Project No. 85-B9 - Navel Orangeworm Mite and Insect Research
Control of Mites on Almonds

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Objectives: (1) Select strains of Tetranychus urticae and T.pacificus from almonds that are partially resistant to Omite, Plictran and Vendex to determine how many selections are required to reach a stable plateu. (2) Conduct mode of inheritance tests with resistant colonies of T.pacificus and T.urticae using Plictran and Omite. (3) Determine how stable Omite and Plictran resistances are by initiating colonies with gene frequencies of 0.5 for the resistance gene (assuming it is determined by a single gene) and determine the fate of the resistance over succeeding generations in the absence of selection. (4) Survey spider mites in the Modesto areas for Omite, Plictran and Vendex resistances. (5) Survey European red mite colonies for Omite, Plictran and Vendex resistances. (6) Develop discriminating doses for rapid identification of resistant and susceptible populatons. (7) Conduct an economic analysis, in conjunction with J.C. Headley, on costs/benefits of integrated mite management.

Interpretive Summary: An economic analysis of integrated mite management conducted by J.C. Headley showed the benefits of adopting the program range from $24 to $44/acre, depending upon whether pesticide-resistant M.occidentalis are released or not. Conventional chemical control of mites, using an average of 1.5 applications, costs $75/acre including application costs. Details of the economic analysis will be published in the January 1986 issue of California Agriculture and are available as well in a handout by the Almond Board. A worksheet is available for growers to estimate their own costs in that handout.

A survey of 10 colonies of Pacific mite from Kern county was made for Omite and Plictran resistances; all 10 colonies have survival rates higher than colonies from other areas in California. These increased survival rates indicate that Omite and Plictran resistances could develop rapidly if these products are misused. Use of low rates of Omite and Plictran in the integrated mite management program can still be effective, even in Kern County. It is, however, critical that monitoring be done so that miticides are applied early, if necessary. Furthermore, it is critical that low rates be applied properly. Speed of the sprayer, nozzles, and volume should be carefully checked to be sure that adequate coverage is achieved. Applications should be made as soon as the predator-spider mite ratios become inadequate. Low rates of miticides

should not be expected to work in orchards where M.occidentalis is not well distributed and abundant. The low rate applications were not designed for use in orchards having only generalist predators (lacewings, lady beetles), or phytoseiid predators other than M.occidentalis.

A survey of two-spotted spider mite populations in the Stanislaus and San Joaquin County area indicated no detectable increases in tolerance of either Omite or Plictran. Thus, miticide resistance problems are not uniformly distributed in the almond growing areas.

Because of our concern over miticide resistances in spider mites, we conducted laboratory screenings of several new unregistered miticides. Materials evaluated include Abamectin with and without oil, Thuringiensin, Apollo and hexythiazox (DPX Y5893). Abamectin and Thuringiensin are less toxic to M.occidentalis than to spider mites, but at the proposed field rates would most likely kill these predators. Thus, field trials are required to learn how to use them selectively. Apollo and DPX are ovicides; they kill spider mite eggs but not eggs or active stages of M.occidentalis. It appears they are the most selective miticides tested to date, and should be particularly useful in an integrated mite management program.

Work on Plictran, Vendex and Omite resistance with spider mites continues. We want to determine the mode of inheritance of these resistances and learn how persistent the resistances are under conditions where selection with these materials is lacking.

II. Economic Analysis of the Integrated Mite Management Program

J.C. Headley conducted an economic analysis of the benefits to a grower of adopting the integrated mite management program. In addition, he developed data on the cost-benefits of the entire program. These analyses will be reported in the January issue of California Agriculture and in a technical journal (MS included).

The conclusions are that growers that adopt the integrated mite management program have a strong economic incentive to do so. Despite costs of monitoring and, in some cases, of releasing pesticide-resistant M.occidentalis, the program provides savings of $24 to $44/acre per year, assuming the average grower applies 1.5 acaricides per year. The higher figure is for sites where native M.occidentalis are present and can be managed as part of the IMM program. The details are presented in the attached California Agriculture article.

California Agriculture

The Economics of Integrated Mite Management in California Almonds

J. C. Headley and Marjorie A. Hoy

An integrated mite management program has been developed at the University of California that is designed to control spider mites and reduce almond growers' mite control costs. Since spider mites are serious pests in a majority of the 395,000 bearing acres of almonds grown in California, the integrated mite management program could have a significant effect on growers' income. Growers currently make 0-3 acaricide applications per season and average about 1.5 acaricide applications per season 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 through the combined use of a) selective insecticides for control of the navel orangeworm (Ameylois transitella (Walker)) and peach twig borer (Anarsia lineatella Zell), b) use of lower-than-label rates of selective acaricides, and c) the 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 program often can be used with native M. occidentalis because they generally are sufficiently resistant to organophosphorus compounds so that Guthion (azinphosmethyl) and Imidan (phosmet) and Diazinon (diazinon) can be used to control the navel orangeworm and/or peach twig borer. Sevin (carbaryl) and Pounce/Ambush

(permethrin) can't be used without disrupting the native predatory mites. If growers wish to use carbaryl, they can release the laboratory-selected strain of M. occidentalis that is resistant to carbaryl, sulfur and organophosphorus compounds. This strain has been mass produced commercially since 1983. It will establish, persist for at least 5 years in the orchard and provide substantial spider mite control as well as expand the grower's navel orangeworm control options.

IPM programs are rarely as simple as conventional chemical control programs. Therefore, before growers adopt an IPM practice, they want to be sure that it works and that it generates benefits that exceed its costs. It has been demonstrated that the integrated mite management program works based on five years of tests in commercial almond orchards in California.

The purpose of this paper is to evaluate the economic advantages of integrated mite management compared to conventional chemical control. We compare the costs of the conventional chemical control program using label rates of Omite (propargite), Plictran (cyhexatin), or Vendex (hexakis) with the costs of using lower-than-label rates of these acaricides in conjunction with biological control by native M. occidentalis. In addition, the costs of releasing the laboratory-selected insecticide-resistant M. occidentalis in conjunction with lower-than-label rates of acaricides are compared with the conventional chemical control program for spider mites. Whether the grower uses lower-than-label rates of acaricides (with or without releasing the predator mites), monitoring of the orchard is necessary to assure that the proper predator-spider mite ratios exist and these monitoring costs are included.

