Project No. 86-B10 - Navel Orangeworm Mite and Insect Research

Control of Mites on Almonds

December 1986

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Mite Management

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Objectives: (1) Conduct mode of inheritance tests with Plictran (and if possible Omite) resistant strains of spider mites. (2) Determine how stable Plictran (and if possible) Omite resistance is by initiating colonies with gene frequencies of 0.5 for the resistance gene (assuming it is caused by a single gene) and determine the fate of the resistance over succeeding generations in the absence of selection. (3) Determine the toxicity of pesticides used in almonds during the winter and spring to diapausing (M. occidentalis through tests of laboratory and field-collected diapausing females. (4) Evaluate and compare the stimulatory effects of Triforine (Funginex) and Savey on M. occidentalis as a potential method for increasing predator populations in orchards or in mass rearing facilities. (5) Compare the temperature and relative humidity tolerance of European red mites from almonds to that of a colony from Watsonville apples. The goal is to determine whether the almond European red mites represent a new heat and low relative humidity-tolerant bio-type. (6) Develop and assemble data on the effects of pesticides registered for use on almonds to M. occidentalis in a handy reference chart for growers and PCAs. (As planned, funds to come from UC-IPM.)

Interpretive Summary:

During 1986, we evaluated the mode of inheritance of Plictran/Vendex resistance in the Pacific spider mite, Tetranychus pacificus. We used a resistant colony collected from a Wasco almond orchard that we selected 18 times more in the greenhouse and laboratory with Plictran to purify the resistance. Plictran resistance in this colony fits a model in which the resistance is a major semi-recessive trait. F_1 progeny are more resistant than their susceptible (S) parent, but less resistant than their resistant (R) parent. Backcrosses further indicate the resistance is not determined by many genes. The Plictran-resistant colony, a susceptible colony, and two colonies initiated by crossing the R and S colonies and using their F_1 progeny to initiate them, were held in the greenhouse for 5 months without Plictran/Vendex sprays to determine how stable the Plictran resistance might be. Every 2 weeks, we tested each colony with a standard concentration of Plictran to determine whether the Plictran resistance was declining. After 5 months comparative concentration/response curves were obtained. The R colony did not lose its Plictran resistance; the S colony remained susceptible (indicating no contamination occurred), and the colonies derived from reciprocal F_1 progeny had resistance levels only slightly lower than 5 months previously. The implications of these data for the use of Plictran/Vendex in the field are speculative because field populations may be less pure in their R levels and immigration of R and S spider mites in the field will influence the purity of R populations. However, we suggest that: 1) once Plictran/Vendex resistance becomes purified in orchard populations of T. pacificus, disuse of Plictran/Vendex for a year

is unlikely to be sufficient to allow the R level to decline to a low level. 2) Because even the colonies derived from F_1 progeny lost little of their resistance over the 5 month interval, use of Plictran/Vendex could also remain difficult even in populations that are not genetically pure.

Pesticides registered for use in almonds were tested for their toxicity to the Western predatory mite, Metaseiulus occidentalis, in the laboratory. Fungicides used in the spring were tested using both starved and well-fed females to determine whether newly-emerged predators in the spring are more susceptible to pesticides than well-fed females. The results do not indicate any substantial differences in starved vs. well-fed females' responses to the pesticides tested. These results are included in a handout on the effects of pesticides registered for use in almonds to M. occidentalis. The handout is available from the Almond Board or at our table at the Conference. We also tested new acaricides that may be registered in almonds in the next year or two. Apollo and Savey, two ovicides, are nearly nontoxic to M. occidentalis and thus look especially valuable for integrated mite management. Thuringiensin and Abamectin are more toxic to spider mites than to M. occidentalis, but at the proposed field rates, laboratory data suggest they could be toxic to M. occidentalis. Thus, field experiments may be necessary to determine the rates best suited for integrated mite management with these products.

Work on biotypes of the European red mite will begin in January.

II. Genetic Analysis of Plictran Resistance in T. pacificus

A. Selection of T. pacificus for Plictran Resistance

The Wasco colony of T. pacificus was collected from almonds in Kern County in June 1984. While it was our most Plictran-tolerant colony, it was not clear that it was sufficiently pure genetically so that we could use it in a genetic analysis to determine the mode of inheritance of Plictran resistance. Therefore, we reared it on pinto bean plants in the U.C. Berkeley greenhouse and selected it with Plictran 18 times over a 13 month period before we felt it was pure. It has been selected on additional 5 times in seven months to maintain its purity (Table 1). The first three selections were conducted in the laboratory. For these laboratory selections, 50 active, gravid females were placed on pinto bean leaf disks on wet cotton in plastic trays. An average of 500 females were selected each time using 4.0 lb. 50 WP Plictran/100 gallons water (2400 ppm). Solutions were made fresh each time using Plictran 50 WP and distilled water. Leaf disks were sprayed using a Crown Spra-Tool. The mites were then held at 78-84°F under an 18 hr daylength for 48 hr. Mites scored as alive could walk when touched with a fine camels hair brush. Survivors were placed on clean leaf disks and these disks were placed on clean bean plants in cages in the greenhouse where they multiplied. Colonies were selected again after two to three generations (Table 1).

Subsequent selections (4 through 23) were done in the greenhouse using whole bean plants held in cages (Table 1). Bean plants were sprayed that were either infested or uninfested with mites. If uninfested, Plictran-treated plants were subsequently infested by cutting old foliage and placing it on the

Table 1. Selection for Plictran resistance using the Wasco colony of *T. pacificus*.

Date selected and Method	Selection no.	Dose lbs. 50WP/100 gal (ppm)	% survival - 48 hr selected colony	% survival - 48 hr base colony
Leaf spray - Laboratory				
1985				
4 February	1	4.0 (2400)	47	-
11 March	2	4.0 (2400)	30	37
24 April	3	4.0 (2400)	33	41
Single dose slide dip analysis of selected colony number three				
		4.0 (2400)	34	47
Bean flat spray - Greenhouse				
29 July	4	1.0 (600) - new flat*	moderate***	
6 August	5	1.0 (600) - new flat	moderate	
16 August	6	0.2 (1200) - old flat**	high	
22 August	7	0.5 (300) - new flat	moderate	
30 August	8	1.0 (600) - old flat	high	
6 September	9	2.0 (1200) - new flat	moderate	
13 September	10	2.5 (1500) - old flat	moderate	
23 September	11	2.5 (1500) - new flat	high	
12 October	12	3.0 (1800) - new flat	high	
Single dose slide dip analysis of selected colony number 12				
		3.0 (1800)	49	33

Table 1. (continued)

Date selected and Method	Selection no.	Dose lbs. 50WP/100 gal (ppm)	% survival (ppm)
Bean flat spray - Greenhouse			
8 November	13	4.0 (2400) - old flat	high
25 November	14	4.0 (2400) - new flat	high
6 December	15	4.2 (2520) - old flat	high
1986			
14 February	16	16.0 (9600) - old flat	low (~30%)
28 February	17	16.0 (9600) - old flat	low
17 March	18	16.0 (9600) - old flat	moderate
6 May	19	flowable 60 ppm - old flat	high
16 May	20	flowable 90 ppm - new flat	high
8 July	Colony subcultured with 1000 ♀♀. Contaminated with *Amblyseius californicus*.		
25 July	21	flowable 90 ppm - old flat	high
15 August	22	flowable 120 ppm - new flat	high
5 September	Colony subcultured with 1000 ♀♀. Contaminated with *Amblyseius californicus*.		
29 October	23	flowable 120 ppm - new flat	high

* new flat - uninfested flat of beans was sprayed and allowed to dry. Foliage from old flat was placed on new flat and mites walked onto new, freshly treated foliage.

** old flat - infested flat of beans was sprayed. Mites had direct contact with spray.

*** An estimate of survival of adult females on bean flats was made one week after flats were sprayed.

High survival > 70%
Moderate = 30 - 70%
Low < 30%

clean new plants and allowing mites to walk off. Plictran concentrations used ranged from 0.2 lb. 50 WP Plictran/100 gallons (120 ppm) to 16.0 lb. 50 WP Plictran/100 gallons (9600 ppm) for selections 4 through 18. Beginning with selection 19, we used the flowable formulation of Plictran (50 W), which is more toxic to mites. Doses ranged from 60 to 120 ppm for selections 19 through 23. These selections were conducted to maintain the Plictran resistance in the colony. Colonies were examined one week following selection to estimate their survival rate. If populations were high, the Plictran concentration used in the next selection was increased. This selection method exposed all live stages to Plictran.

A mode of inheritance test was conducted using the colonies selected 18 (Wasco-18) and 20 (Wasco-20) times, and is discussed later in this chapter.

B. Documentation of Selection Responses and Development of Test Methods

Concentration/mortality lines were obtained for the base colony (Wasco) and selected colonies (Wasco-15 and Wasco-18) using adult females and larvae and compared to a susceptible colony (Chapla) to determine whether the selected line was sufficiently pure for a mode of inheritance test. The concentration responses of the Chapla, Wasco, and Wasco-15 colonies are shown in Figure 1 and Table 2. The lines for the Wasco and Wasco-15 colonies are clearly different from that of the susceptible Chapla colony (Figure 1). The 15 selections had also resulted in a shift in the LC_{50} and LC_{90} values of the Wasco colony. Larvae, like adult females of the Wasco, Wasco-15, and Chapla colonies have different responses to Plictran. The larvae of the Wasco-15 colony survive better than the larvae of the Wasco base colony,

Figure 1. Concentration/mortality responses of adult females of the Wasco, Wasco-15, and Chapla colonies of T. pacificus using a leaf spray technique and the wettable powder (WP) formulation of Plictran. The Wasco-15 colony was selected 15 times with Plictran in the laboratory and greenhouse.

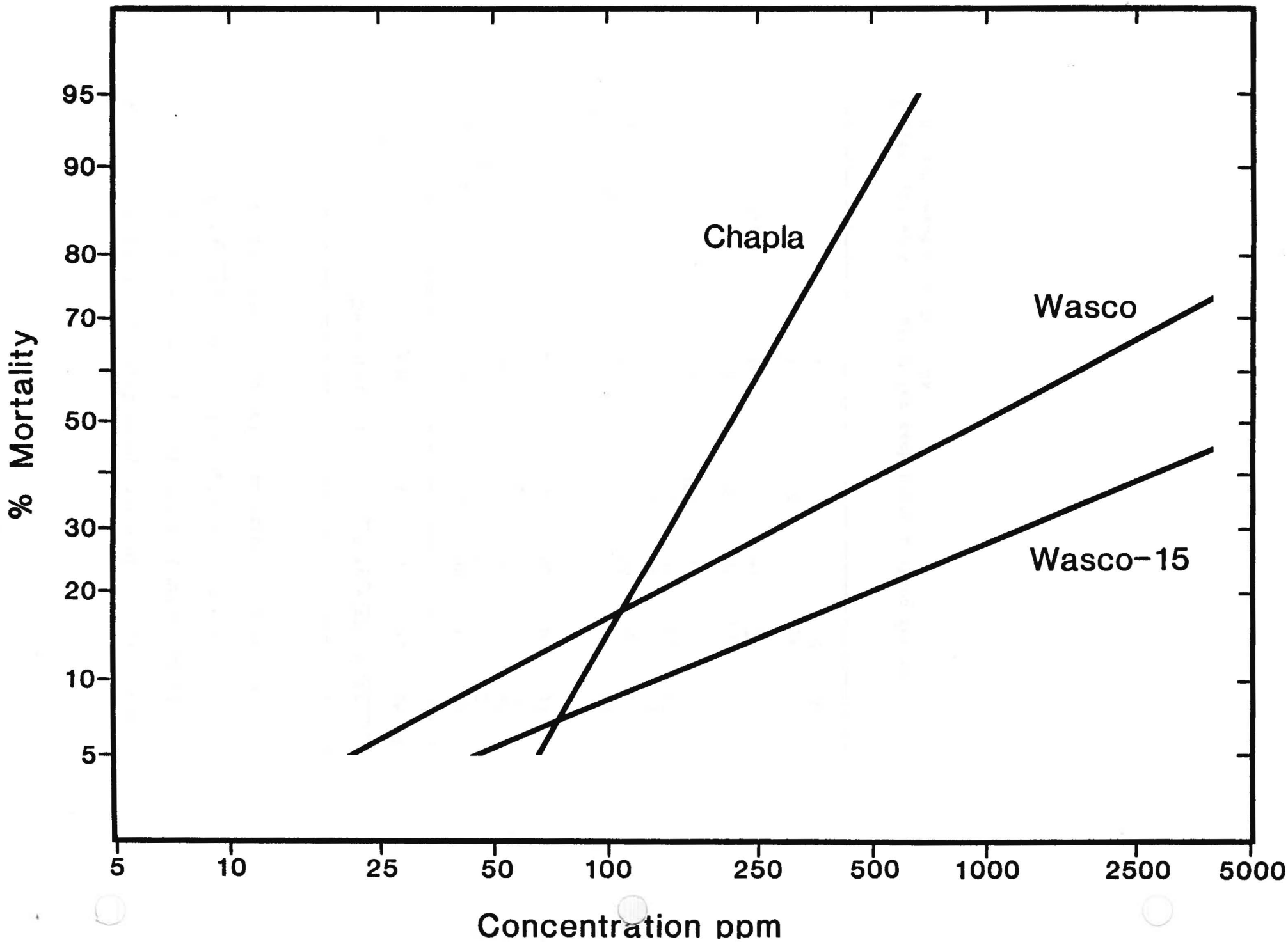

95
90
80
70
50
30
20
10
5
% Mortality
Chapla
Wasco
Wasco-15
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

Table 2. Concentration/mortality responses of resistant (Wasco base and Wasco-15) and susceptible (Chapla) larvae of T. pacificus using a leaf spray technique and a wettable powder (50 WP) formulation of cyhexatin.

Colony	Concentration	% survival after			
	ppm	24	48	72	96 h[a/]
Wasco base (resistant)	0	100	98	94	80
	300	92	84	84	52
	600	92	80	74	42
	1200	92	90	58	40
	2400	64	62	46	30
Wasco-15 (selected resistant)	0	100	100	98	80
	1200	94	94	80	64
	2400	96	92	76	58
	3600	96	98	80	58
	4800	100	90	78	68
Chapla (susceptible)	0	100	100	100	94
	60	82	84	26	2
	300	74	62	22	0
	600	36	34	16	0
	1200	0	0	0	0

[a/] Fifty larvae were tested for each concentration for each colony using 5 larvae/disk.

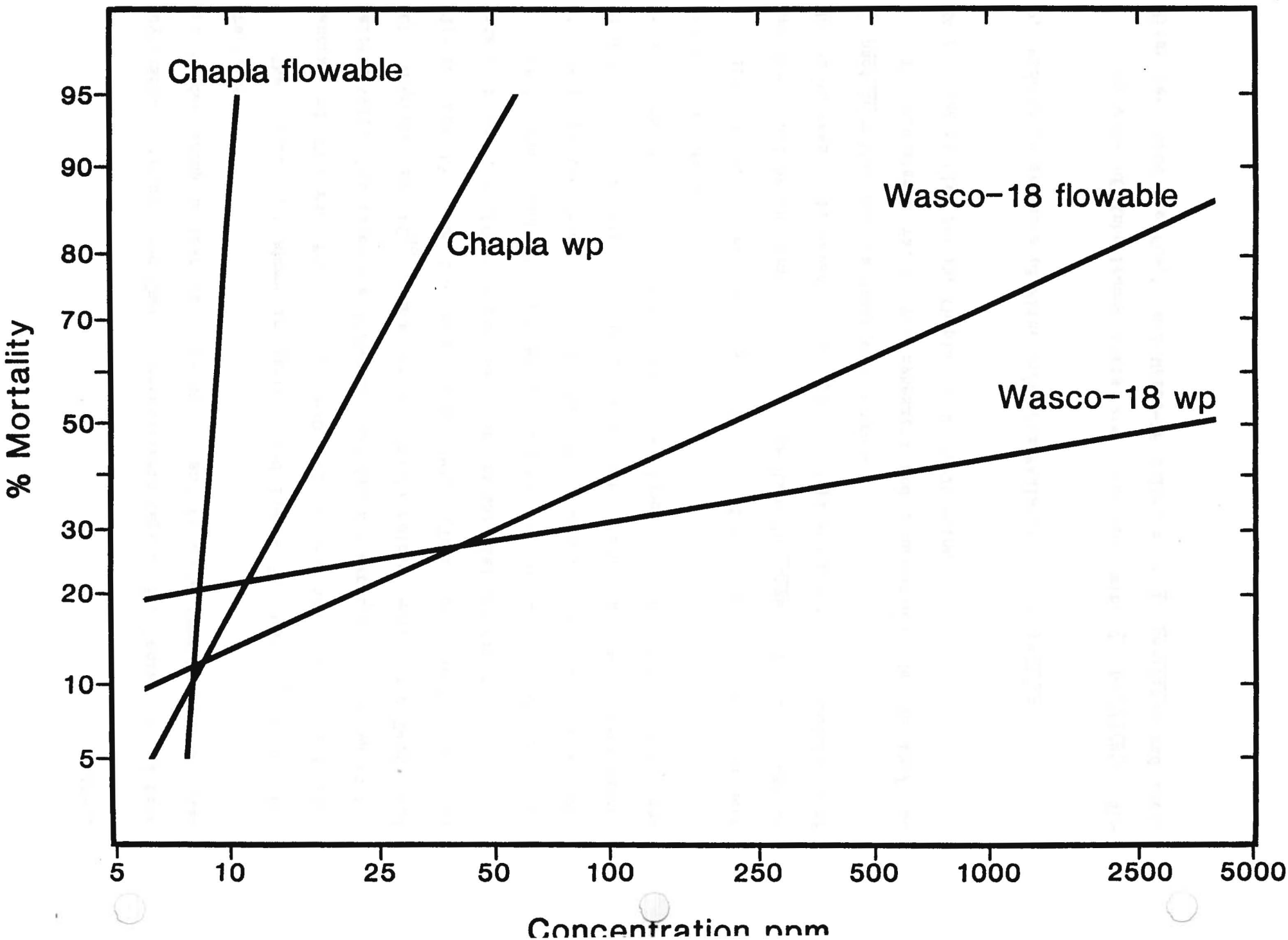
suggesting the selection with Plictran yielded a selection response. The above tests were done using the wettable powder formulation of Plictran.

Because the lines of the Wasco and Wasco-15 colonies are flat (Figure 1), we conducted a test with the Wasco and Wasco-18 and Chapla colonies, using a different formulation of Plictran to determine if the slopes of the lines could be improved. These data, comparing the wettable powder (WP) and flowable (W) formulations, are shown in Figure 2. Both the Chapla and Wasco-18 colonies' concentration/response lines are steeper when tests are conducted using the flowable rather than the wettable powder formulation (Figure 2). The Chapla and Wasco-18 lines obtained with the flowable formulation overlap very little and are thus suitable for a mode of inheritance test. The data for the Wasco-18 colony obtained with the flowable formulation is more reliable (Table 4). The LC_{90} value calculated for the WP formulation (ca. 33 million) is clearly unrealistic and this is reflected by the fact that no confidence limits (C.L.) are provided by the POLO program. The flowable formulation is not currently registered for use in almonds. However, should it become registered for use in almond, it might be significantly more efficacious in the field than the WP formulation, particularly in areas where Plictran resistance is developing.

C. Relationship between Plictran & Vendex Resistances in T. pacificus

The Wasco colony of T. pacificus has been selected a total of 23 times with cyhexatin (Plictran) in the laboratory and greenhouse to date. Because Vendex (fenbutatin-oxide) is similar in chemistry to cyhexatin, we compared the concentration/responses of the adult females of the Wasco-20

Figure 2. Comparisons of the concentration/mortality responses of the Chapla (susceptible) Wasco-18 (selected) colonies of T. pacificus obtained by using flowable (W) and wettable powder (WP) formulations of Plictran (cyhexatin) in a leaf spray assay.


Chapla flowable
Chapla wp
Wasco-18 flowable
Wasco-18 wp
% Mortality
95
90
80
70
50
30
20
10
5
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

(cyhexatin-resistant) and Chapla (cyhexatin-susceptible) colonies of Plictran and Vendex using a leaf spray technique and flowable formulations of each acaricide.

The results are shown in Table 3 and Figure 3. The LC_{50} values for Vendex and Plictran for the Wasco-20 colony are 526.9 and 327.2 ppm, respecitvely. The lines are different, and are not parallel, according to the POLO program. The LC_{50} values for the Chapla colony tested with Vendex and Plictran are 15.2 and 17.3 ppm, respectively (Table 3). These lines and intercepts are not different and the lines are parallel (Figure 3).

While the lines obtained with Plictran and Vendex are statistically different for the Wasco-20 colony, they are similar. Clearly, 20 selections with Plictran have yielded a strain with major levels of Vendex resistance. In fact, the LC_{50} for Vendex is actually higher than that for Plictran, and the slope is steeper.

The data do not conclusively prove that Plictran and Vendex resistances are determined by the same allele(s). The data do <u>suggest</u> that field use of Vendex instead of Plictran may not provide improved control in populations of <u>T. pacificus</u> that are resistant to Plictran.

The resistance ratios for cyhexatin and fenbutatin-oxide are 18.7 and 34.7, respectively, for the Chapla and Wasco-20 colonies.

D. Mode of Inheritance of Plictran/Vendex Resistance in <u>T. pacificus</u>

Two mode of inheritance tests were conducted with <u>T. pacificus</u>. The first test used the Chapla and Wasco-18 colonies of <u>T. pacificus</u> and their

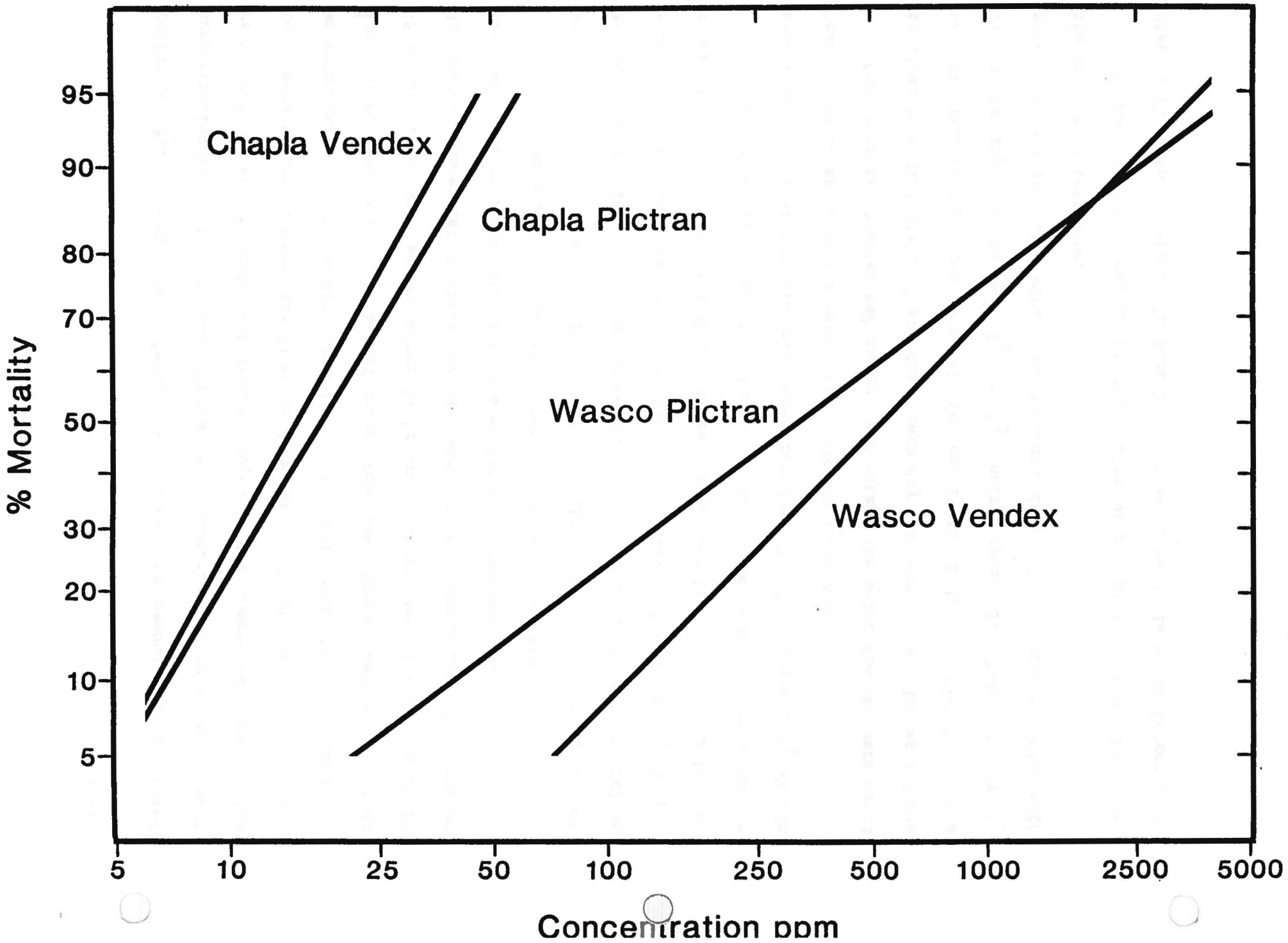
Table 3. Comparison of concentration/mortality responses of the Wasco-20 and Chapla colonies of T. pacificus obtained with Vendex and Plictran, using a leaf spray technique and flowable formulations.

