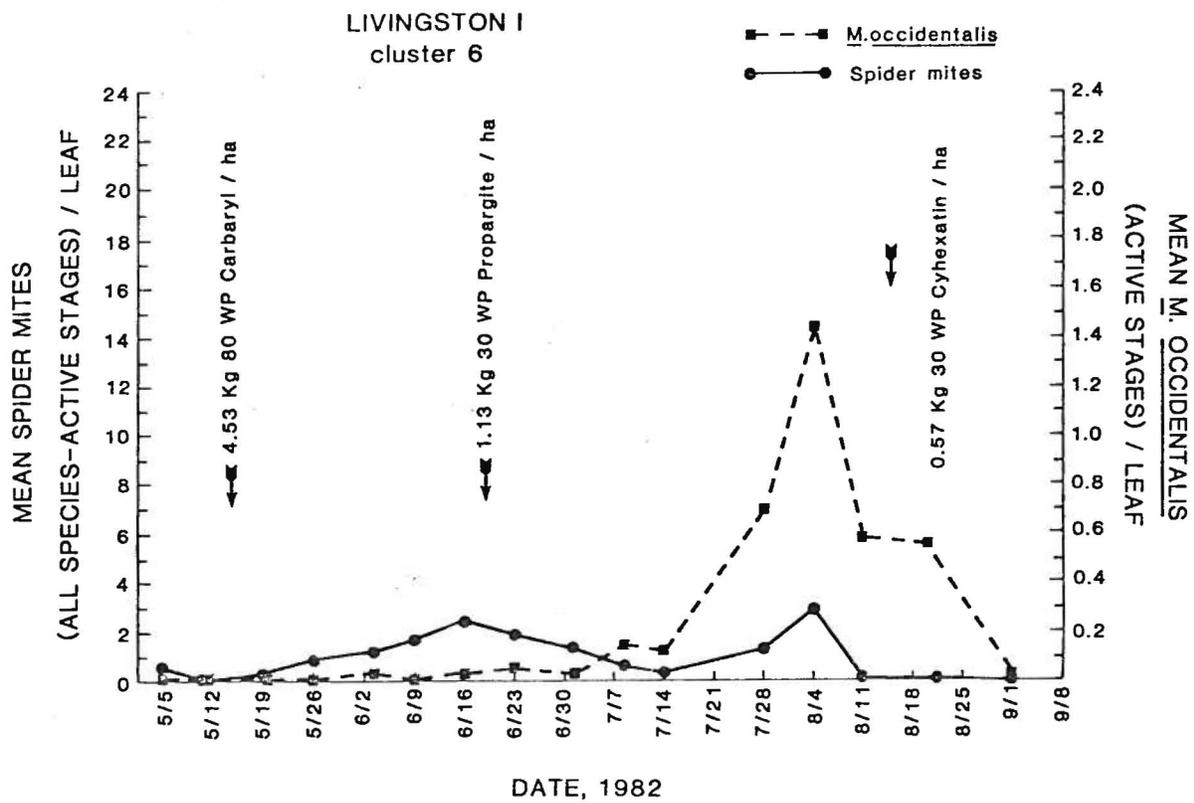


Fig. 10. This graph illustrates the spider mite and M. occidentalis densities on 5 trees at one of the six different sample sites of Livingston I during 1982.



LIVINGSTON II

This block is 32 rows by 24 trees in size (ca. 10 acres) and is comprised of Mission, Nonpariel, and NePlus varieties in a 1:2:1 pattern. It is located along Longview Avenue near Livingston. Carbaryl-OP resistant M. occidentalis were released (350 females/tree) into every third tree into every third row on September 15, 1981. This block had received permethrin applications during the 1981 field season, so there should have been few native M. occidentalis present. Because of a severe spider mite outbreak, there was little foliage on the trees when the release was made in September 1981, and little prey remained on the foliage for the predators. Thus, the establishment rate may have been very low. M. occidentalis collected from bands during December 1981 had low levels of resistance to carbaryl (7.5 and 11% of the females survived in these tests), indicating that the released predators were present in low numbers.

Carbaryl (4 lb 80 WP/acre) was applied on 14 May 1982 by air blast sprayer (50 gal/acre) to this block, and Bill Barnett sampled the foliage from June 1 until August 10. M. occidentalis were present in the block in June (Table 2) and provided substantial control of spider mites. Part of this block was also treated with Guthion (4 lb 80 WP/acre) on 15 July, 1982, and the Guthion killed the spider mites so that both predators and spider mite densities crashed in that sector (Table 2). Carbaryl (80 WP, 6 lbs/acre) was applied 15 July 1982 as well to part of the block. Omite (30 WP, 1 lb/acre) was applied at the same time by air blast sprayer (50 gal/acre) to the section receiving Sevin. (Omite (2 lbs. 30 WP/acre) was applied to the section receiving the Guthion.) Thus, this block received only one application of a low rate of Omite, and foliage condition was generally good.

Table 2. Spider mites and M. occidentalis in the Livingston-II almond block during 1982 (Data obtained by B. Barnett).

Sample date	Mean active mites/leaf	
	spider mites	<u>M. occidentalis</u>
May 14	carbaryl applied	
June 1	0.5	0.02
29	10.1	0.62
July 6	16.1	0.67
13	17.1	1.46
15	carbaryl or Guthion applied with Omite	
20	10.1	0.68
27	2.4 (0.23) ^{a/}	0.48 (0.03) ^{a/}
Aug. 3	3.9 (0.15)	2.30 (0.04)
10	0.01 (0.0)	0.44 (0.05)

^{a/} Numbers in parentheses are counts in area where Guthion was applied July 15, 1982. This sector received 2 lbs Omite/acre; the section sprayed with Sevin received 1 lb Omite/acre.

LIVINGSTON III

The Livingston III almond block is ca. 45 acres in size and consists of Mission, Nonpariel, and NePlus varieties in a 1:2:1 spacing. The block is 64 rows by 53 trees. On 15 May 1982, carbaryl (80 WP, 4 lb./acre) was applied by air blast sprayer (50 gal/acre) to the block. Carbaryl-OP-sulfur resistant predators were released in two different patterns on 28 May 1982. Two sectors received 900 females in every third tree in every third row and two sectors received 100 females in every tree (see Fig. 11 for map). This means that the same number of predators were released on a per acre basis; only the release pattern varied. A total of 300,000 predator females were released in this block. On 15 July 1982 carbaryl (80 WP, 6 lb/acre) was applied by air blast sprayer (50 gal/acre) to most of the block. Omite (1 lb. 30 WP/acre) was applied at the same time. In Section A-1 of the orchard (Fig. 11) Guthion along with Omite (2 lb 30 WP/acre) was applied by accident on July 15 by air blast sprayer (50 gal/acre).

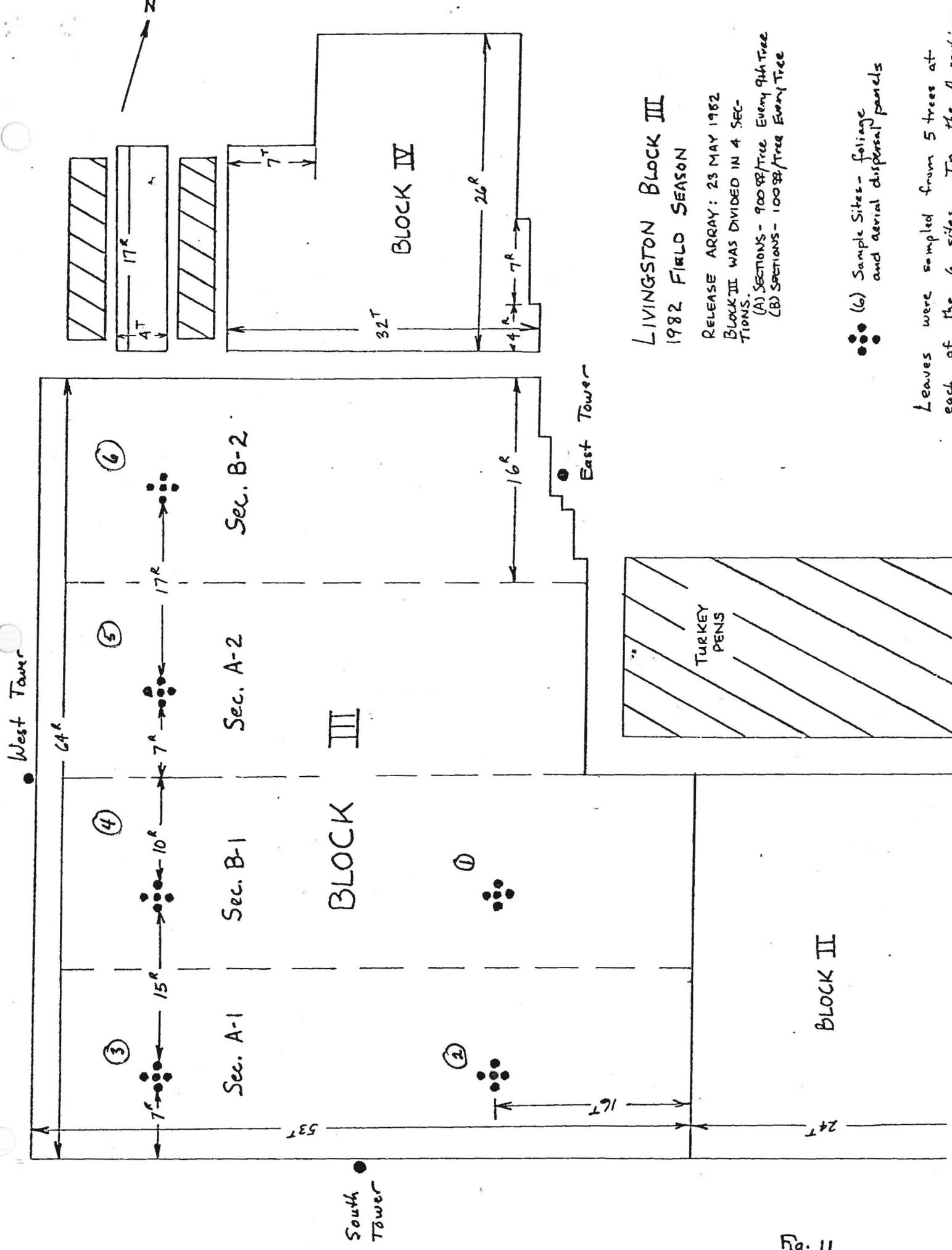
M. occidentalis populations were large in this block during 1982 and provided substantial control of spider mites (Figs. 12, 13, 14, 15).

Releasing predators in every tree may give better control immediately after the release. The spider mite densities appear to be lower in trees where 100 predators were put in each tree than where predators were put into every ninth tree (cf. Fig. 15 with 14). The differences in spider mites are not statistically different in the two release sectors, however, and the predators did move from release to nonrelease trees fairly quickly through the air (see Section V).

The Guthion that was accidentally applied to Section A-1 on July 15 had a dramatic impact on both spider mites and predators in sample sites 2 & 3 (Fig. 15). Guthion killed spider mites, and the predator populations crashed. It seems unlikely that Guthion is toxic to this M. occidentalis strain, as its Guthion LC_{50} value is about 6 lb. a.i./100 gal water (see Section VII for details). It seems more likely that the predator population crashed because the prey were eliminated.

The spider mite and M. occidentalis foliage counts are reported for each sample (= cluster) area (Figs. 16-21). These graphs indicate the predators were widespread in the block and gave good control of spider mites. Variability in densities from site to site is also evident.

Fig. 11. Map of Livingston III stie indicating locations of the sample sites (clusters) where foliage samples were taken and where greased panels were located, 1982. In the A Sections, 900 females were released into every third tree in every third row. In the 2B sections, 100 females were placed in every tree in every row, so that the number released per acre was equivalent in the 4 sections.



LIVINGSTON BLOCK III
1982 FIELD SEASON

RELEASE ARRAY: 23 MAY 1982
BLOCK III WAS DIVIDED IN 4 SECTIONS.
(A) SECTIONS - 900 98/TREE EVERY 9th TREE
(B) SECTIONS - 100 98/TREE EVERY TREE

●●●●● (6) Sample Sites - foliage and aerial dispersal panels

Leaves were sampled from 5 trees at each of the 6 sites. In the A sections

Fig. 11

Fig. 12. Spider mite and *M. occidentalis* counts pooled for all 6 sample sites at Livingston III - 1982. Carbaryl-OP-sulfur resistant predators were released May 28, 1982 in two different patterns: 100 females were put into every tree in 2 sections and 900 ♀♀ were put into every third row. Guthion was applied to 2 of the six sample sites in July so the counts for those sites are excluded after July 15.

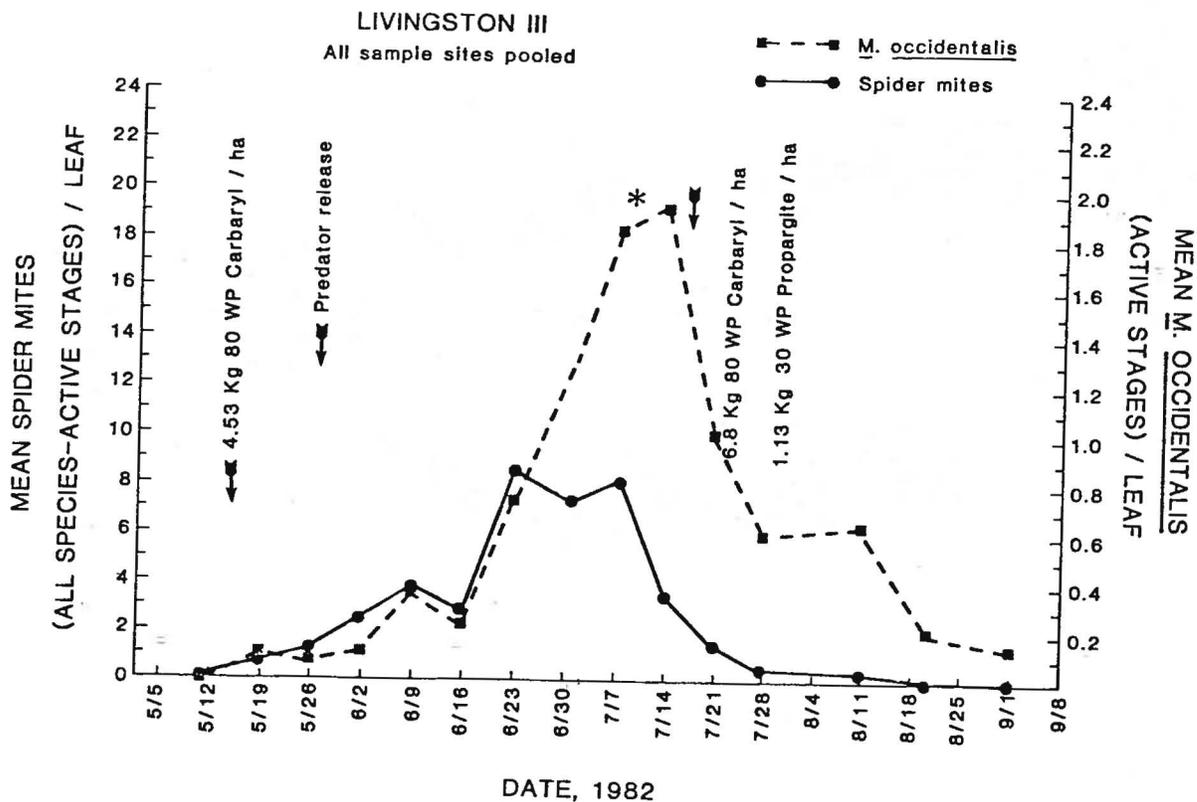


Fig. 13. Counts of spider mites and *M. occidentalis* in Livingston III, Sections B-1, B-2 where 100 ♀♀ were released into every tree - 1982.

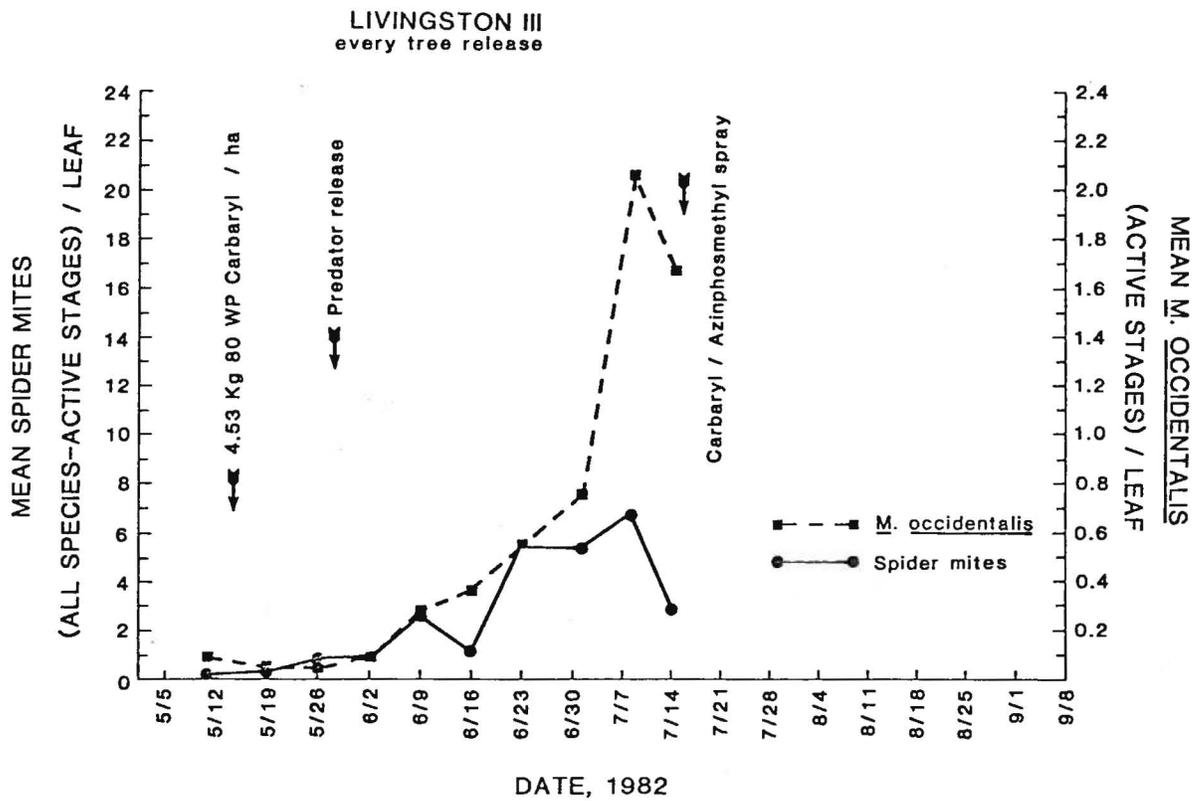


Fig. 14. Counts of spider mites and *M. occidentalis* in Livingston III where 900 ♀♀ were released into every third tree in every third row - 1982 (Sections A-1, A-2).

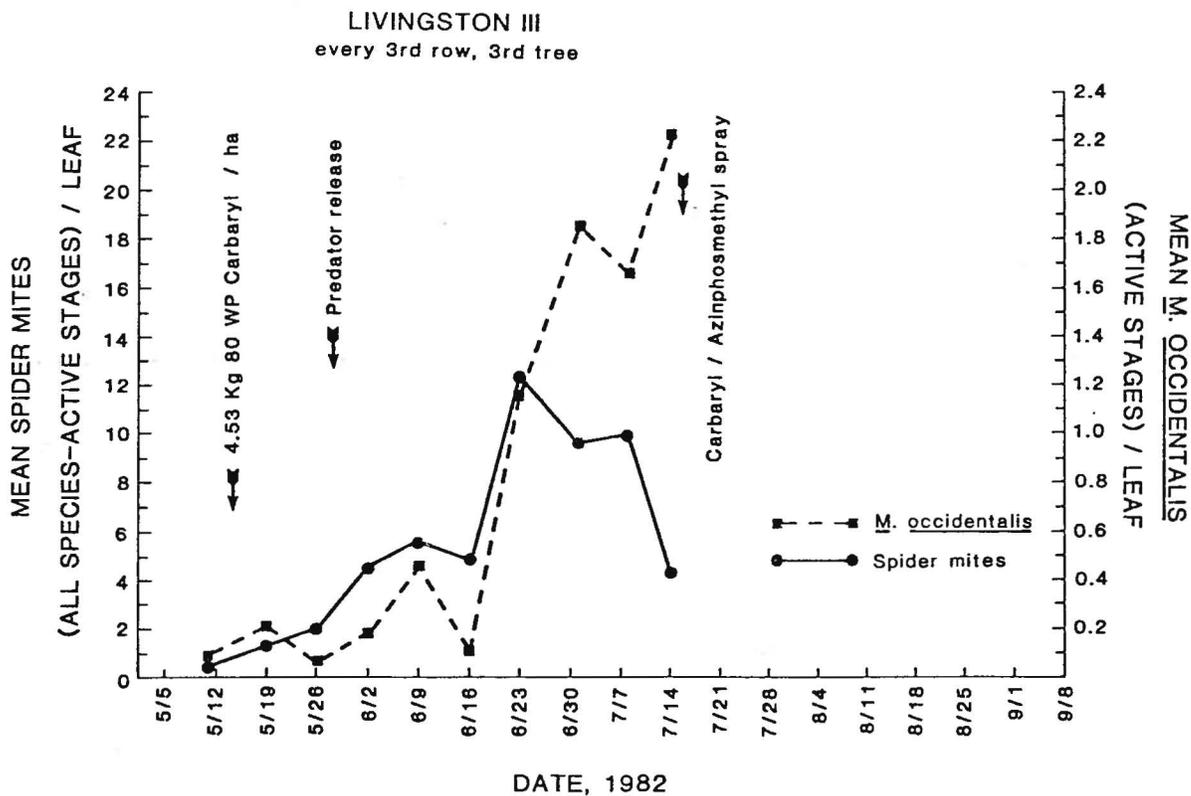


Fig. 15. Counts of spider mites and *M. occidentalis* in Livingston III in sample sites 2 and 3 where Guthion was accidentally applied - 1982.

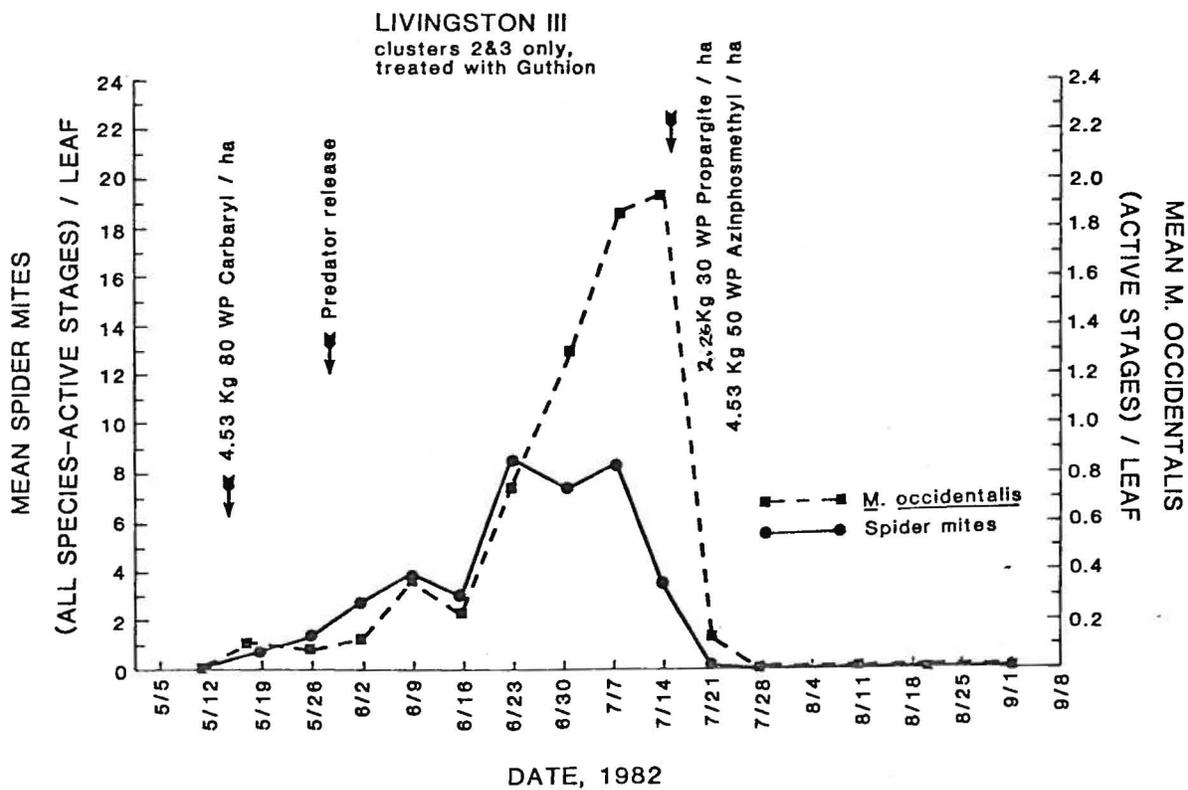


Fig. 16. Foliage counts of spider mites and *M. occidentalis* in the Livingston III almond orchard - 1982. Each "cluster" is a different sample area consisting of 5 trees. Clusters 1, 2, and 5 had 900 carbaryl-OP-sulfur resistant *M. occidentalis* ♀♀ released into every third tree in every third row. Clusters 1, 4, and 6 had 100 ♀♀ released into every tree on May 28, 1982.