The evaluation is in two parts. First, the cost savings to the grower of adopting integrated mite management with and without releases of predator

mites, are computed and presented. Second, the aggregate economic benefits of the program to the almond industry are calculated considering the probable rate of adoption and giving consideration to the initial research investment that made the program possible.

Basic Assumptions

In order to estimate the benefits of the integrated mite management program, some basic assumptions are necessary. They are:

1) growers currently spend, on the average, $75 per acre, including application costs, for 1.5 acaricide treatments under the conventional chemical control program per year.*
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 has the ability to persist in the orchard for at least five years, based on data from a Bakersfield orchard that received predators in 1979.
3) the cost of monitoring predator - spider mite ratios is $10 per acre per year in orchards where predators are established.
4) costs for using lower-than-label rates are $6 per acre for acaricide material plus up to $15 per acre costs of application per year.**

* The costs of acaricide treatments can vary depending on whether acaricides are applied alone or in a tank mix with NOW controls. In this study, a conservative approach has been taken and application costs have been charged for all acaricides as though applied alone. Costs could be lower if acaricides are applied as a tank mix with other treatments.

** Lower-than-label rates were estimated to be about 0.1 times the average rate of acaricide application.

(IMM)

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 kinds of growers; a) those with orchards that have spider mite problems requiring intervention, but which do not need releases of insecticide-resistant predator mites, and, b) those with orchards that have spider mite problems requiring intervention, but the native predator mites are too few to achieve effective control and, therefore, releases of the insecticide-resistant predator mites are required.

The cost savings computed under the assumptions above are $44 per acre for growers who adopt lower-than-label rates of acaricide use and have sufficient native predator mites to achieve control (Table, Plan 1). For those growers requiring releases of predators, the computed cost savings are $24 per acre for the first year and $44 per acre thereafter until or unless there is need for another release of predator mites. Since the predators are known to have the ability to persist for at least 5 years, the sum of the 5 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 5 years (Table, Plan 2). 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 assure that the predators can control the damaging spider mites. An annual cost of $10 per acre will provide this monitoring service, which is necessary to the success of the integrated mite management program. There is no large "front end" capital investment at risk by the grower. Therefore, economic risk of adoption is relatively low. Considering the magnitude of the cost savings, and the low risk involved, the adoption of the integrated mite management program should be attractive to growers.

To assist growers with their decisions concerning mite management, a worksheet has been provided so that each grower can make his or her own estimate of the cost savings (Table 2). For example, if a grower estimates that his or her lower-than-label acaricide costs including application will be $15 per acre rather than $21, $15 can be entered on line 4 of the worksheet. Or, if a grower's conventional acaricide costs including application and material are $50 per acre rather than $75 as suggested, $50 can be entered on line 2 of the worksheet. In this way, each grower can obtain an individual estimate of the cost savings of the integrated mite management program.

Industry Benefits

The decision by an individual grower to adopt the integrated mite management program is based solely on benefits expected by the grower. The conclusion that the integrated mite management program has or has not justified the investment in its development is different. Whether the

program is economically justified as an industry technology depends upon the cost saving per acre and how many acres growers commit to the program. Estimates by UC-IPM Extension personnel are that 80% of the 395,000 almond bearing acres have spider mite problems requiring intervention. An evaluation of the entire program was done under three alternative assumptions concerning the rate and extent of adoption. These alternatives were: 1) growers with 25% of the acreage with spider mite problems adopt the first year, but none adopt later, 2) growers with 50% of the acreage with spider mite problems adopt by the end of two years, 25% per year, and 3) growers with 75% of the acreage with spider mite problems adopt by the end of the first three years, 25% per year. Consequently, the alternatives give a 25, 50 and 75% adoption by growers with spider mite problems respectively. It was assumed that 20% of the acreage with spider mite problems will need releases of predator mites each year.

An initial investment in the program was made by various agencies, both public and private, through research funds to the second author to develop the program. These funds which included extramural grant support, 44% 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 can compute the net present value as of 1985 of the industry cost savings over 5 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 and represent how much more could have been invested and still earn 12% on the initial research investment.*

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 returns above an initial research cost of $823,877** and result in benefit-cost ratios of 15, 26, and 35, respectively. These benefits translate into an annual return of 280 to 370 percent on the initial research investment. If the program is used longer than 5 years, additional benefits to the initial research investment will accrue, although costs for ongoing education and adaptation will continue.

A program such as this has much to recommend it since it is not expected to increase yields. Therefore, in the short run, the cost saving benefits accrue to the growers directly and totally helping to ease financial stress in almond production.

The integrated mite management program is a unique program in that it incorporates, as a component, a laboratory-selected predator. An additional unique feature is the fact that a large portion of the

* In order to allow for the realities of inflation, all costs were inflated by 5 percent per year compounded.

** Total funds allocated to the research beginning in 1976 and ending in 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 up through 1984. The costs do not reflect the efforts of University of California Extension personnel or the collaborators who cooperated in developing the presence - absence monitoring system (see Zalom etal., California Agriculture May-June 1984). Costs by University Extension for education and implementation during 1984-85 are also excluded.

development costs of the program can be documented to determine the economic justification of the endeavor.

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

California Agriculture - acknowledgements

J. C. Headley is Professor, Department of Agricultural Economics, University of Missouri, Columbia, and Marjorie A. Hoy is Professor and Entomologist, Department of Entomological Sciences, University of California, Berkeley. The authors thank W. Bentley, D. Cahn, D. Castro, L. Hendricks, C. Kitayama, D. Lee, W. Reil, and B. Wilk, and F. Zalom for information. William W. Barnett, Area Specialist, UC/IPM, Fresno County, and Robert Curtis, Almond Board of California, provided valuable advice. This project has been supported in part by funds from the Almond Board of California; UC/IPM Program; Experiment Station Project 3522-H; Western Regional Project-84; and the California Department of Food and Agriculture. Information on the Integrated Mite Management Program is available in UC/IPM Publ. 1, 1984, "Managing Mites in Almonds, An Integrated Approach", from University of California Extension offices.

Table 1. Grower Cost Savings Analysis for Integrated Mite Management in Almonds.