Colony and Pesticide	No. ♀♀ tested	LC_{50} ppm	95% C.L.	LC_{90} ppm	95% C.L.	Slope (± S.D.)
Wasco-20						
Vendex 4 L [a/]	675	526.9	357.0 - 737.8	2442.7	1494.9 - 6884.9	1.92 (.24)
Plictran 50 W	675	327.2	233.1 - 442.7	2637.9	1644.6 - 5590.0	1.41 (.16)
Chapla						
Vendex 4 L [b/]	675	15.2	12.8 - 17.4	35.9	31.0 - 43.5	3.43 (.29)
Plictran 50 W	675	17.3	13.6 - 20.7	44.6	35.6 - 64.7	3.11 (.30)

a/ Lines and intercepts are not the same ($P < 0.05$); lines are not parallel. (Savin et al. 1977).

b/ Lines and intercepts are the same; lines are parallel.

Figure 3. Concentration/mortality responses of resistant (Wasco-20) and susceptible (Chapla) colonies of T. pacificus tested with flowable formulations of cyhexatin (Plictran 50 W) and fenbutatin-oxide (Vendex 4 L) in a leaf spray method.


Chapla Vendex
Chapla Plictran
Wasco Plictran
Wasco Vendex
% Mortality
95
90
80
70
50
30
20
10
5
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

reciprocal F_1, progeny, using females and males. The second test evaluated concentration/mortality of the Chapla and Wasco-20 colonies and their reciprocal F_1 and F_2 male and female progeny. All concentration/mortality tests were conducted using the flowable formulation of Plictran (50 W) because we obtained better lines with this formulation than with the WP formulation. Adult mites were tested with a leaf spray technique; females were scored after 48 hr and males were scored after 24 hr and held at 78-82°F under an 18 hr daylength. Concentration/mortality data were analyzed using the POLO computer program; the likelihood ratio test tested for equal response curves.

Crosses were performed in the laboratory using 72 virgin females and 72 males for each cross; virgins were obtained by isolation quiescent deutonymphal females. Eight quiescent females and adult males were placed on each of 9 pinto bean leaf disks for each cross: Wasco-18 x Wasco-18 , Chapla x Chapla, Wasco-18 females x Chapla males, Chapla females x Wasco-18 males for Test 1, and Wasco-20 x Wasco-20, Chapla x Chapla, Wasco-20 females x Chapla males, Chapla females x Wasco-20 males for Test 2. In addition, F_1 virgin females and males in Test 2 were used to produce F_2 progeny.

Once parental females had emerged and mated, the mated females were moved to clean bean leaf disks, 3 per disk, each day for seven days. The eggs these parental females deposited were held for ca. 10 to 11 days at 25-29°C under a 24 hr daylength until new F_1 or F_2 adults appeared. These F_1 or F_2 progeny were then tested within one to three days, after becoming adults with the leaf spray technique.

In Test 1, five females or five males were placed on pinto bean leaf disks 1.75 cm in diameter. In Test 2, ten females were placed on larger disks

2.4 cm in diameter. When males were tested, five males and five females were placed on the same disk to reduce the amount of runoff by males. For those doses at which only males were tested in Test 2, two females were added to help retain males.

Leaf disks were sprayed with Plictran (50 W) concentrations, or distilled water, made fresh each day. A Crown Spra-Tool was held ca. 9 inches away and sprayed for 5 seconds. After 24 hr (males) or 48 hr (females), mites were scored as dead or alive. Live mites could walk when touched with a fine camels' hair brush. All others were scored as dead.

Results

Results of Test 1 are shown in Tables 4 and 5 and Figures 4 and 5. The resistant Wasco-18 females had an LC_{50} of 175.5 ppm. The susceptible Chapla females' LC_{50} was 17.6 ppm, a 9.97-fold difference. The reciprocal F_1 female progeny had LC_{50} values of 39.0 and 50.3 ppm, respectively, for the Wasco-18 female x Chapla male and Chapla female x Wasco-18 male crosses (Table 4, Test 1). These are significantly different from each other, but the lines are parallel (Figure 4). The reciprocal F_1 females' LC_{50} values are intermediate between those of the Chapla and Wasco-18 colonies (Figure 4, Table 4). Calculations of dominance were made using the formula

$$D = \frac{2X_2 - X_1 - X_3}{X_1 - X_3}$$

where X_1 = log of the LC_{50} of the resistant (PR) colony

X_2 = log of the LC_{50} of the heterozygous (RS) colony

X_3 = log of the LC_{50} of the susceptible (SS) colony

Table 4. A mode of inheritance test of cyhexatin resistance using adult females of T. pacificus, using a leaf spray technique and the flowable formulation of cyhexatin (50 W): analysis of F_1 females.

Colony or Cross	No. ♀♀ tested	LC_{50} ppm[a/]	C.L. 95%	LC_{90} ppm[a/]	C.L. 95%	Slope (± S.D.)
TEST 1						
Wasco-18 ♀ x Wasco-18 ♂ (resistant)	960	175.5 [113.4]	144.5 - 209.1 [93.5 - 134.2]	728.1 [366.9]	577.3 - 984.7 [296.2 - 489.3]	2.07 (.16)
Wasco-18 ♀ x Chapla ♂	765	39.0 [33.8]	33.4 - 44.5 [27.5 - 39.4]	98.5 [75.6]	84.0 - 121.1 [64.9 - 92.8]	3.18 (.27)
Chapla ♀ x Wasco-18 ♂	780	50.3 [47.4]	39.2 - 60.3 [38.2 - 55.3]	156.6 [105.9]	123.4 - 232.0 [89.3 - 137.0]	2.60 (.32)
Chapla ♀ x Chapla ♂ (susceptible)	750	17.6 [16.1]	15.9 - 19.3 [14.2 - 17.6]	31.0 [25.1]	27.3 - 37.8 [22.6 - 29.7]	5.25 (.58)
TEST 2						
Wasco-20 ♀ x Wasco-20 ♂ (resistant)	500	172.3	110.1 - 251.4	1049.7	642.7 - 2378.7	1.63 (.19)
Wasco-20 ♀ x Chapla ♂	245	92.9	70.0 - 120.5	287.9	203.8 - 531.4	2.61 (.37)
Chapla ♀ x Wasco-20 ♂	525	47.0	36.0 - 58.0	140.7	107.9 - 215.3	2.69 (.26)
Chapla ♀ x Chapla ♂ (susceptible)	460	19.4	15.1 - 22.5	33.2	28.7 - 41.4	5.47 (.63)

a/ Tests were held at ca. 80° F and scored after 48 hrs. Numbers in [ ] are for scores at 72 hrs; their C.L. are also in [ ].

Table 5. A mode of inheritance test of cyhexatin resistance using adult males of T. pacificus, using a leaf spray technique and the flowable formulation of cyhexatin (50 W): F_1 analysis of males.

Colony or Cross	No. ♀♀ tested	LC_{50} ppm[a/]	C.L. 95%	LC_{90} ppm	C.L. 95%	Slope (± S.D.)
TEST 1						
Wasco-18 ♀ x Wasco-18 ♂ (resistant)	316	121.4	32.0 - 236.2	1163.3	574.0 - 5607.5	1.31 (.27)
Wasco-18 ♀ x Chapla ♂	280	79.7	27.7 - 149.6	758.6	390.6 - 2565.7	1.31 (.22)
Chapla ♀ x Wasco-18 ♂	350	21.5	15.1 - 26.8	55.5	42.2 - 99.3	3.12 (.59)
Chapla ♀ x Chapla ♂ (susceptible)	360	25.6	19.9 - 30.4	43.5	36.0 - 63.7	5.57 (1.02)
TEST 2						
Wasco-20 ♀ x Wasco-20 ♂ (resistant)	132	158.8	49.2 - 344.5	973.1	432.5 - 6925.0	1.63 (.32)
Wasco-20 ♀ x Chapla ♂ (F_1) 1.62		130	215.9	-	1333.3	- (.55)
Chapla ♀ x Wasco-20 ♂ (F_1) 3.75		145	19.2	-	42.0	- (1.21)
Chapla ♀ x Chapla ♂ (susceptible)	140	18.8	11.1 - 24.0	45.0	35.0 - 78.0	3.38 (.86)

a/ Tests were held at ca. 80° F and scored after 24 hrs.

Figure 4. Concentration/mortality responses to cyhexatin of females from the Wasco-18 and Chapla colonies and the reciprocal F_1 females derived from crosses between them. The circles represent responses of the females from the cross of Chapla females x Wasco-18 males. Triangles are of F_1 females from Wasco-18 female x Chapla males cross.

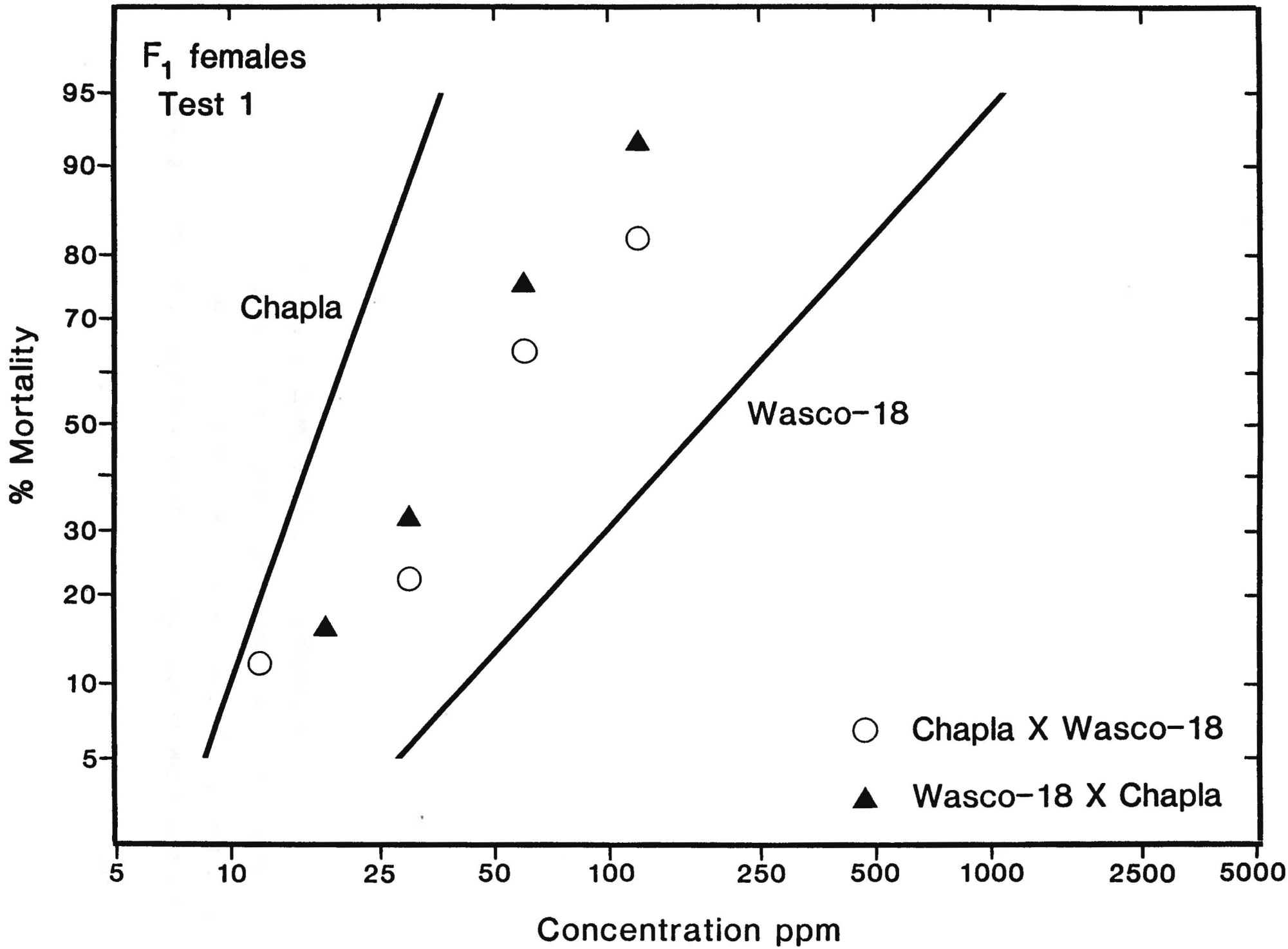
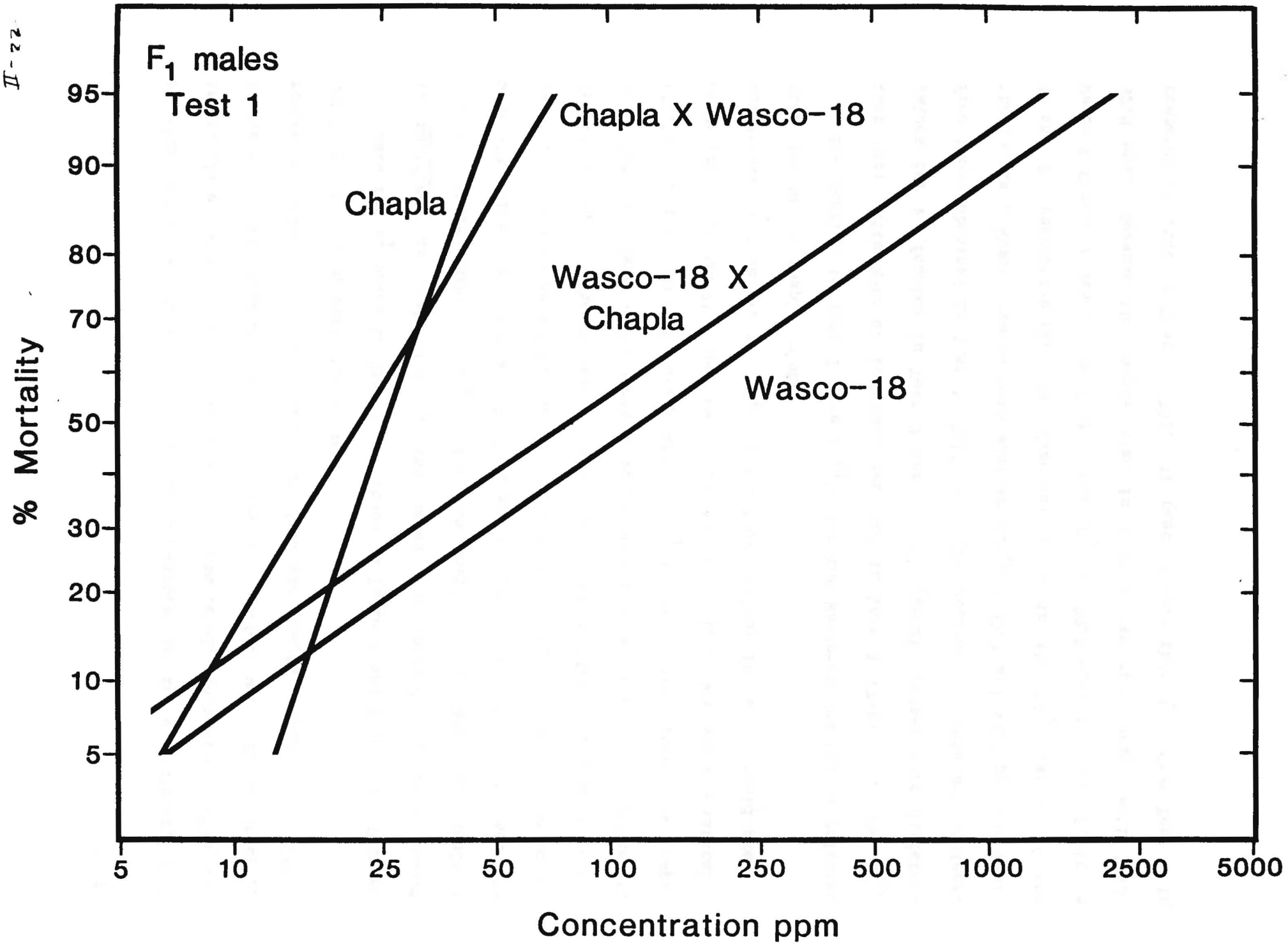

F1 females
Test 1
95
90
80
70
50
30
20
10
5
% Mortality
Chapla
Wasco-18
Chapla X Wasco-18
Wasco-18 X Chapla
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

Figure 5. Concentration/mortality responses to cyhexatin of males from the Wasco-18 and Chapla colonies and the reciprocal F_1 derived from crosses between them. Tests were conducted using a leaf spray technique and the flowable formulation of cyhexatin.


F1 males
Test 1
Chapla X Wasco-18
Chapla
Wasco-18 X
Chapla
Wasco-18
% Mortality
95
90
80
70
50
30
20
10
5
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

By this scale, a rating of +1 means resistance is fully dominant, 0 = intermediate, and -1 means resistance is completely recessive. When the female parent was from the Wasco-18 colony, D = -0.308, which is incompletely recessive. When the parent female was from the Chapla colony, D = -0.087, which is also incompletely recessive.

Data for F_1 males in Test 1 are shown in Table 5 and Figure 5. Because T. pacificus is arrhenotokous, and males are haploid, F_1 sons should resemble their mothers. LC_{50}'s for the Chapla colony and the Chapla x Wasco-18 colony are 25.6 and 21.5, respectively. These lines are not the same, nor are they parallel. The difficulty of working with males, due to run off of males, and the relatively small sample sizes (Table 5, Test 1) could have led to these differences through experimental error. In contrast, LC_{50}'s for the Wasco-18 colony and the F_1 males of the Wasco-18 x Chapla cross are 121.4 and 79.7 ppm, respectively. These lines are not statistically different. For males, the LC_{50} of the Wasco colony is ca. 4.7-fold greater than that of the Chapla colony.

The females in Test 2 gave LC_{50}'s for the Wasco-20 and Chapla colonies that were quite similar to those obtained in Test 1 (Table 4). The LC_{50} values for F_1 females in Test 2 for the reciprocal crosses were different from those obtained in Test 1 (Table 4). The reasons for this are unclear; the Chapla x Wasco crosses were similar (LC_{50} = 50.3 and 47.0 ppm for Tests 1 and 2, respectively). The discrepancy is in the LC_{50} values of the Wasco-X Chapla crosses. In Test 1 the LC_{50} is 39.0 ppm; for Test 2, it is 92.9 ppm. Because the sample size in Test 2 was relatively small (245) compared to that in Test 1 (765), it seems likely that data from Test 1 is

more reliable. This is reflected in the smaller confidence limits of the two LC_{50} values, as well.

The lines of the reciprocal F_1 females are not the same, although they are parallel (Figure 6). The dominance values estimated in Test 2 are -0.1896 and 0.4343, respectively, for the Chapla female x Wasco-20 male cross and the Wasco-20 female x Chapla male cross. In the first case, the resistance is incompletely recessive; in the second it is incompletely dominant. Because three of the four estimates are negative, we conclude that Plictran resistance is incompletely recessive in this colony.

Concentration/mortality lines of F_1 males in Test 2 are shown in Figure 7. The Chapla Colony males and the F_1 males derived from Chapla females x Wasco-20 males have lines that are the same (Table 5). Likewise, the Wasco-20 colony males and F_1 males from the Wasco-20 female x Chapla male cross are significantly different.

Because T. pacificus is an arrhenotokous species, crosses of F_1 males x F_1 females are particularly interesting. Genetically, they are backcrosses (see Figure 8 for a diagrammatic explanation). As a result, F_2 females from the Wasco-20 x Chapla cross should be homozygous or heterozygous for the resistance. In contrast, F_2 females from the reciprocal cross (Chapla x Wasco-20) should be heterozygous for the resistance and homozygous susceptible in a 1:1 ratio. As expected, the F_2 females' lines are not the same (Figure 9). The lines for the Chapla x Wasco-20 cross would be expected to inflect at the 50% mortality level, and this may be occurring (Figure 9). Likewise, the F_2 females from the Wasco-20 x Chapla cross should have an inflection at the 75% mortality level, and this appears to occur (Figure 9).

Table 6. Mode of inheritance test of cyhexatin resistance using adult females of T. pacificus, using a leaf spray technique and the flowable formulation of cyhexatin (50 W): F_2 analysis of females.

Colony or Cross	No. ♀♀ tested	LC_{50} ppm[a/]	C.L. 95%	LC_{90} ppm	C.L. 95%	Slope (± S.D.)
TEST 2						
Wasco-20 ♀ x Wasco-20 ♂ (resistant)	1335	200.8	171.1 - 231.8	861.2	712.7 - 1089.9	2.03 (.12)
Wasco-20 ♀ x Chapla ♂ (F_1 x F_1)	1525	87.1	75.2 - 100.0	412.8	333.6 - 541.6	1.90 (.11)
Chapla ♀ x Wasco-20 ♂ (F_1 x F_1)	1475	22.9	20.1 - 25.8	75.9	65.5 - 91.1	2.47 (.14)
Chapla ♀ x Chapla ♂ (susceptible)	1335	15.2	13.9 - 16.4	24.4	22.6 - 26.8	6.29 (.44)

a/ Tests were held at ca. 80° F and scored after 48 hrs.

Figure 6. Concentration/mortality responses to cyhexatin of adult females of the Chapla and Wasco-20 colonies and the reciprocal F_1 females derived from crosses between them. The circles represent females from the cross of Chapla females x Wasco-20 male. Triangles represent females from Wasco-20 females x Chapla males.

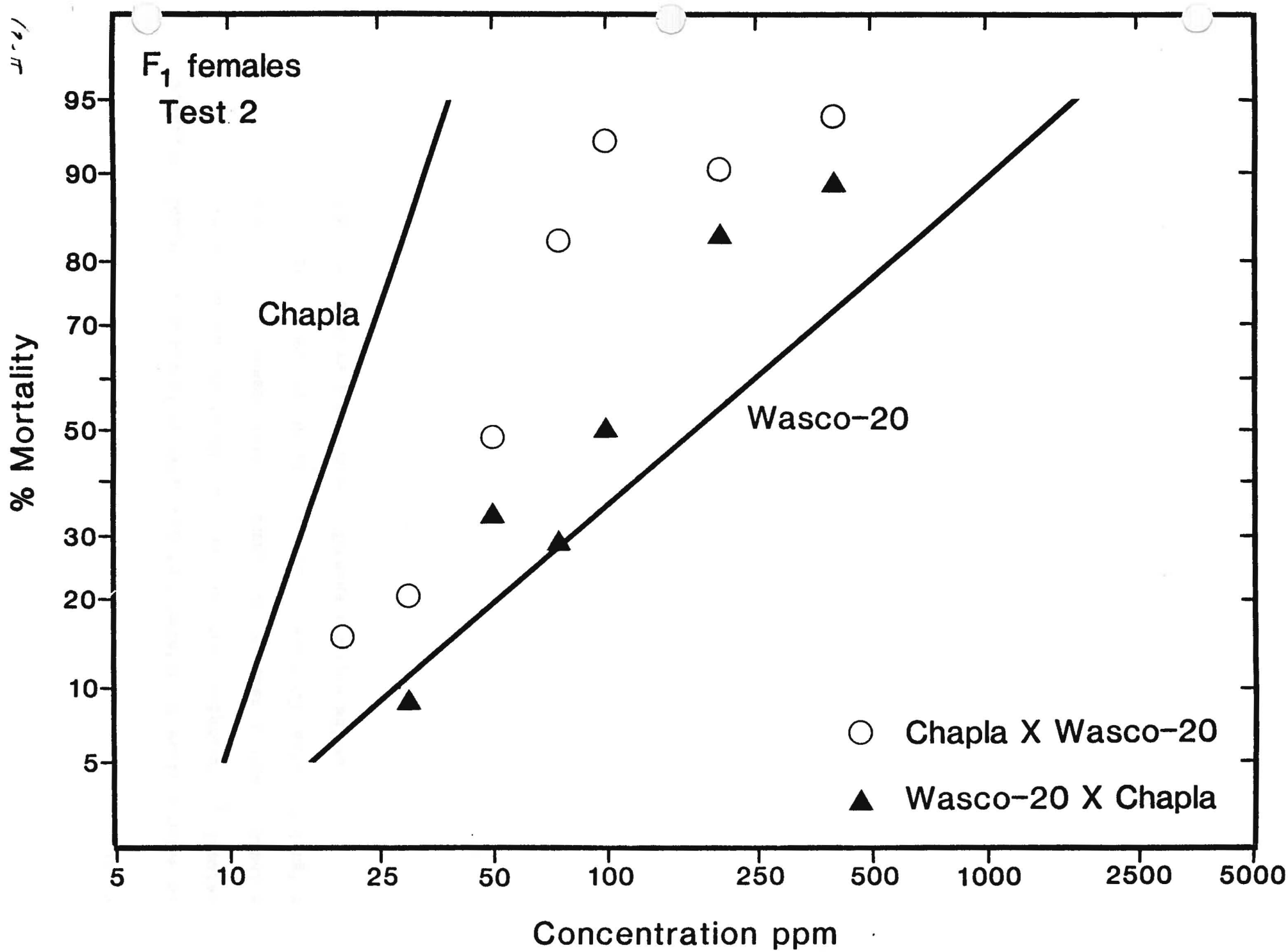

F1 females
Test 2
Chapla
Wasco-20
% Mortality
95
90
80
70
50
30
20
10
5
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm
Chapla X Wasco-20
Wasco-20 X Chapla

Figure 7. Concentration/mortality responses to cyhexatin of males of the Chapla and Wasco-20 colonies and the reciprocal F_1 males from crosses between them.