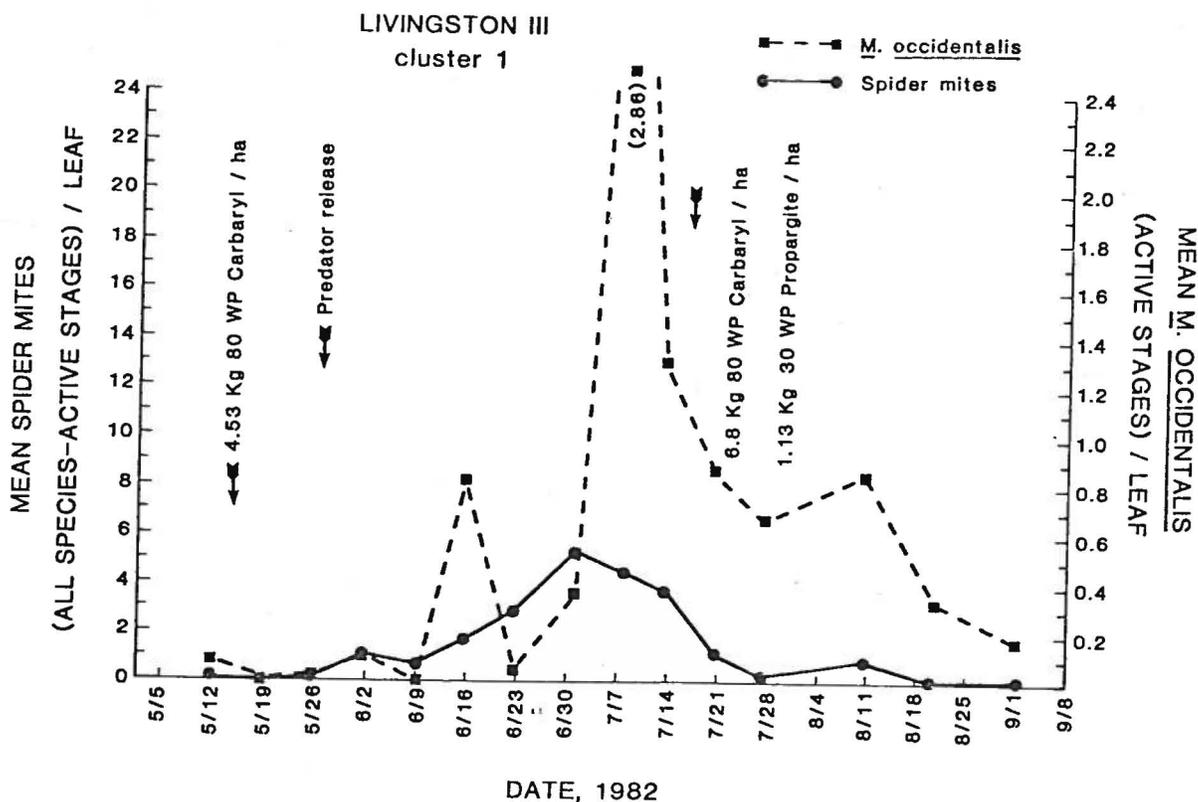


Fig. 17. Foliage counts of spider mites and *M. occidentalis* in the Livingston III almond orchard - 1982. Each "cluster" is a different sample area consisting of 5 trees. Clusters 1, 2, and 5 had 900 carbaryl-OP-sulfur resistant *M. occidentalis* ♀♀ released into every third tree in every third row. Clusters 1, 4, and 6 had 100 ♀♀ released into every tree on May 28, 1982.

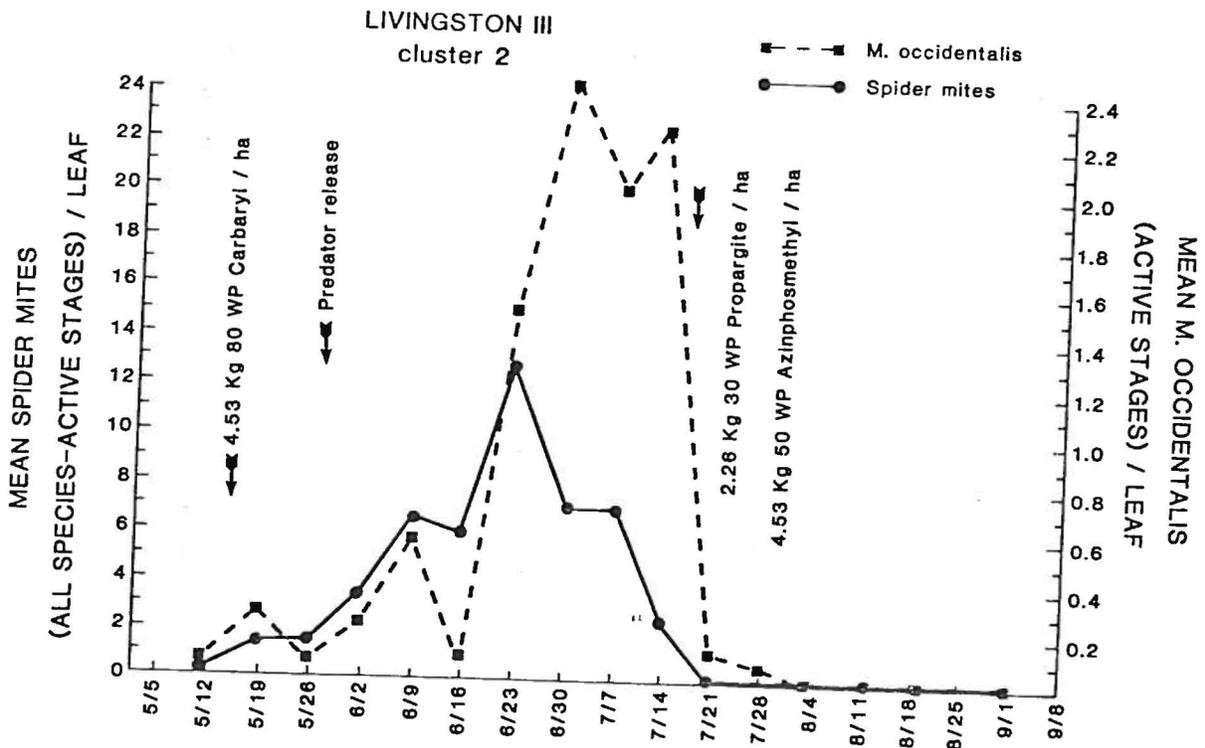


Fig. 18. Foliage counts of spider mites and *M. occidentalis* in the Livingston III almond orchard - 1982. Each "cluster" is a different sample area consisting of 5 trees. Clusters 1, 2, and 5 had 900 carbaryl-OP-sulfur resistant *M. occidentalis* ♀♀ released into every third tree in every third row. Clusters 1, 4, and 6 had 100 ♀♀ released into every tree on May 28, 1982.

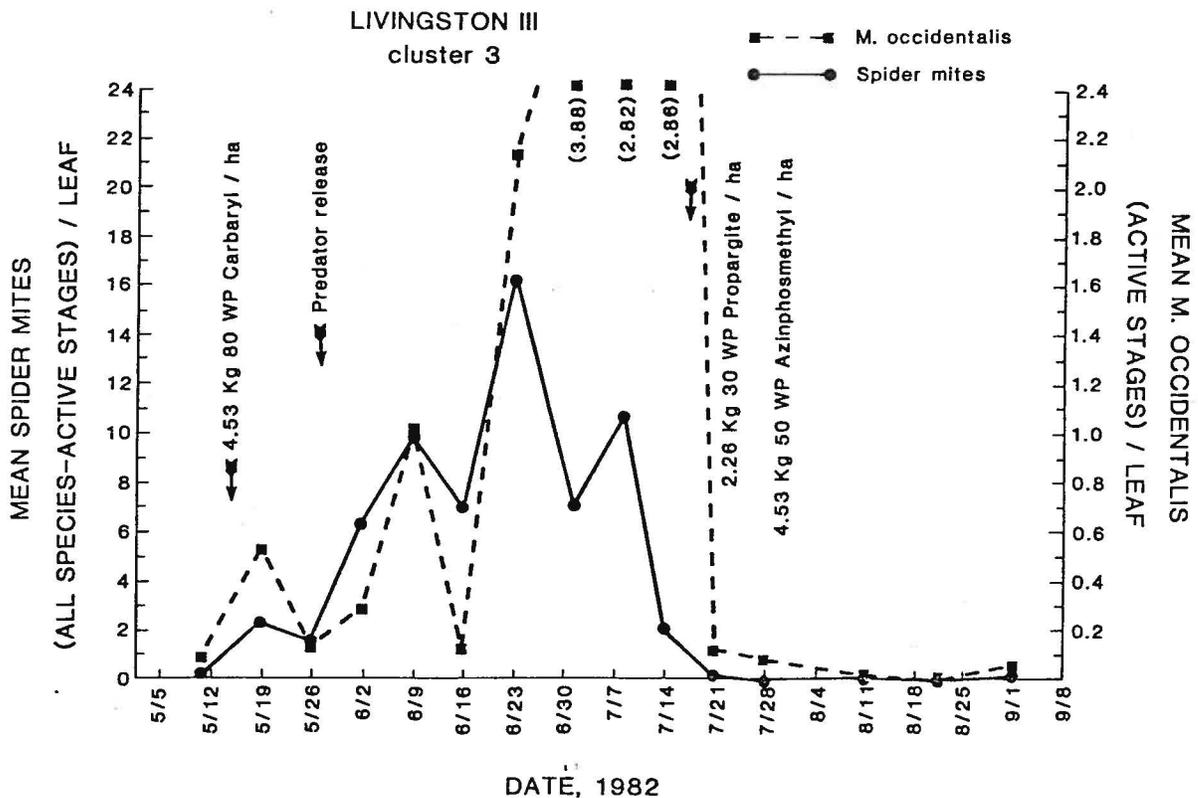


Fig. 19. Foliage counts of spider mites and M. occidentalis in the Livingston III almond orchard - 1982. Each "cluster" is a different sample area consisting of 5 trees. Clusters 1, 2, and 5 had 900 carbaryl-OP-sulfur resistant M. occidentalis ♀♀ released into every third tree in every third row. Clusters 1, 4, and 6 had 100 ♀♀ released into every tree on May 28, 1982.

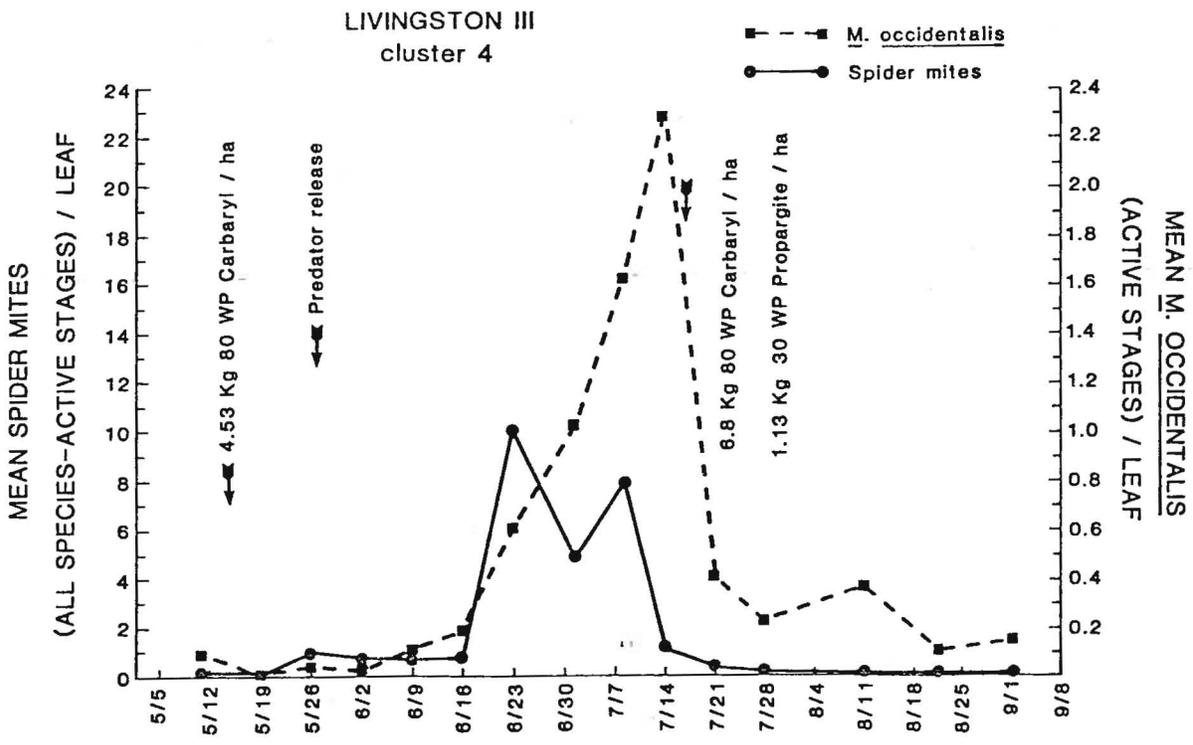


Fig. 20. Foliage counts of spider mites and *M. occidentalis* in the Livingston III almond orchard - 1982. Each "cluster" is a different sample area consisting of 5 trees. Clusters 1, 2, and 5 had 900 carbaryl-OP-sulfur resistant *M. occidentalis* ♀♀ released into every third tree in every third row. Clusters 1, 4, and 6 had 100 ♀♀ released into every tree on May 28, 1982.

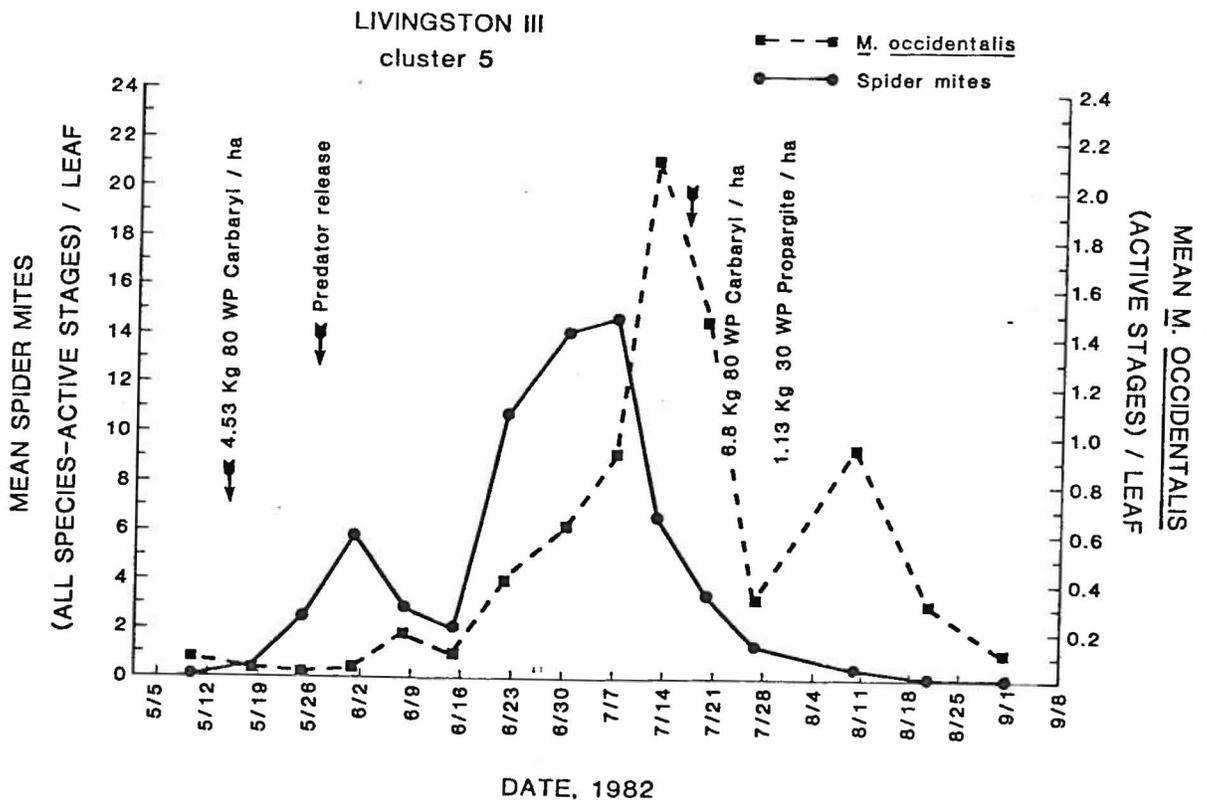
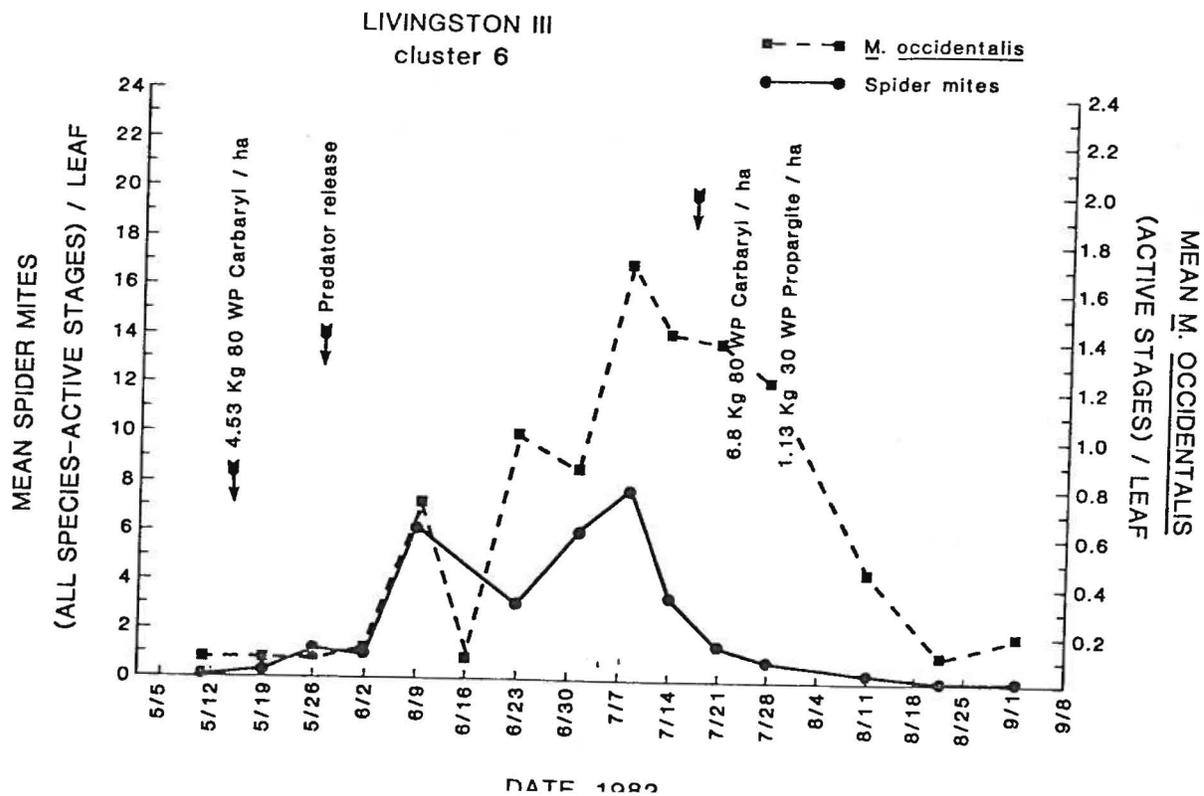


Fig. 21. Foliage counts of spider mites and *M. occidentalis* in the Livingston III almond orchard - 1982. Each "cluster" is a different sample area consisting of 5 trees. Clusters 1, 2, and 5 had 900 carbaryl-OP-sulfur resistant *M. occidentalis* ♀♀ released into every third tree in every third row. Clusters 1, 4, and 6 had 100 ♀♀ released into every tree on May 28, 1982.

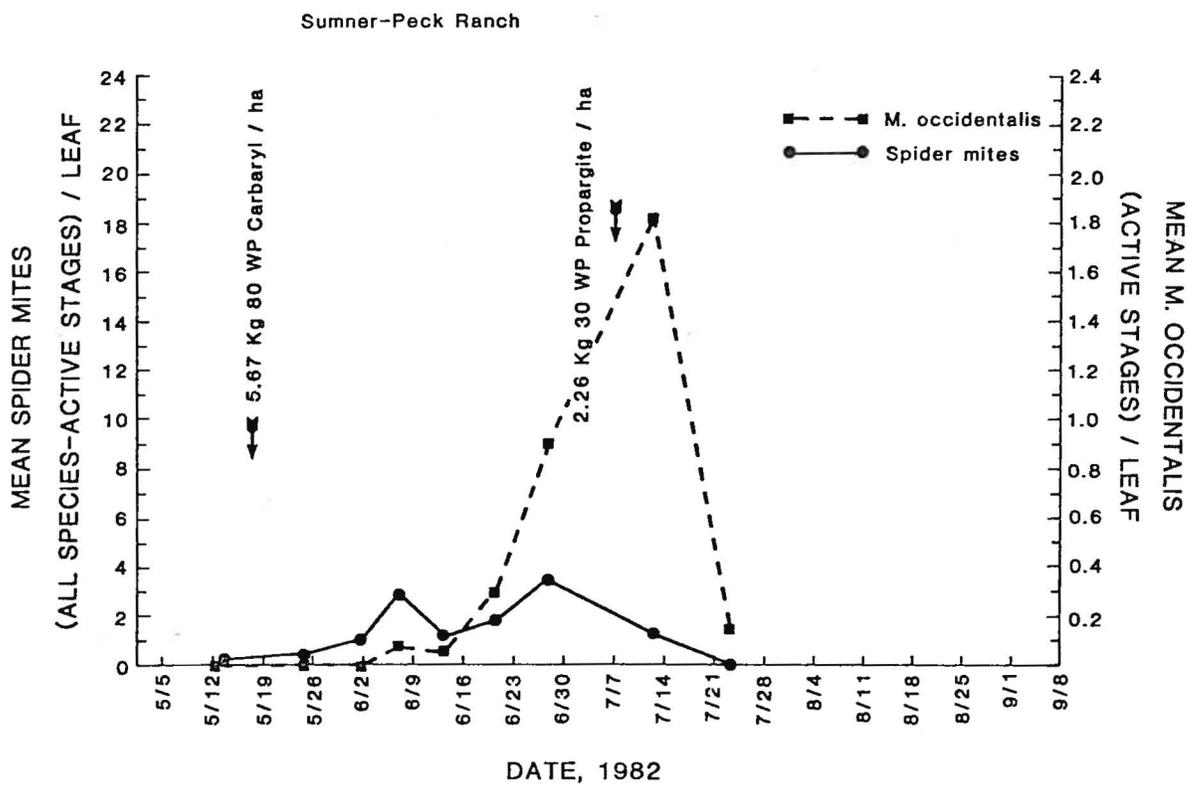


SUMNER - PECK RANCH

This 80 acre block consists of Nonpareil and Carmel varieties, and is located on Hwy. 33 and Mountain View Avenue, near Three Rocks in Fresno County. Carbaryl-OP resistant M. occidentalis were released on July 10, 1981. About 350 females were released into every third tree in every third row and a total of 555,000 were released in the block. The block received a carbaryl spray at hullsplit in 1981. Carbaryl was applied in May 1982, and only ca. 20 acres were monitored rather than 80 acres.

Leaf samples were taken during 1982 by B. Barnett (Fig. 22), and indicate that predators were detectable by late June in the block. On July 7, 1982 Omite (2 lb 30 WP/acre) was applied by air to the block to dampen the spider mite population. After July 23, no leaf counts were made because spider mite and predator densities remained extremely low. The predators appear to be well established and providing some means of control here.

Fig. 22 Foliage counts from the Sumner-Peck almond orchard, 1982 -
by B. Barnett.



MADERA ALMONDS

This almond block (owned by Mr. Deniz) is located at Road 20 and Avenue 18, near Madera. Carbaryl-OP resistant M. occidentalis were released into ca. 400 trees on July 21, 1981 into every tree. Three hundred females (total 150,000) were released. On June 1, 1982, carbaryl (80 WP, 5 lb/acre) was applied by ground. On July 15, 1982, carbaryl (80 WP, 5 lb/acre) and Omite (30 WP, 2 lb/acre) were applied by ground. On August 3, 1981, Plictran (30 WP, 0.25 lb/acre) was applied by air to the block.

The M. occidentalis recovered from bands during December 1981 had good levels of carbaryl resistance: 53 and 25% survived the test dose in colonies taken from release and nonrelease trees, respectively.

The foliage counts from the block during 1982 indicate that predators were present in the block throughout the season, but they did not give complete control, and the August 2 Plictran application (0.25 lb/acre) was necessary to prevent excessive damage. This block has had a history of severe mite problems, and the fact that the predators clearly had a substantial impact on the spider mite population is most encouraging especially when you consider that two carbaryl sprays were applied. The predators should be well distributed in the block and it will be interesting to determine if the predators give even better control during the 1983 field season.

Table 3. Foliage counts in the Madera almond block during 1982 - B. Barnett.

Sample date 1982	Mean mites (active stages)/leaf	
	Spider mites	<u>M. occidentalis</u>
June 1	carbaryl applied to block	
2	0.17	0.01
29	6.58	0.07
July 6	16.59	0.06
12	21.73	0.26
15	carbaryl and Omite applied	
19	10.34	0.23
26	8.37	0.37
Aug. 2	17.44	1.23
3	Plictran applied by air	
9	1.29	2.29
16	0.03	0.56

WASCO ALMONDS

This 15 acre block is located at Hwy. 46 and Palm Avenue, near Wasco in Kern County. Carbaryl-OP resistant M. occidentalis (1880 females/tree) were released into every fifth tree in every fifth row on May 28, 1981 (total 200,000 females). This block was treated twice by the grower with permethrin in 1981, and yet the carbaryl-OP resistant strain survived and successfully overwintered. During May 1982, predators were collected from release and nonrelease trees in the block and tested with carbaryl (2.4 grams a.i./liter water). Females from the release trees exhibited 32% survival while females from nonrelease trees exhibited 23% survival; resistant and susceptible control females had 75 and 3% survival rates, respectively.

During 1982, carbaryl (3 lb 80 WP/acre) was applied by ground on May 14; Omite (5 lb 30 WP/acre) was applied on June 25, and Guthion (4 lb 80 WP/acre) was applied on July 16. The leaf counts of spider mites and predators, taken by Walt Bentley, are shown in the next graph. This block looked good at the end of the 1982 field season, which is a marked contrast with the situation in previous years. This block has had a history of mite problems. The fact that the carbaryl-OP resistant predators established in this block suggests that the predators are more durable than we expected. The predators were not expected to survive the two permethrin applications made in 1981, and their moderately good control effort in 1982 is quite encouraging. This block should be monitored during 1983.

High late season predator populations seem to indicate that predator populations in the following season will be well distributed in the orchard. We anticipate much better control in the 1983 season.