Plan #1 (No Releases of Predacious 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

Year #1	Year #2	Year #3	Year #4	Year #5	Present Value* at 12%
$44.00	$44.00	$44.00	$44.00	$44.00	$158.62

Plan #2 (Release of Predacious 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

Year #1	Year #2	Year #3	Year #4	Year #5	Present Value* at 12%
$24.00	$44.00	$44.00	$44.00	$44.00	$140.76

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*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.

Table 2. Worksheet for Estimating Annual Benefits of Integrated Mite Management Program

1.	Acres requiring treatment	_____ac.
	A. Conventional Treatment	
2.	Cost of Acaricide Treatment ac. (Normal rate for material and include application cost)	$_____
2A.	Cost of Mite Monitoring/ac.	$_____
2B.	Total cost of Monitoring (multiply value from line 2A times the value from line 1)	$_____
3.	Total Cost of Conventional Treatment (Line 2 times line 1 plus line 2B)	$_____
	B. Integrated Mite Management Program.	
4.	Cost of lower-than-label rate acaricide treatment/ ac. (low rate for material and include application cost)	$_____
5.	Total cost of low rate treatment (line 4 times line 1)	$_____
6.	Cost of mite monitoring/ac.	$_____
7.	Total Cost of monitoring (line 6 times line 1)	$_____
8.	Total Cost of Integrated Mite Management Treatment (line 5 plus line 7)*	$_____
9.	Benefits of Integrated Mite Managment (line 3 minus line 8)	$_____
10.	Benefits per acre (line 9 divided by line 1)	$_____

*If releases of resistant predacious 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 found on line 8, before computing benefits on line 9.

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October 18, 1985

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Dear Marjorie:

Enclosed is the latest version of the paper. I'm at a loss to do anything else to it. If it meets your criteria let's try it.

I'll be in Europe at a Congress on the variability of the food supply from 23 November to 9 December.

Have a good Thanksgiving!

Sincerely,

J.C. Headley

JCH:mr
enc: (1)

Version 11/15/85

BENEFIT-COST ANALYSIS OF A GENETIC IMPROVEMENT PROGRAM: EVALUATION OF AN AGRICULTURAL RESEARCH INVESTMENT

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ABSTRACT

Genetic selection of a predator of spider mites in the laboratory resulted in an improved, pesticide-resistant strain. Introduction of the strain in an integrated mite management program for California almonds has begun. Economic analysis demonstrates the profitability of integrated mite management for growers. Programmatic benefit-cost analysis shows annual returns to the research investment of 280 to 370 percent. The high rate of return on the research investment is due, at least in part, to resources allocated to field testing and implementation.

Agricultural integrated pest management (IPM) systems in the U.S. are based on host plant resistance, biological control, cultural manipulations, pest monitoring and application of, if possible, selective pesticides only when necessary (1). Incorporating biological control into IPM systems is difficult because pesticides, which may be needed for one pest, are frequently toxic to natural enemies of another, and can lead to secondary pest outbreaks. Thus, research continues in an effort to learn how to use pesticides selectively through choice of materials, placement, application methods and timing (2). Developing resistant strains of biological control agents is a novel form of pesticide selectivity and provides a unique opportunity for integrating biological control into agricultural IPM systems (3).

Genetic manipulation of arthropod biological control agents has long been discussed as a tactic in pest management (4) but until recently has not been shown to yield biological control agents that are efficacious in the field. Recently the predatory mite Metaseiulus occidentalis (Nesbitt) was shown effective in California almond orchards after undergoing laboratory selection for pesticide resistances. Three genetically-manipulated predator strains met the criteria for field success, namely: establishment, overwintering, resistance to pesticides, and ability to control pest spider mites (5). Currently one multi-resistant strain is being used commercially in California almond orchards.

This paper describes the economics of the genetic improvement program, including the research conducted to introduce the carbaryl-organophosphorus-sulfur resistant strain into an integrated mite management (IMM) program, and analyzes the net economic benefits of the program for the aggregate of those who adopt the program and the individual almond grower. Because the research was conducted primarily in one laboratory over seven years, most of the

research and development costs can be calculated. The analysis provides clues as to the potential value of genetic improvement projects of arthropod biological control agents, whether they utilize conventional artificial selection or, potentially, genetic engineering techniques (6).

One of the unusual characteristics of biological control programs is that, if the technology is to be adopted, the public institution that does the basic research must continue with field testing and commercial adaptation. Such programs create knowledge and biological entities which usually are not proprietary and are, therefore, in the public domain. Consequently, unless the biological control agent can be patented, there is little incentive for a private firm to finance the field research only to have the result become common property (11).

There were two phases to the research which occurred in sequence. The first consisted of selecting resistant strains of M. occidentalis, developing multi-resistant strains through laboratory crosses and selection, laboratory evaluation of the fitness of the strains, analysis of the mode of inheritance of the resistances, and evaluating the strains in small experimental plots. This first phase began in 1976 and required about four years to accomplish (5).

The second phase consisted of the research necessary to implement the improved predators in commercial almond orchards (7). Mass production methods were devised and two monitoring techniques were developed to ascertain that appropriate predator-spider mite ratios existed. Orchard management strategies include optimal timing and release rates of the resistant predators, and use of selective acaricides at lower-than-label rates to assist the predators in controlling the spider mites. Acaricides are

pesticides that are primarily toxic to spider mites and selective ones are nontoxic, or exhibit lower toxicity to the predatory mites.

These components combined as follows: Almond orchards are surveyed to determine if native populations of M.occidentalis are present. If so, the native population, which is resistant to organophosphorus insecticides used to control the navel orangeworm (Ameylois transitella (Walker)), is managed as the primary biological control agent of spider mites. If native M.occidentalis are absent or rare, releases of the multi-resistant strain are made. This strain provides the grower with a new option in selective insecticides (carbaryl). All orchards, whether containing native or released M.occidentalis, are monitored to determine whether appropriate predator-prey ratios exist. If predators are too rare, lower-than-label rates of a selective acaricide are applied to assist the predator (7). Lower-than-label rates are necessary to retain these predators in the orchard. Since they are obligatory predators, they will starve or disperse out of the orchard if high rates of acaricide are applied, which eliminates their spider mite prey.

Commercial implementation of the integrated mite management program began in 1984. By May of 1985, approximately 4,800 hectares of almonds in California had received releases of the resistant M. occidentalis and ca. 36,000 hectares were being managed under IMM guidelines, but did not require predator releases (8).