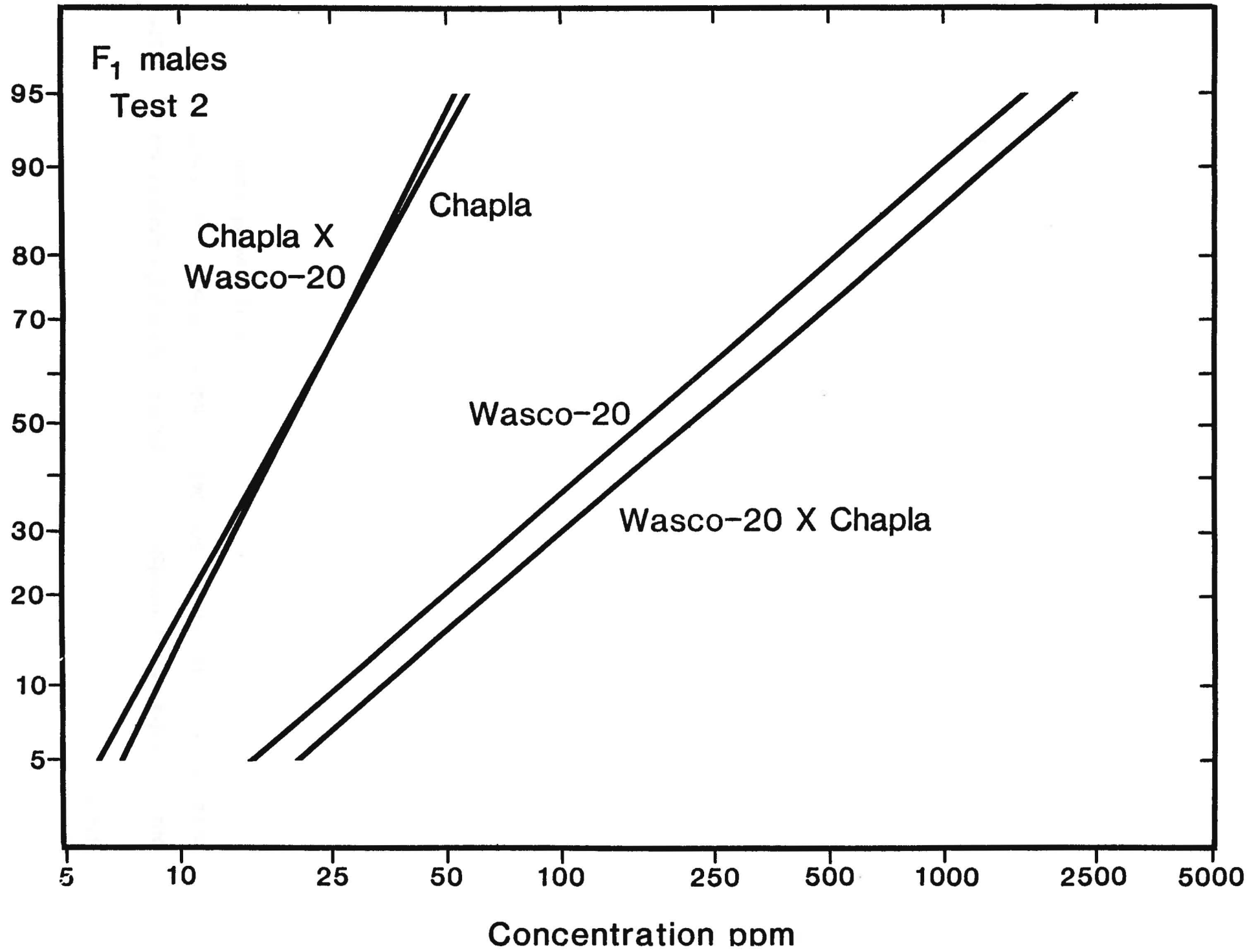

F1 males
Test 2
95
90
80
70
50
30
20
10
5
Chapla
Chapla X
Wasco-20
Wasco-20
Wasco-20 X Chapla
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

Figure 8. Outline of the consequences of the arrhenotokous genetic system of spider mites with regard to expectations of the mode of inheritance of acaricide resistance. Colored symbols represent a resistant mite, open circles represent a susceptible mite.

a) Reciprocal crosses of resistant X susceptible spider mite colonies will give different F_1 progeny. In the cross where the female parent is resistant, and her (haploid) sons will also be resistant. In the reciprocal cross, the sons of susceptible mothers are all susceptible. I.e., male spider mites inherit their resistance traits from their mothers.

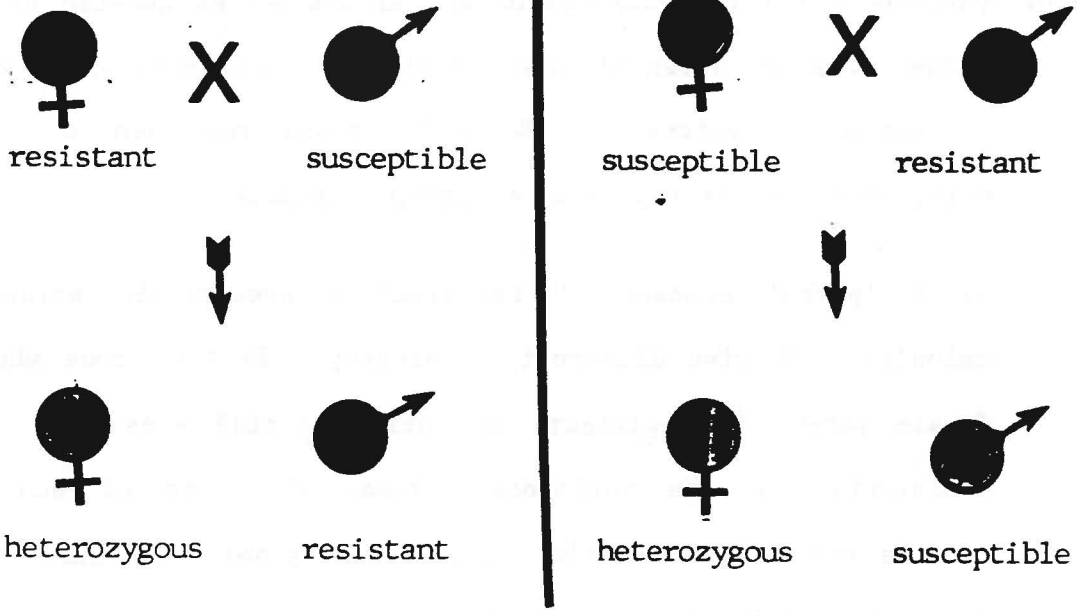
b) If the mother is heterozygous for the resistance allele(s), she will produce sons in a 1:1 ratio of resistant:susceptible.

c) Because the F_1 sons are susceptible in a cross where the mother was susceptible, the resistance of the F_2 female progeny will also differ from that of the reciprocal cross.

In this cross, the F_2 females are susceptible and heterozygous for resistance in a 1:1 ratio. The females of the reciprocal cross would have F_2 daughters that are homozygous resistant and heterozygous resistant in a 1:1 ratio.

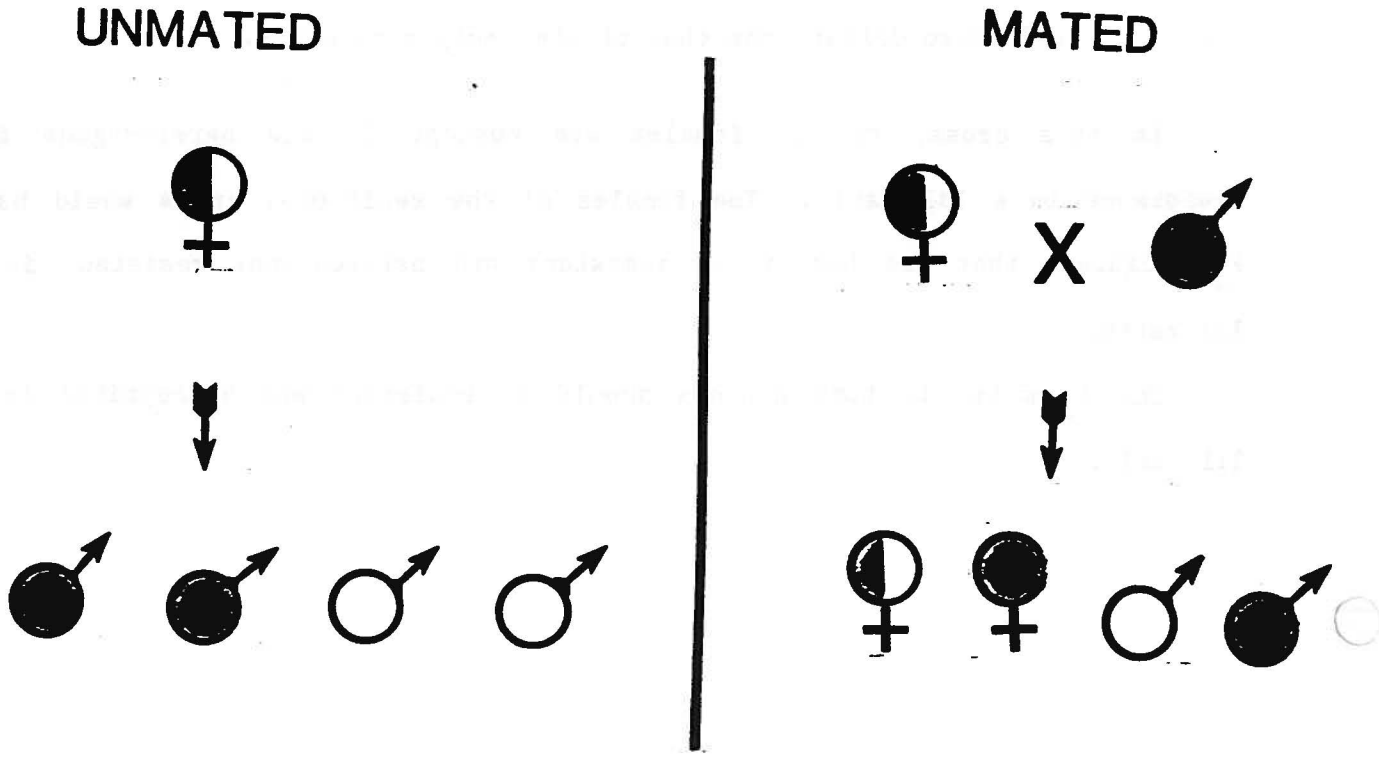
The F_2 males in both crosses should be resistant and susceptible in a 1:1 ratio.

a)
Reciprocal crosses



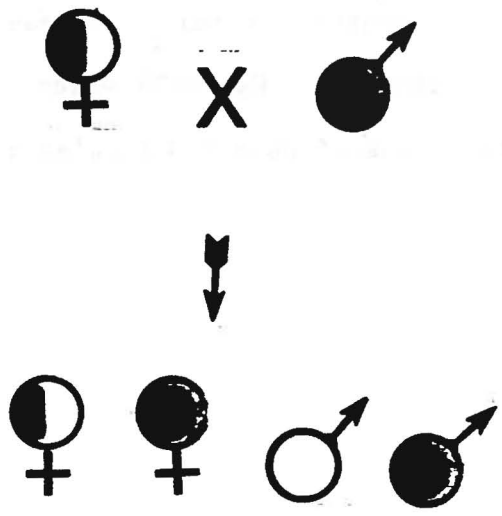
b)

Heterozygous mothers produce resistant & susceptible sons in a ratio of 1: 1.



c)

Resistance patterns of F_2 females in the reciprocal crosses.



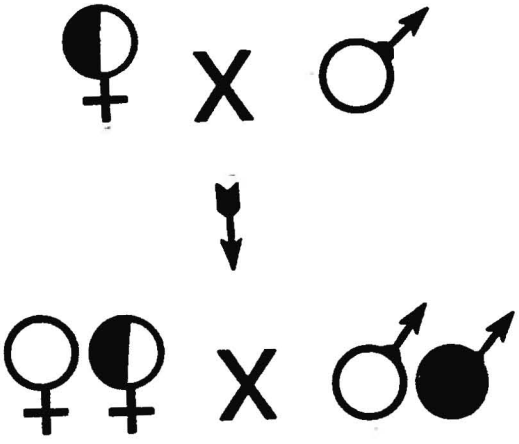
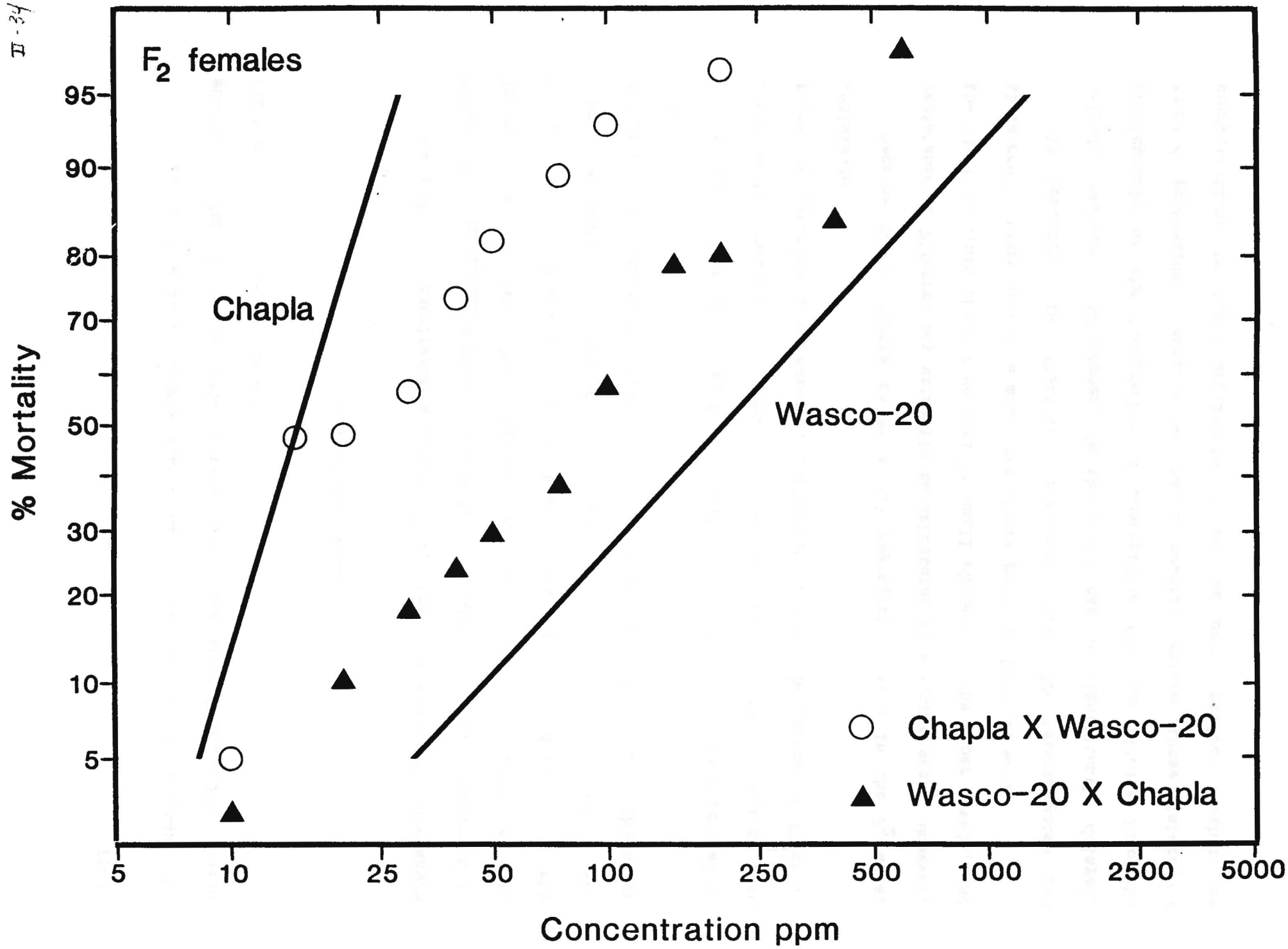


Figure 9. Concentration/mortality responses to cyhexatin of adult females of the Chapla and Wasco-20 colonies and F_2 females derived from their reciprocal crosses. Circles represent F_2 females from the cross of Chapla females x Wasco-20 males. Triangles represent F_2 females from the cross of Wasco-20 females x Chapla males.


F2 females
Chapla
Wasco-20
% Mortality
95
90
80
70
50
30
20
10
5
Chapla X Wasco-20
Wasco-20 X Chapla
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

F_2 males from both crosses should have equal numbers of resistant and susceptible individuals and this is reflected in the lines (Figure 10). These lines are not different (Table 7).

General Discussion

The mode of inheritance analyses of Plictran resistance in the Wasco colony of T. pacificus appear to fit a model in which Plictran resistance is incompletely recessive. The reciprocal crosses in Tests 1 and 2 yielded data compatible with this conclusion in 3 of 4 estimates of dominance. In the fourth estimate, the sample size used for the LC_{50} calculation was substantially smaller, and thus this estimate is less reliable than the other three.

Because there are significant differences in concentration/mortality lines in the reciprocal F_1 females, we can not exclude the possibility that there are cytoplasmic or maternal influences on the inheritance of Plictran resistance.

Because there appears to be a 1:1 segregation ratio in the F_2 data, resistance to Plictran may primarily be attributed to a single gene. However, the lines obtained there also contain small changes at the upper levels, and there could, therefore, be a minor resistance gene involved, as well.

If resistance is effectively recessive (i.e., RS heterozygotes are killed), resistance development in the field can be significantly delayed, particularly by the immigration of susceptible (SS) individuals into the treated population. Because we can't readily relate these laboratory concentrations to field application rates, we can't predict whether the

Figure 10. Concentration/mortality responses to cyhexatin of males of the Chapla and Wasco-20 colonies and of F_2 males derived from reciprocal crosses of the two colonies. Circle represent F_2 males from crosses of Chapla females x Wasco-20 males. Triangles represent F_2 males from crosses between Wasco-20 females x Chapla males.

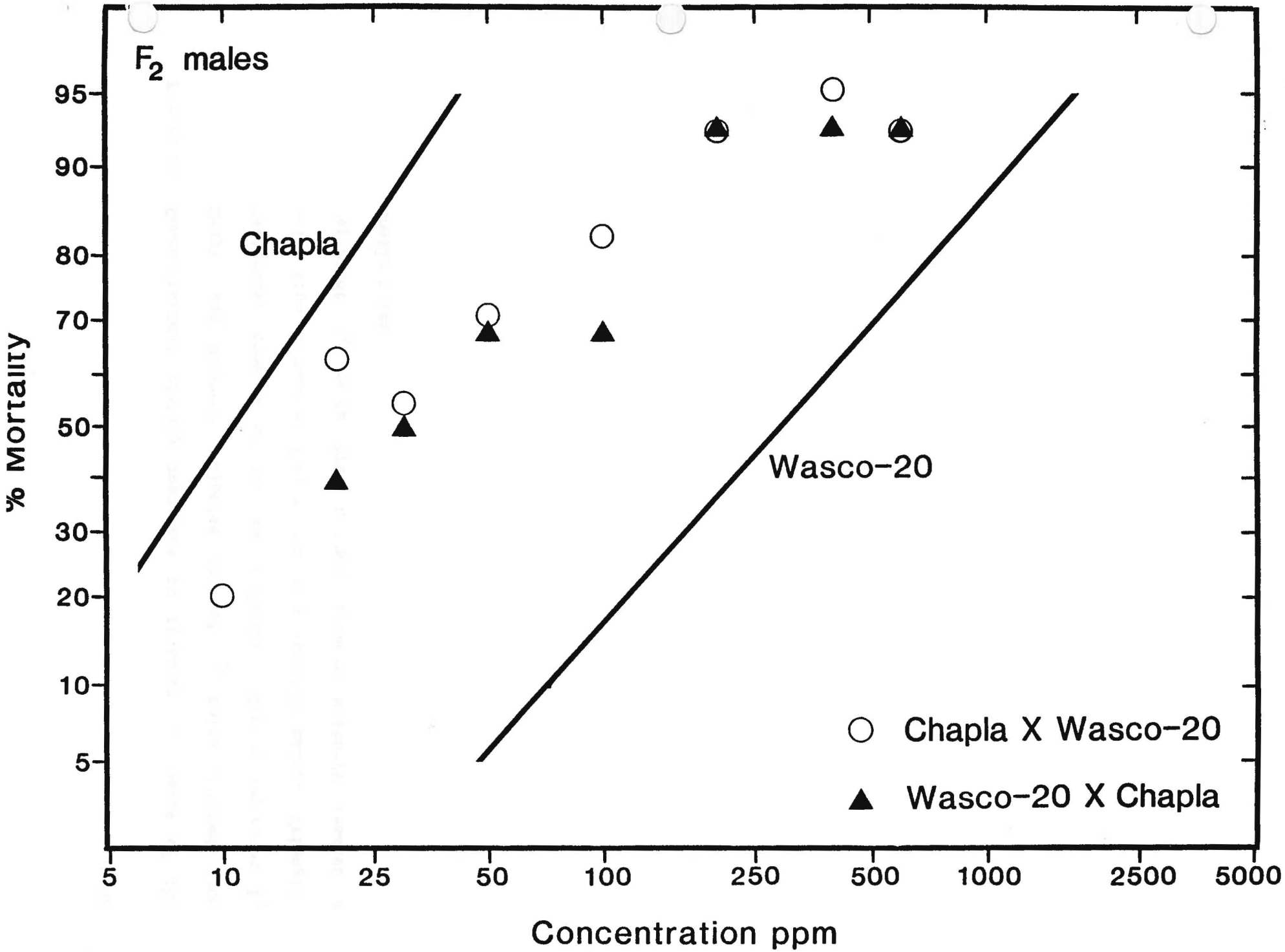

F2 males
95
90
80
70
50
30
20
10
5
% Mortality
Chapla
Wasco-20
Chapla X Wasco-20
Wasco-20 X Chapla
5
10
25
50
100
250
500
1000
2500
5000
Concentration ppm

Table 7. Mode of inheritance test of cyhexatin resistance using adult males of T. pacificus, using a leaf spray technique and the flowable formulation of cyhexatin (50 W): analysis of F_2 males.

Colony or Cross	No. ♀♀ tested	LC_{50} ppm[a/]	C.L. 95%	LC_{90} ppm	C.L. 95%	Slope (± S.D.)
TEST 2						
Wasco-20 ♀ x Wasco-20 ♂ (resistant)	340	289.1	161.4 - 418.7	1151.2	752.2 - 2687.2	2.14 (.36)
Wasco-20 ♀ x Chapla ♂ (F_1 x F_1)	325	35.2	19.7 - 54.9	230.8	139.7 - 501.1	1.57 (.20)
Chapla ♀ x Wasco-20 ♂ (F_1 x F_1)	430	20.0	10.6 - 30.8	199.5	123.8 - 427.0	1.28 (.16)
Chapla ♀ x Chapla ♂ (susceptible)	320	10.5	5.1 - 14.3	30.9	23.8 - 52.3	2.74 (.53)

a/ Tests were held at ca. 80° F and scored after 24 hrs.

heterozygotes (RS) will be able to survive in the field or not. However, the fact that resistance is not a completely recessive trait (i.e., D rages from -0.3080 to +0.4343 in F_1 females) suggests that selection in the field will occur more rapidly and lead to pure resistant populations more rapidly.

III. Stability of Plictran Resistance in T. pacificus

Introduction

Plictran resistance has been reported to be unstable in the two-spotted spider mite. However, we know nothing about the stability of Plictran/Vendex resistance in the Pacific mite, Tetranychus pacificus McGregor, in California almond orchards. If Plictran/Vendex resistance were unstable, then alternation of acaricides (with Omite or newly registered materials) would allow populations to revert to Plictran/Vendex-susceptibility, and would allow us to use Plictran/Vendex longer.

Accordingly, we wanted to determine at what rate our colonies of T. pacificus would lose their resistance to Plictran/Vendex if they were held without selection by Plictran/Vendex for several months. We held a resistant and susceptible strain on bean plants in the University of California, Berkeley greenhouse and colonies derived from reciprocal crosses of the resistant and susceptible strains. In addition we continued to treat a resistant strain with Plictran for comparison. Colonies were tested regularly for Plictran/Vendex resistance levels.

Materials & Methods

Rearing Methods

Crosses were set up using 200 pairs of spider mites for each cross: Chapla x Chapla (susceptible), Wasco-18 x Wasco-18 (a resistant colony selected 18 times with Plictran), Wasco-18 x Chapla (Wasco females mated with

Chapla males), and Chapla x Wasco-18 (Chapla females mated with Wasco-18 males). Female deutonymphs and adult males were moved to cut leaves on moist cotton in plastic trays and were held in the laboratory at 25 to 28°F and under a 24 hr day length. After two days, females had mated, and were subsequently moved to clean leaves every 2 to 3 days to deposit eggs. When eggs had hatched, the leaves containing larvae were placed on plants in cages in the greenhouse. Two colonies were started for each cross, using at least 4000 individuals per cage. The cages were placed on two laboratory benches in the greenhouse in a randomized block design with cages about 60 cm apart. Cages rested on water moats to minimize mite movement from cage to cage. Each cage contained two pots of beans, one of which was replaced with a fresh pot each week. Ca. 16 to 20 generations of mites developed in these cages under the greenhouse conditions during the test interval from May to November 1986. In addition, the Wasco-18 colony was regularly selected with Plictran in the greenhouse and used as a comparison with the colonies that received no selections with Plictran.