BAKERSFIELD ORCHARD (Bidart)

Carbaryl-OP resistant M. occidentalis were released into a few trees only of this block located near Coffee Rd. and 7th Standard near Bakersfield (Bidart orchard) in 1979. The predators spread quickly throughout the block. Carbaryl resistance levels in M. occidentalis from this site have been monitored several times (Hoy, in press). Predators recovered January 7, 1982 from cloth bands had a 37.5% survival rate (cf. 55% and 0% for resistant and susceptible laboratory colonies, respectively). Thus, the resistant predators have retained excellent resistance levels despite the lack of carbaryl selection pressure since July 1980, when ca. half the block was treated with carbaryl. No carbaryl was applied in 1981 or 1982 to the block.

People often question how long the carbaryl resistance will be retained in populations at the release sites and how often carbaryl will have to be applied to retain high resistance levels. The longest field experience with the carbaryl-OP resistant strain is in this orchard; it should be monitored yearly to assay the rate of change in resistance levels. It is noteworthy that very few carbaryl resistant predators were used to inoculate the orchard, and abundant native predators were present in the orchard at the time. This suggests that the carbaryl resistance, determined by a single semidominant gene, is capable of spreading throughout the native population. The results in this orchard support the previous greenhouse results obtained by R. T. Roush which indicated that carbaryl resistance was retained at expected levels in a population derived by crossing the resistant with a susceptible strain, despite the fact that no carbaryl was applied during the interval in which ca. 20 generations developed. It thus appears that carbaryl resistance will be lost slowly, and that carbaryl applications once every 3/4 years may be sufficient to keep high levels in the orchard.

BLACKWELL'S LAND COMPANY

Permethrin-OP resistant M. occidentalis were released into every third tree in every third row in 80 acres of almonds (Block 32-4), at the Blackwell Land Company orchard near Lost Hills during 1981. After the releases were made, the trees experienced extensive defoliation after permethrin was applied, and on September 16, 1981 no predators were found in a foliage sample. Bands (74) placed on the trees on that date were monitored during the winter, and only one predator was recovered. This plot was not monitored during the 1982 growing season. It is likely that few, if any, of the predators established in this block; the reasons are unknown.

MERCED & PALM AVENUE -- WASCO

On September 15, 1981, 8600 permethrin-OP resistant M. occidentalis females (200/tree) were released into a 20 acre block located on Merced and Palm Avenues, near Wasco. The trees were ca. 95% defoliated due to permethrin-induced spider mite outbreaks when releases were made. Bands were placed on 15 of the trees on September 15, and predators were absent in the December/January assay. It is possible too little time existed between releases and when the predator population would have had to enter diapause in late September. This block was not monitored during the 1982 growing season. It appears that predator releases made after mid August and into orchards which are substantially defoliated do not result in establishment. We therefore do not recommend post-harvest releases of M. occidentalis in almonds.

TURLOCK ALMONDS

Carbaryl-OP and permethrin-OP resistant M. occidentalis were released on July 31, 1981 into an almond orchard located near North Palm and North Avenue near Turlock. The cooperator was Dale Ravetto, of Cortez Growers. Samples taken during the 1981 growing season, and from cloth bands during the winter, indicated that both of the resistant strains established in their respective sections of the orchard. However, Mr. Ravetto indicated that the grower was not interested in continuing the plot during 1982, so no leaf samples were taken there in 1982.

GENERAL CONCLUSIONS

The carbaryl-OP resistant strain of M. occidentalis performed well in commercial almond orchards during 1981 and 1982. The strain has established, overwintered, and controlled spider mites; resistance levels are sufficient to allow use of carbaryl without serious disruption. The permethrin-OP resistant strain is performing well in pear and apple orchards in Washington, Oregon, and California where it has been released. No almond orchards containing this strain are being monitored at this time. It is difficult to recommend that the permethrin resistant strain be used in almonds since both OPs and Sevin give control of navel orangeworm with less disruption of other biological control agents.

After the second season of monitoring spider mites and resistant M. occidentalis in commercial almond orchards, it is clear that this predator can reduce the number of applications of acaricides and their rates and maintain

spider mites at low densities. The inoculative releases of the resistant predators do require extra efforts during the first season or two, however. It is simpler, although not cheaper, to simply apply label rates of acaricide to the orchard. This management strategy is likely to be a poor choice in both the long and short term, however. High rates and frequent applications of acaricides are likely to induce acaricide resistance in spider mites. Furthermore, it is more costly to apply these materials than it is to rely upon predators for most (or all) of the control effort.

If a grower has M. occidentalis (or other predators) present in the orchard and adequate mite control is currently being achieved, then releases of the resistant strain(s) are of dubious value. If the orchard lacks predators, or the predators are not uniformly distributed, or if they appear to be disrupted by pesticides applied to control navel orangeworm or peach twig borer, then inoculative releases of the carbaryl-OP or carbaryl-OP-sulfur resistant M. occidentalis strains should be beneficial. The grower will have to monitor the orchard closely during the first season or two to ensure that adequate control is occurring, and may need to modify the spray program to use lower than label rates of Omite or Plictran to ensure that adequate prey is preserved. They can use materials such as Imidan, diazinon, Guthion or Sevin -- which are not disruptive to the Sevin-OP-sulfur or Sevin-OP resistant M. occidentalis. Malathion, Orthene, and Cygon (dimethoate) are OP insecticides that are not labelled for use in almonds and are toxic to the OP-resistant strains. Therefore, these materials can't be used for selecting pure soybean field plot colonies.

It is possible to mass rear and introduce predators into hundreds to thousands of acres of almonds. The main problem seems to be the availability of trained pest control advisors to assist in the rearing, release, and monitoring phases of the projects. At this time we do not know whether, once the predators are well distributed and established in the orchard, they will be able to control spider mites without any further acaricide applications. We simply haven't had sufficient experience to be able to say what will happen during a third year after release.

Releases of pesticide resistant M. occidentalis must be done when there are prey present in the orchard. We seem to have our best luck with releases made in the late June through late July interval. Releases made during September seem to occur too late to allow M. occidentalis to reproduce and spread in the orchard before the predators enter their overwintering sites in diapause. Also, spider mite populations have often crashed by then, so prey is a limiting factor then, as well. Therefore, the field plot rearing system is not as useful if the season is cool and the predators can't be harvested until late August, as they were this season. Further improvements in the field plot system are needed.

Greenhouse rearing can be done if adequate space and trained people are available; season long predator production is possible. A final concern is to maintain quality control over the predators; if resistant M. occidentalis are not kept isolated from susceptible M. occidentalis, or other phytoseiid species, then the released predators will have dubious resistance levels. Periodic sprays in the laboratory/greenhouse/soybean field plot will be necessary to ensure that the resistance levels of the predators to be released is known. This is not difficult, but should not be ignored as a component of the project.

Another concern is that excessive claims regarding the likelihood of control within the first season should be avoided. Currently, we are releasing ca. 350 female M. occidentalis per tree in every third tree in every third row (one tree in nine). If the releases are made in late June, the predators have spread to adjacent trees in all almond orchards to date, but if releases are made later in the season it is irrational to expect any mite control at all during that first season. Thus, it must be made clear that careful monitoring and appropriate timing of low rates of acaricides will be necessary. Releases made by commercial interests are potentially subject to abuse because of constraints of time and energy. It seems crucial that the buyer/user be made aware of the limits (as well as virtues) of the predator releases through educational programs.

The carbaryl-OP resistant strain has met our expectations in every respect. It has rapidly spread and established, weathered pesticide applications well, was primarily responsible for spider mite control and overwintered. Every orchard where this strain has been released has, without exception, enjoyed reduced chemical costs and improved mite control compared to previous years.

The permethrin-OP resistant strain, while performing well in apple and pear orchards in Oregon and Washington, has been disappointing in California almond orchards. Because often uncontrollable spider mite disruptions occur after permethrin use, we do not recommend use of the permethrin-resistant strain since other materials are available to control navel orangeworm and peach twig borer.

The first season in which predators are released is the most critical time. If carbaryl resistant predators are released, carbaryl should be applied in May prior to predator releases. Usually this May application causes a spider mite flareup and careful monitoring (leaf counts) is necessary. Lower than label rates of Omite (1 lb 30 WP/acre) should be applied when the spider mite densities reach ca. 100 mite days or 4-5 actives/leaf. This application must not be made too soon as the resultant low spider mite populations will limit the successful establishment of predators. Applications made too late will result in some damage and defoliation and higher rates of Omite (2 lb 30 WP/acre) may then be necessary to stop the growth of the spider mite populations. A second lower than label rate of Omite (1 lb/acre) is likely to be required in July during the first season. If carbaryl is applied a second time at hullsplit, Omite should definitely be included (1 or 2 lbs 30 WP/acre). It is important to have spider mites and predators in the orchard throughout the growing season so that adequate multiplication and dispersal occurs and overwintering populations are abundant.

During the second season, control of spider mites should be simpler. Carbaryl should probably be kept for hullsplit use only, although it appears that establishment of the resistant predators does not require that a carbaryl application be made during the second season. Monitoring is still necessary, however, and lower than label rates of Omite or Plictran may still be necessary. Application of acaricide should be made as early as it becomes clear that the rate of spider mite increase is exceeding the rate of increase of predators, or if it is clear that predators are not well

distributed throughout the orchard. Early adjustment of spider mite: predator ratio by mid June may be the optimal strategy to employ, and should be investigated further during 1983. If this early adjustment is made, we predict that acaricides later in the season may be avoided and the low level spider mite-predator interaction could be kept throughout the season without the disruptive crash-boom cycles typical of orchards where disruptions occur. The early intervention had the advantage of avoiding the necessity of making decisions during the very hot hullsplit interval.

A number of questions remain to be answered or improvements made. We don't know what will happen during the third season after releases. We don't know how best to distribute predators. During the 1983 season, we will supply seed cultures to growers and PCAs (1/2 flats/request) and provide information to assist them in rearing their own resistant predators. Quite frankly, we think this approach may yield serious failures, as it took us a couple of years of experience to work out all the difficulties in the greenhouse rearing system, and we still have some improvements to make in the soybean plot system. It is likely that a centralized rearing location (perhaps in each county) with trained personnel doing the rearing may be more efficient and reliable. A rearing method which can provide a large number of predators in June is highly desirable. Additionally, simplified sampling techniques for spider mites and predators are essential if most PCAs and growers are going to have the time to monitor their orchards effectively. Accordingly, we need to continue to test/improve the rapid sampling system with Frank Zalom and Bill Barnett.

Integrated mite management is obviously not as simple as calendar applications of label rates of acaricides. However, the cost savings to growers makes predator releases desirable. Future increases in chemical costs and increased life span of such selective acaricides as Omite and Plictran add to the value of this approach.

Aerial Movements of Spider Mites and Metaseiulus
occidentalis into and out of two Almond Orchards - 1982

Aerial dispersal of the carbaryl-OP resistant strain of Metaseiulus occidentalis was documented during part of the 1981 field season (Hoy et al. 1982; Hoy, in press). During the 1982 field season, we monitored two sites, Livingston I and III, to answer the following questions: 1) Do spider mites and predators disperse throughout the season? 2) Do both disperse inside the orchard? 3) Is movement into and out of the orchard uniform, or is the movement predominately associated with prevailing winds from the northwest? 4) Is there a relationship between the number of predators and spider mites on the foliage and the number trapped on greased panels?

To answer these questions, greased panels were placed inside and outside two almond orchards (Block I and III) located near Livingston, California (Fig. 1, 2). Block I is about 14 acres in size, with Mono, Yosemite, and Mission varieties planted in a 1:2:1 pattern with trees 15 X 25 (4.57 X 7.62 m) feet apart (Fig. 1). Carbaryl-OP resistant M. occidentalis were released on 9 June 1981 into every third row, every third tree with 350 females/tree released. During 1982, carbaryl (80 WP at 4 lb/acre or 4.53 kg/ha) was applied on May 14 by an air blast sprayer (50 gal/acre). Propargite (Omite 30 WP) was applied on June 19, using 1 lb/acre (1.31 kg/ha) by air blast/sprayer at 50 gal/acre. On August 4, cyhexatin (Plictran 30 WP) was applied, 0.5 lb/acre (0.57 kg/ha) by air.

Livingston III consists of ca. 45 acres of Mission, Nonpareil, and NePlus trees in a 1:2:1 spacing with trees 24 X 24 ft (7.3 X 7.3 m) apart (Fig. 2). The block is 64 rows by 53 trees. Carbaryl-OP-sulfur resistant predators were released on 28 May 1982. The block was divided into 4 strips and predators were released in 2 different patterns: in two strips, 900 predator females/tree were released into every third tree in every third row. In two strips, 100 females were released into every tree. A total of 300,000 predators were released into the block. On 14 May 1982, carbaryl (80 WP) was applied using 4 lb/acre with an air blast sprayer (50 gal/acre). On 15 July 1982, carbaryl was applied at a rate of 6 lb/acre along with 1 lb propargite (30 WP)/acre by air blast sprayer. Part of the block accidentally received azinphosmethyl and propargite on that same date. Data from that sector were analyzed separately after July 15.

The clear plexiglass panels, (3 X 6.5" (76 X 165 mm) (Fig. 3), were placed on towers 25 feet (7.62 m) outside the two plots on all four sides (except the north side for Block III) (Fig. 4). The panels were located 6.3, 12, 7 and 19 ft (1.93, 3.86, and 5.79 m) above ground level and two panels at each height were directed toward and away from the orchard, respectively; thus each tower held 12 panels. The trees in Block I and III were estimated to be 26 - 30 feet (8 - 9 m) tall and the panels did not sample the top of the canopy. The panels were covered with a thin film of grease on one side only and replaced each week or two weeks. The spider mites and predators were counted using a dissecting microscope. After counting, the panels were

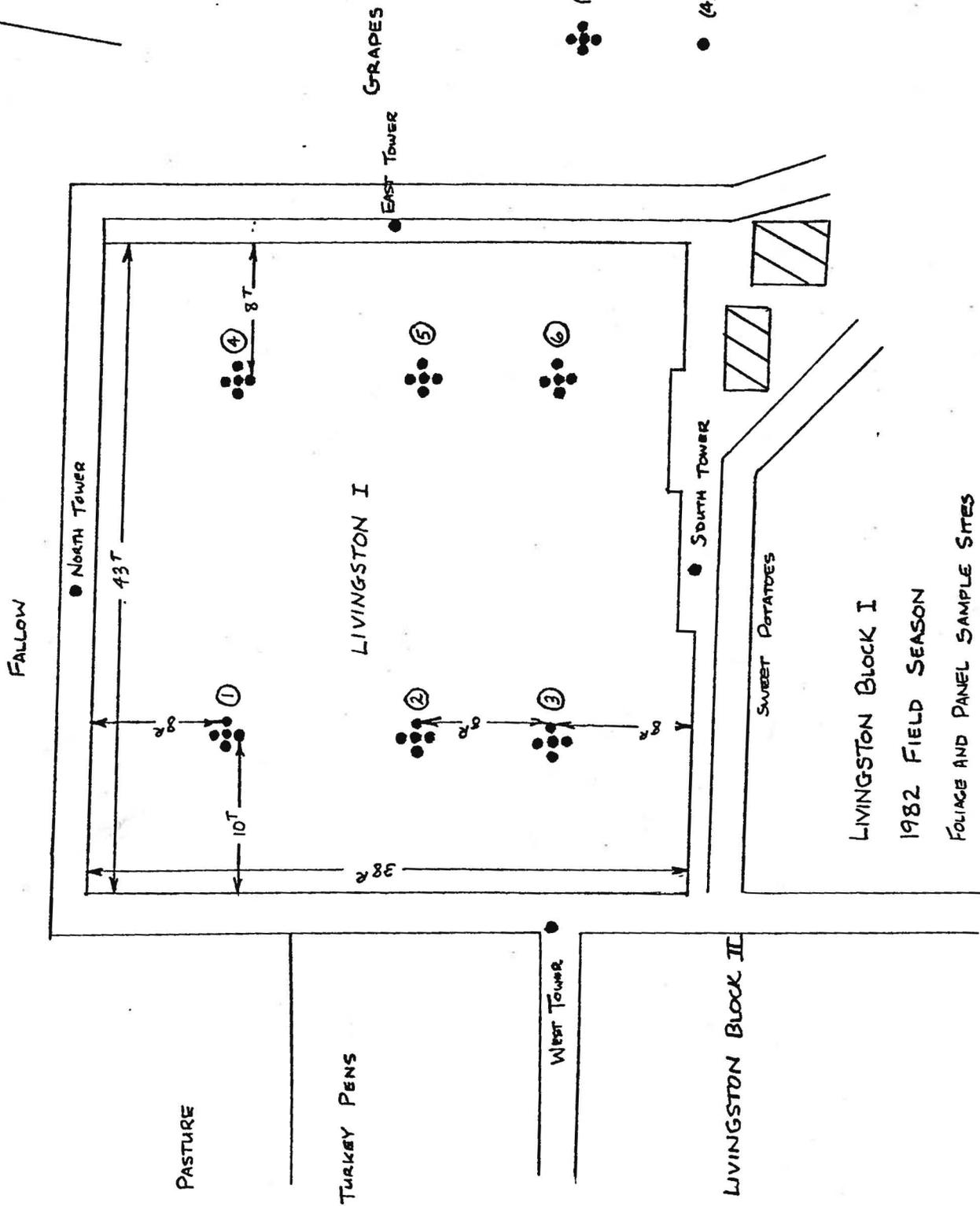
washed and reused. Two complete sets of panels were made so that panels were continuously present from May 5 until September 1 outside Block I, and from May 26 until August 11 outside Block III.

The same size panels were also hung inside the orchard using a rope and pulley system so that farm equipment could be driven down the rows (Fig. 5). The panels were used to monitor movement of spider mites and predators within the orchard. Leaf samples were taken in each block as well so that the relationship between the numbers of mites on the foliage and the number on the panels could be determined. Five trees were sampled near each of the six hanging panels. Ten leaves were sampled from each of the 5 trees, brushed and counted. Data were recorded for the "cluster" of five trees.

RESULTS

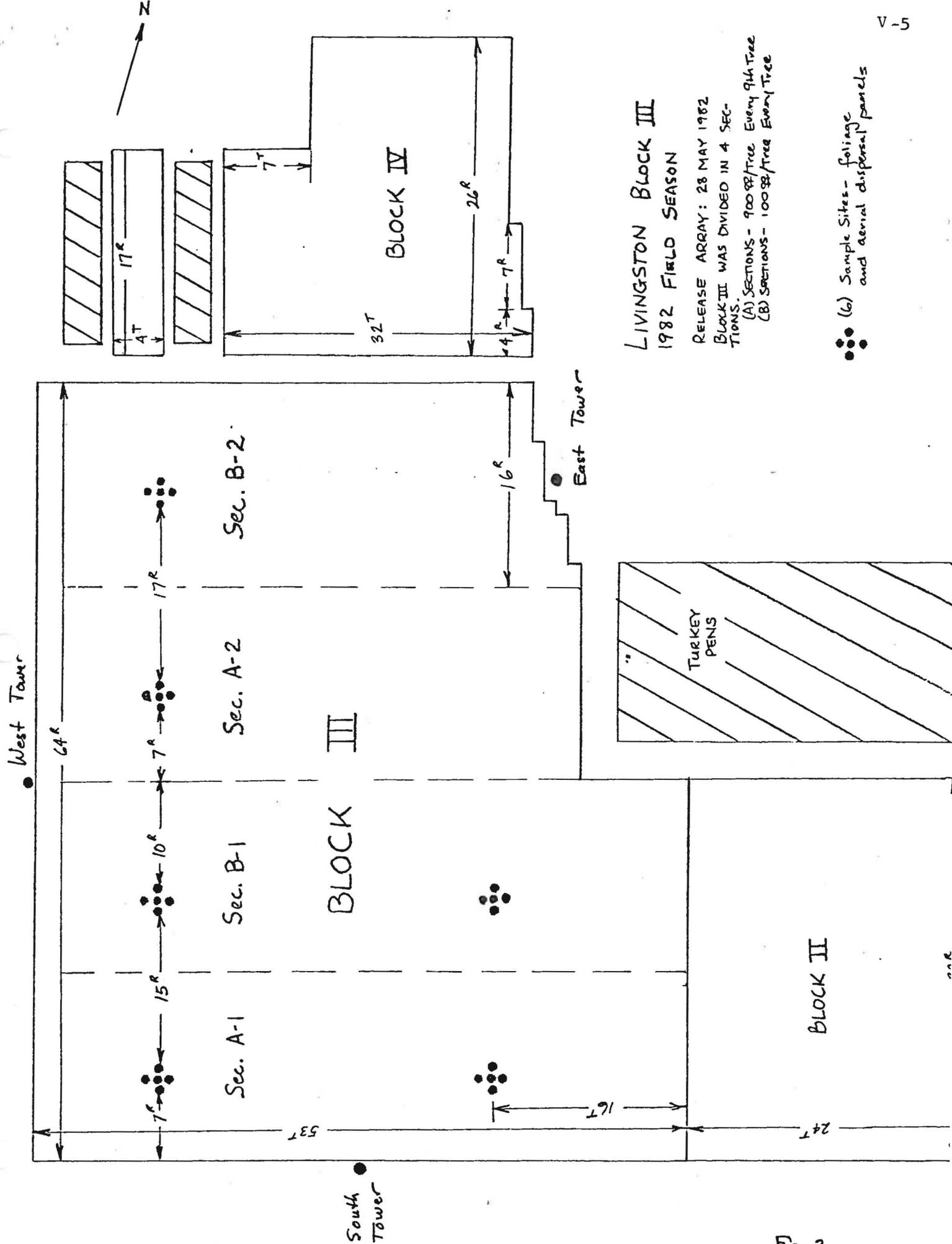
Data are still being analysed, but the preliminary findings indicate that substantial aerial dispersal of both spider mites and predators occurred in the two almond orchards during 1982.

MOVEMENTS INTO AND OUT OF THE ORCHARD -- More than 90% of the M. occidentalis collected on greased panels were adult females. In the Livingston-I almond orchard, no predators were found on greased panels outside the orchard until the July 7-14 sample interval and all movements ceased by the September 1 sample interval (Table 1).



LIVINGSTON BLOCK I
 1982 FIELD SEASON
 FOLIAGE AND PANEL SAMPLE SITES

11
 45.1

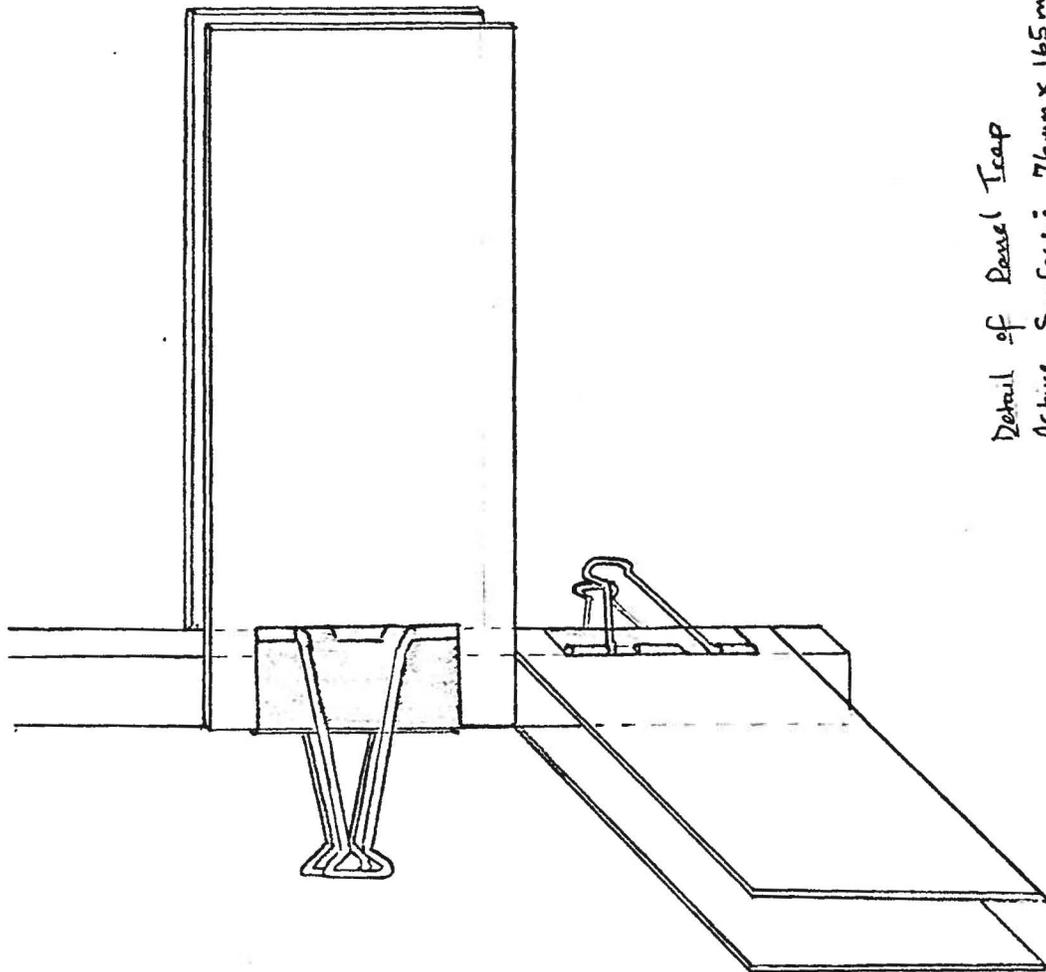


LIVINGSTON BLOCK III
1982 FIELD SEASON

RELEASE ARRAY: 28 MAY 1982
BLOCK III WAS DIVIDED IN 4 SECTIONS.
(A) SECTIONS - 900 FT/Tree Every 9th Tree
(B) SECTIONS - 1000 FT/Tree Every Tree

(6) Sample Sites - foliage and aerial dispersal panels

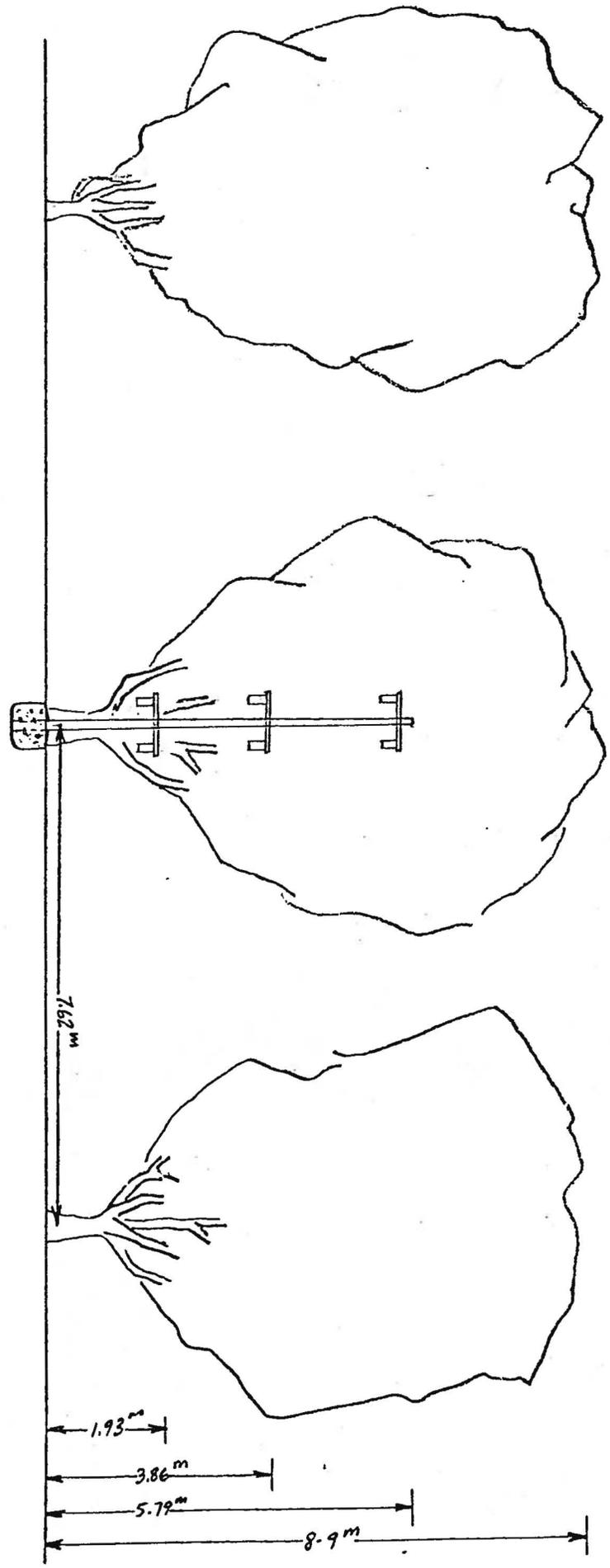
Fig. 2



Detail of Panel Trap
Active Surface: 76 mm x 165 mm

Fig. 3

Fig. 4. Design and location of towers with greased panels located outside the Livingston (I and III) almond orchards during 1982.