The total identified costs of research to develop the integrated mite management program were $537,661. . Phase I, which included the laboratory selection of the pesticide-resistant predators and the laboratory and small plot testing, cost $148,024. Phase II, which involved large scale field testing and commercial adaptation of the program cost $389,637. When these

costs were compounded at a 12 percent rate of interest, the total research and development costs as of 1 January 1985, amounted to $823,877 (9).

The benefits to almond growers of adopting the IMM program are in the form of savings in mite control costs through the reduced numbers of acaricide applications, and, where applications are applied, through the reduced rate of acaricides applied per hectare. Clearly the programmatic cost savings benefits are a function of the area of almond orchards in need of an alternative to the conventional chemical control of spider mites and the rate of adoption by those growers for whom the program would provide cost savings.

To compute the programmatic cost savings from the program, the following projections were made for a three year adoption scenario:

(a) 80 percent of 158,000 hectares (126,400) hectares have spider mite problems requiring intervention by the grower.

(b) 20 percent of the area using integrated mite management will need releases of M. occidentalis because native predators are absent or rare,

(c) the balance of the problem acreage will continue to use conventional acaricide programs during the first year,

(d) releases of M. occidentalis cost $50 per hectare; mite monitoring, needed by all growers using integrated mite management, costs an additional $25 per hectare; conventional acaricide treatment, including application, costs $187.50 per hectare to provide an average of 1.5 treatments per year, compared to an average of $52.50 per hectare for lower-than-label rates of selective acaricides applied in the integrated mite management program.

(e) resistant M. occidentalis, once released, will persist for at least 5 years forming the planning horizon for the evaluation.

Based on these figures, programmatic budgets were developed to compute the annual cost savings to the adopting almond producers in California (Table 1) during the projected three year adoption period. The stream of cost saving benefits was then discounted for three different alternative adoption levels of 25, 50 and 75 percent of the area in need of spider mite control.

Projected economic benefits in the form of the present value of cost savings from the program for a five year planning horizon are from 15 to 35 times the research funds invested to develop the program. With benefits of this magnitude, the annual rate of return on the initial research investment is between 280 and 370 percent.

Reports from University of California Extension personnel and others indicate that releases of resistant M. occidentalis had been made in 4,800 hectares by May 1985 (8). This is near the projected 6,320 hectares (20% of 126,400) used in computing first year cost savings (Table 1).

For almond growers, the decision to adopt new technology is by necessity based on the perceived benefits to the producer. If growers expect that adoption of the IMM system will increase the net income of the orchard, adoption will occur. Since almond growers make many management decisions each year about pollination, irrigation, fertilization, weed control, navel orangeworm and spider mite control, technologies that are simple, as well as profitable, are likely to become popular.

A decision to use the IMM program is relatively uncomplicated. Since the IMM program only affects the control of spider mites and the key insect pest, the navel orangeworm, the grower need only choose a selective insecticide for the navel orangeworm that will allow predators to persist. The program was designed for predator releases if necessary; however, growers with adequate populations of native predators benefit from the lower-than-label rate

acaricide treatments. The use of low rates is crucial, allowing retention of some spider mites as a food supply for predators, providing cost savings by reducing expenditures for acaricide applications, and delaying the onset of acaricide resistance.

Growers can adopt the IMM program without investing in new equipment. The inputs required are information about the program and how it works, monitoring to determine predator-prey ratios and releases of insecticide-resistant predacious mites, if needed. Currently, extension pest management specialists have the information available at no cost to the growers, predators are commercially available at $50 per hectare and monitoring services are available for hire at $25 per hectare. If growers have a spider mite problem requiring intervention, they can expect that adoption of the IMM program will generate costs savings of from $60 to $110 per hectare, depending on whether predator releases are needed (10).

The cost savings from the program accrue directly and totally to the grower since the technology does not increase yields and, therefore, is not expected to have a short term effect on the almond prices paid to the grower. It is possible that the availability of IMM might reduce the rate at which existing orchards are removed from production with a long run effect on price and quantity. However, as long as there are almond surpluses, low prices and poor profits (the situation in recent years), reducing the cost of producing almonds by adoption of the IMM program should not have much if any influence on the supply of almonds. When supply and demand are in balance or if there is excess demand, a technology that reduces costs of production will encourage more production and possibly lower prices. This is not the case in 1985 because demand is weak and there is excess supply. It therefore seems that the cost savings estimated (Table 1) will be realized by growers. Given

that the adoption of IMM does not require a large initial investment, the decision is not risky. Since any cost savings will not likely be offset by revenue declines, the program should be very attractive to growers.

The economic analysis reported here is especially unusual, since it encompasses the entire range of activity from selecting a strain of insecticide-resistant predators to the field testing and assurance of an operational program at the grower level. While numerous University personnel contributed to the project (9), the primary researcher remained involved and provided continuity in bringing the research to the commercial application stage. This raises the issue of optimal strategies for developing new technology in universities and the role of the scientist in the development process. Is it in general optimal for the scientist(s) who develop solutions to applied problems to remain involved in the research and development, as in this study. Or, are there situations where the scientist should give way to the engineers and the entrepreneurs? We are not prepared to answer the question except to say that, in this case, the continuity provided by the primary researcher during phases I and II may have been vital.

Genetic engineering using recombinant DNA technology is receiving attention for its potential to create and improve unique organisms or products. Genetic engineering of arthropod biological control agents will operate under the same constraints as were encountered in this project, since once the improved organism is developed, the implementation research must be done. Approximately 65 percent of the identifiable research costs of the IMM program were devoted to implementation research (9). If one assumes that the implementation research would cost the same regardless of the genetic technique employed, then the economic research or cost saving advantage that use of genetic engineering techniques could provide may be limited to 35

percent of the total research budget. Agricultural research designed to develop new technology for ultimate use by growers will be more likely to be adopted, and will be more efficient, if the researchers understand the agricultural production system and are able and willing to continue through to implementation. Furthermore, it should be recognized that ongoing economic inputs are required after the program is adopted. No IPM program can be put in place and be expected to operate without adaptation and change.