All colonies were treated with 1.2 g AI carbaryl/liter water twice to eliminate Amblyseius californicus which was discovered in one cage.

Screening Methods

After the colonies were established, each colony, and the ongoing selected Wasco (resistant) colony, were screened with 45 ppm flowable formulation (50 W) Plictran every two weeks beginning in June. For each test, ca. 200 adult females from each cage were tested at this concentration and ca. 50 females were used as water controls. Females were transferred by using a vacuum pump aspirator system. Ca. 25-30 females were tapped onto leaf disks

3.0 cm in diameter that rested on moist cotton in plastic trays. The trays were then sprayed with 45 ppm Plictran or water, held for 48 hr at 78-84°F and mites were scored as dead, alive, or runoff. Live mites were those that could walk when touched with a fine camels hair brush. All others were recorded as dead.

The single concentration assays were augmented by concentration/mortality curves at the beginning of the experiment and after 5 months, or ca. 16-20 generations. The concentration/mortality lines were developed at the beginning of the experiment as part of a mode of inheritance test, and the methods are described in that section. The second test, conducted after 5 months, was essentially the same (a leaf spray technique using the flowable formulation (50 W) of Plictran), but differed in that more mites were placed on larger leaf disks using the vacuum pump aspirator system. In the first test, mites were individually moved with a fine camels hair brush. We have no reason to believe that this change in methodology affected our concentration/mortality lines.

Results

Table 1 and Figure 1 show that the Plictran resistance is relatively stable over the 5-month interval of the test. For example, the survival rates of the two Wasco-18 x Wasco-18 colonies on June 30, 1986 were 60.0 and 57.8%, respectively, for replicates a and b (Table 1, Test 1). Survival for the same colonies was 68.1 and 59.7%, respectively, on November 3 (Table 1, Test 9). Likewise, survival of the Chapla colonies a and b on June 30 was 0 and 0% at 45 ppm, and was 0 and 0% on November 3.

Table 1. Stability of cyhexatin resistance in T. pacificus using the Chapla (susceptible) and Wasco-18 (resistant) colonies and colonies derived from their reciprocal F_1 progeny.[a/] Colonies were reared on bean plants in the UC Berkeley greenhouse and were tested at 2 week intervals.

Colony and replicate (♀ x ♂)	No. ♀♀ tested	Date tested 1986	% survival 48 hr after treatment with 45 ppm cyhexatin[b/]
TEST 1			
1a) Chapla x Chapla	197	June 30	0
1b) Chapla x Chapla	196	June 30	0
2a) Chapla x Wasco-18	182	June 30	5.1
2b) Chapla x Wasco-18	198	June 30	3.1
3a) Wasco-18 x Chapla	198	June 30	23.1
3b) Wasco-18 x Chapla	191	June 30	15.2
4a) Wasco-18 x Wasco-18	199	June 30	60.0
4b) Wasco-18 x Wasco-18	204	June 30	57.8
TEST 2			
1a) Chapla x Chapla	205	July 14	2.3
1b) Chapla x Chapla	210	July 14	1.5
2a) Chapla x Wasco-18	224	July 14	20.7
2b) Chapla x Wasco-18	199	July 14	20.5
3a) Wasco-18 x Chapla	232	July 14	62.3
3b) Wasco-18 x Chapla	226	July 14	54.5
4a) Wasco-18 x Wasco-18	223	July 14	73.8
4b) Wasco-18 x Wasco-18	228	July 14	77.9
5) Wasco-20 (selected with cyhexatin)	190	July 14	76.5

Table 1. (continued)

TEST 3

1a) Chapla x Chapla	227	July 28	0
1b) Chapla x Chapla	217	July 28	0
2a) Chapla x Wasco-18	224	July 28	23.6
2b) Chapla x Wasco-18	218	July 28	29.5
3a) Wasco-18 x Chapla	220	July 28	41.8
3b) Wasco-18 x Chapla	232	July 28	26.5
4a) Wasco-18 x Wasco-18	228	July 28	80.7
4b) Wasco-18 x Wasco-18	201	July 28	89.3
5) Wasco-20	215	July 28	96.7

TEST 4

1a) Chapla x Chapla	214	Aug. 11	0
1b) Chapla x Chapla	232	Aug. 11	0
2a) Chapla x Wasco-18	233	Aug. 11	11.3
2b) Chapla x Wasco-18	222	Aug. 11	16.0
3a) Wasco-18 x Chapla	213	Aug. 11	48.0
3b) Wasco-18 x Chapla	209	Aug. 11	35.3
4a) Wasco-18 x Wasco-18	228	Aug. 11	87.2
4b) Wasco-18 x Wasco-18	221	Aug. 11	86.1
5) Wasco-21	226	Aug. 11	92.3

TEST 5

1a) Chapla x Chapla	221	Aug. 25	0
1b) Chapla x Chapla	216	Aug. 25	0
2a) Chapla x Wasco-18	223	Aug. 25	7.2
2b) Chapla x Wasco-18	217	Aug. 25	14.4
3a) Wasco-18 x Chapla	217	Aug. 25	44.5
3b) Wasco-18 x Chapla	238	Aug. 25	28.8
4a) Wasco-18 x Wasco-18	227	Aug. 25	73.7
4b) Wasco-18 x Wasco-18	230	Aug. 25	69.6
5) Wasco-22	208	Aug. 25	80.0

Table 1. (continued)

TEST 6

1a) Chapla x Chapla	224	Sept. 8	1.3
1b) Chapla x Chapla	212	Sept. 8	1.5
2a) Chapla x Wasco-18	221	Sept. 8	10.5
2b) Chapla x Wasco-18	212	Sept. 8	20.0
3a) Wasco-18 x Chapla	213	Sept. 8	51.0
3b) Wasco-18 x Chapla	222	Sept. 8	51.5
4a) Wasco-18 x Wasco-18	225	Sept. 8	77.3
4b) Wasco-18 x Wasco-18	216	Sept. 8	77.1
5) Wasco-22	238	Sept. 8	86.5

TEST 7

1a) Chapla x Chapla	228	Sept. 22	0
1b) Chapla x Chapla	229	Sept. 22	0.5
2a) Chapla x Wasco-18	207	Sept. 22	5.9
2b) Chapla x Wasco-18	219	Sept. 22	2.5
3a) Wasco-18 x Chapla	221	Sept. 22	29.2
3b) Wasco-18 x Chapla	220	Sept. 22	18.4
4a) Wasco-18 x Wasco-18	229	Sept. 22	68.3
4b) Wasco-18 x Wasco-18	219	Sept. 22	68.7
5) Wasco-22	225	Sept. 22	75.1

Dose Response test[c/]

1a) Chapla x Chapla		Oct. 6	0
1b) Chapla x Chapla		Oct. 6	0
2a) Chapla x Wasco-18		Oct. 6	8.8
2b) Chapla x Wasco-18		Oct. 6	2.9
3a) Wasco-18 x Chapla		Oct. 6	31.0
3b) Wasco-18 x Chapla		Oct. 6	29.0
4a) Wasco-18 x Wasco 18		Oct. 6	83.0
4b) Wasco-18 x Wasco 18		Oct. 6	81.0
5) Wasco-22		Oct. 6	90.0

Table 1. (continued)

TEST 8

1a) Chapla x Chapla	199	Oct. 20	0
1b) Chapla x Chapla	206	Oct. 20	0
2a) Chapla x Wasco-18	207	Oct. 20	14.6
2b) Chapla x Wasco-18	205	Oct. 20	6.9
3a) Wasco-18 x Chapla	201	Oct. 20	36.5
3b) Wasco-18 x Chapla	195	Oct. 20	27.2
4a) Wasco-18 x Wasco-18	207	Oct. 20	67.5
4b) Wasco-18 x Wasco-18	214	Oct. 20	78.0
5) Wasco-22	206	Oct. 20	71.4

TEST 9

1a) Chapla x Chapla	207	Nov. 3	0
1b) Chapla x Chapla	200	Nov. 3	0
2a) Chapla x Wasco-18	208	Nov. 3	4.7
2b) Chapla x Wasco-18	206	Nov. 3	5.2
3a) Wasco-18 x Chapla	208	Nov. 3	26.4
3b) Wasco-18 x Chapla	206	Nov. 3	16.7
4a) Wasco-18 x Wasco-18	220	Nov. 3	68.1
4b) Wasco-18 x Wasco-18	200	Nov. 3	59.7
5) Wasco-23	202	Nov. 3	92.0

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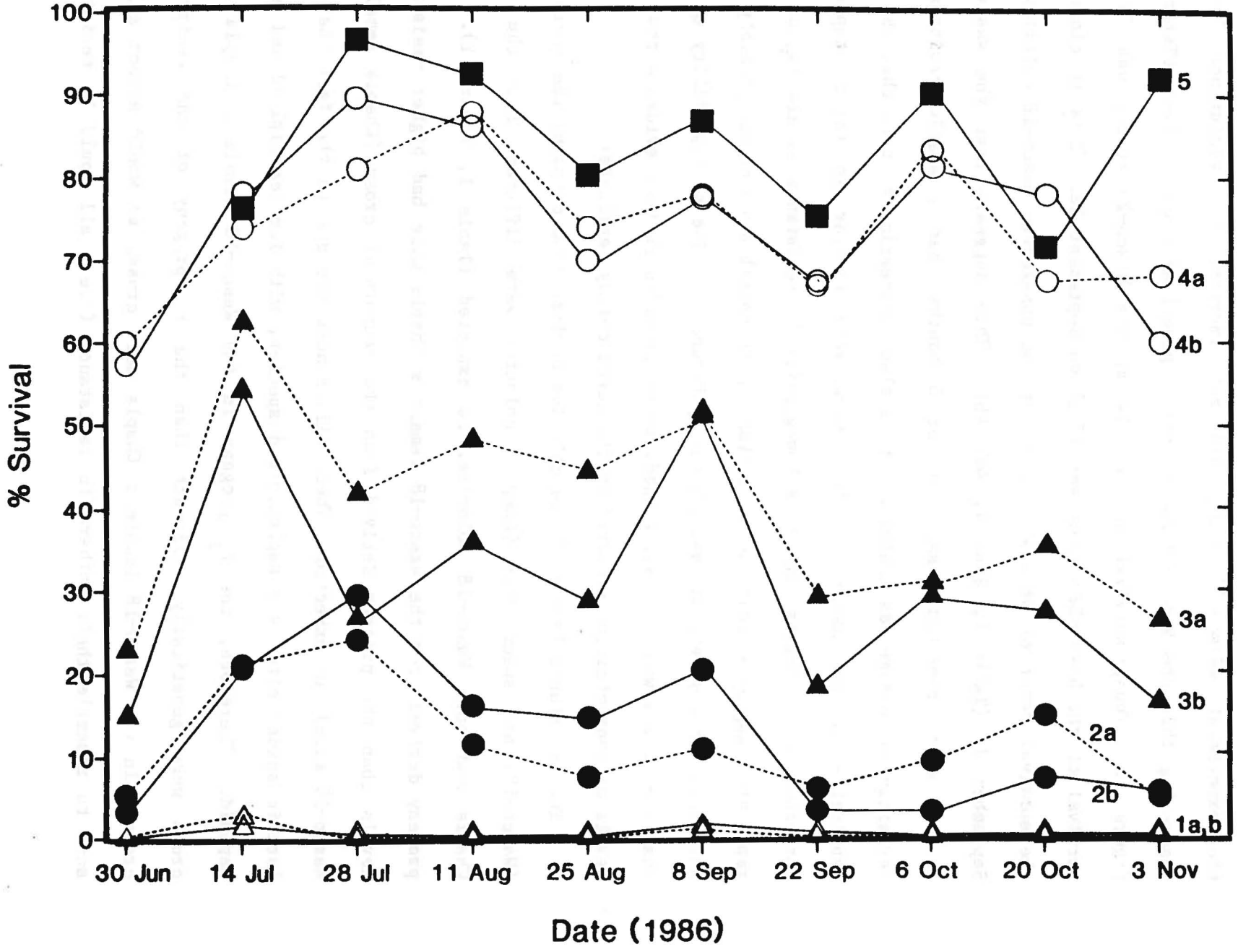
a/ The reciprocal F_1 colonies (Chapla ♀ x Wasco-18 ♂, and Wasco-18 ♀ x Chapla ♂) were initiated in May 1986 using at least 4000 F_1 progeny for each of the two replicates (a,b) as were the control (Chapla and Wasco-18) colonies. The Wasco-18 colony was continually selected and was tested for comparison beginning with test 2, when it was called the Wasco-20, Wasco-21, Wasco-22, or Wasco-23 colony.

b/ % survival is determined 48 hr after adult females were sprayed with the flowable (50 W) formulation of cyhexatin. Data are adjusted by Abbotts formula for control mortality.

c/ Percent survival at 45 ppm was taken from dose response lines.

Figure 1. Stability of cyhexatin resistance evaluated by determining the survival of females of T. pacificus treated with 45 ppm cyhexatin by a leaf spray technique. Females were tested every two weeks using 200 females per cage. Cages 1a, 1b contained the susceptible Chapla colony. Cages 2a, 2b contained progeny derived from F_1 females and males from a cross between Chapla females and Wasco-18 males. Cages 3a, 3b contained progeny derived from F_1 females and males from a cross between Wasco-18 females and Chapla males. Cages 4a, 4b contained Wasco-18 colony mites. These cages were maintained without selection with cyhexatin. Cage 5 contained the Wasco-18 colony and it was treated with cyhexatin on May 6, May 16, July 25, and August 15 to serve as a resistant control.


100
90
80
70
60
50
40
30
20
10
0
% Survival
30 Jun
14 Jul
28 Jul
11 Aug
25 Aug
8 Sep
22 Sep
6 Oct
20 Oct
3 Nov
Date (1986)
5
4a
4b
3a
3b
2a
2b
1a,b

The Wasco-18 colony, which was selected with Plictran periodically during the experiment (Wasco-20 -23), did not increase its resistance level, suggesting that the Wasco-18 colony was a genetically pure colony (Table 1, Figure 1). Thus, survival on July 14 of the Wasco-20 colony was 76.5%; survival of the Wasco-22 colony was 75.1% on September 22. This is close to the survival rates of 68.3 and 68.7%, of the unselected Wasco-18 colonies on September 22 (Table 1, Test 7, 4a, 4b). This suggests that the Wasco-18 colony, which remained unselected for 5 months, has a stable resistance. Certainly any change was minimal. It is also interesting to note that the two replicates of the Wasco-18 colony were very similar in their responses throughout the 5 months, and this homogeneity in resistance levels in the two replicates suggests that contamination by susceptible colonies probably did not occur, or was very minimal (Table 1, Figure 1). The susceptibility of the Chapla colonies was also maintained, which provides further evidence that low levels of contamination occurred in the caged colony replicates.

The resistance levels of the colonies derived from crossing the resistant (Wasco-18) and susceptible (Chapla) colonies were different from the pure Chapla and pure Wasco-18 colonies, as expected (Table 1, Figure 1). The progeny derived from the Wasco-18 female x Chapla male had higher resistance levels than the progeny derived from the reciprocal cross (Chapla female x Wasco-18 male), as expected. These differences are due to the fact that the Pacific spider mite is a haplodiploid species, with females diploid and males haploid. Therefore, the F_1 progeny in the Wasco-18 female x Chapla male cross were genetically different than the F_1 progeny of the reciprocal cross. In the Wasco-18 female x Chapla male cross, we would expect all F_1 sons to resemble their mothers in resistance (i.e., all would be resistant,

assuming the parent females were genetically pure). Likewise, the F_1 males of the reciprocal cross would resemble their susceptible Chapla mothers. Both types of F_1 females would be heterozygous for the Plictran resistance and should be similar in their phenotypic responses. Because the males from the Wasco-18 female x Chapla male cross are all resistant, the gene frequency for Plictran resistance should be higher than in the reciprocal cross, and this should be reflected, as it was, in the responses of the two different types of colonies to Plictran.

As in the other colonies, the replicates of each type of cross were similar in their responses, indicating there was little contamination of colonies. The variation present could be due to sampling error and to experimental error during the bioassays.

Prior to the setting up this test, concentration/mortality lines were of all colonies were obtained (Table 2). At this time, LC_{50} values for the Chapla colony were 17.6 (15.9-19.2) ppm and for the Wasco-18 colony were 175.5 (144.5-209.1) ppm, ca. a 10-fold difference. LC_{90} values were 31.0 (27.3-37.8) and 728.1 (577.3-984.7) ppm, respectively, which is ca. a 23.5-fold difference. The slope of the Wasco-18 colony is flatter than that of the Chapla colony, and this could be due to genetic heterogeneity in the Wasco-18 colony, or to some nonlinear response to the pesticide concentrations. It is possible that penetration or uptake is slower at the higher concentrations. LC_{50} values for the F_1 females were greater than the susceptible Chapla colony, but much less than the resistant Wasco-18 colony (Table 2).

After these colonies were maintained for 5 months in the greenhouse, concentration/mortality tests were again performed (Table 2 and Figure 2). In

Table 2. Stability of cyhexatin-resistance as determined by comparing concentration/mortality data for a cyhexatin-resistant T. pacificus colony (Wasco-18), a susceptible colony (Chapla) and progeny derived from reciprocal crosses. Tests were conducted using a leaf spray technique before and after colonies were reared for five months in the U.C., Berkeley greenhouse without treatment with cyhexatin or fenbutatin-oxide.[a/]

Colony and Test Date	No. ♀♀ tested	LC_{50} ppm	95% C.L.	LC_{90} ppm	95% C.L.	Slope (± S.D.)
I) May Test						
Chapla (Susceptible)	750	17.6	15.9 - 19.2	31.0	27.3 - 37.8	5.25 (.58)
Wasco-18 (Resistant)	960	175.5	144.5 - 209.1	728.1	577.3 - 984.7	2.07 (.16)
Wasco-18 ♀ x Chapla ♂	765	39.0	33.4 - 44.5	98.5	84.0 - 121.1	3.18 (.27)
Chapla ♀ x Wasco-18 ♂	780	50.3	39.2 - 60.3	156.6	123.4 - 232.0	2.60 (.32)
II) October Test						
1a. Chapla (Susceptible)	613	11.1	8.8 - 12.6	18.6	16.7 - 21.7	5.72 (.79)
1b. Chapla (Susceptible)	630	7.7	5.6 - 9.3	17.1	14.5 - 21.4	3.70 (.39)
2a. Chapla ♀ x Wasco-18 ♂	614	17.6	12.7 - 21.3	42.9	34.8 - 62.4	3.31 (.43)
2b. Chapla ♀ x Wasco-18 ♂	628	16.9	12.4 - 20.1	32.5	27.4 - 44.0	4.51 (.52)
3a. Wasco-18 ♀ x Chapla ♂	623	28.2	19.2 - 36.4	92.7	69.4 - 150.9	2.48 (.25
3b. Wasco-18 ♀ x Chapla ♂	616	24.5	17.4 - 31.2	103.8	78.6 - 160.9	2.05 (.23
4a. Wasco-18 (Resistant)	625	93.8	71.7 - 116.3	250.7	194.3 - 373.1	3.00 (.31
4b. Wasco-18 (Resistant)	622	103.7	53.6 - 143.8	353.4	255.4 - 679.8	2.41 (.36
5. Wasco-22 (Selected Resistant)	609	117.5	74.6 - 152.2	305.7	228.6 - 563.6	3.09 (.44

[a/] Tests were conducted using the flowable formulation of cyhexatin.

Figure 2. Concentration/mortality lines of T. pacificus females treated with cyhexatin using a leaf spray technique. 1a, 1b - Chapla (susceptible) colony; 2a, 2b = progeny derived from crossing Chapla ♀ x Wasco-18 ♂; 3a, 3b = reciprocal cross; 4a, 4b = Wasco-18 (resistant) colony; 5 = Wasco-23 colony selected with cyhexatin. Colonies 1-4 were held without selection with cyhexatin in bean plants in a U.C.-Berkeley greenhouse.

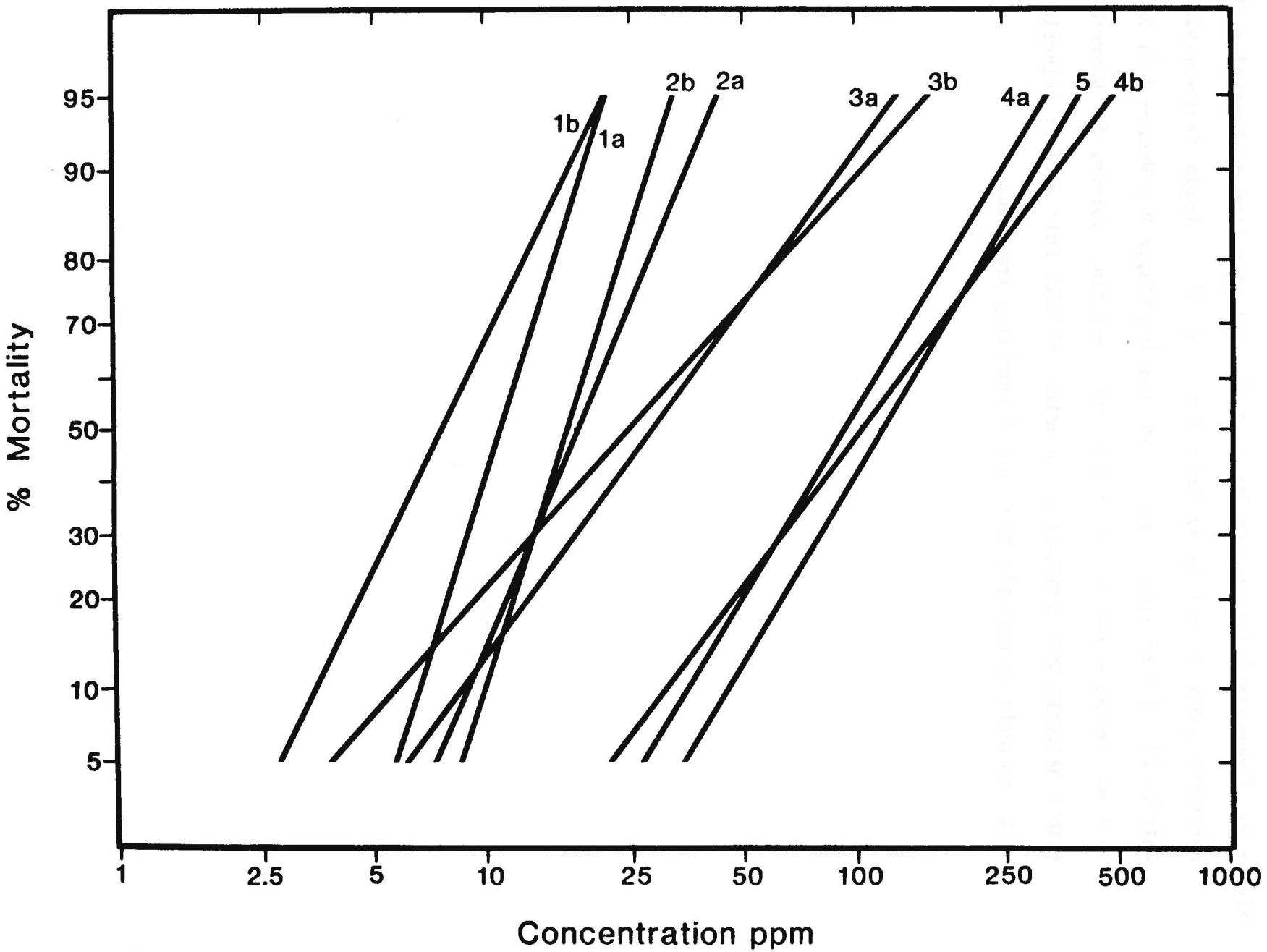

95
90
80
70
50
30
20
10
5
% Mortality
1b
1a
2b
2a
3a
3b
4a
5
4b
1
2.5
5
10
25
50
100
250
500
1000
Concentration ppm

Figure 2 it is clear that the two replicates of each colony yielded similar concentration/mortality lines. Although the lines and slopes for the Chapla colonies (1a, 1b) were statistically different, their relative values are similar. The unselected Wasco-18 colonies (4a, 4b) were not significantly different from the Wasco colony selected an additional 4 times (line 5) (Figure 2, lines 4a, 4b, 5) (Table 2, Test 2).

Concentration/mortality lines for the two colony replicates derived from crossing Chapla females x Wasco-18 males also yielded different lines with different slopes (Table 2). Again, while these lines are statistically different, they are very similar (Figure 2, lines 2a, 2b). The two colony replicates derived from crossing Wasco-18 females x Chapla males had higher LC_{50} values than the colonies drived from the reciprocal crosses (Wasco-18 females x Chapla males). These two lines are the same and are parallel.

General Conclusions

The Plictran/Vendex resistance in this colony of T. pacificus appears to be stable over the 5-month test interval. The unselected Wasco-18 colony retained a high LC_{50} value in both colony replicates and these were statistically the same as that of the selected Wasco-23 colony (Table 2, Figure 2). This suggests the Wasco-18 colony was pure.