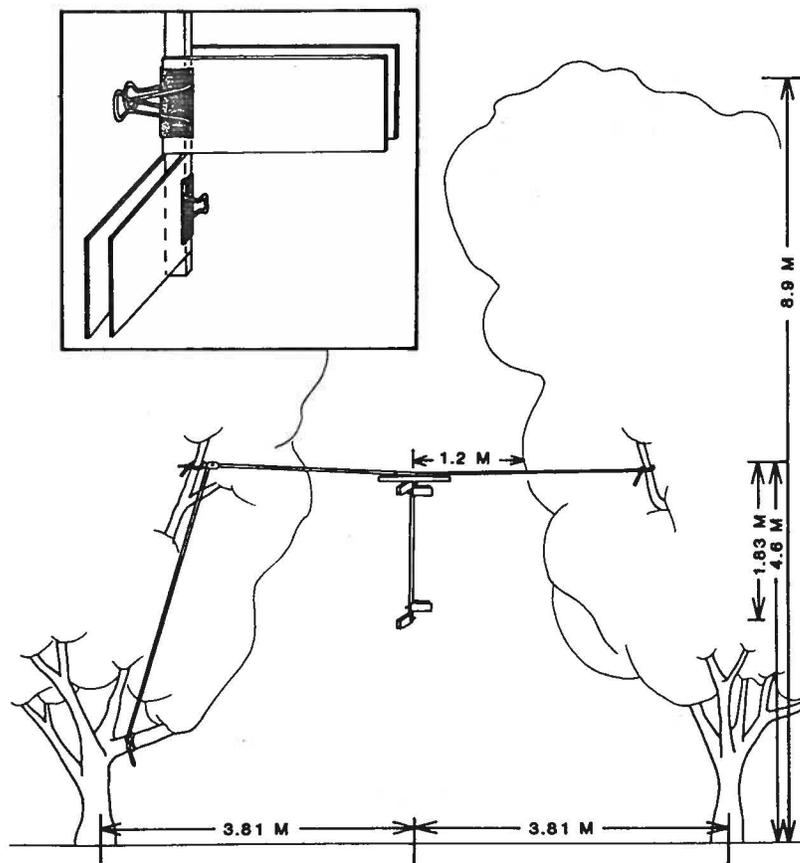


Fig. 5. Design of rope and pulley system for greased panels placed inside Livingston I and III almond orchards - 1982. Inset shows how clear plexiglass panels were fixed to the wooden poles by clips. Only the outside surface was greased to trap mites.

Over the entire season, more mites left the orchard on the south and east side of the orchard. A mean of 7 M. occidentalis females/square foot of panel were collected from panels facing the north side of the orchard; a mean of 8 moved out of the orchard on each square foot of panel on the west side of the orchard. In contrast, 144 and 100 females per sq. foot of panel left the orchard on the south and east sides of the block over the season (Table 1). These data support the hypothesis that prevailing winds from the north and west blow predators out on the south and east sides of the orchard. Over the season, approximately 8,100,000 M. occidentalis females left Block I (consisting of ca. 14 acres) on the south side of the orchard in the airspace sampled by the greased panels. Approximately 8,300,000 predator females left the orchard on the east side (Table 1). These numbers are incredibly large compared to the number placed in the orchard in 1981, and it is important to learn just how far these predators can go on wind currents. Because we did not sample at measured distances from the orchard and did not have marked predators, it is not possible to conclude what impact these pesticide resistant predators might have on adjacent vineyards/orchards.

Equally huge numbers of spider mites moved out of Block I during 1982. Aerial movements of spider mites (predominately adult female Tetranychus pacificus or T. urticae) began in May and June and continued until the September 1 sampling interval, although the peak movements occurred in late July and early August (Table 1). Most spider mites left on the south side of the orchard, as expected if prevailing winds from the northwest were the primary factor in aerial movements of these females. A total of

170 million spider mites left the south side of the orchard over the season in the space sampled by the greased panels (Table 1). These numbers are substantial and should have impact on neighboring orchards and vineyards.

Movements out of Livingston-III were less dramatic than from Livingston-I (Table 2), perhaps because it is less isolated than Block I (Fig. 6). Peak predator movements occurred in late July, and an estimated total of 40, 30, and 97 million M. occidentalis females left Block III over the season (May 26 to August 18) from the South, west and east sides of the block (Table 2). (The north side of the block was not sampled.)

Peak spider mite movements occurred in July as well (Table 2). There, as in Block I, more spider mites left on the orchard on the south and east sides (Table 2), and total of one billion one hundred million spider mites left the orchard on the east side over the season.

MOVEMENTS WITHIN THE ORCHARDS-- Large numbers of spider mites and predators moved within both blocks I and III during 1982 (Tables 3,4).

The data are summarized for the 96 panels located at two heights, for all 4 directions, and for all 6 sites in each block. Statistical analysis (t test) indicated there were no differences in the numbers of spider mites/predators on the greased panels at the two heights. Nor were there substantial differences in the numbers of spider mites and predators on the panels facing north, south, east or west within the orchard (ANOVA). Thus, it appears that the prevailing winds from the northwest had little impact on mite movements within the orchards, probably because the winds are more turbulent within the orchard.

Table 1. Aerial Movements of Mites out of Block I - Livingston, California
Almond Orchard - 1982.

Panel date placed	Mean spider mites/ft ² on greased panels on towers on the				Mean spider mites/ft ² on greased panels on towers on the			
	N	S	W	E side	N	S	W	E side
May 8-5	0.0	-	-	-	0.0	-	-	-
-11	6.9	-	-	-	0.0	-	-	-
-19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
June -2	0.0	1.2	4.6	0.0	0.0	0.0	0.0	0.0
-16	2.3	2.3	0.0	0.0	0.0	0.0	0.0	1.2
July -7	6.9	31.8	1.2	3.5	0.0	1.2	0.0	0.0
-14	32.2	846.2	108.1	101.2	5.8	11.5	0.0	2.3
-28	-	1082.2	66.7	96.6	-	27.6	4.6	5.8
Aug. 8-4	27.6	1105.2	27.6	71.3	1.2	50.6	1.2	13.8
-11	12.7	48.3	4.6	81.7	0.0	47.2	2.3	74.8
8-20	0.0	21.9	0.0	5.8	0.0	5.8	0.0	2.3
Sept.-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
* Season total	89	3141	201	360	7	144	8	100

** Total mites

leaving	5.0×10^6	1.7×10^8	1.7×10^7	3.0×10^7	3.9×10^5	8.1×10^6	6.6×10^5	8.3×10^6
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* Estimate of number of mites/square foot leaving the orchard over the season on the N,S,E, or W sides, respectively.

** Estimate of the number of mites leaving orchard over the season within a rectangular air space 645 ft. x 12 ft. on the North and South sides of the orchard and 950 ft. x 12 ft. on the East and West sides of the orchard.

Table 2. Aerial Movements of Mites out of Block III - Livingston, California
Almond Orchard - 1982.

Panel date placed	Mean spider mites/ft ² on greased panels on towers on the			Mean spider mites/ft ² on greased panels on towers on the		
	S	W	E side	S	W	E side
May 26	3.5	0	2.3	0	0	0
June 2	2.3	0	2.3	0	0	0
16	3.5	2.3	2.3	0	0	0
23	49.5	18.4	17.3	1.2	0	0
July 1	246.1	8.1	64.4	0	0	1.2
7	364.3	39.1	258.8	2.3	0	0
14	488.8	40.3	692.3	51.8	0	15.0
21	503.7	29.9	1761.8	93.2	2.3	59.8
28	327.8	258.8	5462.5	213.9	186.3	653.2
Aug.8-11	6.9	9.2	4.6	2.3	0	3.5
* Season total	2113	406	8269	365	232	721
** Total mites leaving	2.3×10^8	5.4×10^7	1.1×10^9	4.0×10^7	3.1×10^7	9.7×10^7

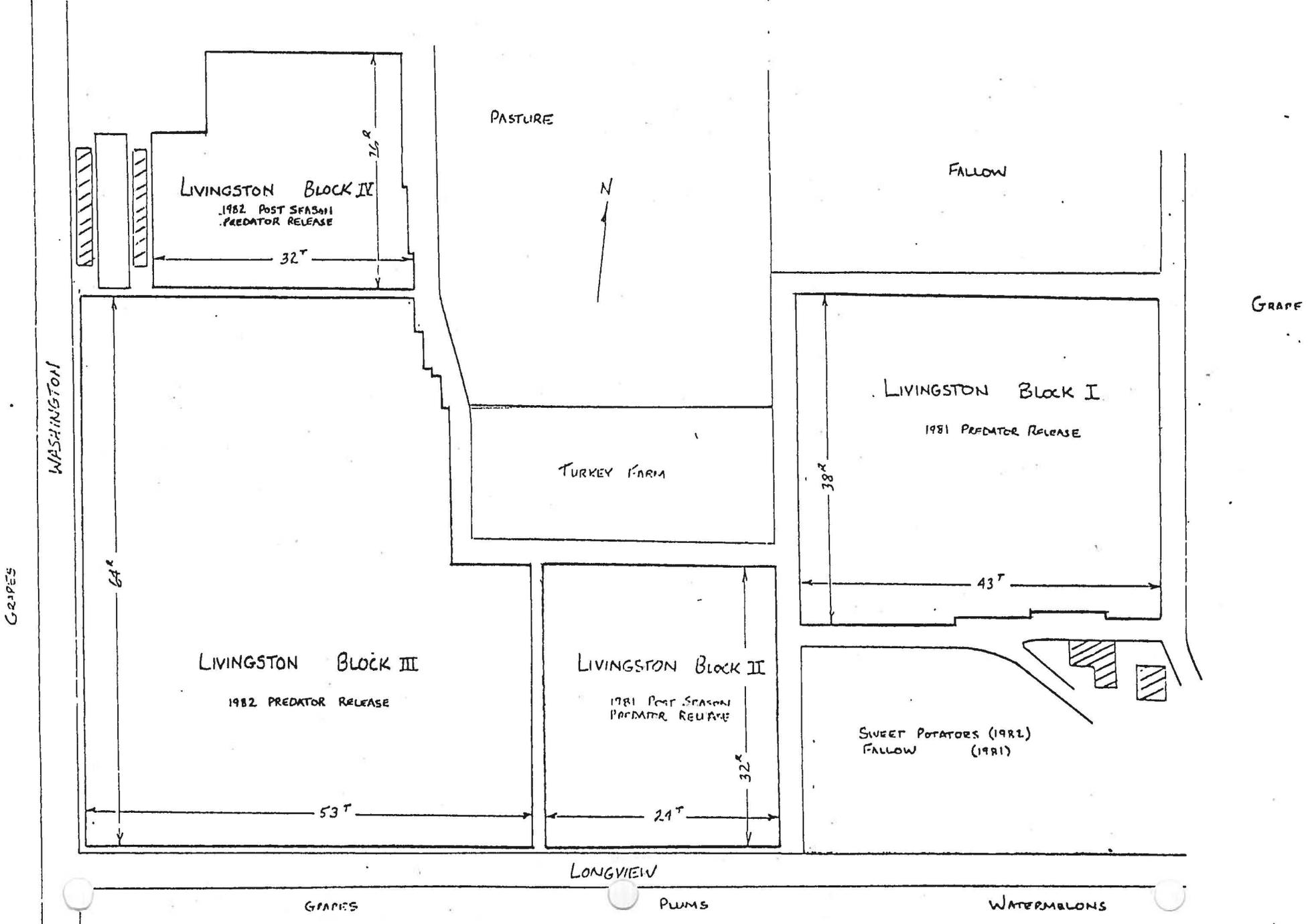
* Estimate of the number of mites/ square foot leaving the orchard over the season on the North, South, West, or East sides respectively.

** Estimate of the number of mites leaving the orchard over the season within a rectangular air space 1272 ft. x 12 ft. on the North and South sides of the orchard and 1536 ft. x 12 ft. on the East and West sides of the orchard.

LIVINGSTON ALMONDS

PREDATORY MITE RELEASE BLOCKS

Fig. 6



Tables 3 & 4 show that movement of spider mites occurs earlier in the season than it does for predators in both blocks I and III, and that large numbers of spider mites and predators are moving in the air between trees within the orchard. Thus, "orchard hot spots" can serve as a focus of infection for the surrounding orchard for both predators and spider mites.

RELATIONSHIP BETWEEN FOLIAGE COUNTS AND MITES ON PANELS-- Figs. 7 & 8

illustrate the pooled foliage counts for spider mites and predators in Blocks I and III.

In Livingston I, spider mite densities (about 5 active stages per leaf) peaked on August 4; predator densities (about 1.1 active stages/leaf) peaked on the same date. Predator numbers peaked on the foliage during the August 4 - August 11 interval (44.6 M. occidentalis females/square foot of panel). Spider mite densities peaked during the July 28 - August 4 interval (399.8 spider mites/sq. foot panel). The relationship is close and indicates there is a relationship between the number of mites on the foliage (Fig. 7, Table 3) and the mites on greased panels located within the orchard.

A similar pattern was observed in Livingston III (Fig. 8, Table 4). Buildup of both spider mites and predators on the foliage was reflected in the relative numbers obtained on the panels.

Similar close relationships exist between the numbers of spider mites and predators on the foliage and the numbers on the panels located on the towers outside the orchard.

Table 3. Within the Livingston-I Almond Orchard - 1982.

Date panels placed in orchard	Mean mites/ft ² panel ^a	
	Spider mites ^b	<u>M. occidentalis</u> ^c
April 22	0.0	0.0
28	0.0	0.0
May 5	2.3	0.0
11	0.1	0.0
19	0.3	0.2
June 2	14.9	0.0
16	9.0	0.0
July 7	143.3	2.4
14	481.7	3.7
28	399.8	17.5
Aug. 4	244.1	44.6
11	11.7	17.7
20	7.4	2.1
Sept. 1	2.1	0.4

a. These estimates are based on the number of mites on the 96 greased panels at 6 sites, facing all 4 directions at 2 heights.

b. Primarily Tetranychus urticae or T. pacificus adult ♀♀.

c. primarily adult ♀♀.

Table 4. Estimates of Mite Movement within the Livingston - III Almond Orchard - 1982.

Date panels placed in orchard		Mean mites/ft ² panel ^a	
		Spider mites ^b	<u>M. occidentalis</u> ^c
May	26	0.5	0.0
June	2	12.7	0.0
	16	34.2	1.5
	23	42.1	0.8
July	1	100.4	4.5
	8	-	5.8
	14	129.6	18.9
	21	43.6	8.0
	28	43.1	23.4
Aug.	11	4.7	3.1

a. These estimates are based on the number of mites on the 96 greased panels at 6 sites, facing 4 directions at 2 heights.

b. Primarily T. urticae or T. pacificus adult ♀♀.

c. Primarily adult ♀♀.

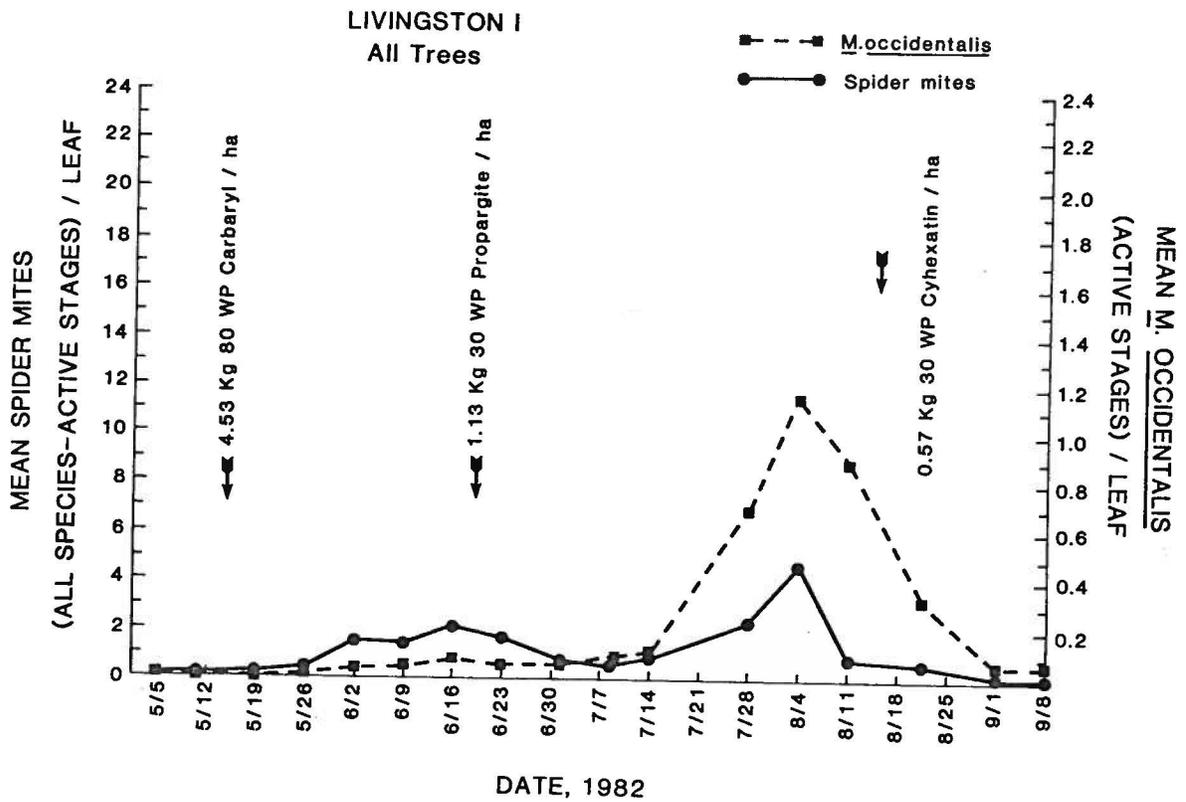


Fig. 7. Mean mites (active stages) per leaf for all sample trees pooled in the Livingston-I almond block - 1982. Carbaryl-OP resistant M. occidentalis were released in 1981.

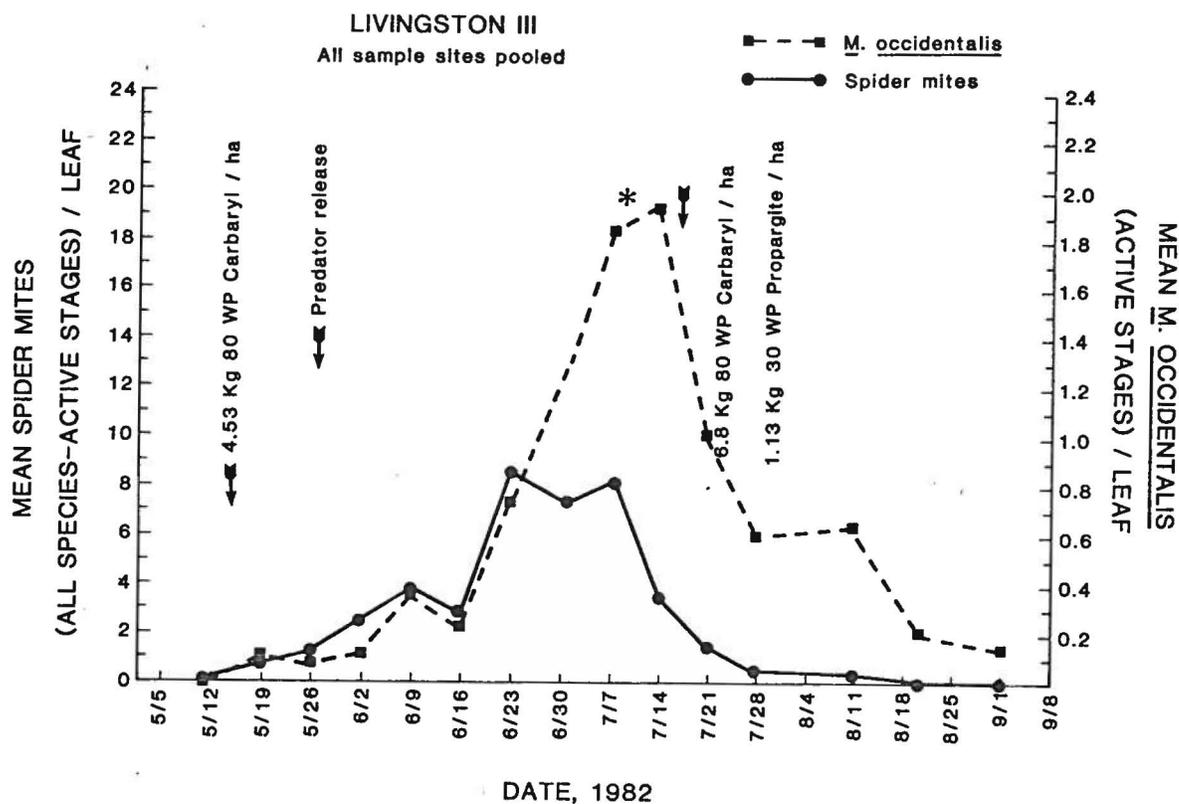


Fig. 8. Mean mites (active stages) per leaf in Block III, Livingston almond orchard - 1982. Carbaryl-OP-sulfur resistant *M. occidentalis* were released in late May - 1982.

* After this date, samples from 2 of the 6 sample sites were excluded from the graph because they were accidentally treated with azinphosmethyl.

VI-Selection of Multi-Resistant Predators.

The enclosed MS describes the progress to date in developing the carbaryl-OP-permethrin and carbaryl-OP-sulfur resistant predator strain. The MS was submitted to the VI International Congress of Acarology, Edinburgh, in August 1982.

The laboratory tests indicate these resistant strains have normal longevity, productivity, sex ratios, and development rates under the conditions of these tests and field testing of these strains is therefore justified.

Genetic Improvement of a Biological Control Agent:
Multiple Pesticide Resistances and Nondiapause in Metaseiulus
occidentalis (Nesbitt) (Phytoseiidae)

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INTRODUCTION

The preliminary aspects of a genetic improvement program utilizing an organophosphorus (OP) resistant strain of Metaseiulus occidentalis (Nesbitt) were described briefly at the V International Congress of Acarology in East Lansing, Michigan (Hoy & Knop 1979). Since then, this effective predator of spider mites was selected in the laboratory for carbaryl and permethrin resistances (Hoy 1979; Hoy & Knop 1981; Roush & Hoy 1981a) and a naturally-acquired sulfur resistance was discovered in San Joaquin Valley California vineyard populations (Hoy & Standow 1982). Carbaryl and sulfur resistances are determined by major semidominant genes (Roush & Hoy 1981a; Hoy & Standow 1982; Roush & Plapp 1982), whereas permethrin resistance is polygenically determined (Hoy & Knop 1981). The laboratory-selected carbaryl-OP and permethrin-OP strains established, survived pesticides, overwintered, dispersed, and had measurable impact on spider mite populations in apples, pears, and almonds in California, Washington and Oregon (Hoy et al. 1980; Roush & Hoy 1981b; Hoy et al. 1982 a,b; Hoy 1982).

This paper describes the development of carbaryl-OP-sulfur, carbaryl-OP-permethrin, and nondiapause-carbaryl-OP resistant strains through laboratory crosses and selection. Their fecundity, longevity, sex ratio,

and development rate are compared with the strains from which they were derived and a wild strain under controlled laboratory conditions. In addition, selection progress with two lines of permethrin-resistant M. occidentalis is reported.