By the summer of 1985, the IMM program was being used on at least 40,000 hectares. Resistant M. occidentalis are being reared and released commercially by private pest control consultants and the area involved is expected to grow. If adoption involves 75% of the area in need of spider mite control, a benefit-cost ratio of 35: 1 is expected to result. The success of the adoption of the technology suggests an excellent return to the resources allocated to four years of implementation research which included field testing.

The IMM research demonstrates: (a) that genetically-improved biological control agents can be integrated with chemical and cultural methods on a commercial basis, (b) this research results in increased productivity and sustainability of a spider mite management system, and (c) agricultural research devoted to implementation is an integral component of development.

Table 1. Projected annual programmatic cost savings from adopting integrated mite management (IMM) programs on California almonds. The cost reduction is total conventional treatment cost minus the sum of IMM costs of acaricides, predator release and the cost for conventional treatment on the area with mite problems, but not under IMM. Net present value is the sum of discounted cost savings over 5 years minus the compounded research costs. The interest rate used for compounding and discounting is 12%. For year 1, it is assumed that 25% of the area requiring spider mite treatment will be treated under IMM with the remainder receiving conventional treatment. In year 2, the IMM area is projected to expand to 50% of the area requiring spider mite treatment and by year 3, the IMM area will have grown to 75% of the area requiring spider mite treatment. Net benefits are then computed for a 5 year planning horizon, a conservative estimate of the persistance of the resistant predators. To reflect possible increases in the price level, costs are inflated by 5% per year.

Item	Unit	25% adoption Year 1	50% adoption Year 2	75% adoption Year 3
1. Total almond area	ha.	158,000	158,000	158,000
2. Area requiring spider mite treatment	ha.	126,400	126,400	126,400
3. Total conventional treatment cost	$	23,700,000	24,885,000	26,129,250
4. Projected area under IMM	ha.	31,600	63,200	94,800
5. Projected area under conventional treatment	ha.	94,800	63,200	31,600
6. Cost for projected conventional treatment area	$	17,775,000	12,442,500	6,532,312
7. Cost for IMM area, acaricides including application plus monitoring	$	2,449,000	5,142,900	8,100,067
8. Cost for predator releases	$	316,000	663,600	1,045,170
9. Total cost for IMM adoption (line 6 + line 7 + line 8)	$	20,540,000	18,249,000	15,677,550
10. Cost reduction due to IMM (line 3 minus line 9)	$	3,160,000	6,636,000	10,451,700

	Research Cost Present value($)	Cost Savings($)					Net Present Value 5 yrs.
		year 1	year 2	year 3	year 4	year 5	$
25% IMM adoption	823,877	3,160,000	3,318,000	3,483,900	3,658,095	3,841,000	11,626,684
50% IMM adoption (25%/yr)	823,877	3,160,000	6,636,000	6,967,800	7,316,190	7,682,000	21,255,816
75% IMM adoption (25%/yr)	823,877	3,160,000	6,636,000	10,451,700	10,974,285	11,522,999	28,239,860

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9. Research costs needed for a benefit-cost analysis include: the salary and benefits of the principal investigator, 0.5 salary and benefits for a laboratory technician for 5 years, plus extramural funds to support the project including supplies, travel expenses, technical assistance and equipment. The cost data are as follows:

Phase I

Date	Expenditures	Value in 1985 with interest Compounded at 12%
1976-77	$16,636	$41,191
1977-78	31,596	69,859
1978-79	36,073	71,208
1979-80	63,719	122,273
Total Phase I	$148,024	$294,531

Phase II

Date	Expenditures	Value in 1985 with interest Compounded at 12%
1980-81	$133,393	$209,961
1981-82	77,859	109,391
1982-83	76,140	95,480
1983-84	102,245	114,514
Total Phase II	$389,637	$529,346
Total Cost- Phase I plus Phase II	$537,661	$823,877

Interest on the expenditures was compounded to reflect the opportunity cost of these resources had they been used by the private sector rather than as public research expenditures. Other costs which are a part of this program are costs of the Univ. of California IPM program and costs of state IPM specialists who were involved in the research to test and implement the integrated mite management program to June 1985. These

costs cannot be documented, but are believed to be 10% or less of the documented expenditures to 1985. Additional investments by these agencies will be required to complete the adoption by growers and to adopt the program as conditions change.

10. Many almond orchards have resistant native predators in which case adopting IMM will mean moving from an average of 1.5 acaricide treatments at $187.50 per ha. to an average of 0.5 treatments at lower-than-label rates costing $52.50 per ha. plus $25 per ha. for monitoring. The cost reduction amounts to $110 per ha. For those orchards where insecticide resistant predatory mites are not present, the first year of IMM will involve the release of resistant predators costing $50 per ha. In these cases, the cost savings due to IMM will be $60 per ha. the first year and $110 per ha. thereafter unless or until the predators need to be replaced.

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III. Evaluation of Avermectin and Thuringiensin as Selective Acaricides

Abamectin (avermectin) and the beta-exotoxin of Bacillus thuringiensis were evaluated as selective acaricides for M.occidentalis. Details of the tests are presented in two published papers on Abamectin (Grafton-Cardwell and Hoy; Hoy and Cave, attached), and in the manuscript on Thuringiensin (attached).

Both unregistered materials are highly toxic to spider mites and are promising acaricides. However, both are also toxic to M.occidentalis, as well. In both cases, the materials are less toxic to the predator than to the spider mites. However, the differential in toxicity is probably not sufficient that applications of these products at the proposed field rates would be selective to M.occidentalis. Therefore, field trials should be conducted to determine what doses, if any, could be used that would provide partial suppression of spider mites without severe mortality effects to the predator. Such reduced rates would offer the bonus of reducing costs to growers, but do create problems (as with Omite and Plictran) in training growers, PCAs and others in how and when to use them. However, learning how to use these products, and their availability, is critically important, if we lose Omite, Plictran and/or Vendex to resistance.

TOXICITY OF B-EXOTOXIN OF *BACILLUS THURINGIENSIS* TO *TETRANYCHUS PACIFICUS* MCGREGOR AND *METASEIULUS OCCIDENTALIS* (NESBITT) (ACARINA: TETRANYCHIDAE AND PHYTOSEIIDAE)

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ABSTRACT

Hoy, M.A. and Ouyang, Y.-L. 1986. Toxicity of B-exotoxin of *Bacillus thuringiensis* to *Tetranychus pacificus* McGregor and *Metaseiulus occidentalis* (Nesbitt) (Acarina: Tetranychidae and Phytoseiidae). Exp. Appl. Acarol., _: .