The colonies derived from reciprocal F_1 crosses (Wasco-18 x Chapla, Chapla x Wasco-18) demonstrated substantial stability in their resistance levels, as well. This stability is particularly interesting. If substantial reductions in fitness were associated with the resistance allele(s), then selection should have operated against the resistance allele(s) since Plictran

was not applied during the project. Because the resistance levels did not decline dramatically, we conclude that the resistance alleles do not confer substantial reductions in overall fitness. This may be expected, since the resistant colony (Wasco-18) had been selected 18 times in the laboratory and greenhouse with Plictran to ensure that a pure colony was used for the mode of inheritance tests. This selection, which occurred over a period of months, could have allowed the accumulation of modifying genes which would restore any loss of fitness originally associated with the resistance allele(s). Alternatively, the resistance allele(s) may have initially lacked negative fitness components. At any rate, if we assume that T. pacificus populations in the field are under selection for fitness, it seems reasonable to assume that our data are predictors of the field situation.

These data strongly suggest that Plictran/Vendex resistance is stable, and that even if resistant populations are not selected with Plictran for a season, they will retain a high level of Plictran/Vendex resistance. We expect to continue the greenhouse trials to determine whether the resistance levels decline over time. At this point, if field populations are highly resistant to Plictran/Vendex, and little immigration by susceptible mites occurs, we suspect that a single year of non-use of these materials will be insufficient to reduce Plictran/Vendex resistance levels dramatically. If field populations are not pure, then the change in resistance gene frequency will depend on a series of population genetics and population ecology variables.

Another consideration should be remembered while attempting to translate these data into predictions of field situations: the data were obtained using one colony of T. pacificus with a particular form of Plictran/Vendex

resistance. Spider mite populations vary in the mechanisms by which they become resistant. For example, some T. urticae populations are resistant to OP insecticides and the resistance is determined by a recessive allele; other populations have resistances conferred by major dominant genes. It is possible that T. pacificus populations from different geographic areas could have different forms of Plictran/Vendex resistance. Thus, our conclusions may not be appropriate for all possible resistances.

We plan to continue these population cage studies as long as possible. In addition, we plan to treat part of the cages with Plictran once to determine the level of Plictran resistance at intervals after the single selection. This could provide ideas on the resurgence rate of Plictran/Vendex resistance after a year of disuse.

IV. Survey of M. occidentalis for Resistance/Tolerance to Insecticides/ Acaricides/Fungicides Used in Almonds

The attached "Supplement to the 1983 Control Guide: Almond Pests, Diseases, and Micronutrient Deficiencies" was developed to update U.C. Leaflet 21343. We rate the effects of pesticides on the western predatory mite, Metaseiulus occidentalis (Nesbitt), using a rating system of low, moderate, high, and not known. All ratings are based on laboratory data. Therefore, the ratings may need to be amended if field data indicate the pesticides are more or less toxic. It is likely that pesticides with low toxicity ratings will have a low impact in the field. Likewise, it is likely that pesticides with a high rating will have a high rating in the field. The most difficult pesticides to interpret are those with a "moderate" rating. It is possible that they could have a high, moderate, or low rating in the field since a number of factors enter into the field impact. These factors include: coverage, duration of residues, impact of pesticides on the spider mite prey, and so on. If some ratings are controversial, we suggest that field trails be conducted to resolve the issues.

At the end of this section, we present a table to provide the new data on which many of our conclusions are based. Some ratings are also based on older tests. The new tests were conducted using two colonies of M. occidentalis: the carbaryl-OP-sulfur resistant strain, and a "native" strain (Blue Gum) collected from almonds. The tests were conducted using a leaf spray technique. While there are limitations to such data, there are virtues, as well. The adult predator females are sprayed while on foliage, which provides a fairly normal substrate. Because the females are scored after 48 hr, we

have time to observe predator behavior and determine the toxicity to spider mite prey. This test does not provide data on toxicity of old residues or the impact of poor coverage.

A SUPPLEMENT TO THE 1983 CONTROL GUIDE: ALMOND PESTS, DISEASES, AND MICRONUTRIENT DEFICIENCIES (U.C. Leaflet 21343): Effects of Pesticides on the Western Predatory Mite, Metaseiulus occidentalis (Nesbitt), Based on Laboratory Data.

These toxicity ratings were obtained from laboratory trials with the Western Predatory Mite (M.o.). Toxicity ratings = low, moderate, high, not known. Unless otherwise noted, ratings pertain to both M.o. strains tested: the carbaryl-OP-sulfur resistant strain and a wild strain with a moderate level of resistance to OP insecticides. Some ratings may need to be confirmed by field trials because laboratory tests may either over- or underestimate field toxicities. Also, because populations of M.o. from different orchards vary in their responses, ratings should be used as general guidelines only. Actual toxicities in specific orchards may be different. For an index to specific pesticides, see page 9.

I. DORMANT

Purpose of Application	Material and Amount per Acre	Toxicity rating to Western Predatory Mite	Comments
Brown almond mite eggs European red mite eggs San Jose scale Olive scale	Supreme or superior type narrow range oils at 4 to 8 gal/ac	Low	Rating based on tests with summer oils and literature data.
Peach twig borer Brown almond mite eggs European red mite eggs San Jose scale Olive scale	Methidathion (Supracide* 2E) at 4 qt/ac and supreme or superior oils at 4 to 8 gal/ac	High	Tests were conducted on leaves. Toxicity rating could be lower in winter since predators are in diapause and hidden in crevices. (100% mortality at 0.5-fold the field rate).
	Chlorpyrifos (Lorsban* 4E) at 1-1/2 to 2 qt/ac and supreme or superior oils at 4 to 8 gal/ac	Moderate	Tests were conducted on leaves. Toxicity rating could be lower in winter since predators are in diapause and hidden in crevices. (60% mortality at field rate).

	Diazinon (Diazinon 50W) at 4 lb/ac and supreme or superior oils at 4 to 8 gal/ac	Low	Most native M.o.are resistant. The carbaryl-OP-sulfur resistant strain is also resistant.
	Parathion (Phoskil* 25 spray or Parawet 25W) at 8 lb/ac and supreme or superior oils at 4 to 8 gal/ac	Low	Based on literature data.
	Phosmet (Imidan** 50WP) at 6 lb/ac and supreme or superior oils at 4 to 8 gal/ac	Low	Most native M.o. populations are resistant. The carbaryl-OP-sulfur strain is resistant.
Zinc deficiency	Zinc sulfate (36 percent zinc) at 30 to 45 lb/ac	-	Not tested.
Sunburn protection	White interior water-base paint	Not known	Mortality could occur due to physical trapping in paint.
Navel orangeworm	Sanitation and early harvest	Not known	Not expected to have any effect on M.o.
Crown gall	Gallex	Not known	Not tested due to restricted application site of Gallex.
	II. PINK BUD		
Brown rot	Benomyl (Benlate 50W) at 1 to 1-1/2 lb/ac. Must be used in combination with a contact fungicide	High or Low, depending on colony used	Benomyl reduces egg production of native M.o.; the carbaryl-OP-sulfur resistant strain is resistant to benomyl.

	Captan (Orthocide 50W) at 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.
	Maneb (Manzate, Dithane M-22) at 6 to 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.
	Thiophanate methyl (Topsin M) at 1-1/2 to 2 lb/ac	Low	Even at 5 times the field rate, there was no mortality.
	III. FIVE WEEKS AFTER PETAL FALL		
Zinc deficiency	Zinc oxide at 15 lb/ac	-	Not tested.
	Basic zinc sulfate at 15 lb/ac	-	Not tested.
Boron deficiency	Soluble boron spray material used according to manufacturer's directions	-	Not tested.
	IV. SPRING		
Shothole	Ziram (Ziram 76W) at 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.
	Captan (Orthocide 50W) at 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.
Leaf blight	Captan (Orthocide 50W) at 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.
	Ziram (Ziram 76W) at 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.

Scab	Captan (Orthocide 50W) at 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.
	Ziram (Ziram 76W) at 8 lb/ac	Low	Both well fed and starved females tolerated sprays well.
Fruittree leafroller Western Tent Caterpillar	Parathion (Phoskil* 25 Spray, Parawet 25W) at 8 lb/ac	Low	Based on literature data.
Peach twig borer	Azinphos-methyl (Guthion** 50WP) at 4 lb/ac	Low to Moderate	Most native M.o. populations are resistant to Guthion; variability exists, however. The carbaryl-OP-sulfur resistant strain is resistant.
	Methidathion (Supracide* 2E) at 4 qt/ac	High	100% mortality at 1/2 the field rate in lab trials.
	Diazinon (Diazinon 50W) at 4 lb/ac	Low	Most native M.o. populations are resistant to Diazinon, as is the carbaryl-OP-sulfur strain.
	Phosmet (Imidan** 50WP) at 6 lb/ac	Low	Most native M.o. populations are resistant to Imidan, as is the carbaryl-OP-sulfur strain.
San Jose scale	Methidathion (Supracide* 2E) at 4 qt/ac	High	100% mortality at 1/2 the field rate in lab trials.
	Diazinon (Diazinon 50W) at 4 lb/ac	Low	Most native M.o. populations are resistant to Diazinon, as is the carbaryl-OP-sulfur strain.
Leaffooted plant bug	Diazinon (Diazinon 50W) at 4 lb/ac	Low	Most native M.o. populations are resistant to Diazinon, as is the carbaryl-OP-sulfur strain.

Navel orangeworm	Azinphos-methyl (Guthion** 50WP) 4 lb/ac	Low to Moderate	Most native M.o. populations are resistant to Guthion; variability exists, however. The carbaryl-OP-sulfur strain is resistant.
	Phosmet (Imidan** 50WP) at 8 lb/ac	Low	Most native M.o. populations are resistant to Imidan, as is the carbaryl-OP-sulfur strain.
	V. LATE SPRING AND SUMMER		
European red mite Pacific spider mite Twospotted spider mite Strawberry spider mite	Propargite (Omite 6E at 1-1/2 to 2 qt/ac or Omite 30W at 7-1/2 to 10 lb/ac)	Moderate to High	WP formulation only tested: Moderate at 5-10 lb/100 gal rates. High at 10-20 lb/100 gal rates. Strains of M.o. could varyin their tolerance.
	Cyhexatin (Plictran 50W) at 1 to 2 lb/ac	Low with WP formulation	The flowable formulation tested was more toxic than the WP formulation to M.o. at equivalent rates. (This formulation is not yet registered in almonds. Field rate of flowable not known.)
	Fenbutatin-oxide (Vendex 50WP) at 1 to 2 lb/ac	Low	4L formulation only was tested using field rate of 2 pints/acre.
Navel orangeworm	Azinphos-methyl (Guthion** 50WP) at 4 lb/ac	Low to Moderate	Most native M.o. populations are resistant to Guthion; variability exists, however. The carbaryl-OP-sulfur strain is resistant.
	Carbaryl (Sevin*-Sprayable) at 6-1/4 lb/ac	High or Low	Native M.o. are susceptible. The carbaryl-OP-sulfur resistant strain is resistant.

	Phosmet (Imidan** 50WP) at 8 lb/ac	Low	Most native M.o. populations are resistant to Imidan, as is the carbaryl-OP-sulfur strain. Variability in natives may exist, however.
Pavement ant Southern fire ant	Diazinon (Diazinon** 14G) at 20 lb/ac	Low	Applied to soil late June-late July. Not expected to influence M.o. populations.
	VI. POSTHARVEST		
Zinc deficiency	Zinc sulfate (36 percent zinc) at 30 lb/ac	-	Not tested
	VII. FALL (late summer to early fall)		
Oak root fungus (armillaria root rot)	Methyl bromide*	Not known	Applied to soil; not expected to influence M.o. populations.
	Carbon bisulfide*	Not known	Not expected to affect M.o. populations. Applied to soil only.

*Permit for purchase or use required from your county agricultural commissioner.
**Material registered for use in California under a special local needs permit. See your county agricultural commissioner for current status of the permit. Permit for purchase or use registered from your county agricultural commissioner.

ADDENDA:

This list includes ratings of pesticides not on the 1983 Control Guide List for Almonds, some of which are not currently registered for use in almonds. The ratings of toxicity to the Western Predatory Mite (M.o.) are based on laboratory tests only.

Pesticide	Type	Toxicity rating	Comments
Abamectin (avermectin B_{1a}) (not registered)	acaricide	Moderate to High	This experimental material is less toxic to M.o. than to spider mites, but at field rates would be likely to kill most M.o.
Ambush and Pounce (permethrin)	insecticide	High	Toxic to all native strains of M.o. tested.
Apollo (clofentezine) (not registered)	acaricide (ovicide)	Low	No negative effects found in lab trials with M.o.
Asana (not registered)	insecticide	High	Toxic to native M.o. in lab tests.
Bacillus thuringiensis	insecticide	Low	Not toxic to M.o. if lacking the ß-exotoxin.
Danitol (fenpropathrin) (not registered)	insecticide	High	Toxic to carbaryl-OP-sulfur resistant strain.
Dibrom (naled)	insecticide	Moderate	Survival was 16% at the field rate and 44 or 80% at 0.5-fold the field rate, for the native and carbaryl-OP-sulfur resistant strains.
Funginex (triforine) (not registered)	fungicide	Low	Native and the carbaryl-OP-sulfur strains of M.o. are tolerant.

Kelthane (dicofol) (not registered)	acaricide	High	Toxic to M.o. based on data in literature.
Pydrin (fenvalerate) (not registered for almonds)	insecticide	High	Toxic to all native M.o. populations tested.
Malathion	insecticide	Low to Moderate	Native and the carbaryl-OP-sulfur strains of M.o. may tolerate low field rate (0.5 lb a.i./100 gallons). Less than 50% survival at high field rate (2 lb a.i./100 gallons).
Rovral (iprodione) (not registered)	fungicide	Low	Carbaryl-OP-sulfur strain of M.o. is very tolerant of Rovral.
Savey (hexythiazox) (not registered)	acaricide (ovicide)	Low	No negative effects found in lab trials with M.o.
Sulfur	fungicide or miticide	Low to High	Toxic to native M.o. The carbaryl-OP-sulfur strain is resistant to sulfur.
Thiodan (endosulfan)	insecticide	Low	Native and carbaryl-OP-sulfur resistant strains of M.o. are tolerant.
Thuringiensin or Di-Beta (Beta-exotoxin of Bacillus thuringiensis) (not registered)	acaricide/insecticide	Moderate to High	This experimental material is less toxic to M.o. than to spider mites, but at proposed field rates would be likely to kill most M.o.
Zolone (phosalone)	insecticide	High	The carbaryl-OP-sulfur strain of M.o. is slightly more tolerant than native populations.

INDEX TO PESTICIDES TESTED

Survival of adult females of M. occidentalis[a/] tested with pesticides used in almonds using a leaf spray method.

Pesticide (formulation) rate tested	No. ♀♀/ colony tested	% survival after 48 hr		Comments
		COS colony	Blue Gum colony	
Captan (50 WP)	(Field rate: 8 lb 50 WP/400 gal)			
Orthocide				
H_2O	50	92	96	No effect on hungry ♀♀
4 lb 50 WP/400 gal	50	98	100	at all rates tested.
8 lb 50 WP/400 gal	50	98	96	
40 lb 50 WP/400 gal	50	100	98	
Dithane M-22 (80 WP)	(Field rate: 6 - 8 lb 80 WP/400 gal)			
Maneb				
H_2O	50	98	98	No effect on hungry ♀♀
4 lb 80 WP/400 gal	50	96	96	at all rates tested.
8 lb 80 WP/400 gal	50	92	96	
40 lb 80 WP/400 gal	50	76	78	
DPX (50 WP)	(Field rate: 1.75 - 3.5 oz AI/400 gal)			
DPX Y5893				
H_2O	180	95	88	
0.4 oz AI/400 gal	80	99	99	

[a/] Two colonies were tested; the COS colony is resistant to carbaryl, sulfur and organophosphorus (OP) pesticides. The Blue Gum colony, collected from an almond orchard in Stanislaus Co., is resistant only to OPs.

0.9 oz AI/400 gal	50	84	62
1.75 oz AI/400 gal	80	99	99
3.5 oz AI/400 gal	180	96	90
14 oz AI/400 gal	130	98	98
17.5 oz AI/400 gal	50	72	70
Funginex (1.6 EC)	(Field rate: 12 - 16 oz 1.6 EC/100 gal)		
Triforine			
H_2O	180	93	86
4 oz 1.6 EC/100 gal	130	87	83
8 oz 1.6 EC/100 gal	80	98	95
16 oz 1.6 EC/100 gal	180	93	86
64 oz 1.6 EC/100 gal	50	84	94
80 oz 1.6 EC/100 gal	50	70	68
Lorsban (4 E)	(Field rate: 1.5 - 2 qt 4 E/400 gal)		
Chlorpyrifos			
H_2O	100	98	98
.5 qt 4 E/400 gal	50	98	90
1 qt 4 E/400 gal	100	90	85
2 qt 4 E/400 gal	100	39	35
Malathion (25 WP)	(Field rate: 2 - 8 lb 25 WP/100 gal)		
Malathion			
H_2O	50	100	100
2 lb 25 WP/100 gal	50	78	88
8 lb 25 WP/100 gal	50	30	58
20 lb 25 WP/100 gal	50	24	20

Naled (8 E)	(Field rate: .5 - 1 pt 8 E/100 gal)			
Dibrom				
H_2O	50	100	92	
.25 pt 8 E/100 gal	50	88	88	
.5 pt 8 E/100 gal	50	88	68	
1 pt 8 E/100 gal	50	16	24	
5 pt 8 E/100 gal	50	0	0	
Omite (30 WP)	(Field rate: 1.25 - 2.5 lb 30 WP/100 gal)			
Propargite				
H_2O	100	93	81	Toxic to spider mites
1 lb 30 WP/100 gal	50	88	90	at all rates tested.
5 lb 30 WP/100 gal	100	59	47	
10 lb 30 WP/100 gal	100	42	58	
20 lb 30 WP/100 gal	100	39	21	
Plictran (50 WP)	(Field rate: 1 - 2.5 lb 50 WP/400 gal)			
Cyhexatin				
H_2O	50	98	90	Toxic to spider mites
1 lb 50 WP/400 gal	50	98	80	at all rates tested.
2 lb 50 WP/400 gal	50	94	80	
10 lb 50 WP/400 gal	50	60	40	
Plictran (50 W) flowable	(Field rate: not known)			
Cyhexatin				
H_2O	50	98	96	300 ppm is equivalent
150 ppm	50	40	22	to 2 lb 50 WP/400 gal.
300 ppm	50	4	2	
1500 ppm	50	0	0	

Supracide (2 E)	(Field rate: 4 - 6 qt 2 E/400 gal)			
Methidathion				
H_2O	50	94	88	Toxic to spider mites
1.5 qt 2 E/400 gal	50	12	20	at all rates tested.
3 qt 2 E/400 gal	50	0	0	
6 qt 2 E/400 gal	50	0	0	
Thiodan (50 WP)	(Field rate: 4 - 5 lb 50 WP/400 gal)			
Endosulfan				
H_2O	50	94	96	Toxic to spider mites
1 lb 50 WP/400 gal	50	94	96	at 2 and 4 lb 50 WP/400
2 lb 50 WP/400 gal	50	98	96	gal.
4 lb 50 WP/400 gal	50	100	88	
Topsin M	(Field rate: 1.5 - 2 lb/400 gal)			
Thiophanate methyl				
H_2O	50	92	94	
1 lb/400 gal	50	94	92	
2 lb/400 gal	50	96	96	
10 lb/400 gal	50	90	90	
Vendex (4 L)	(Field rate: 1 - 2.5 pt 4 L/400 gal)			
Fenbutatin-oxide				
H_2O	50	100	90	Toxic to spider mites
1 pt 4 L/400 gal	50	98	78	at all rates tested.
2 pt 4 L/400 gal	50	92	66	Increased mortality of
10 pt 4 L/400 gal	50	4	8	M.o. after 96 h.

Ziram (76 W)	(Field rate: 8 - 12 lb 76 W/400 gal)			
Ziram				
H_2O	50	98	98	No effect on hungry ♀♀
6 lb 76 W/400 gal	50	96	92	at all rates tested.
12 lb 76 W/400 gal	50	96	92	
60 lb 76 W/400 gal	50	98	90	
Zolone (3 EC)	(Field rate: 6 pt 3 EC/100 gal)			
Phosalone				
H_2O	50	88	88	
2 pt 3 EC/100 gal	50	54	8	
4 pt 3 EC/100 gal	50	12	6	
6 pt 3 EC/100 gal	50	4	0	

VI. Effects of Funginex and Savey (DPX) on Survival and Fecundity of *M. occidentalis*

Prelimary tests conducted during 1984/85 suggested that the fungicide Funginex (triforine) and the acaricide Savey (DPX) might stimulate reproduction in *M. occidentalis*. This could be of economic significance for managing predator populations during mass rearing in greenhouses or even for field populations. Therefore, we examined the effect of these two chemicals on survival and fecundity of females from two colonies of *M. occidentalis*.

In test 1 with Funginex and Savey we tested adult females of unknown age using a leaf spray method. In test 2, females had molted to adulthood within 24 hr. In test 3, females were 24-48 hr into adulthood. Egg production by females after 48 and 96 hr was evaluated in all 3 experiments. Data are presented in Tables VI-1 and VI-2.

Survival of females treated with Funginex at rates of 0.25- to 5-fold the field rate (16 oz 1.6 EC/100 gallons) was not significantly different from the water controls in all three tests for both colonies (Table VI-1). Egg production of these females was significantly different in test 1 and test 3 for both colonies, but egg production was reduced on the Funginex-treated leaf discs compared to water controls (Table VI-2).

In several cases, mean number of eggs was larger on disks tested with Funginex, but these differences were slight and not statistically significant.

DPX, or Savey, at rates 0.25- to 5-fold the field rate (3.5 oz AI/400 gal), was not toxic to either colony of *M. occidentalis* tested (Table VI-3). Females on Savey-treated leaf disks deposited more eggs in some cases (Test 2, COS colony, 48-96 hr; Test 2, COS colony, 0-48 hr), and fever eggs in others (Test 1, 48-96 hr) (Table VI-4).

Because there is no clear pattern of enhanced egg deposition by M. occidentalis on leaf disks treated with either Savey or Funginex, these products do not appear useful for enhancing predator populations in the field or mass rearing facilities.

Table VI-1. Effects of Funginex on survival of M. occidentalis females using a leaf spray method.

Rate[a/] tested	No. ♀♀ / colony tested	% survival after 48 hr		% survival after 96 hr	
		COS colony	Blue Gum colony	COS colony	Blue Gum colony
Test 1 - Tested adult females of unknown age.					
H_2O	50	90	66	76	56
0.25X	50	82	70	70	64
1X	50	90	70	84	62
5X	50	70	68	64	60
Test 2 - Tested adult females 0-24 hr after molt.					
H_2O	80	94	98	91	94
0.25X	80	93	97	91	91
0.5X	80	98	95	95	93
1X	80	96	95	94	86
Test 3 - Tested adult females 24-48 hr after molt.					
H_2O	50	96	94	94	88
1X	50	92	92	86	86
4X	50	84	94	76	88

[a/] Field rate tested (1X) was 16 oz 1.6 EC/100 gal.

Table VI-2. Effects of Funginex on egg production of M. occidentalis using a leaf spray method, 5 ♀♀/leaf disk.

Rate tested*/	$\bar{x}$ no. eggs/disk (S.D.) 0-48 hr		$\bar{x}$ no. eggs/disk (S.D.) 48-96 hr	
	COS colony	Blue Gum colony	COS colony	Blue Gum colony
Test 1 - Tested adult females of unknown age.				
H_2O	21.9 (5.7) a**/	16.2 (3.7) a	21.3 (8.8)	12.6 (7.2)
0.25X	21.1 (3.0) a	15.4 (5.8) a	16.1 (6.1)	11.0 (5.9)
1X	22.0 (5.5) a	14.3 (4.2) a	19.1 (3.8)	16.6 (7.6)
5X	9.3 (5.0) b	4.3 (4.4) b	15.2 (4.8)	12.1 (6.2)
Test 2 - Tested adult females 0-24 hr after molt.				
H_2O	20.0 (2.6)	20.9 (3.7)	24.0 (3.7)	22.5 (4.9)
0.25X	22.1 (3.4)	18.5 (5.1)	24.2 (4.7)	20.6 (5.4)
0.5X	22.0 (2.9)	19.1 (4.0)	25.7 (2.4)	20.4 (4.8)
1X	21.1 (4.0)	17.4 (4.0)	24.8 (4.8)	20.1 (4.4)
Test 3 - Tested adult females 24-48 hr after molt.				
H_2O	27.0 (3.4) a	27.6 (3.9) a	24.2 (3.4)	20.5 (2.9)
1X	25.0 (3.9) a	23.0 (3.8) b	22.1 (4.0)	20.4 (4.1)
2X	18.5 (4.6) b	21.5 (5.8) b	19.8 (6.5)	20.3 (4.9)

*/ Field rate tested (1X) was 16 oz 1.6 EC/100 gal.

**/ Means followed by the same letter are not statistically different (Duncan's multiple range test).

Table VI-3. Effects of Savey (DPX) on survival of M. occidentalis females using a leaf spray method.