MATERIALS AND METHODS

Selection using adults for permethrin resistance--The permethrin-OP resistant strain (WA series) has been selected periodically since Hoy & Knop (1981) reported the results to the 18th selection. A total of twenty-nine selections have been completed (WA-29), using adult females on sprayed bean leaf (Phaseolus vulgaris L) discs, as described by Hoy & Knop (1981).

Selection using immatures for permethrin resistance--The permethrin-OP resistant strain was divided into two lines at selection 11. Selection on one continued using adults only (WA series); the second (Immature Selection-11) was selected using larvae, protonymphs, deutonymphs and males with a wet filter paper technique described by Roush & Hoy (1981a) or an occasional selection of adult females on sprayed bean leaf discs. Selections 11-16 and 34-37 used an average of 725 mites (range: 375-1425) at 2 g AI permethrin/100 liters water; selections 17-33 used 4 g.

Carbaryl-OP-sulfur resistant strain--Beginning in January 1981, the carbaryl-OP resistant strain (Roush & Hoy 1981a) was selected with both sulfur and carbaryl. Since the carbaryl-OP strain had been developed from a mixture of colonies obtained from vineyards and orchards, the sulfur resistance described by Hoy & Standow (1982) was present. Larvae are the only stadium of M. occidentalis susceptible to sulfur (Hoy & Standow 1982). An average of 400 newly-hatched larvae were placed, 5 each per one-cm diam. bean leaf disc that had been dipped in 380 g AI sulfur (80 WP)/100 liter water and air dried.

Tetranychus urticae (Koch) were provided as prey to the survivors, which were left on the sulfur-treated discs until they reached adulthood. Gravid females were then placed on a fresh leaf disc and sprayed with carbaryl (2.4 g AI/1. water). After selection 2, females were selected with sulfur as larvae (20/disc) and carbaryl as adults (5/disc) every 3-6 months.

Carbaryl-OP-permethrin resistant strain--The carbaryl and Immature Selection (resistant) strains are OP resistant, so selection of adult females was conducted with both carbaryl and permethrin on sprayed leaf discs. Immature Selection-28 virgin females (175) were mated to carbaryl-OP males (75) in August 1980. F₁ females were not selected; virgins were backcrossed to Immature Selection males and kept as one subline, or some produced F₂ progeny and were kept as a separate subline. In the first selections, females were tested either with permethrin or carbaryl, but not both. Females from the F₂ and backcross sublines were tested with 1 g AI permethrin/100 l. water (364 & 271 females). F₃ and backcross females were selected with 2.4 g carbaryl/1. (436 & 405 females). F₄ and backcross progeny were tested with 1 g permethrin (299 and 271 females), and F₅ and backcross females were tested with 2.4 g carbaryl (175 & 671 females). In the next generation, all females were selected with both carbaryl (2.4 g) and permethrin (1 g); 807 females were selected with permethrin and the 300 survivors were selected with carbaryl. Survivors of both sublines were pooled and 1225 progeny females were treated with 2 g permethrin. The next selection of 1040 females was with carbaryl, and in all succeeding selections females were tested with both materials (see Table 1 for doses and numbers tested subsequently).

Non-diapause-carbaryl-OP strain--Two different colonies of non-diapausing (ND) M. occidentalis were selected. A colony collected from a California

pear orchard (Bill Jones, Hoy & Knop, 1979) was selected by placing 100 females on each of 3 paraffin-coated paper discs at 26°C under an 18 h daylength in October, 1978. After 2 days, the 3 colonies were placed into a temperature cabinet (Percival E-30 B) at 19°C under an 8 h daylength and fed all stages of ND T. urticae brushed from bean plants. These conditions induce a reproductive diapause in more than 80% of adult females (Hoy & Flaherty 1970; Hoy 1975a,b). The F₁ females' reproductive status was determined, and ND females were transferred to fresh discs and held under 8 h and 19°C. Development at these temperatures is slow, and ca. 6-8 selections are feasible/year. A second colony was developed similarly using ND females provided by R. T. Roush in January 1979 from the carbaryl-OP resistant strain.

Diapause incidence of the carbaryl-OP-ND colony was evaluated in September, 1979 at 4 and 10 h daylengths at 19°C using progeny reared from 25 females each. The number of daughters produced, and the % that oviposited was determined as well for a normal diapausing colony (unselected Bill Jones colony).

Evaluation of multiresistant strains--The carbaryl-OP, carbaryl-OP-sulfur, carbaryl-OP-permethrin, Immature Selection-35 colonies, and a colony collected in August 1981 from an apple block not treated with permethrin in Wenatchee, Washington (Block-4) were tested to determine the mean number of eggs/female/day, total productivity, and longevity of adult females at 26° (24.4-27.2°C) under an 18 h day. Young newly-emerged gravid females (50/colony) were transferred to individual leaf discs with T. urticae and scored daily until they died. Females were transferred to fresh discs weekly and males were added after 10 days since M. occidentalis may need to mate more than once to produce a full complement of eggs (Hoy, unpubl.).

Females of mixed age were removed from the same 5 stock colonies and moved every 2-4 days to fresh paraffin discs. The sex ratio of their progeny

was determined by counting adult males and females. A second estimate of sex ratio was obtained for these colonies by transferring 100 young females (except only 81 were available for the Block-4 colony) to fresh paraffin discs every 2-4 days until they died; adult progeny were counted and sexed.

Development rates of the colonies were compared using 50 eggs of known age from each colony on leaf discs with T. urticae and scoring for molts 3 x/day, or oftener, at 26°C (25-27°C range) under an 18 h daylength.

RESULTS AND DISCUSSION

Selection of adults for permethrin resistance--Additional selection of the WA colony with permethrin yielded no increase in resistance. Females selected (WA-19, 20, and 21) with 4 g AI permethrin/100 l, averaged 29, 18, and 9% survival, respectively. These low survival rates are probably because tests were conducted by a new technician. Selections 22-29 were conducted by other technicians using an average of 400 females. Survival rates were 32, 23, 75, 45, 36, 60, 54, and 65%, when females were tested with 4, 4, 2, 4, 4, 2, 2, and 4 g AI permethrin, respectively.

Selection of immatures for permethrin resistance--No large differences in resistance levels are apparent in the WA and Immature Selection series. Survival of immature stadia and males selected with 2 g AI permethrin/100 l. water in selections 11-16 was: 16, 30, 20, 35, 38, and 49%, respectively. Survival of immatures and males selected with 4 g in selections 17-30 was: 34, 39, 40, 21, 24, 41, 6, 9, 10, 7, 16, 74, 17, and 28%, respectively. Adult females tested with 4 g in selections 31-33 gave 58, 54, and 41% survival rates. Survival at 2 g for immatures and males for selection 34 was 15%. Adult females tested at 4 g in selection 35 had an 84% survival rate, and immatures and males selected with 2 g in selections 36 and 37

had 12 and 51% survival rates, respectively. The reason(s) for the low survival rates in selections 23-27 and 29-30 is not clear but may be due to several factors. There was a virus disease in the colony then (Hess & Hoy, unpublished). Survival also may be higher if a larger proportion of males are tested rather than larvae, protonymphs, or deutonymphs; thus, the age structure of the colony at the time of selection influences survival rate. Methods vary between technicians and finally, the polygenic nature of permethrin resistance may account for part of the variability.

Adult females of the Immature Selection-34 colony were tested on sprayed bean leaf discs and the LC_{50} value was 6.4 g AI permethrin/100 l. water (95% C.I. = 5.3-7.8). This value contrasts with the permethrin-susceptible Berkeley Blackberry colony: LC_{50} = 0.9 g AI/100 l. (0.7-1.1). The LC_{50} of the WA-18 line on sprayed leaf discs was 3.81 (2.53-6.62) (Hoy & Knop 1981).

Selection for carbaryl-OP-sulfur resistant strain--A colony with high levels of resistance to carbaryl, OPs, and sulfur was selected within 7 selections over a 1.5 year interval. Of 110 larvae from the carbaryl-OP resistant strain, 55% survived sulfur in selection I, and 63% of 200 larvae survived in selection II. In most subsequent selections, individuals were treated with sulfur as larvae and with carbaryl as adults. In selection III-a, 68% of 240 larvae survived sulfur and 56% of 75 females survived carbaryl. (The number selected with carbaryl is less than 68% of 240 larvae because some larvae are males and losses occur during rearing from protonymphs to adults). Susceptible (S) and resistant (R) control colonies tested with carbaryl had 2.5 and 75% survival rates, respectively. Another 400 larvae were selected with sulfur (III-b), and 68% survived; 81% of the 98 females survived carbaryl. Survivors of Selection III-a and b were pooled. In selection IV-a, 61% of 200 larvae survived sulfur and 52% of 44 females survived carbaryl; in IV-b, 56% of 345 larvae survived sulfur

and 50% of 58 females survived carbaryl. Selection V-a larvae had a low survival rate on sulfur (16%), probably due to contamination of glassware with permethrin, so their progeny were tested with carbaryl; 75% of 220 females survived. In Selection V-b, 72% of 450 larvae survived and 63% of 130 females survived carbaryl. In Selection VI, 83% of 440 larvae survived sulfur, and 75% of 150 females survived carbaryl.

The most recent selection (VII) gave 62% survival of 560 larvae; 77% of 300 females survived carbaryl. The R and S controls tested had 45 and 5% and 90 and 0% survival rates with sulfur and carbaryl, respectively. Selection VII females tested with 120 g azinphosmethyl AI/100 l. water exhibited 92% survival; thus, this strain is resistant to OPs as well.

Carbaryl-OP-permethrin resistant strain--Combining permethrin, carbaryl and OP resistances in one strain required repeated selections with permethrin and carbaryl. The F_2 and backcross progeny selected with 1 g AI permethrin/100 l. water had 34 and 51% survival rates, respectively, while a permethrin resistant (R) control had a 70% survival rate. Twenty-one and 16% of the F_3 and backcross sublines survived 2.4 g carbaryl; 50% and 0% of the R and S controls survived. Fourteen and 37% of the F_4 and backcross sublines survived 1 g permethrin, while R and S controls had 85 and 30% survival rates. The F_5 and backcross sublines had 9 and 23% survival rates on carbaryl-treated discs; R controls had a 44% survival rate. In the next generation, females were selected with permethrin and survivors were selected 2 days later with carbaryl; 54% survived permethrin and 26% subsequently survived carbaryl. R and S controls had 93 and 20% and 93 and 7% survival rates on permethrin and carbaryl. The progeny of both sublines were pooled and tested with 2 g permethrin only; 53% survived, while R and S controls had 87 and 10% survival rates. Their progeny were selected with carbaryl; 57% survived, compared to 0 and 70% of the S and R controls. Results of all subsequent

Table 1. Selection of same females with permethrin and carbaryl (2.4 g AI/ liter water) to obtain a carbaryl-OP-permethrin resistant strain of M. occidentalis.

Date and permethrin rate (g AI/100 l)	Permethrin selection				Carbaryl selection			
	No.	%	Controls;		No.	%	Controls'	
			% survival				% survival	
♀♀ survival*	Resist.	Susc.		♀♀ survival	Resist.	Susc.		
2 March 1981-(2) 6 March	660	76	75	7	380	63	73	17
6 Apr.-(2) 10 Apr.	540	78	83	7	350	82	93	7
1 June-(4) 5 June	520	56	76	0	210	76	73	0
17 Aug.-(4) 21 Aug.	767	67	87	0	396	72	83	0
24 Sept. 28 Sept.-(4)	610	70	77	0	1120	83	90	3
2 Apr.1982-(4) 6 Apr.	940	74	86	3	400	77	87	0
9 July-(4) 13 July	800	60	54	0	300	51	88	0

* Survival on permethrin assessed after 48 h; ♀♀ moved to clean paraffin discs with prey for 48 h before next selection with carbaryl. The order of selection was reversed in Sept.

selections are in Table 1.

The carbaryl-OP-permethrin colony is resistant to azinphosmethyl; 90% of the females survived when tested in February, 1982 on leaf discs sprayed with 120 g AI/100 l. water. This multiresistant strain is being evaluated in orchards during 1982.

Nondiapause-carbaryl-OP strain--Two colonies were successfully selected for nondiapause (ND). The incidence of ND females in the Bill Jones colony was low; 1/201, 4/249 and 0/210 F₁ females on the 3 paraffin discs were ND. These 5 females founded the ND Bill Jones colony which was kept at 19°C under an 8 h day from October 1978 to April 1979. It was discarded then because a carbaryl-OP-ND colony had been selected from a few apparently ND females. Of 387 carbaryl-OP progeny tested in Feb. 1979, only 4 were ND. Progeny of these females were reared at 19°C and 8 h light until September 1979 and tested at 4 and 10 h daylengths at 19°C; 89% of the carbaryl-OP females were ND at 10 h, and 95.6% were ND at 4 h. The control (unselected Bill Jones) had 9 and 38% ND females, and the 38% ND level at 4 h is probably because M. occidentalis has a photoresponse curve in which the % entering diapause declines as daylengths become shorter than 8 h (Hoy 1975a).

Field (1981) used the carbaryl-OP-ND colony to determine if it could control T. urticae on roses in greenhouses. He evaluated behavior of this ND colony and found that ND females tended not to enter "overwinter" shelters. The ND trait appears to be stable; Field evaluated the colony at 26°C and 18 h light and a high level of ND was retained as only 18% entered diapause under a 10 h photoperiod at 19°C after 18 months without selection (Field 1981).

Evaluating multiresistant strains--No large differences in fecundity

existed in the colonies tested, especially over the first 7 days when most of the total egg production occurs. Carbaryl-OP females deposited 2.5 (S.D.=.42); carbaryl-OP-sulfur 2.7 (.35), carbaryl-OP-permethrin 2.4 (.42), Immature Selection 2.4(.38) and Block-4 2.1(.57) eggs/female/day over 7 days. Mean egg production (S.D.)/female/day over their entire lifetime was: 2.3(.41), 2.4(.48), 1.95(.5), 2.0(.4) and 2.0(.62) for the carbaryl-OP, carbaryl-OP-sulfur, carbaryl-OP-permethrin, Immature Selection and Block-4 females. Total egg production (S.D.) over their lifetimes was: 25.6(9.5), 22.9(6.8), 27.8(14.1), 25.3(11.5) and 13.4(8.5), for these colonies at 26°C. Total eggs deposited by the carbaryl-OP-permethrin females (27.8) was higher than expected if projections are made based on the mean number of eggs/day; this is because carbaryl-OP-permethrin females lived longer to deposit more eggs.

Longevity of adult females varied; 50% of Block-4 females died within 6 days after becoming adults and 100% died by day 18, hence productivity was reduced. The reasons for this are unknown, but the females could have been virus diseased (Hess & Hoy, Unpubl.). The carbaryl-OP-permethrin females lived longest: 50% died by day 16.5 and 100% died by day 32. Next in longevity was the Immature Selection-35 colony; 50% died by day 14 and 100% by day 26. The carbaryl-OP-sulfur and carbaryl-OP colonies were similar in survival rates; 50% died by day 11 and 100% were dead by day 20.

Development rate at 26°C among the colonies did not differ substantially. Mean hrs (S.D.) for eggs to hatch: carbaryl-OP 60 (4.4), carbaryl-OP-sulfur 58 (4.3), carbaryl-OP-permethrin 56.7 (3.2), Immature Selection 58.2 (4.3), Block-4 57 (3.6), and Modesto almonds 56 (1.4). Time (S.D.) from egg to protonymph averaged 80.6 (3), 78.5 (3.5), 77.9 (2.9), 79.3 (4.8), 76.1 (3.3), and 74.7 (2.2) hrs, respectively. Because it was difficult to be sure when males became adults without checking the number of exuvia (which was impractical with 250 discs being checked at least 3X a day) hrs to adulthood

was calculated for females only; carbaryl-OP 129.9 (5.8), carbaryl-OP-sulfur 125.1 (6.7), carbaryl-OP-permethrin 123.2 (4.6), Block-4 122 (9.4), and Modesto almonds 119 (5.1). The two "wild" colonies tested (Block-4 and Modesto almonds) have the most rapid development, but the maximum difference (between them and the carbaryl-OP colony) was 10.9 hrs, which may not be significant under field conditions.

Sex ratio of the colonies varied over time among tests and among strains, but the significance of this is unclear. Progeny of 100 females of mixed age had sex ratios (female:male) as follows: carbaryl-OP (2.42 and 3.02 for transfers 1 & 2), carbaryl-OP-sulfur (2.57 & 2.10), carbaryl-OP-permethrin (1.63 & 2.67), Immature Selection-35 (2.13 & 3.28), and Block-4 (2.4 & 2.83), based on 111-328 progeny/colony/transfer.

The sex ratio of progeny from 6-8 transfers of 100 young females (until they died) from each of the colonies also varied. For the carbaryl-OP stock, sex ratios of progeny from 6 transfers were: 1.44, 2.0, 2.44, 1.97, 1.55, and 1.75. The overall average was 2.10. For the carbaryl-OP-sulfur colony, sex ratios were: 1.5, 1.84, 2.23, 1.81, 1.92, and 1.5, averaging 1.97. Carbaryl-OP-permethrin: 1.39, 1.47, 2.21, 1.85, 2.0, 2.7, and 2.0, averaging 1.86. Immature Selection: 0.63, 1.56, 1.98, 1.50, 2.53, 2.20, 5.50 and 1.0, averaging 1.78. Block-4: 1.35, 1.78, 2.10, 2.22, 1.94, 3.33, 4.0, and 2.33, averaging 1.99. Ratios are based on 47-387 progeny/transfer/colony. The counts also estimated the number of adult progeny produced by each female/day for 8 days: carbaryl-OP (1.93 adult progeny/female/day), carbaryl-OP-sulfur (1.52), carbaryl-OP-permethrin (1.56), Immature Selection-35 (1.47) and Block-4 (1.12).

SUMMARY

Strains of M. occidentalis that are of potential value in IPM programs have been developed through crosses and selection; they are carbaryl-OP-sulfur and carbaryl-OP-permethrin resistant, and carbaryl-OP-nondiapausing.

The apparent normality of attributes such as longevity, sex ratio, productivity, and development rate indicates the strains should be field tested,

REFERENCES

- Field, R. P. (1981) Ph.D. thesis, Univ. Calif., Berkeley, 116 pp.
- Hoy, M. A. (1975a) J. Insect Physiol. 21, 745-751.
- Hoy, M. A. (1975b) J. Insect Physiol. 21, 605-611.
- Hoy, M. A. (1979) In: Hoy, M. A. & McKelvey, J. J., (eds.) Genetics in relation to insect management, Rockefeller Found. Press, N.Y. 106-115.
- Hoy, M. A. (1982) Ent. Exp. Appl. (in press).
- Hoy, M. A. & Flaherty, D. L. (1970) Ann. Entomol. Soc. Am. 63, 960-963.
- Hoy, M. A. & Knop, N. F. (1979) Rec. Adv. Acar. I, 89-94.
- Hoy, M. A. & Knop, N. F. (1981). Ent. Exp. Appl. 30, 10-18.
- Hoy, M. A., Knop, N. F., & Joos, J. L. (1980) Calif. Agric. 23, 11-12.
- Hoy, M. A. & Standow, K. A. (1982) Ent. Exp. Appl. 31, 316-323.
- Hoy, M. A., Barnett, W. W., Reil, W. O., Castro, D., Cahn, D., Hendricks, L. C., Coviello, R., & Bentley, W. J. (1982a). Calif. Agric. 36(1-2), 8-10.
- Hoy, M. A., Westigard, P. H., & Hoyt, S. C. (1982b). J. Econ. Entomol. (in press).
- Roush, R. T. & Hoy, M. A. (1981a) J. Econ. Entomol. 74, 138-141.
- Roush, R. T. & Hoy, M. A. (1981b) J. Econ. Entomol. 74, 142-147.
- Roush, R. T. & Plapp, F. W. (1982). J. Econ. Entomol. 74, 304-307.

VARIABILITY IN OP RESISTANCE LEVELS OF NATIVE M. OCCIDENTALIS
FROM SAN JOAQUIN VALLEY ALMOND ORCHARDS

Colonies of Metaseiulus occidentalis were collected during 1980, 1981 and 1982 from several almond orchards. These colonies were reared in the laboratory and tested in the fall, 1982 with Guthion (azinphosmethyl) using a slide dip technique to obtain LC_{50} values. Gravid adult females are placed on their backs on sticky tape on microscope slides and dipped into distilled water solutions of azinphosmethyl (50 WP) prepared freshly each day. Doses tested were: 0.5, 1, 2, 4, 8 and 16 lbs active ingredient/100 gallons distilled water. At least 100 females were tested at each dose (20 females/slide), and control slides were dipped into distilled water. Females were scored after 48 hrs at 18 hr light at 25 C. LC_{50} values were calculated using logit analysis.

Colonies were obtained from the following sources:

Modesto almonds: 24 predators collected 2 Sept. 1981 from Stanislaus County.

Wasco almonds: collected from Hwy 46 & Palm, Kern County, 21 predators recovered on 25 May 1981.

Steffan almonds: North and Rolinda Ave., Fresno County, 60 active stages collected 30 June 1981.

Sumner-Peck Ranch: Hwy, 33 & Mountain View, Three Rocks, Fresno County, 107 actives collected 30 June 1981.

DeFreitas almonds: near Caruthers, Fresno County, collected 9 Sept. 1980.

Sunset & Dwight, Livingston: Merced County, 47 actives collected on almonds 20 August 1982.

Brawley & Manning: east of Raisin City, Fresno County, 26 actives collected from almonds 25 August 1982.

Golden State & Rd. 20: Madera County, 30 females collected from almonds 25 August 1982.

Los Banos: from Hwy 152 & Rd. 16, 10 females collected from almonds August 25, 1982.

Two other colonies were tested at the same time as comparisons for resistance levels:

Raven: a colony collected from a Fresno County vineyard, June 1980.

Carbaryl-OP-sulfur: laboratory strain resistant to Sevin, OP and sulfur.

LC₅₀ values given in Table 1 indicate that low to high levels of resistance to Guthion are present in colonies of M. occidentalis collected from San Joaquin Valley almond orchards. The lowest value (1.21 lbs a.i./100 gallons) and the highest (10.33) are from orchards located in the central part of the Valley. LC₅₀ values of predators from the rest of the orchards vary around 2 to 4 lbs.

Like the variability seen in surveys of M. occidentalis from pear orchards and vineyards, these variable LC₅₀ values probably reflect differing pesticide treatment histories for the orchards, although treatment histories were not obtained for these orchards. What do these values mean for Almond IPM?

It is difficult to translate laboratory-derived LC₅₀ values into actual field doses the predators will survive. However, we know that the LC₅₀ value of the carbaryl-OP-sulfur resistant strain (6.57 lbs. azinphosmethyl/100 gallons water) gives sufficient resistance to allow survival at field doses of Guthion, Imidan, or diazinon in almond orchards. The lower levels

exhibited by native populations (in the 1-2 lb range) might indicate that Guthion would kill a proportion of the native predators under field conditions. This may or may not induce spider mite outbreaks, as the OP resistance levels of the spider mites in almond orchards also may vary. For example, during the 1982 field season azinphosmethyl was accidentally applied to 2 of 6 sample sites in the Livingston III block; this application killed the resident spider mites and the predators were suddenly out of food and their population crashed.

Releases of predators (such as the carbaryl-OP-sulfur resistant strain) with known high levels of OP resistance would be beneficial to almond growers that currently lack predators in their own orchards, or that have had disruptions of predators following OP applications. The precise benefit to an individual grower of releases of the carbaryl-OP-sulfur resistant strain would depend upon the number and resistance levels of the native predators already present in the grower's orchard. However, it is clear that such releases are unlikely to lower the resistance levels of the native predators and such releases may also provide more thorough distribution of these spider mite predators.

Table 1. LC_{50} values for M. occidentalis colonies tested for Guthion resistance -
Fall, 1982

Colony	No. tested	$LC_{50}^{a/}$	95% limits	LC_{90}	95% limits
Modesto almonds	598	8.69	-	22.77	-
Steffans almonds	599	1.21	-	105.03	-
DeFreitas almonds	698	10.33	-	240.92	-
Wasco almonds	498	2.48	1.39-3.45	8.79	5.75-26.34
Summer-Peck Ranch	620	4.42	2.45-7.60	39.68	18.09-266.94
Sunset & Dwight	500	3.04	1.41-4.60	18.64	10.04-134.65
Brawley & Manning	600	3.25	1.63-6.51	43.12	15.03-1702.62
Golden State & Rd. 20	600	4.49	3.35-5.32	8.64	6.93-15.38
Los Banos	496	2.75	1.39-5.03	16.02	7.52-204.30
Carbaryl-OP-sulfur	600	6.57	4.25-9.18	22.81	14.22-93.34
Raven vineyard	500	6.46	-	24.89	-

a/ lbs. active ingredient azinphosmethyl (Guthion 50 WP)/100 gallons water.

The following is a draft of a handout designed to be given to people interested in releasing pesticide-resistant predators (Metaseiulus occidentalis) into orchards or vineyards.

RELEASING PESTICIDE RESISTANT SPIDER MITE PREDATORS

Metaseiulus occidentalis (Nesbitt) is also called Typhlodromus occidentalis. It is a predaceous mite in the family Phytoseiidae and is found in the western U.S.A. in deciduous orchards (pears, apples, almonds, walnuts, etc.) and vineyards. It has varying levels of organophosphate (OP) insecticide resistance (Guthion, diazinon, Imidan, Cygon), probably depending upon past treatment history in each site, although some populations are susceptible to OPs. No native populations of this predator are resistant to Sevin or to the new synthetic pyrethroids such as Ambush/Pounce or Pydrin. These materials will kill most of the predators, and spider mite outbreaks often follow.

This predator is most effective as a predator of the Pacific, twospotted, Atlantic, or Willamette spider mites. It also feeds on pear rust mites and other eriophyid mites. It will feed on European red mites and citrus red mites, but is not a fully effective predator of them.

Through laboratory selection, two new strains of this predator are now available. One is resistant to Sevin-OP-sulfur pesticides, and one is resistant to Sevin-OP-permethrin (Ambush/Pounce) pesticides. If these predators are established these materials can be used to control insect pests in orchards or vineyards without killing the persistent predators. If the predators survive, they can continue to control the spider mites, and fewer acaricide applications, or lower rates of acaricide applications, should be needed if the predators can do their job.