The beta-exotoxin of *B.thuringiensis* (thuringiensin) is toxic to adult females of *T.pacificus* and *M.occidentalis* within 48-96 hrs when treated at rates from one-eighth to four times the proposed field rate. Egg production by treated females of both species declined within 48 hrs. Larvae treated were unable to molt to the adult stage. Eggs treated hatched, but larvae of both *M.occidentalis* and *T.pacificus* failed to molt successfully to the adult stage.

Thuringiensin is an effective, but, at these rates, unselective acaricide. Because intrinsic selectivity is not present at the proposed field rates, selectivity will have to be achieved through other means if the product is to be incorporated into integrated pest management programs where this predator is important.

INTRODUCTION

Bacillus thuringiensis has been studied intensively during the last 20 years because of its promise for the biological control of insects (Faust and Bulla 1982, Miller et al. 1983). This organism is produced by several companies and is registered for use on a variety of crops. Seven different toxins have been described from *B. thuringiensis*, including a thermostabile exotoxin known as beta-exotoxin or thuringiensin (Faust and Bulla 1982, Sebesta et al. 1981, Vankova 1978). The beta-exotoxin is heat stable, secreted to the outside of the bacterial cell into the culture medium during the active phase of vegetative growth, water soluble and dialyzable, absorbent at 260 mu, and nucleotidelike in structure (Faust and Bulla 1982). Thuringiensin is known to inhibit the terminal stages of RNA biosynthesis (Sebesta et al. 1981). Thuringiensin kills insects in the orders Lepidoptera, Diptera, Coleoptera, Hymenoptera (including honeybees), Isoptera and Orthroptera. It is active mainly against larvae and the effects vary greatly with dose, mode and time of application. Toxicity is most marked during physiologically critical developmental stages such as molting, pupation, or metamorphosis. Adult insects may be infertile or have reduced fecundity and longevity (Sebesta et al. 1981). Thuringiensin is not a contact poison, and must be ingested to be effective.

The effect of thuringiensin on acarines is less well known. Krieg (1968) demonstrated the effectiveness of a supernatant of a beta-exotoxin-positive strain of *B. thuringiensis* on active stages of *Tetranychus telarius* (L). Hall et al. (1971) showed the beta-exotoxin, which was isolated from *B. thuringiensis*, was highly toxic to adults and immatures of the citrus red mite, *Panonychus citri* (McGregor), and suggested it was also highly effective against the two-spotted spider mite, *Tetranychus urticae* Koch, and the Pacific spider mite, *T.pacificus* McGregor. Grebelski et al. (1972) reported Bitoxibacilin, a thuringiensin-containing preparation, varied in its toxicity to ixodid ticks, depending on whether it was used before or after blood meals. No information is available on the toxicity of

thuringiensin to predatory mites in the family Phytoseiidae.

The control of spider mites by chemicals alone often leads to the rapid development of resistance. Integrated mite management programs, utilizing predatory mites (Phytoseiidae) and selective acaricides offer several benefits to the pest management specialist and grower: 1) the onset of acaricide resistance in spider mite species is delayed because control exerted by predatory mites reduces selection pressure exerted by acaricides (Tabashnik in press), and 2) selective acaricides can often be applied less often and at lower rates, which also reduces selection pressure and can delay the onset of resistance as well as reducing costs to the grower (Headley and Hoy 1986). Therefore, we investigated the toxicity of thuringiensin to the western predatory mite, Metaseiulus occidentalis (Nesbitt), which is a key predator of spider mites in the western U.S.A. in deciduous orchards and vineyards (Huffaker et al. 1970, Flaherty and Huffaker 1970, Hoy et al. 1985). The Pacific spider mite, Tetranychus pacificus, was also tested to obtain comparative toxicities.

MATERIALS AND METHODS

Pesticide Thuringiensin (beta-exotoxin of B.thuringiensis) was obtained from Abbott Laboratories (ABG-6162) as an EC formulation, 1.5% a.i./w/w. Test solutions were prepared daily using distilled water. The field rate was assumed to be 20 g.a.i./100 gallons of water (5.28 g. a.i./100 liters water). Other rates tested were 0.125, 0.25, 0.5, 2, and 4 X the proposed field rates.

Test Colonies The colony of M.occidentalis tested is resistant to sulfur, carbaryl and organophosphorus pesticides (Hoy 1984). The T. pacificus colony was collected from almond orchards in Kern County, California in June 1984 and reared on bean plants (Phaseolus vulgaris L.) in the greenhouse. It is resistant to cyhexatin (Plictran) (Hoy and Conley, unpubl. information).

Adult females Gravid M.occidentalis females were placed, 10 per leaf, on five intact bean leaves for each dose. Each leaf received

a surplus of T.urticae as prey before being sprayed with 0, 0.125, 0.25, 0.5, 1, 2 and 4 X the proposed field rate of thuringiensin. Gravid T.pacificus females were tested in a similar way but no T.urticae were added. The undersurface of the bean leaves containing the mites were sprayed to drip using a Crown Spray-Tool^{R} in one tray and then moved to a clean tray containing water-soaked cotton. The intact leaf was placed bottom side up with the petiole inserted into the moist cotton. Females were held at 26 $\pm$ 2 ^{0}C and 57 $\pm$ 8 % relative humidity under continuous light. When eggs and larvae were tested, they were also held under these conditions. Survival was recorded after 24, 48, and 96 hrs. Fecundity was assessed by counting the number of eggs on each leaf after 48 hours. Comparisons of the survival of T.pacificus and M.occidentalis females at each rate of thuringiensin were made using a t-test. Fecundity was analyzed using ANOVA and Duncan's multiple range test.

Larvae Newly-hatched larvae of T.pacificus and M.occidentalis were placed, 10 per leaf, on the undersurface of five intact bean leaves. T.urticae were added to leaves containing the predators and both predators and prey were sprayed with thuringiensin, using 0, 0.125, 0.25, 0.5, 1, 2, and 4 X the field rate. Survival and runoff were assessed 24, 48, 72, 96, 120, and 144 hrs after treatment. The number of nymphs, individuals molting, and adults were counted. Differences in survival of T.pacificus and M.occidentalis at each rate of thurienginsin were compared by t-test.