Rate tested[a/]	No. ♀♀/ colony tested	% survival after 48 hr		% survival after 96 hr	
		COS colony	Blue Gum colony	COS colony	Blue Gum colony
Test 1 - Tested adult females of unknown age.					
H_2O	50	90	64	76	56
0.25X	50	84	62	52	54
1X	50	88	72	72	52
5X	50	72	70	62	58
Test 2 - Tested adult females 0-24 hr after molt.					
H_2O	80	96	100	92	87
0.25X	80	99	99	96	91
0.5X	80	99	99	96	92
1X	80	99	99	96	95
4X	80	99	95	95	85
Test 3 - Tested adult females 24-48 hr after molt.					
H_2O	50	98	100	96	85
1X	50	100	100	96	98
4X	50	96	100	90	94

[a/] Field rate tested (1X) was 3.5 oz AI/400 gal.

Table VI-4. Effects of Savey (DPX) on egg production of M. occidentalis using a leaf spray method.

Rate tested*/	$\bar{x}$ no. eggs/disk (S.D.) 0-48 hr		$\bar{x}$ no. eggs/disk (S.D.) 48-96 hr	
	COS colony	Blue Gum colony	COS colony	Blue Gum colony
Test 1 - Tested adult females of unknown age.				
H_2O	21.9 (5.7)	16.2 (3.7)	21.3 (8.8) a**/	12.6 (7.2)
0.25X	20.4 (2.7)	17.3 (3.2)	12.1 (4.0) b	13.8 (7.1)
1X	23.7 (3.8)	18.5 (5.6)	19.6 (7.7) a	12.9 (6.1)
5X	18.9 (3.9)	18.4 (6.1)	16.1 (7.1) ab	12.8 (6.9)
Test 2 - Tested adult females 0-24 hr after molt.				
H_2O	22.2 (3.3) b	19.9 (4.2)	25.5 (3.2) ab	17.2 (5.4)
0.25X	22.6 (2.5) b	19.2 (3.8)	27.2 (2.6) a	16.7 (3.2)
0.5X	23.6 (3.4) ab	21.6 (2.9)	25.6 (2.3) a	16.1 (3.7)
1X	23.6 (2.4) ab	21.7 (3.5)	24.7 (1.2) b	16.1 (2.6)
4X	25.1 (2.4) a	21.7 (2.7)	23.7 (2.3) b	15.1 (4.4)
Test 3 - Tested adult females 24-48 hr after molt.				
H_2O	27.5 (1.2)	30.8 (1.3)	30.0 (3.0)	29.8 (2.2)
1X	28.6 (1.9)	30.5 (2.1)	30.9 (2.8)	28.4 (4.8)
2X	27.2 (3.6)	28.4 (3.7)	28.8 (3.2)	29.5 (4.4)

*/ Field rate tested (1X) was 3.5 oz AI/400 gal.

**/ Means followed by the same letter are not statistically different (Duncan's multiple range test).

VII. Selection for Omite Resistance in T. pacificus

Resistance to Omite in T. pacificus was detected in a colony collected from the Bidart almond orchard in Kern County in 1984. This colony has been selected with Omite (30 WP) during 1985 and 1986 in the laboratory and greenhouse a total of 23 times (Table VII-1). Once the colony appears to be fully pure, we expect to conduct a mode of inheritance test with it. A complete concentration/mortality test will be conducted first using the selected colony and an Omite-susceptible colony to determine the appropriate concentrations to be used in the genetic analyses and to determine whether lines are straight. We also need to determine whether lines overlap.

Table VII-1. Selection for Omite resistance using the Bidart colony of *T. pacificus*.

Date Selected and Method	Selection no.	Dose lbs 30 WP/100 gal	% survival 48 hr Selected Colony	% survival 48 hr Base Colony
1985				
Leaf Spray - Laboratory				
18 March	1	1.0	47	-
23 March	2	1.0	66	57
13 May	3	1.0	67	54
1 July - Slide dip analysis of selected colony number three.				
		1.5	34	45
Bean Flat Spray - Greenhouse				
29 July	4	0.5 - new flat	moderate*	-
6 August	5	0.5 - new flat	low	-
16 August	6	0.1 - old flat	low	-
22 August	7	0.1 - new flat	moderate	-
30 August	8	0.2 - old flat	moderate	-
6 September	9	0.5 - new flat	moderate	-
13 September	10	1.0 - old flat	low	-
12 October	11	1.0 - new flat	high	-
23 October - Slide dip analysis of selected colony number eleven.				
		1.5	38	37

Date Selected and Method	Selection no.	Dose lbs 30 WP/100 gal	% survival 48 hr Selected Colony	% survival 48 hr Base Colony
6 November	12	1.0 - old flat	moderate	-
25 November	13	1.5 - new flat	low	-
1986				
31 January	14	1.5 - old flat	moderate	-
28 February	15	2.0 - new flat	moderate	-
17 March	16	3.0 - old flat	low	-
30 April	17	3.0 - old flat	low	-
16 May	18	3.0 - old flat	low	-
16 June	19	3.0 - new flat	moderate	-
9 July - Colony subcultured with 1000 ♀♀. Contaminated with Amblyseius Californicus.				
25 July	20	3.0 - old flat	moderate	-
15 August	21	3.0 (1986 30 WP) - old flat	high	-
5 September	22	3.0 - new flat	high	-
29 October	23	3.0 - new flat	high	-

* An estimate of survival of adult females on bean flats was made one week after flats were sprayed.

High survival 70%

Moderate survival = 30-70%

Low survival 30%

VIII. Publications

Headley, J. C. and M. A. Hoy 1986. The economics of integrated mite management in California almonds. Calif. Agric. 40(1/2): 28-30.

Hoy, M. A. 1985. Integrated mite management for California almond orchards. pp. 299-310. In: W. Helle and M.W. Sabelis (eds.): Spider Mites. Their Biology, Natural Enemies and Control. Volume 1B. Elsevier Science Publishers B.V., Amsterdam.

Hoy, M. A. and Y.-L. Ouyang (in press). Toxicity of Beta-exotoxin of Bacillus thuringiensis to Tetranychus pacificus McGregor and Metaseiulus occidentalis (Acari: Tetranychidae and Phytoseiidae). J. Econ. Entomol.

Hoy, M. A. and Y.-L. Ouyang 1986. Selectivity of the acaricides clofentezine and hexythiazox to the predator Metaseiulus occidentalis (Acari: Phytoseiidae). J. Econ. Entomol. 79: 1377-1380.

Selectivity of the Acaricides Clofentezine and Hexythiazox to the Predator *Metaseiulus occidentalis* (Acari: Phytoseiidae)

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ABSTRACT Two new ovicidal acaricides were tested in the laboratory to determine their relative toxicity to the predator *Metaseiulus occidentalis* (Nesbitt) and the Pacific spider mite, *Tetranychus pacificus* McGregor. Clofentezine and hexythiazox caused little mortality of adult females, larvae, or eggs of *M. occidentalis*. It seems unlikely that, at the proposed field rates, these ovicides will be toxic to this predator. Clofentezine is equally toxic to eggs (0–24 h old) of the spider mites *T. pacificus* and *T. urticae* Koch. However, both clofentezine and hexythiazox are less toxic to eggs of *T. pacificus* 49–72 h old than to younger eggs. Fecundity of *M. occidentalis* and *T. pacificus* females was significantly increased within 48 h on disks sprayed with hexythiazox at rates 0.5-fold the field rate and above.

KEY WORDS *Metaseiulus occidentalis, Tetranychus urticae, Tetranychus pacificus*, clofentezine, hexythiazox, selective pesticides, integrated mite management

INTEGRATED MITE MANAGEMENT in almonds is based on use of selective insecticides to control the key pest, the navel orangeworm, *Ameylois transitella* (Walker); cultural practices to reduce the effect of dust and water stress on the almond tree; and monitoring of spider mite/predator ratios to determine if the predators require assistance in maintaining mites below the treatment level. If predators need assistance, low rates of selective acaricides such as propargite, cyhexatin, and fenbutatin-oxide have been used to adjust these ratios, thereby reducing grower's costs (Hoy 1984, Hoy et al. 1984, Hoy 1985, Headley & Hoy 1986). The useful life of these long-used selective acaricides could be limited if high levels of resistance develop in the major spider mite pests, *Tetranychus urticae* Koch and *T. pacificus* McGregor. Accordingly, new selective acaricides are needed that could be used as components of an integrated mite management program.

Clofentezine (Apollo) and hexythiazox (Savey) are ovicides and neither is considered to be an adulticide (Neal et al. 1986; J. Aldridge, personal communication; F. Marmor, personal communication). Both are considered effective against eggs of several spider mite species and provide residual control. Preliminary field data from apples, almonds, and peaches suggest that both might be selective for the western predatory mite, *Metaseiulus* (=*Typhlodromus* or *Galendromus*) *occidentalis* (Nesbitt) (Bower & Thwaite 1984; S. Hoyt, personal communication; R. Rice, personal communication.)

Here we report the results of experiments conducted to determine the toxicity of these ovicides to *M. occidentalis* and to the Pacific spider mite, *T. pacificus*. a key pest of almonds in California. We also tested eggs of *T. urticae* and *T. pacificus* with clofentezine to determine whether this acaricide is equally toxic to eggs of these two species and we compared the toxicity of clofentezine and hexythiazox to different aged eggs of *T. pacificus*.

Materials and Methods

Acaricides Tested. Clofentezine, a tetrazine compound, was obtained from Nor-Am Chemical in a 50% aqueous based flowable-suspension concentrate (SC) formulation. Application rates expected for use in almonds are 78.1–156.2 ml (AI)/100 liters water assuming 3,741 liters are applied per ha (2–4 oz [AI]/acre, assuming 400 gal is applied per acre). The field rate was, thus, assumed to be 156.2 ml (AI)/100 liters water (4 oz [AI]/400 gal), and rates 0.125-, 0.25-, 0.5-, 1-, and 2-fold the proposed field rate were tested.

Hexythiazox (DPX Y5893-9 or Savey) was obtained from Dupont in a 50 wettable powder (WP) formulation. Proposed field rates for almonds are likely to be 3.28–6.56 g (AI)/100 liters water (1.75–3.5 oz [AI]/acre, assuming 400 gal is applied per acre). The field rate for these tests was, thus, assumed to be 6.56 g (AI)/100 liters water, assuming application rates of 3,741 liters/ha (3.5 oz [AI]/400 gal per acre), and rates 0.125-, 0.25-, 0.5-, 1-, and 2-fold the proposed field rate were tested.

All tests were conducted using freshly prepared solutions in distilled water, at 25–27°C, 38–58% RH, under continuous light.

Colonies Tested. The colony of *M. occidentalis* tested is resistant to sulfur, carbaryl, and organophosphorus pesticides (Hoy 1984). The *T. pacificus* colony was collected from almonds in Kern County, Calif., in June 1984 and reared on bean

plants, *Phaseolus vulgaris* (L.), in the greenhouse. It is resistant to cyhexatin (M.A.H. & J. Conley, unpublished data). The *T. urticae* colony tested is a greenhouse colony that has been exposed to various pesticides in the past.

Survival and Fecundity of Females. For each dose, gravid *M. occidentalis* females were placed (five per bean leaf disk) on disks (2.1 cm diam) placed bottom side up on water-soaked cotton. A total of ten replicates were set up on two dates. A surplus of all stages of *T. pacificus* was placed on each disk to serve as prey before the disk was sprayed with 0-, 0.125-, 0.25-, 0.5-, or 1-fold the field rate for clofentezine and the same rates plus 2-fold the proposed field rate of hexythiazox. Gravid *T. pacificus* females were tested in a similar way. The undersurface of the bean leaf disks containing the mites were sprayed to drip with an aerosol apparatus (Crown Spray-Tool). Survival was recorded after 48 and 96 h. Fecundity was assessed by counting the number of eggs on each leaf disk after 48 h. Comparisons of the survival of *T. pacificus* and *M. occidentalis* at each rate were made using a *t* test. Survival and fecundity were analyzed using analysis of variance and Duncan's (1955) multiple range test.

Effects of Rearing *M. occidentalis* Larvae on Treated Eggs. Larvae of *M. occidentalis* were placed (five per bean leaf disk) on disks with *T. pacificus* eggs that had been sprayed with water or 0.5-fold the field rate of clofentezine and 1.0-fold the field rate of hexythiazox. To obtain eggs of known age, *T. pacificus* females had been placed on the disks for 24 h and then removed. After the eggs were sprayed, *M. occidentalis* larvae were added. The number of larvae becoming adults after 96 h was determined and an analysis of variance was conducted to determine if *M. occidentalis* larvae survival on treated disks differed from that on the water controls. In addition, the new adults were monitored after 144 h to be sure the females could deposit eggs.

Effects on Eggs of *M. occidentalis* and *T. pacificus*. Adult females of *T. pacificus* and *M. occidentalis* were placed on bean leaf disks, allowed to deposit eggs for 24 h, and removed. The number of eggs was then adjusted to 10 per disk on each of 10 disks for each rate tested; the 10 replicates were set up on three different days. All stages of *T. pacificus* were added to disks with eggs of *M. occidentalis* and the mites and disks were then sprayed with 0-, 0.125-, 0.25-, 0.5-, 1-, and 2-fold the proposed field rates of clofentezine or hexythiazox. Egg hatch and development to adulthood were assessed after 48, 96, and 144 h by recording the number of eggs, larvae, nymphs, and adults. Comparisons of the survival at each rate compared with controls (*T. pacificus* and *M. occidentalis* treated with water) were made using Duncan's (1955) multiple range test.

Comparative Toxicity of Clofentezine to *T. urticae* and *T. pacificus* Eggs. Eggs of *T. pacificus* and *T. urticae* 0–24 h old were tested with 0-, 0.25-, 0.5-, and 1-fold the proposed field rate of clofentezine to determine whether these two species differ in their sensitivity. Fifty eggs were tested at each dose with a total of five replicates of 10 eggs set up on two different dates. The number of larvae and nymphs or adults on each disk was recorded after 192 h. A *t* test was conducted to compare the survival of the eggs of the two species at each dose tested.

Toxicity to *T. pacificus* Eggs of Different Ages. *T. pacificus* females were placed on bean leaf disks and removed after different times to obtain eggs 0–12, 13–24, 25–48, and 49–72 h old at 25–27°C. Eggs were removed to leave 10 eggs per disk, and five disks per treatment were sprayed at the same time with water, 0.5-fold the field rate of clofentezine, or 1-fold the field rate of hexythiazox. The number of eggs that hatched and the number of larvae or nymphs present were compared after 144 h by *t* test to determine if there were differences in hatch and development compared with the water controls of different aged eggs of *T. pacificus*.

Results and Discussion

Survival and Fecundity of Females. Neither clofentezine or hexythiazox were toxic to adult female *T. pacificus* or *M. occidentalis*. Survival after 96 h at 0-, 0.125-, 0.25-, 0.5-, 1-, or 2-fold the field rate of hexythiazox was 94, 90, 84, 88, 84, and 86% for *M. occidentalis* and 96, 78, 80, 78, 78, and 72% for *T. pacificus*, respectively. None of these values was significantly different ($P > 0.05$). Survival of *M. occidentalis* females 96 h after treatment with clofentezine was 82.9, 82.9, 76.4, 82.9, and 65.8% at 0-, 0.125-, 0.25-, 0.5-, and 1-fold the field rate; for *T. pacificus*, survival at these rates was 72.9, 75.7, 76.9, 70.0, and 71.4%, respectively. None of these values was significantly different ($P > 0.05$).

Egg deposition by hexythiazox-treated *M. occidentalis* and *T. pacificus* females was affected (Table 1). The number of eggs deposited by *M. occidentalis* females within 48 h ranged from a mean (±SD) of 15.3 (±2.8) on leaf disks treated with water alone to 20.2 (±5.0) for females treated with 2-fold the field rate of hexythiazox. These differences were significantly different (Table 1). The apparent increase in egg deposition by *M. occidentalis* females at all rates tested above 0.125-fold the field rate was unexpected and we have no explanation for it. The number of eggs deposited by *T. pacificus* females ranged from a mean of 23.7 (±4.8) to 32.9 (±14.0) (Table 1). Again, females appeared to deposit increasing numbers of eggs with increasing doses of hexythiazox. The reason for this is unknown. Because this enhanced egg deposition could result in reduced control, we assessed the ability of these eggs deposited on dried residues to hatch after 192 h (Table 1). Hatch was

Table 1. Effect of hexythiazox and clofentezine on egg deposition by *T. pacificus* and *M. occidentalis* females and residual toxic effects on eggs of *T. pacificus*

Doses tested (field rate)	$\bar{x}$ eggs deposited by 5 ♀♀ per disk within 48 h (±SD)		$\bar{x}$ eggs hatched (±SD) per disk after 192 h	
	Clofentezine	Hexythiazox	Clofentezine	Hexythiazox
M. occidentalis				
0	16.8 (4.9)a	15.3 (2.8)a	—[a]	—
0.125	11.4 (4.7)bc	15.4 (3.4)a	—	—
0.25	8.8 (5.2)c	20.8 (2.8)b	—	—
0.5	13.3 (5.8)ab	21.0 (5.0)b	—	—
1	9.6 (6.3)bc	20.1 (2.9)b	—	—
2	—	20.2 (5.0)b		
T. pacificus				
0	58.6 (14.6)a	23.7 (4.8)a	—	19.8 (4.5)a
0.125	57.6 (11.5)a	21.0 (6.6)a	—	15.4 (5.7)b
0.25	53.2 (15.7)a	20.5 (4.5)a	—	15.0 (5.9)b
0.5	55.4 (18.0)a	27.7 (10.0)ab	—	9.7 (4.5)c
1	61.2 (20.7)a	29.0 (7.4)ab	—	3.7 (3.7)d
2	—[a]	32.9 (14.0)b	—	2.3 (1.8)d

Means in each column for each species followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955] multiple range test).

[a] —, data not collected

dramatically reduced on disks treated with ≥0.5-fold the field rate of hexythiazox compared with the water controls. Thus, the residual activity of hexythiazox is substantial. However, this apparent enhancement of reproduction in *T. pacificus* is worrisome. If resistance to hexythiazox were to develop, and if the resistant females also deposited more eggs, then resistant mites could very quickly overwhelm the orchard. We do not know, however, whether egg deposition is enhanced over the entire lifetime of the females. Total productivity, thus, may not be increased. Despite this possibility, early reproduction results in more rapid population increases, and this could also create severe spider mite outbreaks.

Mean (±SD) egg deposition by clofentezine-treated *M. occidentalis* was apparently reduced as doses increased (Table 1) from 16.8 (±4.9) for the water controls to 9.6 (±6.3) for the females treated with 1-fold the field rate. Egg deposition by clofentezine-treated *T. pacificus* females was not affected, ranging from a mean of 58.6 (±14.6) to 61.2 (±20.7).

Effects on Eggs of *M. occidentalis* and *T. pacificus*. There were no significant effects of hexythiazox or clofentezine on hatch of *M. occidentalis* eggs at any of the rates tested ($P > 0.05$) (Table 2). Once hatched, larvae successfully developed to nymphs and adults on the treated leaf disks; no significant differences in developmental success were observed at the rates tested ($P > 0.05$).

Hexythiazox and clofentezine are toxic to *T. pacificus* eggs (Table 2). At 0.5-, 1-, and 2-fold the field rates of hexythiazox, no eggs hatched. Hatch and development to the nymphal stage (26%) was

Table 2. Effects of clofentezine and hexythiazox on eggs (0–24 h old) of *M. occidentalis* and *T. pacificus*

Doses (field rate)	% hatched eggs after 96 h		% nymphs + adults after 144 h	
	Clofentezine	Hexythiazox	Clofentezine	Hexythiazox
M. occidentalis				
0	88a	88a	80a	76a
0.125	92a	91a	78a	79a
0.25	89a	89a	83a	86a
0.5	87a	96a	78a	77a
1	88a	92a	82a	82a
2	82a	88a	65a	74a
T. pacificus				
0	57a	75a	86a	80a
0.125	37b	25b	66b	26b
0.25	51ab	1c	72b	2c
0.5	42ab	0c	50c	0c
1	10c	0c	12d	0c
2	5c	0c	6d	0c

Numbers in each column for each species followed by the same letter are not significantly different ($P > 0.05$; Duncan's [1955] multiple range test).

observed at the 0.125-fold field rate, but this was significantly reduced compared with that of the water control (80%). At 0.25-fold the field rate of hexythiazox, 2% of the eggs successfully hatched and larvae reached the nymphal stage.

Clofentezine appeared to be somewhat less toxic to *T. pacificus* eggs. After 96 h, 57, 37, 41, 42, 10, and 5% of the eggs had successfully hatched at 0-, 0.125-, 0.25-, 0.5-, 1-, and 2-fold the field rate. *T. pacificus* nymphs were present within 144 h even at the 0.5-, 1-, and 2-fold field rates (Table 2).

Comparative Toxicity of Clofentezine to *T. urticae* and *T. pacificus* Eggs. No significant differences in sensitivity were found in eggs of *T. pacificus* and *T. urticae* at any of the rates tested ($P > 0.05$; t test). The numbers of nymphs and adults present after 192 h were not different (t test). For *T. pacificus*, 82, 66, 20, and 30% of the 50 eggs tested at each dose (0-, 0.25-, 0.5-, and 1-fold the field rate) had hatched and developed to the nymphal stage. For *T. urticae*, 92, 38, 22, and 16% of the eggs had reached the same stage after 192 h.

Effects of Rearing *M. occidentalis* Larvae on Treated Eggs. Larvae of *M. occidentalis* that were fed eggs of *T. pacificus* treated with water, 0.5-fold the field rate of clofentezine, or 1-fold the field rate of hexythiazox developed normally on this diet of killed eggs. After 96 h, 90, 92, and 90% of the larvae tested on water, 0.5-fold clofentezine, or 1-fold hexythiazox, respectively, were adults. The new adult females were also able to deposit eggs. Thus, a diet of hexythiazox- or clofentezine-treated (killed) eggs did not prevent larvae of *M. occidentalis* from developing successfully to adults. This suggests that *M. occidentalis* populations could maintain themselves in the field on killed eggs of *T. urticae* or *T. pacificus*, which would enhance

Table 3. Toxicity of clofentezine and hexythiazox to different aged eggs of *T. pacificus*

Age of eggs (h)	% larvae or nymphs within 144 h after treatment (field rate)		
	Water	Clofentezine (0.5-fold)	Hexythiazox (1.0-fold)
0–12	66a	20a	8a
13–24	86a	30a	14a
25–48	88a	84b	64b
49–72	92a	74b	72b

Numbers within each treatment followed by different letters are not significantly different ($P < 0.05$; Duncan's [1955] multiple range test).

their ability to prevent resurgences of spider mite populations.

Toxicity to *T. pacificus* Eggs of Different Ages. Clofentezine and hexythiazox were significantly more toxic to young eggs of *T. pacificus* than they were to eggs 25–72 h old (Table 3). Eggs (0–12 h old) treated with water, 0.5-fold the field rate of clofentezine, or 1-fold the field rate of hexythiazox yielded 66, 20, and 8% nymphs within 144 h, and the numbers on the acaricide-treated disks were significantly different from the water controls ($P < 0.05$; t test). Eggs treated when 13–24 h old yielded 80, 30, and 14% nymphs within 144 h, and the numbers on the acaricide-treated disks were also significantly different ($P < 0.05$). Sixty-four percent of eggs 25–48 h old treated with 1-fold the field rate of hexythiazox became nymphs within 144 h; this is significantly different from the number in the water controls (88%). Equivalent numbers of eggs treated when 49–72 h old became nymphs after 114 h compared with the water control. Thus, both hexythiazox and clofentezine appear to be less toxic to eggs of *T. pacificus* that are ready to hatch. This may also be beneficial in integrated mite management programs using *M. occidentalis* because prey is essential in maintaining populations of this obligate predator throughout the growing season in almond orchards.

Conclusion. Both hexythiazox and clofentezine are selective ovicides effective against *T. urticae* and *T. pacificus*, yet appear nontoxic to the predatory mite *M. occidentalis*. The fact that these ovicides are not toxic to older eggs or active stages of these spider mites should allow the long-term retention of these obligate predators in the almond orchard. Thus, these ovicides may be particularly useful in an integrated mite management program where acaricides are applied only to adjust the predator/spider mite ratios.

Note Added in Proof

A new, more finely ground formulation of clofentezine was recently tested and is more toxic to *T. pacificus* than the older formulation. The new formulation is not more toxic to *M. occidentalis*.

Acknowledgment

We thank Jack Aldridge (Nor-Am Chemical) and Fred Marmor (DuPont Chemical) for providing materials for testing and information on field rates. We thank Frances Cave for her assistance in the project and Richard Rice, William Barnett, and Stanley Hoyt for providing information on their unpublished field trials with these materials.

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3.2.3 Almonds (California)

MARJORIE A. HOY

INTEGRATED MITE MANAGEMENT FOR CALIFORNIA ALMOND ORCHARDS

INTRODUCTION

Almonds, *Prunus amygdalus* Batsch, have been grown for over 140 years in California and bearing orchards now cover approximately 340 000 acres (137 600 ha) in the Central Valley (Fig. 3.2.3.1). Almonds apparently originated in western Asia and were domesticated in the Mediterranean region of Europe (Ross, 1978). Because almond flowers are susceptible to frost injury, Mediterranean-type climates with a rainy, mild winter followed by a warm, rainless spring and summer provide ideal growing conditions. Almonds are deep rooted and grow and produce best on deep, well-drained soils. Currently, all commercially produced almonds are grown under irrigation in California. Fruit bud differentiation begins in summer and continues through the autumn and winter. Therefore the management of spider mites is important throughout the season in order to minimize leaf injury and defoliation. Irrigation practices during the season also can reduce or enhance the impact of spider mites on almonds.