This predator does not feed on leaves, or become a pest. If spider mites or eriophyid mites are not available for it as prey, it will starve, or migrate out of the orchard or vineyard. Therefore, low numbers of prey must be kept in the orchard/vineyard at all times during the growing season or the predators will be lost. This may require that fewer acaricide applications be made, and only if there is imminent danger of damage. Unneeded acaricide treatments might be harmful if the predators are starved out as a result. The trick will be in keeping the predator-prey ratio within the range you can live with without suffering excessive damage. What that ratio is will depend on the season, how many predators and spider mites there are, how well the crop is watered, how much dust there is, and other concerns relevant to managing an orchard or vineyard. There is no simple schedule for deciding when to spray, or not to spray, for spider mites.

HOW TO RELEASE

The predators will be on soybean plants containing twospotted spider mites as prey. If the soybean plant is placed into the crotch or foliage of the tree or vine, the predators will walk off the wilting foliage and into the tree. If they find spider mites there, they will settle down and reproduce. We know that they can spread from tree to tree or vine to vine in a matter of days or weeks. The number released will probably be insufficient to control the spider mites in the first season after release; the goal is to establish them permanently in your orchard/vineyard. During this first season they should multiply, spread throughout the release tree/vine, spread

to adjacent trees/vines, and overwinter. This predator goes into a diapause (hibernation stage) and overwinters in crevices of the bark, under scale covers, in peduncles, etc. in trees. In vineyards, it seems to overwinter predominantly under the bud scales of the canes.

After release, you need to watch your orchard/vineyard carefully. Decisions to apply acaricides should be made carefully so that there are some spider mites left to provide food for the predators. We have had success applying lower-than-label rates of Omite or Plictran IF the predators are present and well-distributed, (the weather was not too hot, and the plants were not water stressed. Use of lower than label rates of acaricides is experimental.)

WHEN TO RELEASE

We anticipate the predators will be available in late July or early August. We have had poor success in establishing the predators if there were fewer than 1-2 spider mites (eggs and actives) per leaf. Less food than that seems to reduce chances of establishment. Releases made late in the season (September) may not allow multiplication of the predators after release, since they will enter diapause then. Thus, spread and dispersal may not occur well later in the season.

HOW MANY TO RELEASE?

The predators being released are not expected to control the mites in your orchard/vineyard this season; releases should be made with the idea

that they will establish and effect control in future field seasons. We have obtained establishments by releasing 250 to 1000 females/tree or vine in every third tree in every third row. In Australia, establishments of this predator have occurred with releases made into every fifth tree in every fifth row. In some cases, releases into every tree may be required to get a rapid establishment.

HOW TO MONITOR RELEASE RESULTS

There are no fast, cheap ways to sample predators and spider mites in orchards/vineyards. Leaf samples that are brushed and counted provide researchers with estimates of predator:prey ratios, but are often impractical for growers or PCAs. To determine if the predators are present, examining release trees (flagged or otherwise marked) should provide information about the presence or absence of M. occidentalis in the tree, and the relative abundance of spider mites. A hand lens is usually necessary to see M. occidentalis. (See the attached photo of an adult female M. occidentalis feeding on a twospotted spider mite nymph.)

WHAT TO SPRAY WITH

The Sevin-OP-sulfur resistant predator strain is resistant to field doses of OP insecticides such as Guthion, diazinon and Imidan. It is also resistant to Sevin, but not to Lannate. It is resistant to sulfur dusts, wettable powder sulfurs, and somewhat resistant to lime sulfur.

The Sevin-OP-permethrin resistant strain is resistant to the above pesticides (although only at a low level to sulfur), and to permethrin

(Ambush/Pounce). Permethrin resistance is determined by several genes; this means that if this predator strain interbreeds with permethrin susceptible predators, it will lose its permethrin resistance rapidly. Therefore it should NOT be released unless permethrin has been applied previously (recently) to the orchard and removed the native (susceptible) M. occidentalis.

In contrast, sulfur and Sevin resistances are determined by single dominant genes, and the progeny of susceptible and resistant parents are resistant. Therefore, it is less critical that sulfur or Sevin be applied to eliminate the native predators with the Sevin-OP-sulfur strain although it is probably useful to do so.

HOW OFTEN TO SPRAY

Establishing resistant predators will require sprays of the relevant insecticides for a season or two. Thus, to establish the Sevin-OP-sulfur strain, Sevin should be applied once a year for the first two seasons to ensure the resistance is well established. After that time, the resistant strain will probably persist with only occasional applications of Sevin. Applying Sevin to the site prior to releasing this strain is desirable as it improves the ratio of resistant (released) predators to susceptible (native) predators.

The permethrin resistant strain can only be established if permethrin is applied prior to release of the strain, and permethrin will have to be applied once a year to ensure persistence of the permethrin resistance. Occasional applications of Sevin will help retain the Sevin resistance in this strain.

The Sevin-OP-permethrin strain can tolerate low-moderate rates of permethrin (up to 0.2 lbs a.i./acre) and it has survived multiple applications of permethrin in one season in a pear plot. The permethrin resistance is not complete and permethrin applications will still partially reduce the resistant predators; thus these orchards must be monitored carefully to ensure acaricides are applied if necessary.

SELECTIVE ACARICIDES

Acaricides such as Plictran, Omite and Vendex are selective. They control spider mites but have little impact on M. occidentalis at low to moderate rates, although they will kill M. occidentalis if used at high rates. High rates (top of the label) also affect M. occidentalis indirectly by killing its prey so that it starves. Kelthane is not a selective acaricide for M. occidentalis.

Our hope is that we can learn how to MANAGE spider mites and predators better in orchards and vineyards. To do so, we need to know how many spider mites we can live with if M. occidentalis is present and well distributed in the orchard/vineyard.

We are still learning how to release and manage these new pesticide resistant strains of M. occidentalis. Your feedback to us regarding your experiences will be greatly valued. Please share your experiences with your Farm Advisor, or contact Marjorie A. Hoy, 201 Wellman Hall, Department of Entomology, University of California, Berkeley, California 94720.



Publications

- Hoy, M. A. (1982). Aerial dispersal and field efficacy of a genetically improved strain of the spider mite predator Metaseiulus occidentalis. Ent. Exp. Appl. (In press).
- Hoy, M. A. (In press). Genetic improvement of Metaseiulus occidentalis: implementing pesticide resistant strains -- progress and problems. Proc. Australasian Workshop on Development and Implementation of IPM, Auckland, New Zealand. July 1982.
- Hoy, M. A. (In press). Genetic improvement of a biological control agent: Multiple pesticide resistances and nondiapause in Metaseiulus occidentalis (Nesbitt) (Phytoseiidae). Proc. VI Intn. Congr. Acar. Edinburgh, August 1982.
- Hoy, M. A., W. W. Barnett, W. O. Reil, D. Castro, D. Cahn, L. C. Hendricks, R. Coviello and W. J. Bentley 1982a. Large-scale releases of pesticide-resistant spider mite predators. Calif. Agric. 36(1, 2): 8-10.
- Hoy, M. A., D. Castro and D. Cahn. 1982b. Two methods for large scale production of pesticide-resistant strains of the spider mite predator Metaseiulus occidentalis (Nesbitt) (Acarina, Phytoseiidae). Zeitsch. ange. Entomol. 94, H. 1, 1-9.
- Hoy, M. A., P. H. Westigard and S. C. Hoyt. 1982c. Release and evaluation of a laboratory-selected pyrethroid resistant strain of the predaceous mite Metaseiulus occidentalis in southern Oregon pear orchards and a Washington apple orchard. In press. J. Econ. Entomol.

Genetic Improvement of a Biological Control Agent:
Multiple Pesticide Resistances and Nondiapause in Metaseiulus
occidentalis (Nesbitt) (Phytoseiidae)

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INTRODUCTION

The preliminary aspects of a genetic improvement program utilizing an organophosphorus (OP) resistant strain of Metaseiulus occidentalis (Nesbitt) were described briefly at the V International Congress of Acarology in East Lansing, Michigan (Hoy & Knop 1979). Since then, this effective predator of spider mites was selected in the laboratory for carbaryl and permethrin resistances (Hoy 1979; Hoy & Knop 1981; Roush & Hoy 1981a) and a naturally-acquired sulfur resistance was discovered in San Joaquin Valley California vineyard populations (Hoy & Standow 1982). Carbaryl and sulfur resistances are determined by major semidominant genes (Roush & Hoy 1981a; Hoy & Standow 1982; Roush & Plapp 1982), whereas permethrin resistance is polygenically determined (Hoy & Knop 1981). The laboratory-selected carbaryl-OP and permethrin-OP strains established, survived pesticides, overwintered, dispersed, and had measurable impact on spider mite populations in apples, pears, and almonds in California, Washington and Oregon (Hoy et al. 1980; Roush & Hoy 1981b; Hoy et al. 1982 a,b; Hoy 1982).

This paper describes the development of carbaryl-OP-sulfur, carbaryl-OP-permethrin, and nondiapause-carbaryl-OP resistant strains through laboratory crosses and selection. Their fecundity, longevity, sex ratio,

and development rate are compared with the strains from which they were derived and a wild strain under controlled laboratory conditions. In addition, selection progress with two lines of permethrin-resistant M. occidentalis is reported.

MATERIALS AND METHODS

Selection using adults for permethrin resistance--The permethrin-OP resistant strain (WA series) has been selected periodically since Hoy & Knop (1981) reported the results to the 18th selection. A total of twenty-nine selections have been completed (WA-29), using adult females on sprayed bean leaf (Phaseolus vulgaris L) discs, as described by Hoy & Knop (1981).

Selection using immatures for permethrin resistance--The permethrin-OP resistant strain was divided into two lines at selection 11. Selection one continued using adults only (WA series); the second (Immature Selection-11) was selected using larvae, protonymphs, deutonymphs and males with a wet filter paper technique described by Roush & Hoy (1981a) or an occasional selection of adult females on sprayed bean leaf discs. Selections 11-16 and 34-37 used an average of 725 mites (range: 375-1425) at 2 g AI permethrin/100 liters water; selections 17-33 used 4 g.

Carbaryl-OP-sulfur resistant strain--Beginning in January 1981, the carbaryl-OP resistant strain (Roush & Hoy 1981a) was selected with both sulfur and carbaryl. Since the carbaryl-OP strain had been developed from a mixture of colonies obtained from vineyards and orchards, the sulfur resistance described by Hoy & Standow (1982) was present. Larvae are the only stadium of M. occidentalis susceptible to sulfur (Hoy & Standow 1982). An average of 400 newly-hatched larvae were placed, 5 each per one-cm diam. bean leaf disc that had been dipped in 380 g AI sulfur (80 WP)/100 liter water and air dried

Tetranychus urticae (Koch) were provided as prey to the survivors, which were left on the sulfur-treated discs until they reached adulthood. Gravid females were then placed on a fresh leaf disc and sprayed with carbaryl (2.4 g AI/1. water). After selection 2, females were selected with sulfur as larvae (20/disc) and carbaryl as adults (5/disc) every 3-6 months.

Carbaryl-OP-permethrin resistant strain--The carbaryl and Immature Selection (resistant) strains are OP resistant, so selection of adult females was conducted with both carbaryl and permethrin on sprayed leaf discs. Immature Selection-28 virgin females (175) were mated to carbaryl-OP males (75) in August 1980. F_1 females were not selected; virgins were backcrossed to Immature Selection males and kept as one subline, or some produced F_2 progeny and were kept as a separate subline. In the first selections, females were tested either with permethrin or carbaryl, but not both. Females from the F_2 and backcross sublines were tested with 1 g AI permethrin/100 l. water (364 & 271 females). F_3 and backcross females were selected with 2.4 g carbaryl/1. (436 & 405 females). F_4 and backcross progeny were tested with 1 g permethrin (299 and 271 females), and F_5 and backcross females were tested with 2.4 g carbaryl (175 & 671 females). In the next generation, all females were selected with both carbaryl (2.4 g) and permethrin (1 g); 807 females were selected with permethrin and the 300 survivors were selected with carbaryl. Survivors of both sublines were pooled and 1225 progeny females were treated with 2 g permethrin. The next selection of 1040 females was with carbaryl, and in all succeeding selections females were tested with both materials (see Table 1 for doses and numbers tested subsequently).

Non-diapause-carbaryl-OP strain--Two different colonies of non-diapausing (ND) M. occidentalis were selected. A colony collected from a California

pear orchard (Bill Jones, Hoy & Knop, 1979) was selected by placing 100 females on each of 3 paraffin-coated paper discs at 26°C under an 18 h daylength in October, 1978. After 2 days, the 3 colonies were placed into a temperature cabinet (Percival E-30 B) at 19°C under an 8 h daylength and fed all stages of ND T. urticae brushed from bean plants. These conditions induce a reproductive diapause in more than 80% of adult females (Hoy & Flaherty 1970; Hoy 1975a,b). The F₁ females' reproductive status was determined, and ND females were transferred to fresh discs and held under 8 h and 19°C. Development at these temperatures is slow, and ca. 6-8 selections are feasible/year. A second colony was developed similarly using ND females provided by R. T. Roush in January 1979 from the carbaryl-OP resistant strain.

Diapause incidence of the carbaryl-OP-ND colony was evaluated in September, 1979 at 4 and 10 h daylengths at 19°C using progeny reared from 25 females each. The number of daughters produced, and the % that oviposited was determined as well for a normal diapausing colony (unselected Bill Jones colony).

Evaluation of multiresistant strains--The carbaryl-OP, carbaryl-OP-sulfur, carbaryl-OP-permethrin, Immature Selection-35 colonies, and a colony collected in August 1981 from an apple block not treated with permethrin in Wenatchee, Washington (Block-4) were tested to determine the mean number of eggs/female/day, total productivity, and longevity of adult females at 26° (24.4-27.2°C) under an 18 h day. Young newly-emerged gravid females (50/colony) were transferred to individual leaf discs with T. urticae and scored daily until they died. Females were transferred to fresh discs weekly and males were added after 10 days since M. occidentalis may need to mate more than once to produce a full complement of eggs (Hoy, unpubl.).

Females of mixed age were removed from the same 5 stock colonies and moved every 2-4 days to fresh paraffin discs. The sex ratio of their progeny

was determined by counting adult males and females. A second estimate of sex ratio was obtained for these colonies by transferring 100 young females (except only 81 were available for the Block-4 colony) to fresh paraffin discs every 2-4 days until they died; adult progeny were counted and sexed.

Development rates of the colonies were compared using 50 eggs of known age from each colony on leaf discs with T. urticae and scoring for molts 3 x/day, or oftener, at 26°C (25-27°C range) under an 18 h daylength.

RESULTS AND DISCUSSION

Selection of adults for permethrin resistance--Additional selection of the WA colony with permethrin yielded no increase in resistance. Females selected (WA-19, 20, and 21) with 4 g AI permethrin/100 l, averaged 29, 18, and 9% survival, respectively. These low survival rates are probably because tests were conducted by a new technician. Selections 22-29 were conducted by other technicians using an average of 400 females. Survival rates were 32, 23, 75, 45, 36, 60, 54, and 65%, when females were tested with 4, 4, 2, 4, 4, 2, 2, and 4 g AI permethrin, respectively.

Selection of immatures for permethrin resistance--No large differences in resistance levels are apparent in the WA and Immature Selection series. Survival of immature stadia and males selected with 2 g AI permethrin/100 l. water in selections 11-16 was: 16, 30, 20, 35, 38, and 49%, respectively. Survival of immatures and males selected with 4 g in selections 17-30 was: 34, 39, 40, 21, 24, 41, 6, 9, 10, 7, 16, 74, 17, and 28%, respectively. Adult females tested with 4 g in selections 31-33 gave 58, 54, and 41% survival rates. Survival at 2 g for immatures and males for selection 34 was 15%. Adult females tested at 4 g in selection 35 had an 84% survival rate, and immatures and males selected with 2 g in selections 36 and 37

had 12 and 51% survival rates, respectively. The reason(s) for the low survival rates in selections 23-27 and 29-30 is not clear but may be due to several factors. There was a virus disease in the colony then (Hess & Hoy, unpublished). Survival also may be higher if a larger proportion of males are tested rather than larvae, protonymphs, or deutonymphs; thus, the age structure of the colony at the time of selection influences survival rate. Methods vary between technicians and finally, the polygenic nature of permethrin resistance may account for part of the variability.

Adult females of the Immature Selection-34 colony were tested on sprayed bean leaf discs and the LC_{50} value was 6.4 g AI permethrin/100 l. water (95% C.I. = 5.3-7.8). This value contrasts with the permethrin-susceptible Berkeley Blackberry colony: LC_{50} = 0.9 g AI/100 l. (0.7-1.1). The LC_{50} of the WA-18 line on sprayed leaf discs was 3.81 (2.53-6.62). (Hoy & Knop 1981).

Selection for carbaryl-OP-sulfur resistant strain--A colony with high levels of resistance to carbaryl, OPs, and sulfur was selected within 7 selections over a 1.5 year interval. Of 110 larvae from the carbaryl-OP resistant strain, 55% survived sulfur in selection I, and 63% of 200 larvae survived in selection II. In most subsequent selections, individuals were treated with sulfur as larvae and with carbaryl as adults. In selection III-a, 68% of 240 larvae survived sulfur and 56% of 75 females survived carbaryl. (The number selected with carbaryl is less than 68% of 240 larvae because some larvae are males and losses occur during rearing from protonymphs to adults). Susceptible (S) and resistant (R) control colonies tested with carbaryl had 2.5 and 75% survival rates, respectively. Another 400 larvae were selected with sulfur (III-b), and 68% survived; 81% of the 98 females survived carbaryl. Survivors of Selection III-a and b were pooled. In selection IV-a, 61% of 200 larvae survived sulfur and 52% of 44 females survived carbaryl; in IV-b, 56% of 345 larvae survived sulfur

and 50% of 58 females survived carbaryl. Selection V-a larvae had a low survival rate on sulfur (16%), probably due to contamination of glassware with permethrin, so their progeny were tested with carbaryl; 75% of 220 females survived. In Selection V-b, 72% of 450 larvae survived and 63% of 130 females survived carbaryl. In Selection VI, 83% of 440 larvae survived sulfur, and 75% of 150 females survived carbaryl.

The most recent selection (VII) gave 62% survival of 560 larvae; 77% of 300 females survived carbaryl. The R and S controls tested had 45 and 5% and 90 and 0% survival rates with sulfur and carbaryl, respectively. Selection VII females tested with 120 g azinphosmethyl AI/100 l. water exhibited 92% survival; thus, this strain is resistant to OPs as well.

Carbaryl-OP-permethrin resistant strain--Combining permethrin, carbaryl and OP resistances in one strain required repeated selections with permethrin and carbaryl. The F_2 and backcross progeny selected with 1 g AI permethrin/100 l. water had 34 and 51% survival rates, respectively, while a permethrin resistant (R) control had a 70% survival rate. Twenty-one and 16% of the F_3 and backcross sublines survived 2.4 g carbaryl; 50% and 0% of the R and S controls survived. Fourteen and 37% of the F_4 and backcross sublines survived 1 g permethrin, while R and S controls had 85 and 30% survival rates. The F_5 and backcross sublines had 9 and 23% survival rates on carbaryl-treated discs; R controls had a 44% survival rate. In the next generation, females were selected with permethrin and survivors were selected 2 days later with carbaryl; 54% survived permethrin and 26% subsequently survived carbaryl. R and S controls had 93 and 20% and 93 and 7% survival rates on permethrin and carbaryl. The progeny of both sublines were pooled and tested with 2 g permethrin only; 53% survived, while R and S controls had 87 and 10% survival rates. Their progeny were selected with carbaryl; 57% survived, compared to 0 and 70% of the S and R controls. Results of all subsequent

Table 1. Selection of same females with permethrin and carbaryl (2.4 g AI/ liter water) to obtain a carbaryl-OP-permethrin resistant strain of M. occidentalis.

Date and permethrin rate (g AI/100 l)	Permethrin selection				Carbaryl selection			
			Controls;				Controls'	
	No.	%	% survival		No.	%	% survival	
	♀♀ survival*	Resist.	Susc.		♀♀ survival	Resist.	Susc.	
2 March 1981-(2) 6 March	660	76	75	7	380	63	73	17
6 Apr.-(2) 10 Apr.	540	78	83	7	350	82	93	7
1 June-(4) 5 June	520	56	76	0	210	76	73	0
17 Aug.-(4) 21 Aug.	767	67	87	0	396	72	83	0
24 Sept. 28 Sept.-(4)	610	70	77	0	1120	83	90	3
2 Apr.1982-(4) 6 Apr.	940	74	86	3	400	77	87	0
9 July-(4) 13 July	800	60	54	0	300	51	88	0

* Survival on permethrin assessed after 48 h; ♀♀ moved to clean paraffin discs with prey for 48 h before next selection with carbaryl. The order of selection was reversed in Sept.

selections are in Table 1.

The carbaryl-OP-permethrin colony is resistant to azinphosmethyl; 90% of the females survived when tested in February, 1982 on leaf discs sprayed with 120 g AI/100 l. water. This multiresistant strain is being evaluated in orchards during 1982.

Nondiapause-carbaryl-OP strain--Two colonies were successfully selected for nondiapause (ND). The incidence of ND females in the Bill Jones colony was low; 1/201, 4/249 and 0/210 F₁ females on the 3 paraffin discs were ND. These 5 females founded the ND Bill Jones colony which was kept at 19°C under an 8 h day from October 1978 to April 1979. It was discarded then because a carbaryl-OP-ND colony had been selected from a few apparently ND females. Of 387 carbaryl-OP progeny tested in Feb. 1979, only 4 were ND. Progeny of these females were reared at 19°C and 8 h light until September 1979 and tested at 4 and 10 h daylengths at 19°C; 89% of the carbaryl-OP females were ND at 10 h, and 95.6% were ND at 4 h. The control (unselected Bill Jones) had 9 and 38% ND females, and the 38% ND level at 4 h is probably because M. occidentalis has a photoresponse curve in which the % entering diapause declines as daylengths become shorter than 8 h (Hoy 1975a).

Field (1981) used the carbaryl-OP-ND colony to determine if it could control T. urticae on roses in greenhouses. He evaluated behavior of this ND colony and found that ND females tended not to enter "overwinter" shelters. The ND trait appears to be stable; Field evaluated the colony at 26°C and 18 h light and a high level of ND was retained as only 18% entered diapause under a 10 h photoperiod at 19°C after 18 months without selection (Field 1981).

Evaluating multiresistant strains--No large differences in fecundity

was calculated for females only: carbaryl-OP 129.9 (5.8), carbaryl-OP-sulfur 125.1 (6.7), carbaryl-OP-permethrin 123.2 (4.6), Block-4 122 (9.4), and Modesto almonds 119 (5.1). The two "wild" colonies tested (Block-4 and Modesto almonds) have the most rapid development, but the maximum difference (between them and the carbaryl-OP colony) was 10.9 hrs, which may not be significant under field conditions.

Sex ratio of the colonies varied over time among tests and among strains, but the significance of this is unclear. Progeny of 100 females of mixed age had sex ratios (female:male) as follows: carbaryl-OP (2.42 and 3.02 for transfers 1 & 2), carbaryl-OP-sulfur (2.57 & 2.10), carbaryl-OP-permethrin (1.63 & 2.67), Immature Selection-35 (2.13 & 3.28), and Block-4 (2.4 & 2.83), based on 111-328 progeny/colony/transfer.

The sex ratio of progeny from 6-8 transfers of 100 young females (until they died) from each of the colonies also varied. For the carbaryl-OP stock, sex ratios of progeny from 6 transfers were: 1.44, 2.0, 2.44, 1.97, 1.55, and 1.75. The overall average was 2.10. For the carbaryl-OP-sulfur colony, sex ratios were: 1.5, 1.84, 2.23, 1.81, 1.92, and 1.5, averaging 1.97. Carbaryl-OP-permethrin: 1.39, 1.47, 2.21, 1.85, 2.0, 2.7, and 2.0, averaging 1.86. Immature Selection: 0.63, 1.56, 1.98, 1.50, 2.53, 2.20, 5.50 and 1.0, averaging 1.78. Block-4: 1.35, 1.78, 2.10, 2.22, 1.94, 3.33, 4.0, and 2.33, averaging 1.99. Ratios are based on 47-387 progeny/transfer/colony. The counts also estimated the number of adult progeny produced by each female/day for 8 days: carbaryl-OP (1.93 adult progeny/female/day), carbaryl-OP-sulfur (1.52), carbaryl-OP-permethrin (1.56), Immature Selection-35 (1.47) and Block-4 (1.12).

SUMMARY

Strains of M. occidentalis that are of potential value in IPM programs have been developed through crosses and selection; they are carbaryl-OP-sulfur and carbaryl-OP-permethrin resistant, and carbaryl-OP-nondiapausing.

The apparent normality of attributes such as longevity, sex ratio, productivity, and development rate indicates the strains should be field tested,

REFERENCES

- Field, R. P. (1981) Ph.D. thesis, Univ. Calif., Berkeley, 116 pp.
- Hoy, M. A. (1975a) J. Insect Physiol. 21, 745-751.
- Hoy, M. A. (1975b) J. Insect Physiol. 21, 605-611.
- Hoy, M. A. (1979) In: Hoy, M. A. & McKelvey, J. J., (eds.) Genetics in relation to insect management, Rockefeller Found. Press, N.Y. 106-115.
- Hoy, M. A. (1982) Ent. Exp. Appl. (in press).
- Hoy, M. A. & Flaherty, D. L. (1970) Ann. Entomol. Soc. Am. 63, 960-963.
- Hoy, M. A. & Knop, N. F. (1979) Rec. Adv. Acar. I, 89-94.
- Hoy, M. A. & Knop, N. F. (1981). Ent. Exp. Appl. 30, 10-18.
- Hoy, M. A., Knop, N. F., & Joos, J. L. (1980) Calif. Agric. 23, 11-12.
- Hoy, M. A. & Standow, K. A. (1982) Ent. Exp. Appl. 31, 316-323.
- Hoy, M. A., Barnett, W. W., Reil, W. O., Castro, D., Cahn, D., Hendricks, L. C., Coviello, R., & Bentley, W. J. (1982a). Calif. Agric. 36(1-2), 8-10.
- Hoy, M. A., Westigard, P. H., & Hoyt, S. C. (1982b). J. Econ. Entomol. (in press).
- Roush, R. T. & Hoy, M. A. (1981a) J. Econ. Entomol. 74, 138-141.
- Roush, R. T. & Hoy, M. A. (1981b) J. Econ. Entomol. 74, 142-147.
- Roush, R. T. & Plapp, F. W. (1982). J. Econ. Entomol. 74, 304-307.