Eggs Adult females of T.pacificus and M.occidentalis were placed on intact bean leaves, allowed to deposit eggs for 24 hrs, and removed. The number of eggs were then adjusted to consist of 20 per leaf on 2 leaves for each rate of thuringiensin tested. All stages of T.urticae were added to the leaves containing M.occidentalis and the mites and leaves were then sprayed with 0, 0.125, 0.5, and 2 X the field rate of thuringiensin. Egg hatch and development to adulthood were assessed after 48, 72, 96, 120, 144, and 196 hrs by recording the number of eggs, larvae, nymphs, adults

and individuals in the process of molting. Comparisons of the survival of T.pacificus and M.occidentalis at each thuringiensin rate were made using a t-test.

RESULTS

Survival and fecundity of females

M.occidentalis females survived thuringiensin treatments significantly better than T.pacificus females (Figure 1). Significant differences were found after 48 hr on residues of 0.25, 1, 2, and 4X the field rate, and on residues 0.25 and 1X the field rate after 96 hrs. However, these differences in mortality are not sufficiently great that field rates of thuringiensin will be selective for M.occidentalis. Thus, field rates will induce both direct mortality (only 20 % of M.occidentalis females survived after 96 hr at the field rate) and indirect mortality because this predator is dependent upon prey. At the field rate, only 4% of the T.pacificus females survived (Figure 1).

Egg production by T.pacificus and M.occidentalis females exposed to all rates of thuringiensin decreased significantly compared to the controls. For T. pacificus, ten females produced an average of 71.8 eggs per leaf within 48 hrs on the water controls, whereas only 35.2, 31.4, 19.0, 5.2, 1.8, and 0 eggs per leaf were produced by on leaves treated with 0.125, 0.25, 0.5, 1, 2, and 4 X the field rate. Egg production at the field rate, and higher, was significantly reduced in T.pacificus compared to the 0.125 and 0.25 X rate. Likewise, egg production by M. occidentalis was reduced from an average of 20.2 eggs per leaf after 48 hrs on the control leaves to 5.2, 8.0, 5.8, 4.0, 2.2, and 3.0 eggs per leaf, respectively, for females on leaves sprayed with thuringiensin. Egg production at the three highest rates was different from the 0.25 X rate and overlapped with the 0.125 and 0.5 X rate. In general, it appeared that M.occidentalis females deposited the eggs they contained, and then discontinued egg deposition after treatment.

Survival of Larvae

Survival of M.occidentalis and T.pacificus treated as larvae

at all rates was nil after 144 hrs. A few T.pacificus larvae were able to molt to the nymphal stage at the lower rates (0.125, 0.25 X field rate) but none successfully developed to adults. Survival after 48 and 96 hr is shown in Figure 2. Some larvae of M.occidentalis were able to become nymphs at all rates tested (Figure 2), but none became adults. Development rate of M.occidentalis may be influenced by thuringiensin, as well; 86% of the control predators became nymphs within 48 hrs, while only 32% of the thuringiensin-treated predators had molted to nymphs at the lowest rate tested. The influence of thuringiensin on development rate is difficult to interpret, however, because mortality and development rate are not independent.

Survival of Eggs

Eggs of M.occidentalis and T. pacificus were sprayed with 0.125, 0.5, and 2 X the field rate of thuringiensin. Nearly all eggs hatched, but development of larvae to the protonymphal stage was affected, particularly at the 2X dose (Figure 3). Those few that developed to protonymphs did not develop successfully to deutonymphs or adults at any of the doses tested. Thus, even though hatch required several days, and was successful, larvae of both species were unable to develop successfully. Because thuringiensin must be ingested to be toxic (P. Grau, personal communication), the predators most likely obtain a toxic dose by feeding on treated prey.

DISCUSSION

Thuringiensin is effective against adults and active immature stages of T. pacificus, although it reduces egg hatch only slightly at the rates tested. It is less toxic to active stages of M.occidentalis than to T.pacificus, but at the rates tested thuringiensin is still sufficiently toxic that it would probably be difficult to use it in a selective manner in the field unless rates substantially lower than these were used. Thuringiensin would cause both direct and indirect mortality of M.occidentalis. Indirect mortality could occur because the loss of prey needed by this obligatory predator would result in death, or dispersal, of the predators from the site. Laboratory-derived toxicity data are useful predictors of relative field toxicities. They can't be directly translated into absolute predictions of field toxicities. Therefore, field trials are still needed, using lower rates of thuringiensin, to determine whether this acaricide can be used selectively with M.occidentalis under field conditions.

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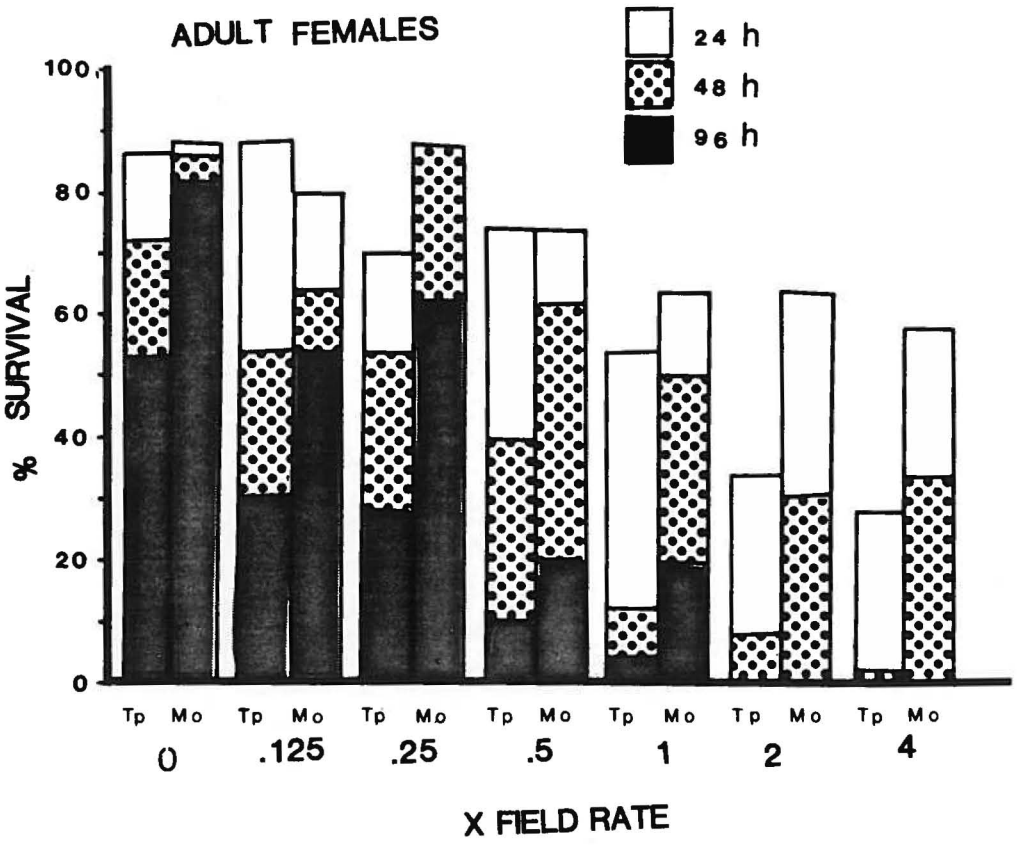
Figure Legends