MAJOR ARTHROPOD PESTS OF ALMONDS

In California, the major arthropod pests of almonds include the navel orangeworm, *Amyelois transitella* (Walker), the peach twig borer, *Anarsia lineatella* Zeller, the San Jose scale, *Quadraspidiotus perniciosus* (Comstock), and spider mites (Barnes and Curtis, 1979; Rice, 1978; Summers, 1962). The key pest, navel orangeworm, caused annual damages estimated at $U.S.35 million during 1978–1980 (Headley, 1983), and chemical control of this pest can exacerbate spider mite problems.

Spider mites are considered by many growers to be primary, rather than secondary, pests of almonds, although some orchards rarely have detectable densities. Six species of tetranychid mite infest almond trees in the Central Valley of California, including the European red mite, *Panonychus ulmi* (Koch), the citrus red mite, *P. citri* (McGregor), the brown almond mite, *Bryobia rubrioculus* (Scheuten), the two-spotted spider mite, *Tetranychus urticae* Koch, the Pacific spider mite, *T. pacificus* McGregor, and the strawberry mite, *T. turkestani* (Ugarov & Nikolski) (Andrew and Barnes, 1981; Hoy et al., 1978, 1979; Summers, 1962). In the field it is difficult to distinguish between *T. urticae*, *T. pacificus* and *T. turkestani* and they are treated in this paper as a group of species (*Tetranychus* species) since they appear to cause similar damage. Detailed information on their phenologies in almonds is not available. The spider mite species present in different

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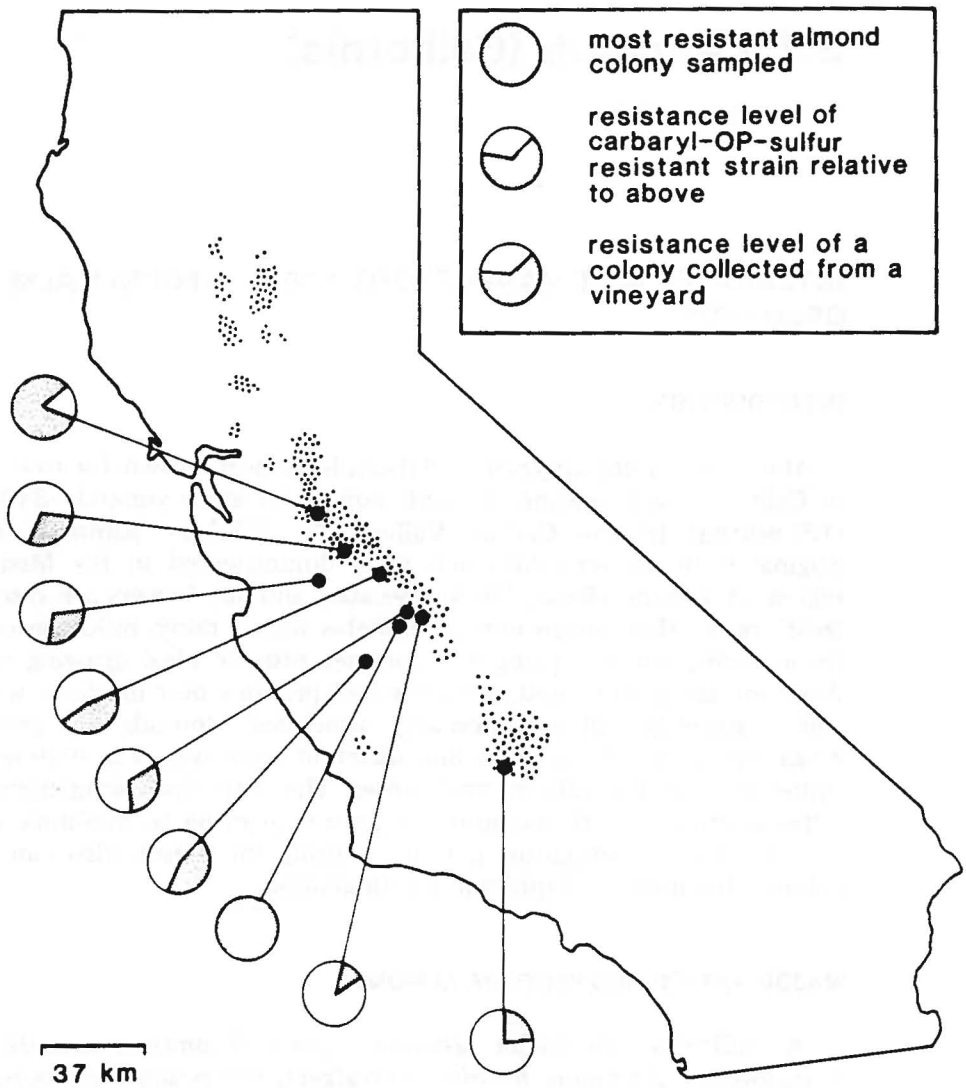

Fig. 3.2.3.1. Distribution and abundance of almonds in California are indicated by the small black dots, which represent 1000 acres (405 ha) of almonds. The shaded circles represent colonies of native *M. occidentalis* collected from almond orchards. The fully shaded circle represents the colony with the highest LC_{50} value for azinphosmethyl, using a slide-dip method. The proportion of the other circles that are shaded indicates their resistance levels; the carbaryl-OP-sulphur-resistant laboratory colony and a native colony from a commercial vineyard were tested at the same time for comparison.

almond orchards vary in terms of seasons and of geographic location. *P. ulmi* generally is more common in the central area of almond distribution while *Tetranychus* species are generally more prevalent in the more northern and southern extremes of the almond distribution. However, weather or other unknown factors can alter these general patterns; for example, European red mite dominated in more orchards than usual during 1983. The phenologies of the different mites also vary, perhaps because of microclimatic differences prevalent in the widespread almond-growing sites in California (Fig. 3.2.3.1).

EFFECTS OF SPIDER MITES ON ALMONDS

Few studies have documented the impact spider mites have on almond

tree yield and growth, so precise information on economic thresholds for all the mite species found in almonds has not been obtained. Barnes and Andrews (1978) found that 'high' populations of *Tetranychus* species did not adversely affect almond tree growth and productivity during the year in which the infestations occurred. However, yields of unprotected trees were an average of 13 and 19% lower compared to trees protected with an acaricide and the length of the terminal shoots was reduced by 11 and 48% in 2 orchards during the year after the infestation. Trunk growth was reduced by 19% in the unprotected trees. Andrews and LaPré (1979) showed that chlorophyll content of almond leaves was negatively correlated with the number of *Tetranychus* species mite-days per leaf. (A mite-day is 1 spider mite feeding on a leaf for 1 day.) Welter et al. (1984) further quantified the role of *Tetranychus* species in reducing development, growth and yield in the following season: terminal shoot extension was reduced by 24 and 9% after 517 and 311 mite-days, respectively. Mean leaf size was reduced the following season by 6.5 and 4% after 517 and 424 mite-days, respectively. Trunk girth was not significantly affected by mites nor were the number of flowers produced influenced by mite feeding during the previous season. However, the number of fruit that set was significantly reduced (by 20%) after 178 mite-days of injury induced during the preceding season in a 6-year old orchard.

To prevent such losses, growers may apply an acaricide such as propargite or cyhexatin, either whenever they see webbing or stippling from spider mite feeding, or on a preventative calendar basis. Thus, an acaricide may often be added to the insecticide timed to control the navel orangeworm at 10% hull split of the nuts in early July. Often this is done without concern for the presence or absence of spider mites or their natural enemies. Such treatments are costly and may be disruptive. For example Headley (1983) estimated that a single acaricide application costs $U.S.50.50 per acre.

BIOLOGY AND PEST STATUS OF SPIDER MITES

Of all the spider mite species that occur in almond orchards, the most serious pests are *T. urticae*, *T. pacificus*, and *T. turkestani* since the feeding damage associated with these mites causes leaf stippling and defoliation at densities lower than those observed to cause similar damage by *P. ulmi*, *P. citri*, or *B. rubrioculus*.

Bryobia rubrioculus

B. rubrioculus rests on the woody portions of the tree and moves out to feed chiefly on the upper surfaces of leaves during limited periods of the day or night. Because this mite moves off the foliage a specific sampling method was developed (Summers and Baker, 1952). *B. rubrioculus* can cause severe stippling to foliage (Summers and Stocking, 1972), and even defoliation. The effects of large populations can result in a 29.8% reduction in leaf area after feeding has occurred during the interval from petal fall until June 1. Usually damage from this mite is limited, however, since there are typically only 2 generations per year.

Hatching of overwintering eggs begins in late February and proceeds throughout the blooming season in California. The second generation develops in May and a partial third may develop in June. Infestations are typically localized in the lower central portions of the trees and decline during late June because most of the eggs laid on twigs during this

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period are in diapause and do not hatch until the following spring.

Overwintering eggs can be destroyed by dormant sprays containing oil and an organophosphorus insecticide, so that in-season sprays to control the active stages are not often necessary. If such dormant sprays are applied, *B. rubrioculus* is rarely abundant. Little is known of the natural enemies of this mite, and large populations of *B. rubrioculus* are generally limited to the cooler almond growing areas in California, and to orchards receiving few pesticide applications.

Panonychus ulmi

The European red mite, *Panonychus ulmi*, is found throughout California but generally predominates in cooler areas where almonds are grown. It, too, overwinters in diapause in the egg stage and dormant sprays, properly timed, can give good control. However, unlike *B. rubrioculus*, this species persists all season long in California almond orchards and can reach very high densities (several hundred per leaf). *P. ulmi* does not aggregate in well-defined colonies, as do *Tetranychus* species, but is found well dispersed on both upper and lower leaf surfaces. Feeding damage from *P. ulmi* results in stippled foliage, and defoliation has been initiated after ~ 400 mite-days of feeding (author's own observations, 1983). At present no phytoseiids that are specialist predators of *P. ulmi* are recognized or abundant in California. A carbaryl-OP-resistant strain of *Typhlodromus pyri* (Scheuten) obtained from New Zealand was released during 1983, but no recoveries have been made. During 1983, *Amblyseius hibisci* (Chant) and *Metaseiulus occidentalis* (Nesbitt) were observed to be effective predators of *P. ulmi* in several orchards. Occasionally, high densities of brown lacewings (*Hemerobius* spp.) have been found feeding on *P. ulmi* but these predators do not appear to be reliably present or capable of maintaining low densities in commercial orchards (Hoy et al., 1978).

Panonychus citri

Panonychus citri is found in almond orchards primarily in the southern part of the Central Valley. This mite moves into almond orchards from nearby citrus groves (Andrews and Barnes, 1981). Aerial movements of *P. citri* into almonds apparently must occur each season since this species lacks a diapause and therefore cannot overwinter on almonds in California. *P. citri* rarely reaches damaging levels by itself, but it may add to the damage inflicted by *Tetranychus* species. Like *P. ulmi*, it produces little webbing.

Tetranychus species

Tetranychus urticae, *T. pacificus* and *T. turkestani* may occur in the same almond orchards in the southern half of the Central Valley and mixed populations can be found on individual leaves (Andrews and Barnes, 1981; Hoy et al., 1979). Elsewhere *T. urticae* and *T. pacificus* may predominate. The presence of *T. turkestani* throughout the almond growing area has not been confirmed. Because these species cause similar feeding damage and comparable amounts of webbing, they will be discussed here as '*Tetranychus* species'. Certainly growers and pest control advisors do not distinguish between them in their management programs.

Tetranychus species overwinter as red or orange adult females in diapause under rough bark scales and in ground litter and rubbish. These mites typically feed and develop colonies on the underside of almond leaves, but

can be found on the upper leaf surface when densities are high. Their feeding causes leaf stippling and yellowing, and the high populations associated with the hot summer months typically begin in mid- to late June. Leaves, branches, and entire trees can become webbed over from high densities making it difficult to achieve adequate coverage or control with an acaricide (see colour plate in front of this volume).

Early in the growing season (March–May) *Tetranychus* species are typically found in the central and lower portions of the trees, as they colonize these areas first after they move out from their overwintering sites. By mid- to late June, however, the distribution of these mites is uniform over the tree unless they are removed from the lower portions of the trees by the washing action of sprinkler irrigation (Wilson et al., 1984; Zalom et al., 1984a,b). During late June, July, and August, *Tetranychus* species densities build up and orchard-wide outbreaks can develop. The outbreaks may begin from 'hot spots' and sweep through the orchard through aerial dispersal of the mites (Hoy, 1982a; Hoy et al., 1984). Entire orchards can become defoliated, and severe foliage damage can develop rapidly at the high temperatures and low relative humidities prevalent in California's Central Valley during July and August (Plate 1A, page vii). Outbreaks often begin in areas where trees are water stressed. Feeding damage is accentuated if orchards are improperly irrigated. Trees located along unpaved roads are exposed to more heat and dust than trees in the centre of the orchard and the edges of orchards typically have larger *Tetranychus* species populations than do the central regions. *Tetranychus* species populations often undergo a rapid decline in late August and September as the females begin entering diapause.

NATURAL ENEMIES OF TETRANYCHIDS IN CALIFORNIA ALMONDS

Several different natural enemies of spider mites are found in Californian almond orchards (Andrews and Barnes, 1981; Hoy et al., 1978). The most important and widespread natural enemy in pesticide-treated almond orchards is the phytoseiid mite *Metaseiulus occidentalis* (Nesbitt). Other phytoseiids are rarely found in treated almond orchards. During 1983, *Amblyseius hibisci* (Chant) was found in several almond orchards feeding on *P. ulmi*; these orchards were not treated in season and this may account for their unusual abundance. Insect predators of spider mites occur sporadically and may have a substantial impact on local populations; however, because they typically require very high prey densities to reproduce and persist in the orchard, they are not considered to be able to regulate and maintain low spider mite densities. Also, they are often quite susceptible to insecticides used to control the navel orangeworm. However, under outbreak conditions, predation by the six-spotted thrips, *Scolothrips sexmaculatus* (Pergande), can yield dramatic and rapid results (Barnes and Andrews, 1978), and a few growers are rearing and releasing *S. sexmaculatus* into their almond orchards. Other insect predators are encountered less often, including the green lacewing, *Chrysopa carnea* Stephens, *Stethorus picipes* Casey, *Orius* sp., *Geocoris* sp., and cecidomyid larvae. In unsprayed almond orchards, brown lacewings (*Hemerobius* sp.) have been observed controlling large populations of *P. ulmi* (Hoy et al., 1978).

Surveys of almond orchards conducted during 1979 showed that *M. occidentalis* occurs in many California almond orchards, particularly those where *Tetranychus* species predominate (Hoy et al., 1979). After *M. occidentalis* was shown to be widespread and effective, a survey of native populations was made to determine whether or not resistance to organo-

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phosphorus (OP) insecticides existed, as it does in populations established in pear and apple orchards in California (Hoy and Knop, 1979). The survey showed that the native *M. occidentalis* collected from almonds have variable levels of resistance to organophosphorus insecticides such as azinphosmethyl (Fig. 3.2.3.1). This pattern of variability was observed in California pear orchards and vineyards and suggests that patterns of local pesticide usage determine the resistance levels of the residents in each site. Thus, the Central Valley does not have a single uniform population of *M. occidentalis*, but has many locally adapted populations, at least with regard to OP resistance levels. Treatments to control the navel orangeworm using azinphosmethyl, diazinon, or phosmet are not often disruptive to spider mite control. However, because the native predators are variable in their resistance levels (Fig. 3.2.3.1) and are also susceptible to carbaryl and to permethrin, which are insecticides used in some orchards for navel orangeworm control, the mass rearing and release of strains of *M. occidentalis* with known levels of resistances seems warranted (Hoy et al., 1984b). If carbaryl or permethrin are applied, the native predators are eliminated and dramatic spider mite outbreaks can occur, unless acaricides are applied at the same time. In some orchards, azinphosmethyl will also induce mite outbreaks because the native *M. occidentalis* are OP-susceptible. Applications of acaricides together with the insecticide are not always effective because carbaryl and permethrin influence dispersal and/or increase the reproductive capacity of the spider mites. Thus, more than 1 application of propargite or cyhexatin may be required to prevent serious damage and defoliation by spider mites.

CAUSES OF SPIDER MITE OUTBREAKS

Tetranychus species outbreaks in almond orchards commonly occur in July and August, although densities can become quite high but very localized even in March or April when the females terminate diapause and infest the lower and central portions of the tree. Usually these early season populations are not treated. Outbreaks are caused by several factors, singly or in combination, including water stress due to inadequate irrigation, excessive dust, high temperatures, and the use of disruptive pesticides that influence either the spider mites and/or the predators. Almond varieties appear to vary in their susceptibility to mites, but no systematic survey has been conducted to compare the susceptibility of the numerous commercial almond varieties.

Tetranychus species outbreaks are also fostered by a management practice designed to reduce navel orangeworm damage, namely early harvest. The early harvest is induced by withholding irrigation water shortly after hull split begins in early July to induce rapid drying and splitting of the hull and to reduce mechanical harvest damage to the tree. Because the trees become water stressed, they exhibit more spider mite damage. Under these conditions the foliage may also serve as a more nutrient-rich host for the mites, resulting in a higher rate of reproduction on the water-stressed foliage.

There is no evidence that any of the spider mite species in California almond orchards have acquired high levels of resistance to the selective acaricides cyhexatin or propargite. This is probably because, compared with other crops such as strawberries or greenhouse-grown ornamentals, growers apply relatively few acaricides within a season, generally ranging from none to a maximum of 3. To date, failure to control spider mites in almonds with acaricides appears to be due to inadequate coverage rather than to genetic resistance in the pest. Control is difficult to achieve after *Tetranychus* species webbing becomes extensive, as the webbing and accumulated dust on the foliage prevents complete coverage.

INTEGRATED MITE MANAGEMENT

The development of an integrated mite management program began several years ago and has focused on the use of pesticide-resistant strains of the predatory mite *M. occidentalis* in combination with the use of lower-than-label rates of the selective acaricides propargite and cyhexatin (Hoy, 1982b; Hoy et al, 1984b). The pesticide-resistant strains were developed through laboratory selection and crosses (Hoy, 1984). Currently, integrated mite management is practised over thousands of acres, with additional growers interested in the program. Two groups of pest management advisors are mass rearing and selling a multi-resistant strain of *M. occidentalis* that is resistant to carbaryl, sulphur, phosmet, diazinon, and azinphosmethyl. Growers are interested in the project because it reduces their acaricide costs and provides spider mite control which is as good as, or better than, spider mite control with acaricides alone (Fig. 3.2.3.2).

Because native populations of *M. occidentalis* have variable levels of resistance to organophosphorus insecticides (Fig. 3.2.3.1), it is difficult to predict the impact of azinphosmethyl, diazinon, or phosmet on predator populations in specific orchards unless the predators are known to have survived these pesticides in the past. In many orchards, negligible numbers of native predators are present owing to the past use of disruptive pesticides such as permethrin or carbaryl; native *M. occidentalis* are susceptible to these insecticides. For these reasons, inoculative releases of the multi-resistant strain of *M. occidentalis* are recommended, unless an orchard has an abundant population of a strain of predators able to survive the OP insecticides and the grower does not use carbaryl or permethrin. The multi-resistant strain provides the grower with the option of using carbaryl to control navel orangeworm or peach twig borer without leading to spider mite disruption (Roush and Hoy, 1980, 1981; Hoy, 1982a, b; Hoy et al., 1982a, b, 1984b; Hoy, 1984).

The predators have been released in the orchards in several different patterns (i.e. into every third tree in every third row; into every third tree in every row; or into every tree). Establishment and dispersal of the multi-resistant or carbaryl-OP-resistant strains occur rapidly and the specific release pattern seems to be unimportant. Aerial dispersal of *M. occidentalis* has resulted in good control of spider mites in the orchard within the first season of release, although adequate distribution and multiplication should not be expected until the season following releases if the releases are made late in the season (Hoy, 1982; Hoy et al., 1984a,b; Roush and Hoy, 1980), as a ratio of 1 *M. occidentalis* to 10 *Tetranychus* spp. is required to control the spider mites within 2 weeks (Wilson et al., 1984).

Growers must be provided with information regarding the array of pesticides that are safe to use because, while the predators are multi-resistant, they do not survive all pesticides and permethrin, malathion and acephate are all highly toxic to this strain.

A revised acaricide program must be adopted if pesticide-resistant *M. occidentalis* are part of the management program. If label rates of propargite or cyhexatin are applied, control of spider mites is generally so good that there is a short-term lack of prey for *M. occidentalis*. As a result, the predators starve or disperse from the orchard and secondary outbreaks of spider mites have been observed in orchards where full label rates were applied. In order to maintain adequate densities of *M. occidentalis* in the orchard throughout the season, and from season to season, it is necessary to maintain prey throughout the season as well, since *M. occidentalis* does not feed on pollen or honeydew. Accordingly, the mite management program

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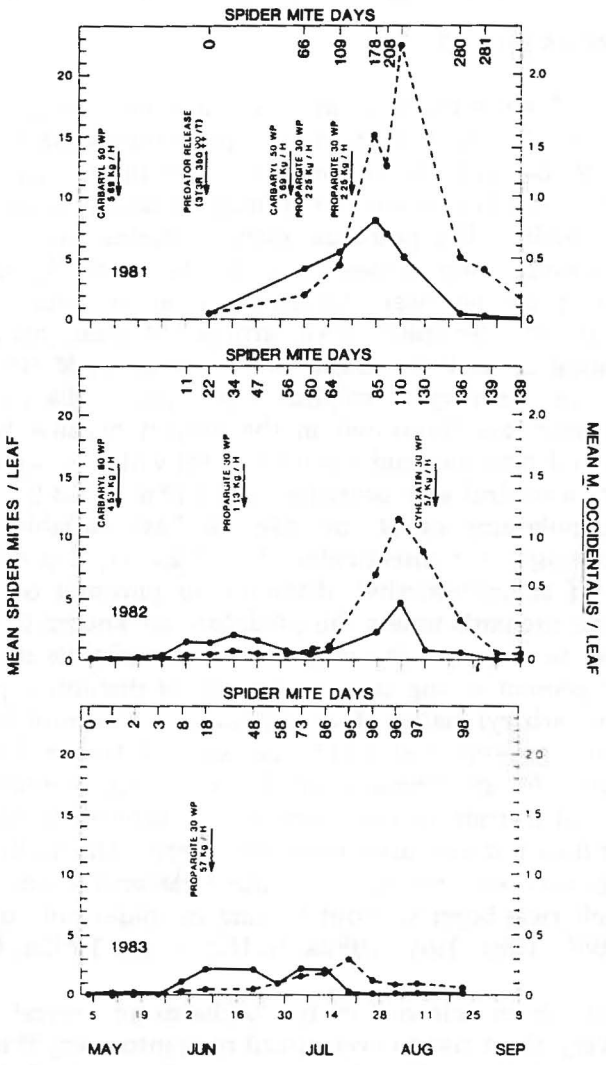
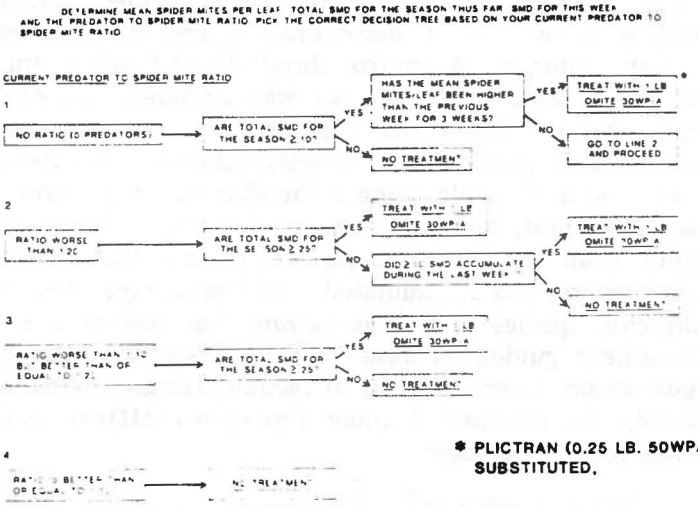


Fig. 3.2.3.2. Establishment and efficacy of a carbaryl-OP-resistant strain of *M. occidentalis* in a California almond orchard near Livingston during 1981—83. Three hundred and fifty adult females were released into every third tree in every third row in 1981. The mean number of active stages of spider mites (all species) and *M. occidentalis* are presented, as are the cumulative number of spider mite days on each sample date. Up to 10% defoliation occurred in 1981, 0.5% in 1982, and none in 1983. Solid lines represent spider mites; dashed lines, *M. occidentalis*.

recommends the use of very low rates of propargite or cyhexatin. For example, growers commonly use 5—10 lbs 30 WP Omite per acre in almonds. If *M. occidentalis* is present and well distributed in the orchard, we recommend 1—2 lbs 30 WP Omite per acre, 1/5 to 1/10 the standard rate. These low rates allow adjustment of the ratios of spider mites to predators without eliminating the prey, since both propargite and cyhexatin are selective for the predator at these rates. The goal is to maintain low levels of both predators and prey in the orchard through the season (Figs. 3.2.3.2 and 3.2.3.3).