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Release and Evaluation of a Laboratory-Selected
Pyrethroid Resistant Strain of the Predaceous Mite
Metaseiulus occidentalis in Southern Oregon Pear Orchards
and a Washington Apple Orchard^{1,2/}

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ABSTRACT

A laboratory-selected strain of the spider mite predator Metaseiulus occidentalis was released into 2 southern Oregon pear orchards and a Washington apple orchard in June 1980. The permethrin and organophosphorus insecticide (OP)-resistant predators established in all three orchards, overwintered, and survived repeated permethrin applications during 1980 and 1981. By summer 1981, the predators had spread into adjacent trees in release areas in both states. Foliage damage was substantially reduced compared to trees without the permethrin-OP resistant predators in Oregon in 1981. In Washington in 1980, spider mite populations were significantly lower and M. occidentalis populations significantly higher on release trees compared to control trees. In 1981 the frequency and rates of permethrin applications caused high mortality of the resistant M. occidentalis and high spider mite densities developed on all sampled trees. Permethrin resistance levels remained high in the orchard populations after 2 field seasons despite the polygenic nature of this resistance. Future releases should be considered, especially where releases can be made into each tree and selective acaricides can be used to manage spider mite-predator densities until a more stable relationship occurs.

Synthetic pyrethroid pesticides are potentially valuable chemicals for the control of the codling moth, Cydia pomonella (L.), in pear and apple orchards (Hoyt et al. 1978; Zwick and Fields 1978). Use of these insecticides in a summer program for suppression of the above pest, however, results in dramatic increases in spider mite densities (Hoyt et al. 1978) due to their toxicity to the important predaceous mite Metaseiulus (Typhlodromus) occidentalis (Nesbitt) (Roush and Hoy 1978; Hoy and Knop 1979, 1981). M. occidentalis has been selected in the laboratory for resistance to several insecticides, including the pyrethroid permethrin (Hoy and Knop 1979, 1981; Roush and Hoy 1981). Establishment of effective pyrethroid resistant strains of this predator in apple and pear orchards would permit the use of pyrethroid chemicals for codling moth control while minimizing the disruptions to spider mite population suppression by these predators.

The objectives of this study were to evaluate establishment, survival, spread and overwintering of a permethrin-organophosphorus insecticide (OP) resistant strain of M. occidentalis in 2 southern Oregon pear orchards and a Washington apple orchard. Survival after repeated exposure to permethrin sprays for codling moth control and measurement of the degree of spider mite suppression achieved by the resistant strain also were evaluated to determine the efficacy of this laboratory selected "genetically-improved" predator.

Materials and Methods

Oregon pear orchards

Permethrin-OP resistant predators (WA-18) were reared at the University of California, Berkeley (Hoy and Knop 1981), transported to Medford, Oregon, and released onto trees in each of 2 orchards containing populations of the two spotted spider mite Tetranychus urticae Koch. Orchard 1 was 1.2 ha and composed of 60 year old Bosc variety pears, while orchard 2 was 0.4 ha and of the Comice variety. Approximately 1000 permethrin-OP resistant female M. occidentalis were released into each of 3 trees in orchard 1 and 6 trees in orchard 2 on June 16, 1980. Release trees in both orchards were separated by 5 and 10 non-release trees, respectively, a distance of 38 and 76 m. Six weeks prior to the 1980 release, and again ca. 4 weeks following release, both orchards were treated with permethrin (113 g AI/ha). The first treatment was made to eliminate native M. occidentalis which, if crossed with released mites, could dilute the degree of permethrin resistance established in the laboratory selection program (Hoy et al. 1980; Hoy and Knop 1981). In 1981 both orchards received a dormant stage treatment of the pyrethroid fenvalerate (170 g AI/ha) and summer treatments of permethrin (57 g AI/ha) on May 16 and June 6, and a third treatment (113 g AI/ha) on July 16, 1981. Chemical treatments were made using an air carrier sprayer set to deliver 100 gpa.

Washington apple orchard

Similar releases of the permethrin-OP resistant strain (WA-18) were made on June 4, 1980 in a 1.5 ha orchard of apples in Wenatchee, Washington. The trees in this orchard ranged in age from 30 to 40 years and were of the 'Red Delicious,' 'Golden Delicious' and 'Winesap' varieties. Only the 'Red Delicious' trees were used for release or as controls, and release or control trees were separated from each other by 2 "buffer" trees (21 meters). Seven pairs of trees were selected with one tree of each pair randomly designated as a release tree and the other as a control. The entire orchard was treated with permethrin (140 g AI/ha) on April 16, 1980, and the release and control trees were again treated with permethrin (56 g AI/ha) on May 15, 1980; these treatments were made to eliminate native M. occidentalis.

Foliage heavily infested with a mixture of T. urticae and T. mcdanieli McGregor was placed in each release and control tree on May 8, 1980, and again on June 3, 1980, to insure a relatively uniform food supply for predators. Following release of the resistant predators, challenge doses of permethrin (56 g AI/ha) were applied to the entire orchard on July 11 and August 21, 1980. In 1981 the orchard was divided into 2 sections and treated with permethrin as listed in Table 3.

Persistence of resistance

Predators were collected in September, 1980, from release trees in pear orchard 1 at Medford and their progeny were tested with 2 g permethrin AI/100 liter water on leaf discs to determine their resistance level. LC₅₀ values were obtained for colonies collected in September, 1981, from the release trees in pear orchard 1 at Medford, and from the release trees, control trees, and a non-release area several hundred meters from the release site at Wenatchee, and from several laboratory colonies for

comparative purposes: a permethrin-susceptible colony collected from Berkeley blackberries (Hoy and Knop 1981); the WA-18 colony, unselected with permethrin since the releases in June 1980; and a permethrin-OP resistant colony selected periodically during 1980 and 1981 (Immature Selection). For each colony ca. 100 females each were tested at 5 doses on pinto bean leaf discs sprayed with water solutions of permethrin. The number surviving were scored after 48 h (Hoy and Knop 1981). The LC_{50} values were calculated using the POLO program for logit analysis (Russell et al. 1977).

Spider mite and predator densities were estimated at weekly or biweekly intervals by selecting 25 mature leaves/tree from shoots and spurs along the major scaffold limbs. The mites were removed with a mite brushing machine and counted with ^{the} aid of a dissecting microscope. The total number of eggs and postembryonic stages for each species were recorded. Leaf samples were taken from release and adjacent non-release trees in Medford and from release and control trees in Wenatchee in order to compare mite levels and to evaluate rate of intertree dispersal of the predatory mites.

RESULTS

Results during 1980 - Medford

No native M. occidentalis were detected in samples from orchards 1 or 2 following permethrin treatments on May 29 prior to release of the resistant strain on June 16. The first sample taken 2 weeks following

release showed predators were present on all release trees (Table 1), indicating establishment had occurred. Subsequent sampling in orchard 2 showed the predators persisted through the season. In orchard 1 predators established in 1 of the 3 release trees (Table 1). The failure of the released predators to survive in 2 areas may be attributed to low initial prey density, which averaged only 0.4 T. urticae/leaf for the 8 week period just following predator release (Table 1). Previously, we have found it difficult to obtain establishment if spider mite densities are low and highly dispersed (Hoy, unpubl.). No spread of predators from release trees to adjacent trees was recorded in either orchard in 1980 (Table 1). Predator densities declined in both orchards immediately following the permethrin treatment on July 22, 1980. Recovery of predator densities to pretreatment levels was not obtained for 3-4 weeks. In orchard 1, no overall reduction in spider mite levels attributable to predator activity was apparent in 1980 and examination of release and non-release trees at harvest (late September) showed severe defoliation in both areas, estimated at 60% premature leaf drop or severely damaged foliage.

Results during 1980 - Wenatchee

No native M. occidentalis were found on the release trees on May 17 or June 2 (Table 2) or on the control trees from May 17 to July 9 (single predators were found on 2 of 7 control trees on June 25). Following release of the predators on June 4, females were observed to move quickly from the release sites to the lower surface of leaves. Released M. occidentalis

larvae were observed to have moved to the foliage by June 5, and by June 10 eggs also were found. M. occidentalis was present in the release trees on all sample dates from June 12 until harvest although levels were very low until July 9 (Table 2). Permethrin reduced predator populations about 50% following each application. Predators appeared on the control trees two weeks after the July 11 application of permethrin but were eliminated for two weeks following the August 21 treatment. It is not known if this represents spread of the released predator strain or return of native populations.

Ample prey (T. urticae plus T. mcdanieli and Aculus schlechtendali (Nalepa)) were present to support M. occidentalis on all dates following release (Table 2). Panonychus ulmi (Koch) populations remained low until July 24 and were comparable on both treatments. T. urticae plus T. mcdanieli numbers peaked on the release trees at 31 mites/leaf compared to 60/leaf on the control trees. Seasonal means were compared for release versus control trees by ANOVA. Significant differences in means occurred for T. urticae plus T. mcdanieli ($P = 0.05$) and for M. occidentalis ($P = 0.01$), indicating a substantial degree of control by the resistant predators.

Results in 1981 - Medford

M. occidentalis overwintered successfully under southern Oregon climatic conditions as predators were found in release area 1, orchard 1, on the first sample date (May 1). Despite 3 summer permethrin sprays, the

M. occidentalis densities remained relatively constant through 1981, and increased in August and September after pyrethroid sprays were discontinued. Predators spread to non-release trees, as indicated in the May 1 sample, but predator populations remained low until late August when they were present in most adjacent non-release trees at densities averaging 0.4/leaf (Table 1). In 1981 T. urticae densities were ca. 1/2 of those on non-release trees and leaf injury at harvest was estimated at 10% and 50% in the release and non-release areas, respectively.

Results in 1981 - Wenatchee

Moderate numbers of M. occidentalis were found in samples on May 19 from trees of the 4 treatments (2 rates of permethrin with control and release trees for both), indicating successful winter survival (Table 3). The full codling moth program of permethrin sprays (May 27, June 18, and July 30) at both dosages greatly reduced predator numbers and maintained them at low levels until August. This, coupled with the hot weather of late July and August and a high initial population of T. urticae plus T. mcdanieli, allowed pest mite populations to increase to high levels in all treatments. Significant differences in mean densities of spider mites for release and control trees were not found, apparently due to the spread of the resistant predators to control trees, as suggested below. The full codling moth program and these permethrin application rates were apparently too toxic for adequate survival of this M. occidentalis strain with its current permethrin resistance level.

Counts for P. ulmi and A. schlechtendali were similar on all four treatments and followed the same general trends as in 1980. Therefore, these data are not presented in Table 3.

Persistence of resistance

Permethrin resistance levels remained at least as high in the colonies recovered in September, 1981, as when the resistant strain was released into the field in June 1980. The colonies collected in September, 1981, from release trees in pear orchard 1 and from Washington apples had LC₅₀ values of 5.6 (4.7 - 6.4) and 6.6 (4.0 - 8.0), respectively, indicating that high levels of permethrin resistance had been retained and perhaps increased in the populations in the orchards despite the polygenic nature of the resistance (Hoy and Knop 1981). The colony collected in September 1981 from the control trees at Wenatchee had an LC₅₀ value of 3.9 (3.0 - 4.7) compared to a value of 0.5 (0.16 - 0.76) for the colony from the trees several hundred meters from the release site. These data suggest the released predators had spread (and perhaps interbred with natives) from the release trees to the control trees, a distance of 21 meters. No data are available to determine if the spread has been even greater.

In contrast, a leaf spray LC₅₀ value obtained for the WA-18 colony in April, 1980, was 3.8 (95% C.I. = 2.5 - 6.6) g permethrin AI/100 liter water (Hoy and Knop 1981), but after 18 months without selection in the laboratory, the LC₅₀ value for the WA-18 strain declined to 1.5 (1.2 - 1.8)

in October, 1981. The Immature Selection strain, maintained under periodic permethrin selection, had an LC_{50} value of 6.4 (5.3 - 7.8) in October, 1981. The LC_{50} value for the susceptible Berkeley blackberry colony was 0.2 (0.1 - 0.5) and 0.9 (0.7 - 1.1), in 1980 and 1981, respectively.

DISCUSSION

These data indicate that the laboratory-selected permethrin-OP resistant strain of M. occidentalis successfully established in 2 southern Oregon pear orchards and a Washington apple orchard. These resistant predators persisted year round under the climatic conditions of the two areas and through multiple summer field-applied permethrin sprays. The availability of OP and permethrin resistances in this predator offers new opportunities for IPM programs in these 2 crops. However, several questions must be resolved before large scale releases can be made. How many predators should be released in each tree? Should predators be released into every tree, or in some pattern such as every third tree in every third row? At what time in the season should predators be released?

Results from orchard 1 in Medford in 1980 indicate that successful establishment of these predators may be dependent upon the presence of moderate to high prey levels upon release. Because M. occidentalis exhibited slow inter-tree dispersal in all three orchards, it may be that the permethrin-OP resistant strain disperses more slowly than the carbaryl-OP resistant strain (Hoy, in press). If this is true, changes in release

strategy should be considered, particularly since spider mites treated with pyrethroids may disperse more rapidly than normal and thereby make control more difficult (Penman et al. 1981; Hoy et al. 1979). Releases of lower numbers into every tree may achieve more rapid spider mite suppression than the release of larger numbers into fewer trees. This may be especially important in pears since this crop is particularly susceptible to spider mite feeding damage. It is likely that selective acaricides will be needed as well during the transition period when predators are multiplying and spreading in order to prevent serious foliage damage.

Releases of this permethrin-OP resistant strain are highly desirable to expand the uses of the highly effective pyrethroids and to reduce spider mite problems associated with their use on pears. Large scale releases into thousands of acres should be feasible if the resistant strain is reared outdoors. Hoy et al. (In press) reared 62 million M. occidentalis in a 0.2 ha soybean plot during 1981, and even larger scale rearing should be feasible. Pear growers can no longer afford to rely only on acaricides to control spider mites. Resistance to cyhexatin in spider mites in Oregon pear orchards (Hoyt and Westigard, In prep.) suggests that unrestrained use of acaricides has a limited future and serves as a warning that increased reliance on biological control of spider mites is necessary.

ACKNOWLEDGMENT

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Table 1. Population trends of the two spotted spider mite and released permethrin-resistant M. occidentalis in orchard 1 and 2, Medford, Oregon.

		Average No. <u>Tetranychus urticae</u> (T.u.)/leaf and <u>Metaseiulus occidentalis</u> (M.o.)/10 leaves											
		ORCHARD 1 1980 ^{b/}											
		Sample dates											
Treatment	Release trees	Mite species	7/2	7/14	7/29	8/6	8/14	9/4	9/10	9/24	10/1	\bar{x}	
predator release ^{a/}	1	T.u.	12.7	11.7	34.9	22.1	45.4	89.2	45.6	8.3	7.1	30.8	
		M.o.	4.0	11.0	1.0	0	4.0	14.0	17.0	5.0	7.0	7.0	
	2-3	T.u.	1.2	0.2	0.2	0.2	0.8	1.4	22.7	-	14.0	3.8	
		M.o.	2.0	1.0	0	0	0	0	0	-	0	0.4	
non-release	1-3	T.u.	16.5	11.8	11.9	35.1	17.8	27.0	47.6	16.5	43.4	25.3	
		M.o.	0	0	0	0	0	0	0	0	0	0	
		ORCHARD 1 1981 ^{c/}											
		Sample dates											
			5/1	5/21	6/4	6/16	6/30	7/13	7/30	8/14	8/21	9/21	\bar{x}
predator release	1	T.u.	0	1.9	1.9	3.0	5.4	15.5	9.0	40.3	58.6	18.7	15.4
		M.o.	1.0	1.0	0	1.0	2.0	2.0	2.0	6.0	4.0	9.0	2.8
non-release ^{d/}	1-8	T.u.	10.0	3.3	4.2	13.0	21.8	62.7	10.1	40.4	76.2	47.9	29.2
		M.o.	0.5	0	1.0	0	0	0	0.1	0	0.9	4.0	0.5
		ORCHARD 2 1980 ^{b/}											
		Sample dates											
			5/23	6/23	6/26	7/7	7/18	7/28	8/8	8/26		\bar{x}	
predator release ^{a/}	1-6	T.u.	10.7	2.6	3.3	17.5	1.0	1.0	1.0	0.8		3.9	
		M.o.	0	0.8	1.1	1.3	0.2	0	0.2	0.2		0.5	
non-release	1-6	T.u.	6.7	-	4.8	9.9	2.3	2.9	6.1	5.2		5.2	
		M.o.	0	-	0	0	0	0	0	0		0	

^{a/} Permethrin-OP resistant M. occidentalis were released June 16, 1980.

^{b/} Permethrin applied 5/29, 7/22.

^{c/} Permethrin applied 5/6, 6/6, 7/16.

^{d/} In 1981 eight trees surrounding 1980 release tree No. 1 were sampled.

Table 2. Population trends of mites on predator release and control apple trees at Wenatchee, Washington, in 1980.

Treatment ^{1/}	Mite species	Average numbers of mites/leaf on each sample date									
		5/17	6/2	6/12	6/25	7/9	7/24	8/6	8/19	9/4	9/17
Predator release trees	<u>T.u.</u> ^{2/}	0.1	0.4	2.5	4.2	6.4	6.6	18	19	31	21
	<u>P.u.</u>	0	0.05	0.1	0.7	0.5	6.1	18	6.7	3.4	1.0
	<u>A.s.</u>	17	23	53	230	395	132	37	63	153	109
	<u>M.o.</u>	0	0	0.1	0.05	0.7	0.4	0.7	0.9	0.4	1.1
Control trees (non-release)	<u>T.u.</u>	0.03	0.06	3.5	6.7	14	15	51	51	53	60
	<u>P.u.</u>	0	0	0	0.03	0.9	6.3	13	7.4	4	1.6
	<u>A.s.</u>	16	26	63	268	354	97	39	67	146	90
	<u>M.o.</u>	0	0	0	0.03	0	0.1	0.3	0.9	0	0.5

^{1/}Permethrin resistant predators released on June 4, permethrin (56 g AI/ha) applied July 11 and Aug. 21.

^{2/}T.u. = T. urticae plus T. mcdanieli, P.u. = P. ulmi, A.s. = A. schlehtendali, M.o. = M. occidentalis.

Table 3. Population trends of mites on predator release and control apple trees where two challenge rates of permethrin were applied. Wenatchee, Washington, 1981.

Treatment	Mite species	Average number of mites/leaf on each sample date								
		5/19	6/9	6/23	7/7	7/20	8/4	8/18	8/31	9/14
<u>Permethrin 70 g AI/ha^{1/}</u>										
Predator release trees	<u>I.u.</u> ^{2/}	1.3	0.6	1.7	3.5	21	39	126	2.9	0
	<u>M.o.</u>	0.5	0.1	0	0	0.2	0.4	1.3	4.0	0.5
Control trees	<u>I.u.</u>	6.8	0.5	1.5	7	16	75	109	1	0
	<u>M.o.</u>	1.6	0.2	0	0	0.1	0.3	1.9	4.3	1.0
<u>Permethrin 35 g AI/ha^{1/}</u>										
Predator release trees	<u>I.u.</u>	2.2	0.3	0.8	2.8	13	75	77	0.7	0
	<u>M.o.</u>	0.3	0.1	0	0.1	0.4	0.5	2.4	1.4	0.4
Control trees	<u>I.u.</u>	16	1	4.8	8.2	38	80	144	0.2	0
	<u>M.o.</u>	0.2	0.2	0.2	0	0.2	0.2	4.4	0.8	0.4

^{1/}Permethrin applied on May 27, June 18, and July 30.

^{2/}I.u. = I. urticae plus I. mcdanieli, M.o. = M. occidentalis.

REFERENCES CITED

- Hoy, M. A. 1982. Aerial dispersal and field efficacy of a genetically-improved strain of the spider mite predator Metaseiulus occidentalis, Acarina, Phytoseiidae. Entomol. Exp. Appl. (in press).
- Hoy, M. A. and N. F. Knop. 1979. Studies on pesticide resistance in the phytoseiid Metaseiulus occidentalis in California. Recent Adv. Acarol. 1:89-94.
- Hoy, M. A. and N. F. Knop. 1981. Selection for and genetic analysis of permethrin resistance in Metaseiulus occidentalis: Genetic improvement of a biological control agent. Ent. Exp. App. 30:10-18.
- Hoy, M. A., D. Flaherty, W. Peacock, and D. Culver. 1979. Vineyard and laboratory evaluations of methomyl, dimethoate, and permethrin for a grape pest management program in the San Joaquin Valley of California. J. Econ. Entomol. 72:250-255.
- Hoy, M. A., N. F. Knop and J. L. Joos. 1980. Pyrethroid resistance persists in spider mite predator. Calif. Agric. 34(11-12):11-12.
- Hoy, M. A., D. Castro, and D. Cahn. 1982. Two methods for large scale production of pesticide-resistant strains of the spider mite predator Metaseiulus occidentalis (Nesbitt) (Acarina, Phytoseiidae). Zeitsch. Angew. Entomol. (in press).
- Hoyt, S. C., P. H. Westigard and E. C. Burts. 1978. Effects of 2 synthetic pyrethroids on the codling moth, pear psylla and various mite species in Northwest apple and pear orchards. J. Econ. Entomol. 71:431-434.

- Penman, D. R., R. B. Chapman, and K. E. Jesson. 1981. Effects of fenvalerate and azinphosmethyl on two-spotted spider mite and phytoseiid mites. *Entomol. Exp. Appl.* 30:91-97.
- Roush, R. T. and M. A. Hoy. 1978. Relative toxicity of permethrin to a predator, Metaseiulus occidentalis, and its prey, Tetranychus urticae. *Environ. Entomol.* 7:287-288.
- 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. Entomol.* 74: 138-141.
- Russell, R. M., J. L. Robertson, and N. E. Savin. 1977. POLO: a new computer program for probit analysis. *Bull. Entomol. Soc. Amer.* 23:209-213.
- Zwick, R. W., and G. J. Fields. 1978. Field and laboratory evaluations of fenvalerate against several insect and mite pests of apple and pear in Oregon. *J. Econ. Entomol.* 71:793-796.

Aerial dispersal and efficacy of *M. occidentalis*

AERIAL DISPERSAL AND FIELD EFFICACY OF A GENETICALLY IMPROVED STRAIN OF THE SPIDER MITE PREDATOR *METASEIULUS OCCIDENTALIS*

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In August 1979, a strain of *Metaseiulus occidentalis* resistant to carbaryl and organophosphorus (OP) insecticides was released into a few trees at one edge of a 32-hectare commercial almond orchard near Bakersfield, California. In August 1980, predators collected from 7 widely separated sites in the orchard had moderate to high levels of carbaryl resistance, indicating the resistant strain had established, multiplied, overwintered, and dispersed from the release site. During 1980, the resistant predators had a substantial impact on spider mite populations. Aerial dispersal of *M. occidentalis* was suspected in this orchard because the predators had moved so far so quickly. Predators sampled in April and September 1981 were still carbaryl resistant, indicating that this strain had survived a 2nd year in this commercial almond orchard. The carbaryl-OP-resistant strain also was released into every 3rd tree in every 3rd row in a commercial almond orchard near Livingston, California in June 1981 and inter-tree dispersal occurred within one month. The predators exerted considerable control over the spider mites in this orchard, as well. Aerial dispersal occurred and was monitored by trapping large numbers of *M. occidentalis* females on sticky panels located outside the orchard. This is the first documentation that *M. occidentalis* disperses aerially in the field, and suggests that this carbaryl-OP-resistant strain may be capable of substantial dispersal from release orchards. It is also the first time that this laboratory-selected strain has been shown to be effective in large commercial almond orchards, as previous trials used only 10–30 tree plots.

KEY WORDS: Aerial dispersal — *Metaseiulus occidentalis* — Acarina — Phytoseiidae — Genetic improvement — Biological control — Pesticide resistance — Carbaryl resistance — Spider mites — Almonds.

Metaseiulus (= *Typhlodromus* or *Galendromus*) *occidentalis* (Nesbitt) is an important predator of spider mites in western North American deciduous orchards and vineyards, and is becoming increasingly important in Australian orchards, as well (Field, 1978). *M. occidentalis* acquired resistance to organophosphorus (OP) insecticides and to sulfur through natural selection in orchards and vineyards (Hoyt, 1969; Hoy *et al.*, 1979a; Hoy & Knop, 1979; Hoy & Standow, 1981). Carbaryl and permethrin resistances were developed in this predator through laboratory selection as part of a genetic improvement program (Hoy, 1979; Roush & Hoy 1981a; Hoy & Knop 1979, 1981).

Field tests with the carbaryl-OP and permethrin-OP-resistant strains have been conducted in small plots involving 10–30 trees (Hoy *et al.*, 1980; Roush & Hoy, 1981b; Hoy,

unpubl.). We assumed that the resistant predators would stay in the individual release trees for substantial periods of time (weeks or months), and that predators with different resistances could be released into adjacent trees without fear of their rapid mixture or interbreeding (Croft, 1976). Indeed, Croft & Barnes (1972) found that an OP-resistant strain of *M. occidentalis* did not move substantial distances in their small plot trials in a southern California apple orchard over a 2-year period, and M. A. Hoy & P. H. Westigard (unpubl.) found the permethrin-OP-resistant strain of *M. occidentalis* moved into adjacent trees in small plots in Oregon pear orchards only during the 2nd year. Field (1978), in contrast, found that the OP-resistant strain of *M. occidentalis* spread throughout an Australian peach orchard within one year.

During August 1980, carbaryl-OP-resistant *M. occidentalis* were found in large numbers throughout a 32-hectare commercial almond orchard after having been released in August 1979 into a few trees at one end of the orchard. As it seemed unlikely that the predators could

have dispersed so far so quickly by walking (Penman & Chapman, 1980), aerial dispersal of this laboratory-selected resistant strain was suspected.