To avoid excessive foliage damage from spider mites during the establishment of pesticide-resistant *M. occidentalis*, predator and spider mite populations should be monitored at least once a week so that predictions can be made about the necessity for an acaricide. At present there are 2 ways to monitor spider mites in almonds. A presence—absence sequential sampling

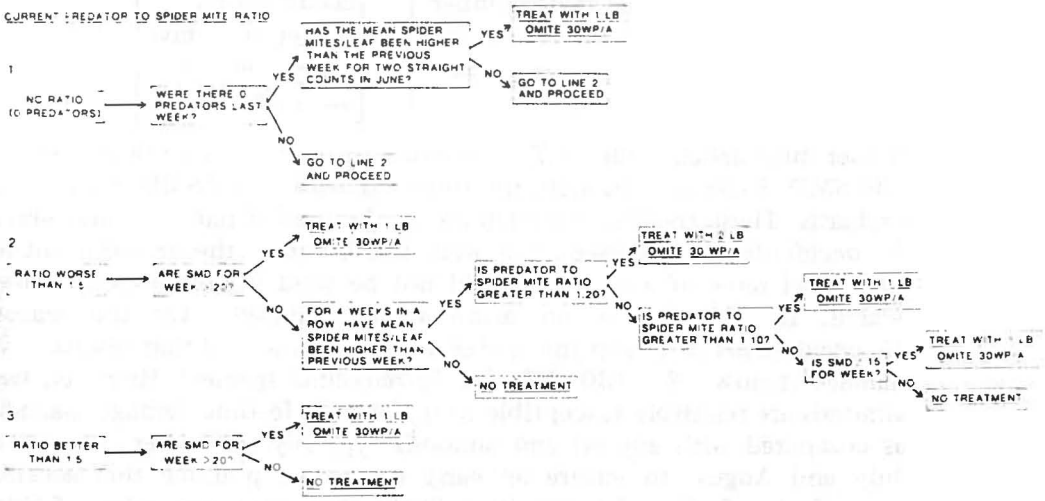
MAY GUIDELINES



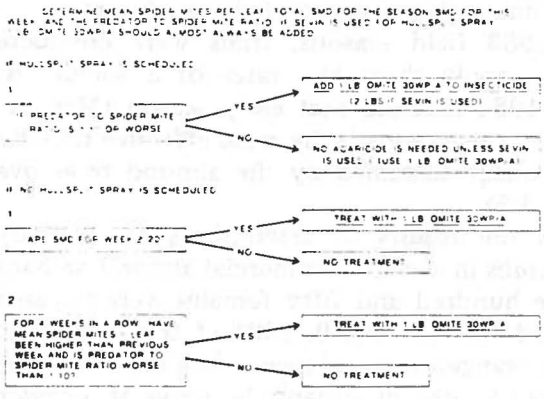
*** PLICTRAN (0.25 LB. 50WP/A) OR VENDEX (4 OZ. 4L/A) COULD BE SUBSTITUTED.**

JUNE GUIDELINES

DETERMINE MEAN SPIDER MITES PER LEAF, TOTAL SMD FOR THE SEASON THUS FAR, SMD FOR THIS WEEK, AND THE PREDATOR TO SPIDER MITE RATIO. PICK THE CORRECT DECISION TREE BASED ON YOUR CURRENT PREDATOR TO PREY RATIO. IF A HULLSPLIT SPRAY IS PLANNED FOR NOW AND IF A DECISION TO APPLY AN ACARICIDE IS MADE IN THE LAST WEEK OF JUNE, CONSIDER COMBINING THE ACARICIDE WITH THE HULLSPLIT SPRAY.



JULY GUIDELINES



AUGUST GUIDELINES

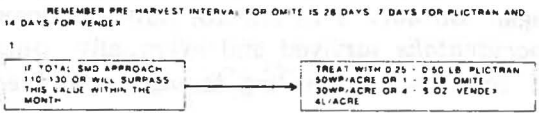


Fig. 3.2.3.3. Monthly guidelines for spider mite management in California almond orchards when *M. occidentalis* is present and well distributed; based on weekly foliage samples that are brushed and counted . Omite = propargite; Plictran = cyhexatin.

method for *Tetranychus* species can be used from mid-June on (Wilson et al., 1984; Zalom et al., 1984a,b). *M. occidentalis* is also sampled, and simple presence or absence is assessed. If *M. occidentalis* is present, one decision table is used; if absent, another. A control threshold of 0.436 proportion of leaves infested with *Tetranychus* species was proposed for orchards with *M. occidentalis* present. The control threshold for orchards lacking *M. occidentalis* was 0.220 proportion infested leaves (Zalom et al., 1984).

A brush-and-count method, while being somewhat more laborious than the presence–absence method, has the advantage of providing more detailed information: namely mean number of spider mites and predators per leaf; predator:spider mite ratios; and accumulated spider mite-days. Also, it can be used for *Panonychus* species as well as *Tetranychus* species as early as May. Different treatment guidelines have been proposed for each month from May to August based on the amount of feeding damage the trees have received (Fig. 3.2.3.3). The number of spider mite-days (SMD) is calculated as follows to estimate feeding damage:

$$\text{Spider mite-days for season} = \begin{bmatrix}0.5 \times \text{number of}\\ \text{days since last}\\ \text{sample date}\end{bmatrix} \times \begin{bmatrix}\text{current average}\\ \text{number of}\\ \text{mites per leaf}\end{bmatrix} + \begin{bmatrix}\text{average number}\\ \text{of mites per leaf}\\ \text{from previous}\\ \text{sample}\end{bmatrix} + \begin{bmatrix}\text{accumulated}\\ \text{spider mite-days}\\ \text{from previous}\\ \text{samples}\end{bmatrix}$$

Spider mite damage due to *Tetranychus* species becomes obvious at ~ 120–130 SMD. Extensive defoliation is obtained after ~ 400 SMD in well-irrigated orchards. These treatment guidelines can be used if native or multi-resistant *M. occidentalis* are present and well distributed in the orchard, but lower-than-label rates of acaricide should not be used if predators are absent or scarce. In some cases no acaricide is required over the season, as *M. occidentalis* can keep the spider mites below a level that results in visible damage (below 120–130 SMD for *Tetranychus* species). However, because almonds are relatively susceptible to spider-mite feeding damage (particularly as compared with apples) and almonds typically are water stressed during July and August to ensure an early harvest, a practice that accentuates the effects of mite damage, it is likely that very low rates of selective acaricides will be required in many seasons to assist the predators.

During the 1982 and 1983 field seasons, trials were conducted to determine the best time to apply these low rates of acaricide. Results obtained during 1983 and 1984 indicate that early season (May or early June) adjustment of predator–prey ratios is the most effective time because it reduces the amount of damage sustained by the almond trees over the season (Figs. 3.2.3.2 and 3.2.3.3).

Figure 3.2.3.2 illustrates the results of establishing the carbaryl-OP-resistant strain of *M. occidentalis* in a small commercial almond orchard near Livingston, California. Three hundred and fifty females were released into every third tree in every third row on June 9, 1981 (1 tree in 9). Carbaryl was applied to control navel orangeworm and peach twig borer in May 1981 and this reduced the number of carbaryl-susceptible native *M. occidentalis*. Establishment and dispersal of the released predators occurred rapidly and when carbaryl was applied again on July 3 to control navel orangeworm, substantial numbers of *M. occidentalis* survived and eventually controlled the spider mites (Fig. 3.2.3.2, top). Because feeding damage was higher than

was desirable, propargite was applied on July 3 and again on July 21. This orchard had ~10% defoliation during 1981 but spider mite control here was substantially better than in the grower s adjacent blocks where no predators were released and full-label rates of acaricide were applied. Approximately 281 SMD of feeding damage accumulated over the season (Fig. 3.2.3.2). The grower was pleased to continue the project in 1982.

During 1982 (Fig. 3.2.3.2, middle), carbaryl was applied in early May, but not in July. A very low rate of propargite (2 lbs 30 WP Omite per acre) was applied in late June to adjust the predator : spider mite ratio. A very low rate of cyhexatin was applied in mid-August. Foliage damage was considerably lower than in 1981 (a total of 139 SMD accumulated over the season) and the grower was pleased with both the mite control achieved and the reduction in acaricide costs over those accorded by a standard spray program.

During 1983, 2 species of phytoseiid, *M. occidentalis* and *Amblyseius hibisci*, controlled spider mites effectively all season long, and the foliage sustained about 98 SMD. Since most of these SMD were due to feeding by European red mite rather than *Tetranychus* species, foliage damage was minimal, and no defoliation occurred. The reasons for the shift from predominantly *Tetranychus* species in 1981 to European red mite in 1982 are unknown. It is noteworthy, however, that *M. occidentalis* and *A. hibisci* were able to control European red mites during 1983. *A. hibisci* may have been successful in this orchard during 1983 because no insecticides were used during the growing season. The amount of propargite applied in 1983 was ~1/10 to 1/20 the standard rate applied (5—10 lbs 30 WP per acre). This block now appears to have a stable predator : spider mite interaction and the predators should provide long-term spider mite control unless they are severely disrupted.

Growers are eager to reduce their acaricide costs, particularly if they can achieve spider mite control which is as good as, or better than, the standard chemical control approach. A reduction in the number, and rates, of acaricides applied should delay the onset of resistance to acaricides in the spider mites. Integrated mite management is being enthusiastically adopted by growers. The passage of time and the price of almonds will determine what proportion of California almond growers adopt this integrated mite management program.

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The economics of integrated mite management in almonds

J. C. Headley □ Marjorie A. Hoy

Five years of tests prove effectiveness and benefits of UC program

An integrated mite management program developed for almonds by the University of California is designed to control spider mites and reduce control costs. Since spider mites are serious pests in a majority of the 395,000 acres of bearing almond orchards in California, this program could have a significant effect on growers' income. Growers now make up to three acaricide applications per season, with an average of about 1.5, according to a survey of growers, University of California Extension personnel, and private pest control advisors.

The mite management program integrates chemical and biological control of spider mites, combining (1) use of selective insecticides to control the navel orangeworm, *Amyelois transitella* (Walker), and peach twig borer, *Anarsia lineatella* Zell, (2) use of lower-than-label rates of selective acaricides, and (3) release of pesticide-resistant predatory mites, *Metaseiulus occidentalis* (Nesbitt), in orchards where native organophosphorus-resistant *M. occidentalis* are lacking or are too rare to achieve control (see *California Agriculture*, July-August 1984).

The integrated mite management (IMM) program often works with native *M. occidentalis*, because they generally are sufficiently resistant to organophosphorus compounds to permit use of azinphosmethyl (Guthion), phosmet (Imidan), and diazinon (Diazinon) to control the navel orangeworm and peach twig borer. Carbaryl (Sevin) and permethrin (Pounce/Ambush) cannot be used without disrupting the native predatory mites.

To use carbaryl, growers can release the laboratory-selected strain of *M. occidentalis* resistant to carbaryl, sulfur, and organophosphorus compounds. This strain has been mass-produced commercially since 1983. It will establish, persist for at least five years in the orchard, and provide substantial spider mite control, while expanding the grower's navel orangeworm control options.

Integrated pest management (IPM) programs are rarely as simple as conventional chemical control. Before adopting an IPM practice, therefore, growers want to be sure that it works and that it generates benefits that exceed its costs. Five years of tests in commercial almond orchards in California have demonstrated that the integrated mite management program is effective. Our purpose here is to compare the economic effects of integrated mite management with those of conventional chemical control.

We have compared the costs of a conventional chemical control program using label rates of propargite (Omite), cyhexatin (Plictran), or hexakis (Vendex) with the costs of an integrated mite management program using lower-than-label rates of these acaricides in conjunction with (1) biological control by native *M. occidentalis* or (2) release of laboratory-selected insecticide-resistant *M. occidentalis*. When the grower uses the integrated mite management program, it is necessary to monitor the orchard to ascertain whether the proper predator-spider mite ratios exist; these monitoring costs have been included.

The evaluation is in two parts: (1) the cost savings to the grower of adopting integrated mite management with and without releases of predator mites and (2) the aggregate economic benefits of the program to the almond industry, taking into consideration the probable rate of adoption and the initial research investment that made the program possible.

Basic assumptions

We made some basic assumptions in estimating the benefits of the integrated mite management program. They are that:

(1) Under the conventional chemical control program, growers spend an average of $75 per acre, including application costs, for 1.5 acaricide treatments per year. (The costs can vary, depending on whether acaricides are applied alone or in a tank mix with navel orangeworm controls. In this study, we have taken a conservative approach and have charged application costs for all acaricides as though applied alone. Costs could be lower if acaricides were applied as a tank mix with other treatments.)

(2) The first-year cost of releasing and monitoring the insecticide-resistant *M. occidentalis* is $30 per acre ($20 for predators plus $10 for monitoring), based on costs supplied by commercial producers, and the predator is able to persist in the orchard for at least five years, based on data from a Bakersfield orchard that received predators in 1979.

(3) Monitoring predator-spider mite ratios costs $10 per acre per year in or-

Worksheet for estimating annual benefits of an integrated mite management program

1. Acres requiring treatment	_____ac.
A. Conventional treatment	
2. Cost of acaricide treatment per acre (normal rate for material; include application cost)	$_____
3. Cost of mite monitoring per acre	$_____
4. Total cost of monitoring (multiply value from line 3 by value from line 1)	$_____
5. Total cost of conventional treatment (line 2 times line 1 plus line 4)	$_____
B. Integrated mite management program	
6. Cost of lower-than-label-rate acaricide treatment per acre (low rate for material; include application cost)	$_____
7. Total cost of low-rate treatment (line 6 times line 1)	$_____
8. Cost of mite monitoring per acre	$_____
9. Total cost of monitoring (line 8 times line 1)	$_____
10. Total cost of integrated mite management treatment (line 7 plus line 9)*	$_____
11. Benefits of integrated mite management (line 5 minus line 10)	$_____
12. Benefits per acre (line 11 divided by line 1)	$_____

*If releases of resistant predatory mites are needed, add the cost of mite releases per acre times line 1, divided by the number of years expected between releases, to the amount on line 10 before computing benefits on line 11.

chards where predators are established.

(4) Yearly costs for using lower-than-label rates are $6 per acre for acaricide material plus up to $15 per acre for application. (Lower-than-label rates were estimated to be about 0.1 times the average rate of acaricide application.)

(5) The integrated mite management program will produce yields as good as, but no better than, the conventional chemical control program.

(6) No new equipment or capital investment is involved in adoption of IMM other than the investment in predators where needed, unless the grower does the monitoring using the brush-and-count method.

Grower benefits

Cost-saving budgets were constructed for two situations, in both of which the orchards have spider mite problems that require intervention. In one case, releases of insecticide-resistant *M. occidentalis* are not needed. In the other, there are too few native *M. occidentalis* to achieve effective control, and releases of the insecticide-resistant strain are required.

The cost savings computed under the basic assumptions are $44 per acre for those who use lower-than-label rates of acaricides and have sufficient native predator mites to achieve control (table 1, plan 1). For growers requiring predator releases, the computed cost savings are $24 per acre for the first year and $44 per acre thereafter unless another release of predator mites is needed (table 1, plan 2). Since the predators are known to be able to persist for at least five years, the total of the five-year benefits for the two types of growers has been computed and discounted at a 12 percent rate of interest. These values are $158.62 and $140.76 per acre, respectively, over five years. The values indicate that the grower could afford to invest as much as $158.62 or $140.76 per acre now to receive the cost savings over the next five years and earn 12 percent on the investment.

The integrated mite management program does not require investment in new equipment. Only in the case where the predator mites are needed is a $20 per acre initial investment in predators required. Specially trained people who understand the critical predator-prey ratios must monitor the orchard to ensure that the predators can control the damaging spider mites. This monitoring service, which is necessary to the success of the integrated mite management program, costs $10 per acre annually. Since there is no large "front end" capital investment, the economic risk of adoption is relatively low. Considering the size of the cost savings and the low risk involved, adoption of the integrated mite management program should be attractive to growers.

The accompanying worksheet gives guidelines for comparing costs in specific orchards. For example, if lower-than-label acaricide costs including application are estimated at $15 per acre rather than $21, $15 would be entered in item 6 of the worksheet. Or, if conventional acaricide costs including application and material are $50 per acre rather than $75 as suggested, $50 would be entered in item 2 of the worksheet.

Industry benefits

The decision by an individual grower to adopt the integrated mite management program is based solely on the benefits that grower expects. A conclusion as to whether or not the integrated mite management program has justified the investment in its development is different. Whether the program is economically justified as an industry technology depends on the cost savings per acre and how many acres growers commit to the program.

UC Cooperative Extension IPM personnel estimate that 80 percent of the 395,000 almond-bearing acres have spider mite problems requiring intervention. We evaluated the entire program under three alternative assumptions concerning the rate and extent of adoption: (1) 25 percent of the acreage with spider mite problems committed to the program the first year, but no new acreage added later, (2) 50 percent of the acreage with spider mite problems committed by the end of two years, at 25 percent per year, and (3) 75 percent of the acreage with spider mite problems committed by the end of the first three years, at 25 percent per year. Consequently, the alternatives give a 25, 50, and 75 percent adoption by growers with spider mite problems. It was assumed that 20 percent of the acreage committed to the program would need releases of predator mites each year.

Various agencies, both public and private, made an initial investment through research funds to the second author to develop the program. These funds, which included extramural grant support, 44 percent of the second author's salary and fringe benefits, and salary and fringe benefits for a staff research associate for five years, are documented and were compounded from the date received at an interest rate of 12 percent through July 1984.

With the development costs documented, we calculated the net present value as of 1985 of the industry cost savings over five years for the three alternative rates of adoption. The net present values are the sums of the annual cost savings benefits discounted at a 12 percent interest rate minus the initial research investment costs compounded at a 12 percent rate from date of allocation up to 1985. These values represent how much more could have been invested and still earn 12 percent on the initial research investment. (To allow for inflation, all costs were inflated by 5 percent per year compounded.)

The net present values for 25, 50, and 75 percent adoption by growers with acreage with spider mite problems, using a 12 percent interest rate, are $11,626,684, $21,255,816, and $28,239,860, respectively. These are re-

TABLE 1. Grower cost savings analysis for integrated mite management in almonds

Item					Amount
PLAN #1 (no releases of predator mites necessary)					
Cost of conventional treatment (includes material plus application/acre)					$ 75.00
Minus low acaricide rate treatment (includes material plus application/acre)					(21.00)
Minus cost of mite monitoring/acre					(10.00)
Cost reduction/acre					$ 44.00
Value of cost savings/acre					**Present value* at 12%**
Year #1	**Year #2**	**Year #3**	**Year #4**	**Year #5**	
$44.00	$44.00	$44.00	$44.00	$44.00	$ 158.62
PLAN #2 (release of predator mites necessary)					
Cost of conventional treatment (includes material plus application/acre)					$ 75.00
Minus low acaricide rate treatment (includes material plus application/acre)					(21.00)
Minus cost of mite monitoring per acre					(10.00)
Minus cost of first year predator releases/acre					(20.00)
First year cost reduction/acre					$ 24.00
Second and following year cost reduction/acre					$ 44.00
Value of savings per acre					**Present Value* at 12%**
Year #1	**Year #2**	**Year #3**	**Year #4**	**Year #5**	
$24.00	$44.00	$44.00	$44.00	$44.00	$ 140.76

*Present value = $\frac{\text{Savings \#1}}{1.12} + \frac{\text{Savings \#2}}{(1.12)^2} + \frac{\text{Savings \#3}}{(1.12)^3} + \frac{\text{Savings \#4}}{(1.12)^4} + \frac{\text{Savings \#5}}{(1.12)^5}$

Where the savings are the same each year, this is the same as the present value of an annuity.

turns above an initial research cost of $823,877. (Total funds allocated to the research from 1976 to 1984 were $537,661. Since society was deprived of the use of these funds for other purposes, compound interest at the rate of 12 percent was charged through 1984. The costs do not reflect the efforts of the UC Extension personnel or the collaborators who cooperated in developing the presence-absence monitoring system [see Zalom *et al.*, *California Agriculture* May-June 1984]. UC Cooperative Extension costs for education and implementation during 1984-85 are also excluded.)

The returns result in benefit-cost ratios of 15, 26, and 35, respectively, which translate into an annual return of 280 to 370 percent on the initial research investment. If the program is used longer than five years, additional benefits to the initial research investment will accrue, although costs for ongoing education and adaptation will continue.

A program like this has much to recommend it, since it is not expected to increase crop yields. Therefore, in the short run, the cost-saving benefits accrue to the growers directly and totally.

The integrated mite management program is unique in that it incorporates, as a component, a laboratory-selected predator. An additional unique feature is the fact that a large portion of the development costs can be documented to determine the economic justification of the endeavor.

By June 1985, an informal survey of pest control advisors and UC Cooperative Extension personnel suggested that nearly 25 percent of the growers with spider mite problems had already adopted the program. In 1984 and 1985, at least 12,000 acres of almonds received releases of the laboratory-selected strain of *M. occidentalis*. Cost savings expected from the first increment of adoption have therefore already been achieved. The outlook is that, by 1987, up to 60 to 70 percent of growers with spider mite problems will have adopted the program, and the projected industry cost savings will be reality.

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'Melogold', a new pummelo-grapefruit hybrid

Robert K. Soost □ James W. Cameron

The second offspring of a pummelo-grapefruit cross — 'Melogold' — is now being released. In 1958, an essentially acidless pummelo, CRC 2240 (*Citrus grandis* Osbeck), which imparts low acidity to its progeny, was crossed as seed parent with a seedy, white tetraploid (having twice the normal number of chromosomes) grapefruit (*C. paradisi* Macf.). The small population from this cross consisted of one tetraploid and six triploids (having 1½ times the normal number of chromosomes), which were field-planted in 1962. Two of the triploids had particularly favorable characteristics and were propagated for further testing. One of these was released in 1980 as 'Oroblanco' (*California Agriculture*, November-December 1980). The second, 6C26,18, is the cultivar 'Melogold'.

Observations have been made and data collected at Riverside (intermediate, interior climate) since 1967. Additional test trees were planted at the University of California Lindcove Field Station at Exeter (also intermediate, interior), the UC South Coast Field Station at Irvine (cool, humid area), and the U.S. Date and Citrus Station, Indio (hot desert climate). Some fruit has been available for testing at these locations since 1975.

'Melogold' appears to be best adapted to the inland citrus areas of California. At Lindcove, the season of production is from early November through February, just slightly earlier than 'Oroblanco'. At Riverside, maturity is from early December into March. 'Melogold' is suitable as a breakfast or salad fruit.

Description

In general characteristics, 'Melogold' resembles the present white-fleshed grapefruit cultivars but is more pummelo-like than 'Oroblanco'. Fruit are larger than 'Marsh' grapefruit and 'Oroblanco' at all test locations. Weight at Riverside from 1967 through 1975 averaged 470 grams (17 ounces) for 'Melogold', 360 grams (13 ounces) for 'Oroblanco', and 280 grams (10 ounces) for 'Marsh'. At Lindcove, from 1975 through 1983 with younger trees, fruit weight averaged 700 grams (25 ounces), 520 grams (18 ounces), and 450 grams (16 ounces), respectively, for the three cultivars.

Fruit shape is comparable to 'Marsh' and 'Oroblanco' with a slight tendency for more stem-end taper. Exterior peel color is slower to develop than in 'Marsh' grapefruit but is comparable late in the season. Exterior peel texture is smooth to slightly pebbled. Average peel thickness is slightly greater than in 'Marsh' but, as a percentage of fruit diameter, is equal to 'Marsh' and thinner than 'Oroblanco'.

Interior color and texture are the same as in 'Oroblanco'. As with 'Oroblanco', the central core hollow is greater than in 'Marsh' at maturity. The flesh is tender and juicy, separating well from the segment membranes. Percent juice has been equal to 'Marsh' and slightly higher than 'Oroblanco'.

'Melogold' may have a slight bitterness, particularly early and late in the harvest season. In taste tests, 'Melogold' was always preferred by a wide margin over 'Marsh' but usually was a very close second to 'Oroblanco'. In flavor, 'Melogold' differs from both 'Oroblanco' and grapefruit and is more like pummelo.

The total soluble solids, titratable acid, and solids-to-acid ratios of 'Melogold', 'Oroblanco', and 'Marsh', have been recorded since 1967 at Riverside and 1975 at Lindcove (tables 1 and 2). Riverside data for 'Melogold' and 'Oroblanco' through 1976 are from the original seedling trees or the first-budded trees on Troyer citrange (*Citrus sinensis* [L.] Osbeck × *Poncirus trifoliata* [L.] Raf.) rootstock. The slightly lower solids and acids in 1975 through 1978 are from younger trees also on Troyer citrange. All trees in Lindcove are also on Troyer citrange.

In comparison with 'Oroblanco', solids have consistently been slightly lower at Riverside but have sometimes been slightly higher at Lindcove. Acidity has also been consistently slightly lower than that of 'Oroblanco' at Riverside but has fluctuated at Lindcove. As with 'Oroblanco', 'Melogold' had much lower acidity than 'Marsh' did on all sampling dates through the season at all test locations.

In the 1981-82 season at Lindcove (table 2), the low acidity with moderate solids produced a much higher ratio than in 'Marsh' at all sampling dates. Fruit from the Coachella Valley and South Coast Field Station also had low acidity and moderate solids, even early in the season.