Dispersal mechanisms in phytoseiid mites are not well understood. Johnson & Croft (1976) described a specific behavior believed to be involved in the aerial dispersal of *Amblyseius fallacis* (Garman). Adult preovipositing ♀♀, ovipositing ♀♀, and to a lesser extent adult ♂♂, altered their behavior from a random search movement to a directed movement toward the edge of an arena when subjected to an air flow of ca. 1600 m/hr. They terminated forward motion, oriented to the air flow and raised their anterior body away from the substrate. Air currents affected dispersal, and starvation and temperature influenced this behavior (Johnson & Croft, 1976). Field (1981) described similar behavior in adult ♀♀ of the carbaryl-OP-resistant strain of *M. occidentalis* under laboratory conditions. Kuchlein (1966) found that old ♀ *M. occidentalis* held at higher densities (10 predators/leaf disc) "migrated" at a higher rate than those at lower densities despite the presence of abundant prey, suggesting that this behavior is density-dependent.

This paper documents the efficacy of the carbaryl-OP-resistant strain of *M. occidentalis* and its extensive dispersal in a Bakersfield almond orchard during 1979—1981. In addition, evidence is presented that *M. occidentalis* dispersed from release to non-release trees within one month and dispersed aerially in large numbers from a commercial Livingston California almond orchard during 1981.

MATERIALS AND METHODS

Bakersfield almond orchard. Approximately 3000 carbaryl-OP-resistant *M. occidentalis* were released by R. T. Roush into 4 trees near the edge of a commercial almond orchard near Bakersfield, California in late August 1979 (Fig. 1). This strain is also resistant to organophosphorus (OP) insecticides such as azinphosmethyl, dimethoate, and diazinon. Both the release area (Block I-A) and Block II-A had been treated with carbaryl (1.8 kg 80S Sevin/ha) in July 1979 to control the navel orangeworm (*Paramyelois transitella* (Walker)), but carbaryl was not applied in Blocks I-B or II-B during 1979 (Fig. 1). Carbaryl nearly eliminated the native, susceptible *M. occidentalis* in Blocks I-A and II-A (Hoy, unpubl.). In 1980, carbaryl was applied on July

15 throughout Blocks I and II, and Block II-B was used to evaluate the use of low rates of propargite to control spider mites. Three rates of propargite were applied on July 29 to Block II-B only. Spider mites, predominantly *Tetranychus urticae* (Koch) and *T. pacificus* (McGregor), and *M. occidentalis* were monitored in Block II-B during 1980 by sampling 20 leaves/tree from each of 4 trees in the 6 check blocks and the 3 propargite rates (0.184, 0.368, and 0.920 kg 30WP Omite/hectare). The leaves from the 96 trees were kept chilled until they could be brushed with a mite brushing machine and counted under a dissecting microscope. Because large numbers of *M. occidentalis* unexpectedly were found throughout the carbaryl-treated Block II-B in August 1980, *M. occidentalis* was collected, colonized, and 80 gravid ♀♀ were tested with 2.4 g AI carbaryl (80 WP Sevin)/l water by spraying the 2 cm-diam pinto bean (*Phaseolus vulgaris* (L.)) leaf discs containing *T. urticae* as prey after the predators were placed on the discs. Survival was assessed after 48 hr. Additional samples were taken from 7 sites in August 1980, from 5 sites in April 1981, and from 2 sites in September 1981 (Fig. 1) and tested with carbaryl. No carbaryl was applied to the orchard during 1981.

Livingston almond orchard. Carbaryl-OP-resistant *M. occidentalis* ♀♀, reared on pinto bean plants in a University of California, Berkeley greenhouse with *T. urticae* as prey, were released into a commercial almond orchard near Livingston, California (Hoy *et al.*, 1982). Cut bean plants containing about 350 predator ♀♀ were placed into the crotch of every 3rd tree, in every 3rd row, on June 9, 1981 (Table II). Carbaryl had been applied previously in May and was applied a second time on July 3. The second application was combined with propargite (.368 kg 30 WP Omite/hectare). Propargite alone was applied at the same rate on July 21. The almond trees in this 8-hectare almond orchard were about 10 years old, spaced 4.6 m apart in rows 7.6 m wide; their canopies touch. The orchard is flood-irrigated.

Leaf samples (10 leaves/tree) from 10 release (R) and 10 nonrelease (NR) trees were taken periodically, brushed, and counted under a dissecting microscope. Two colonies of *M. occidentalis* were obtained on July 17: one colony originated from foliage in the lower half of both R and NR trees; the other was obtain-

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ed by sampling foliage with a pole pruner in the tops of both R and NR trees. The two colonies were tested with 2.4 g AI carbaryl/l water on sprayed leaf discs. Another colony was collected from the lower half of R and NR trees and tested with carbaryl in September 1981.

On July 31, two towers 3.4 m high were placed 7.6 m outside the east end of the almond orchard and on ground about 0.6 m above the level of the orchard floor. The tops of the towers were 4 m above the orchard floor. Each tower had 3 plastic panels (23 x 30 cm), 1 each at 3 heights: low, middle, and high, that were thinly coated with high vacuum grease (Dow Corning*) on the side facing the almond orchard. The prevailing winds in this area are from the northwest to the southeast. After removal from the towers, the panels were scanned with a dissecting microscope and the numbers of spider mites and predators were estimated by counting random sections totalling 1/9 of the panel area (Table III). Samples of the phytoseiids on the panels were removed, cleared, and slide mounted for identification of species and stadium.

RESULTS

Bakersfield almond orchard. The carbaryl-OP-resistant strain of *M. occidentalis* released in August 1979 into a few trees in Block I-A established, overwintered, multiplied, spread, and survived the carbaryl application in July 1980. It is likely that the carbaryl-OP-resistant

strain interbred with the carbaryl-susceptible natives in Block II-B since Block II-B was not treated with carbaryl in 1979 and carbaryl-susceptible *M. occidentalis* were abundant in this block (Hoy, unpubl.). Carbaryl-resistant *M. occidentalis* were present in Block II-B on July 18, 1980, only 3 days after carbaryl was applied (Table I); their moderate to high survival rates (24–80%) support the conclusion that the resistant predators had dispersed widely and interbred with natives (Fig. 1). The survival of native *M. occidentalis* colonies rarely is above 5%. Females from resistant and susceptible laboratory colonies tested at the same time averaged 80 and 2% survival, respectively. Carbaryl resistance in this strain is determined by a single semidominant gene (Roush & Hoy, 1981a).

The carbaryl-resistant predators exerted considerable control on spider mites in Block II-B during 1980 (Table I). After the carbaryl application on July 15, spider mites increased only slightly; this is in contrast to other San Joaquin Valley almond orchards where carbaryl applications usually result in dramatic outbreaks of spider mites that often lead to substantial defoliation, despite the application of propargite (Hoy *et al.*, 1979b; Roush & Hoy, 1981b). The spider mites increased least in the trees where the 3 low rates of propargite were applied, but even in the check trees the predators exerted considerable control (Table I). By September 2, the predators had reduced the

TABLE I

Efficacy of carbaryl-OP-resistant strain of *M. occidentalis* (*M.o.*) to spider mites (*sp.m.*) in Block II-B of the Bakersfield almond orchard

Sample dates	Mean mites ¹ per leaf on trees treated with propargite at								
	600 g ²		240 g ²		120 g ²		Check ²		
1980	sp.m.	<i>M.o.</i>	sp.m.	<i>M.o.</i>	sp.m.	<i>M.o.</i>	sp.m.	<i>M.o.</i>	
June 13	0.01	0	0.02	0	0.01	0	0	0	
July 2	0.2	0	0.03	0	0.02	0.02	0	0	
July 15-carbaryl applied to all trees									
July 18	0.3	0.17	0.6	0	0.5	0.01	0.2	0	
July 28	1.2	0.15	1.7	0.03	1.4	0.05	1.5	0.07	
July 29-propargite applied									
Aug. 1	0.1	0.02	0.1	0	0.3	0.16	0.7	0.03	
Aug. 19	0.8	0.16	7.7	0.65	4.1	0.82	21.3	0.89	
Sept. 2	1.7	0.68	1.2	1.50	1.1	0.95	2.8	1.71	
Sept. 16	0.1	0.44	0.12	0.35	0	0.34	0.1	0.63	

¹ Spider mites were *T. urticae* and *T. pacificus*; counts include eggs and active stages. — ² Twenty leaves from each of 4 trees in 6 replicates sampled.

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spider mites from a peak of 21/leaf to 2.8/leaf the the check blocks and the foliage remained green. No defoliation occurred in this orchard.

The predators survived a second winter in this orchard, as *M. occidentalis* colonies collected in Block I-A, II-A, II-B, across an adjacent road, and in an almond block north of II-A in April 1981 were all carbaryl resistant (Fig. 1). Predators collected in September 1981 from Blocks I-A and II-B were still carbaryl resistant despite the fact that no carbaryl was applied to either Block I or II during 1981 (Fig. 1). This suggests that applications of carbaryl need not occur every year to maintain resistance in these predators.

The rapid spread of carbaryl-OP-resistant *M. occidentalis* from the release site (Block I-A) to Block II-B was unexpected and suggested that aerial dispersal could have occurred, although the trees are large and their canopies touch, so it is possible that the predators were able to walk from tree to tree.

Livingston almond orchard. That the carbaryl-OP-resistant *M. occidentalis* strain can multiply and disperse rapidly was demonstrated again in 1981 in the Livingston almond orchard. Resistant predators (350 ♀♀/tree) were released on June 9 into 10% of the trees, and their progeny were present in both R and NR trees in early July (Table II). It is unlikely that the native predators would have survived both the May and July 3 carbaryl applications (at least not in the lower 3/4 of the trees), yet resistant predators were abundant in both R and NR trees (Table II) by July 17. The 2 predator colonies obtained on July 17 from the "lower level" R and NR trees exhibited 97% survival, while the colony collected from the "tree tops" exhibited 40% survival. A susceptible and resistant laboratory colony tested at the same time exhibited 0 and 65% survival, respectively. Since the NR trees constitute 89% of the trees, substantial movement and multiplication had occurred in this orchard between June 9 and July 17. The higher survival rate of the ♀♀ from the "lower level" sample supports the hypothesis that carbaryl coverage was better there. It is likely that some susceptible native *M. occidentalis* survived in the poorly sprayed tree tops and their inter-mixture or interbreeding with the resistant strain reduced the carbaryl resistance levels of that colony.

Spider mite densities increased during July and, because abundant food was available to

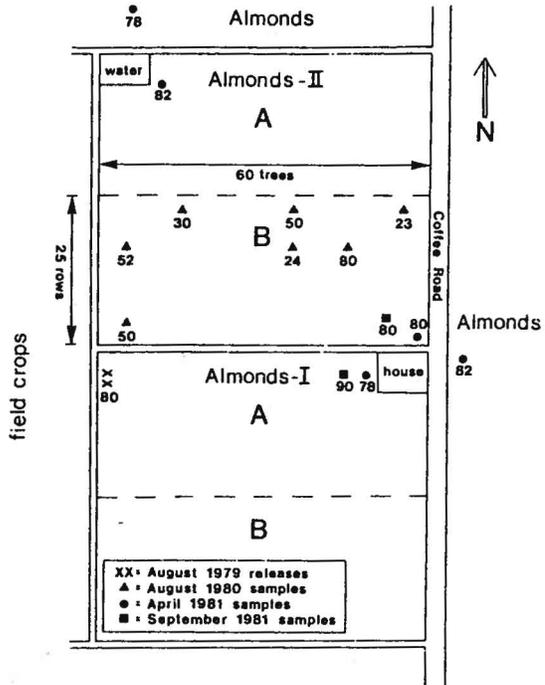


Fig. 1. Establishment and spread of the carbaryl-OP-resistant strain of *M. occidentalis* in a Bakersfield, California almond orchard. Predators released in August 1979 in Block I-A, treated with carbaryl during July 1979. Carbaryl also was applied to Block II-B in 1979 and to II-A and II-B during 1980, but no carbaryl during 1981. Numbers next to circles, squares, or triangles indicate % gravid ♀♀ surviving 48 hr after laboratory testing with 2.4 g carbaryl A.I./l water. Few ♀♀ (0-5%) from carbaryl-susceptible *M. occidentalis* colonies survive this rate.

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M. occidentalis, extensive multiplication continued. Predator: prey ratios in the orchard indicated that the predators exerted considerable control over the spider mites (Table II).

During late July, spider mite and *M. occidentalis* ♀♀ dispersed aerially from the orchard. Large numbers of spider mite and *M. occidentalis* ♀♀ were trapped on the sticky panels in late July and August (Tab. III). All *M. occidentalis* recovered on the sticky panels were ♀♀; no ♂♂ or immatures were recovered. The peak predator dispersal lagged slightly behind the peak spider mite dispersal (Table III).

DISCUSSION

Determining efficacy of genetically selected phytoseiids in the field must include measur-

TABLE II

Rapid dispersal of carbaryl-OP-resistant *M. occidentalis* (M.o.) strain from release to non-release trees in Livingston almond orchard. Sp.m. = spider mites

Sample dates — 1981	Mean mites per leaf ¹ on			
	release trees		non-release trees	
	sp.m.	M.o.	sp.m.	M.o.
June 9 Pre-release sample ²	0.7	0.02	0.2	0.01
July 3 carbaryl & propargite applied; no counts				
July 8	4.5	0.10	3.9	0.03
July 17 ³	4.3	0.61	6.4	0.26
July 21 low rate of propargite applied; no counts				
July 27	10.0	2.4	6.3	0.62
July 31	8.0	1.5	6.0	0.98
Aug. 6	5.0	3.3	5.3	1.20
Aug. 20	0.03	0.6	0.04	0.43
Aug. 28	0.01	0.5	0.03	0.34
Sept. 17	0	0	0	0

¹ Based on 10 brushed leaves/tree; 10 R and 10 NR trees were sampled. Spider mites predominately *T. pacificus* and *T. urticae*; counts include eggs and active stages.

² Immediately after pre-release foliage samples taken, 350 *M. occidentalis* ♀♀ released into every 3rd tree in every 3rd row.

³ Two colonies of *M. occidentalis* obtained and tested in laboratory with 2.4 g AI carbaryl/l water.

TABLE III

Aerial dispersal demonstrated by recoveries of *M. occidentalis* (M.o.) and spider mite (sp.m.) ♀♀ from sticky panels placed at 3 heights on 2 towers 7.6 m outside Livingston almond orchard

Sample interval-1981	Mite species	No. mites per sticky panel ¹ on					
		south tower panels			north tower panels		
		low	middle	top	low	middle	top
July 31—Aug. 6	sp.m.	733	1125	1390	661	1305	1224
	M.o.	5	14	0	0	27	8
Aug. 6—Aug. 20	sp.m.	792	603	729	1098	909	1107
	M.o.	36	63	27	135	117	90
Aug. 20—Aug. 28	sp.m.	9	9	54	18	18	45
	M.o.	36	27	27	27	72	45
Aug. 28—Sept. 17	sp.m.	0	0	0	0	0	0
	M.o.	0	0	0	0	0	0
Sept. 17—Oct. 1	sp.m.	0	0	0	0	0	0
	M.o.	0	0	0	0	0	0

¹ Panels were 23 × 30 cm and lightly coated with high vacuum grease (Dow Corning[®]). Numbers ^{are} estimates for entire panel. ✓ odd are

ing/documenting such attributes as their ability to: 1) establish, 2) survive the relevant pesticide applications, 3) control the pest spider mites, 4) disperse throughout the release tree, 5) disperse to adjacent nonrelease trees unless it is possible to release into every tree in an orchard/vineyard, 6) overwinter, and 7) persist despite lack of selection pressure for reasonable time periods (a year or more). The data presented here from 2 commercial almond or-

chards indicate that this laboratory-selected carbaryl-OP-resistant strain is extremely successful in the field. It established in both almond orchards, multiplied, dispersed, survived commercial application rates of carbaryl, and, despite interbreeding with some susceptible native predators, it maintained its resistance even though it received only one field "selection" with carbaryl. In the Bakersfield orchard, this strain has survived 2 winters.

These results indicate that our ideas about release designs and dispersal rates of *M. occidentalis* may be too conservative. Our earlier small field plots used adjacent trees, and this may not be appropriate. Croft (1976) noted that releases may fail unless predators are placed in close proximity to their prey since phytoseiids' "power of dispersal is greatly limited". Croft & Barnes (1972) concluded that

"inter-tree migrations were initially quite limited in populations of *T. occidentalis*, and releases could be made into individual trees, while adjacent trees receiving dissimilar treatments were unaffected for a considerable period. Because of this semi-isolation, it was expected that rates of dispersal and consequently, genetic exchange or hybridizations between intertree populations of predators would occur at reduced rates. This study confirmed that a condition of both predator-host balance and genetic equilibrium had not been attained after 2 seasons in the release and immediately adjacent areas. Therefore, the ultimate success of the genetic induction of the azinphosmethyl resistance into the native susceptible population is yet to be fully proved. However, study for 2 seasons has indicated that success is very probable."

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The rapid and extensive dispersal reported here with the carbaryl-OP-resistant strain of *M. occidentalis* ^{was} ~~were~~ surprising to us; we do not know if this strain has a higher dispersal ability than other strains of *M. occidentalis*.

The rate of dispersal and degree of interbreeding of native (susceptible) and released (resistant) *M. occidentalis* is of concern in the implementation of a genetic improvement project (Hoy, 1979). If resistant predators are released into orchards or vineyards shortly after the relevant pesticide is applied, the susceptible native predator should be replaced readily in that specific orchard if all the native predators have been killed and if migration into the orchard is low; whether the resistance is polygenically determined or determined by a single major gene should not affect the outcome. However, these data suggest that the resistant strains may disperse aurally. At present we do not know how rapidly, how far, or how many of, these resistant predators will disperse from the release orchards/vineyards and how best to monitor or "manage" the resistant predators in the recipient orchards or vineyards. Nor do we know how many susceptible predators will dis-

perse into the orchard. Considerable work is required to answer these questions. During 1980 and 1981, about 85 hectares of almonds in 8 locations in the San Joaquin Valley of California received inoculations of the carbaryl-OP-resistant strain, and it will be interesting to determine if these orchards will serve as foci for spread of *M. occidentalis* ♀♀ carrying the semi-dominant carbaryl resistance gene into surrounding orchards and vineyards (Hoy *et al.* 1982).

That *M. occidentalis* can disperse through the air in the field is documented for the first time, but the field conditions that induce such dispersal are unknown at present. Our knowledge of *M. occidentalis*' behavior under laboratory or greenhouse conditions is increasing rapidly (Fransz, 1974; Hoy & Smilanick, 1979, 1981; Kuchlein, 1966; Penman & Chapman, 1980; Rabbinge & Hoy, 1980; Sabelis 1982), but our knowledge of *M. occidentalis*' behavior under natural conditions remains a fertile area for research. Coupling laboratory-derived observations with field analyses may provide important solutions to numerous questions asked by biological control workers.

These data indicate that within-orchard dispersal of this carbaryl-OP-resistant strain of *M. occidentalis* can be more rapid than believed formerly. The excellent performance of this strain in two commercial California almond orchards reconfirms that a genetic improvement of this biological control agent has been achieved.

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RÉSUMÉ

Dispersion aérienne et efficacité au verger d'une souche génétiquement contrôlée de Metaseiulus occidentalis, Acarina, Phytoseiida, acarien prédateur de tétranyques

Une souche de *Metaseiulus occidentalis* résistante au carbaryl et aux insecticides organophosphorés a été libérée en août 1979 dans quelques arbres en bor-

dure d'un verger d'amandiers de 32 hectares près de Bakersfield (Californie). En août 1980, des prédateurs récoltés dans 7 points bien séparés du verger avaient des niveaux modérés ou élevés de résistance au carbaryl, montrant que la souche résistante s'était établie et multipliée, avait hiverné et s'était dispersée à partir du lieu de lacher. En 1980, les prédateurs résistants ont eu un effet conséquent sur les populations de tétranyques. La dispersion aérienne de *M. occidentalis* a été subodorée dans ce verger par suite de la distance et de la rapidité. Des prédateurs récoltés en avril et septembre 1981 étaient encore résistants au carbaryl, prouvant que cette souche avait survécu une seconde année dans ce verger commercial d'amandes. La souche résistante au carbaryl a aussi été libérée sur un arbre sur 3, tous les 3 rangs, dans un verger d'amandiers, près de Livingston (Californie) en juin 1981; la dispersion entre les arbres s'est opérée en 1 mois. Les prédateurs ont exercé une protection considérable contre les tétranyques dans ce verger aussi. La dispersion aérienne a été contrôlée en capturant un grand nombre de *M. occidentalis* sur des panneaux englués à l'extérieur du verger. C'est la première observation de dispersion aérienne de *M. occidentalis* dans la nature; elle permet d'envisager que cette souche résistante peut être capable d'une dispersion considérable depuis les vergers où elle est lâchée. C'est aussi la première fois que cette souche sélectionnée au laboratoire s'est montrée efficace dans de grands vergers commerciaux d'amandiers, les essais antérieurs ayant été effectués exclusivement sur des parcelles de 10 à 30 arbres.

REFERENCES

- Croft, B. A. (1976). Establishing insecticide-resistant phytoseiid mite predators in deciduous tree fruit orchards. *Entomophaga* 21: 383—399.
- Croft, B. A. & Barnes, M. M. (1971). Comparative studies on four strains of *Typhlodromus occidentalis*. III. Evaluations of releases of insecticide resistant strains into an apple orchard ecosystem. *J. econ. Entomol.* 64: 845—850.
- & — (1972). Comparative studies on four strains of *Typhlodromus occidentalis* VI. Persistence of insecticide-resistant strains in an apple orchard ecosystem. *J. econ. Entomol.* 64: 211—216.
- Field, R. P. (1978). Control of the two-spotted mite in a Victorian peach orchard with an introduced insecticide-resistant strain of the predatory mite *Typhlodromus occidentalis* Nesbitt (Acarina: Phytoseiidae) *Aust. J. Zool.* 26: 519—527.
- & — (1981). Evaluation of genetically-improved strains of *Metaseiulus occidentalis* (Nesbitt) (Acarina: Phytoseiidae) for integrated control of spider mites on roses in greenhouses. Ph. D. thesis, U. C. Berkeley. 116 pp.
- Fransz, H. G. (1974). *The Functional Response to Prey Density in an Acarine System*. Simulation Monogr., PUDOC, Wageningen, 143 p.
- Hoy, M. A. (1979). The potential for genetic improvement of predators for pest management programs. In: *Genetics in Relation to Insect Management*, Eds.: M. A. Hoy & J. J. McKelvey, Jr., Rockefeller Found. Press, N. Y., 106—115.
- Hoy, M. A., Barnett, W. W., Reil, W. O., Castro, D., Cahn, D., Hendricks, L. C., Coviello, R. & Bentley, W. J. (1982). Large-scale releases of pesticide-resistant spider mite predators. *Calif. Agric.* 36 (1—2): 8—10.
- Hoy, M. A., Flaherty, D., Peacock, W., & Culver, D. (1979a). Vineyard and laboratory evaluations of methomyl, dimethoate, and permethrin for a grape pest management program in the San Joaquin Valley of California. *J. econ. Entomol.* 72: 250—255.
- Hoy, M. A. & Knop, N. F. (1979). Studies on pesticide resistance in the phytoseiid *Metaseiulus occidentalis* in California. *Rec. Adv. Acarol.* 1: 89—94.
- & — (1981). Selection for and genetic analysis of permethrin resistance in *Metaseiulus occidentalis*, genetic improvement of a biological control agent. *Ent. exp. & appl.* 30: 10—18.
- Hoy, M. A., Knop, N. F., & Joos, J. L. (1980). Pyrethroid resistance persists in spider mite predator. *Calif. Agric.* 34: 11—12.
- Hoy, M. A., Roush, R. T., Smith, K. B. & Barclay, L. W. (1979b). Spider mites and predators in San Joaquin Valley almond orchards. *Calif. Agric.* 33 (10): 11—13.
- Hoy, M. A. & Smilanick, J. M. (1979). A sex pheromone produced by immature and adult females of the predatory mite, *Metaseiulus occidentalis*, Acarina: Phytoseiidae. *Ent. exp. & appl.* 26: 291—300.
- & — (1981). Non-random prey location by the phytoseiid predator *Metaseiulus occidentalis*: differential responses to several spider mite species. *Ent. exp. & appl.* 29: 241—253.
- Hoy, M. A. & Standow, K. A. (1981). Resistance to sulfur in a vineyard spider mite predator. *Calif. Agr.* 35 (5—6): 8—10.
- Hoyt, S. C. (1969). Integrated chemical control of insects and biological control of mites on apple in Washington. *J. econ. Entomol.* 62: 74—86.
- Johnson, D. T. & Croft, B. A. (1976). Laboratory study of the dispersal behavior of *Amblyseius fallacis* (Acarina: Phytoseiidae). *Ann. entomol. Soc. Amer.* 69: 1019—1023.
- Kuchlein, J. N. (1966). Mutual interference among the predaceous mite *Typhlodromus longipilus* Nesbitt, Acari, Phytoseiidae I. Effects of predator density on oviposition rate and migration tendency. *Meded. Rijksfac. Landbouw. Wetenschappen Gent*, 31: 740—745.
- Penman, D. R. & Chapman, R. B. (1980). Effect of temperature and humidity on the locomotory activity of *Tetranychus urticae* (Acarina: Tetranychidae), *Typhlodromus occidentalis* and *Ambly-*

- seius fallacis* (Acarina: Phytoseiidae). *Acta Oecologica Applic.* 1: 259—264.
- Rabbinge, R. & Hoy, M. A. (1980). A population model for two-spotted spider mite *Tetranychus urticae* and its predator *Metaseiulus occidentalis*. *Ent. exp. & appl.* 28: 64—81.
- Roush, R. T. & Hoy, M. A. (1981a). Genetic improvement of *Metaseiulus occidentalis*: Selection with methomyl, dimethoate, and carbaryl and genetic analysis of carbaryl resistance. *J. econ. Entomol.* 74: 138—141.
- & — (1981b). Laboratory, glasshouse and field studies of artificially selected carbaryl resistance in *Metaseiulus occidentalis*. *J. econ. Entomol.* 74: 142—147.
- Sabelis, M. W. (1982). Biological control of two-spotted spider mites using phytoseiid predators. Part I. Modelling the predator-prey interaction at the individual level. Agric. Res. Rep. (*Versl. landbouwk. Onderz.*) 910, 242 p.