Figure 1. Toxicity of thuringiensin applied to females of M.occidentalis and T.pacificus after placement on intact bean leaves. Mortality was assessed after 24, 48 and 96 hrs at 27^0 C under continuous light.

Figure 2. Survival and development of larvae of M.occidentalis and T.pacificus after 48 (A) and 96 hrs (B) on bean leaves sprayed with thuringiensin.

Figure 3. Hatch of eggs and development of immatures of M.occidentalis and T.pacificus. Survival and mortality were assessed after 48, 72, 96, 120, 144 and 196 hrs for controls (A), 0.125 X (B), 0.5 X (C), and 2 X the field rate (D) of thuringiensin.

Figure 1.


ADULT FEMALES
24 h
48 h
96 h
% SURVIVAL
100
80
60
40
20
0
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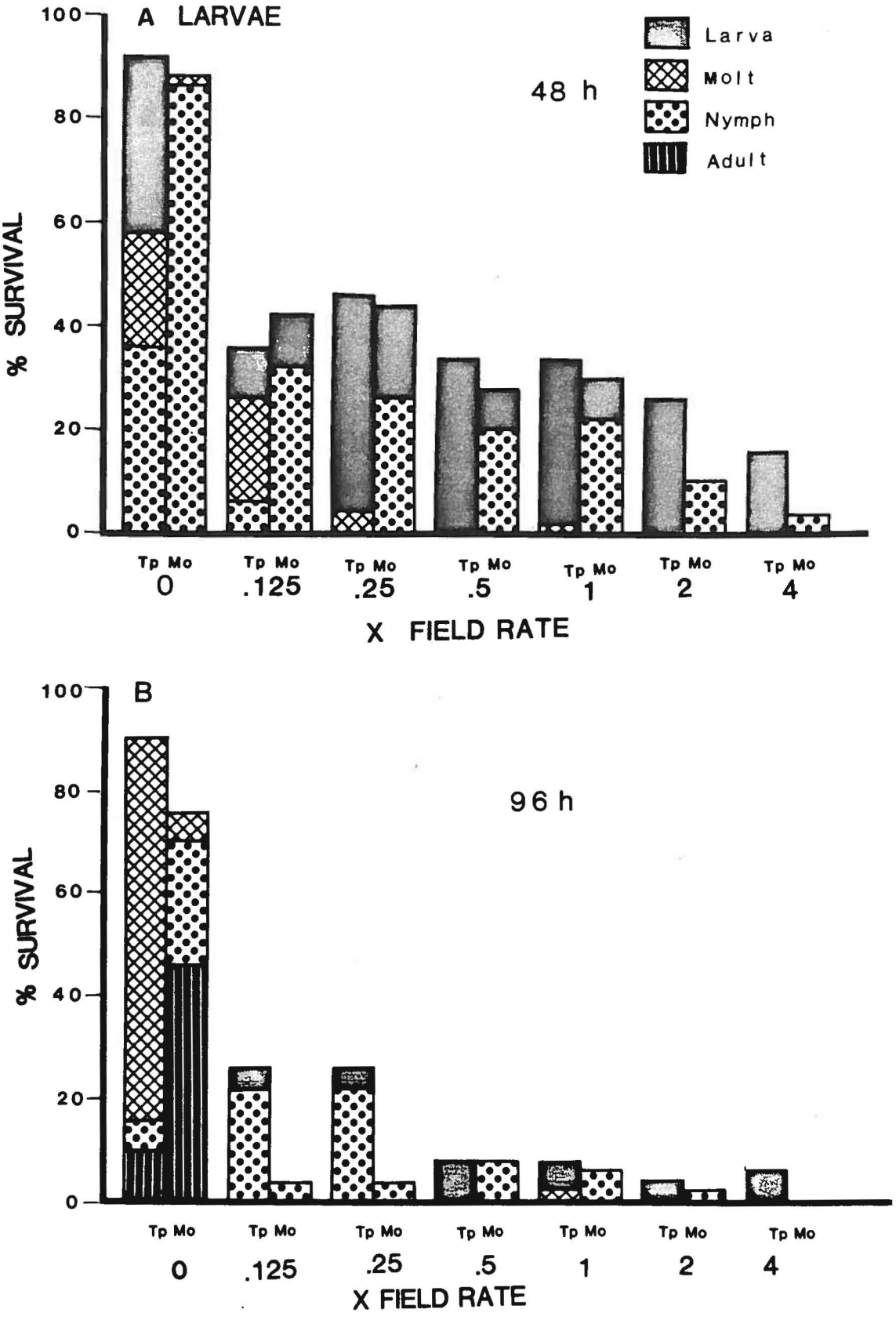
0 .125 .25 .5 1 2 4
X FIELD RATE

Figure 2


A LARVAE
48 h
Larva
Molt
Nymph
Adult
% SURVIVAL
100
80
60
40
20
0
Tp Mo 0
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Tp Mo .25
Tp Mo .5
Tp Mo 1
Tp Mo 2
Tp Mo 4
X FIELD RATE
B
96 h
% SURVIVAL
100
80
60
40
20
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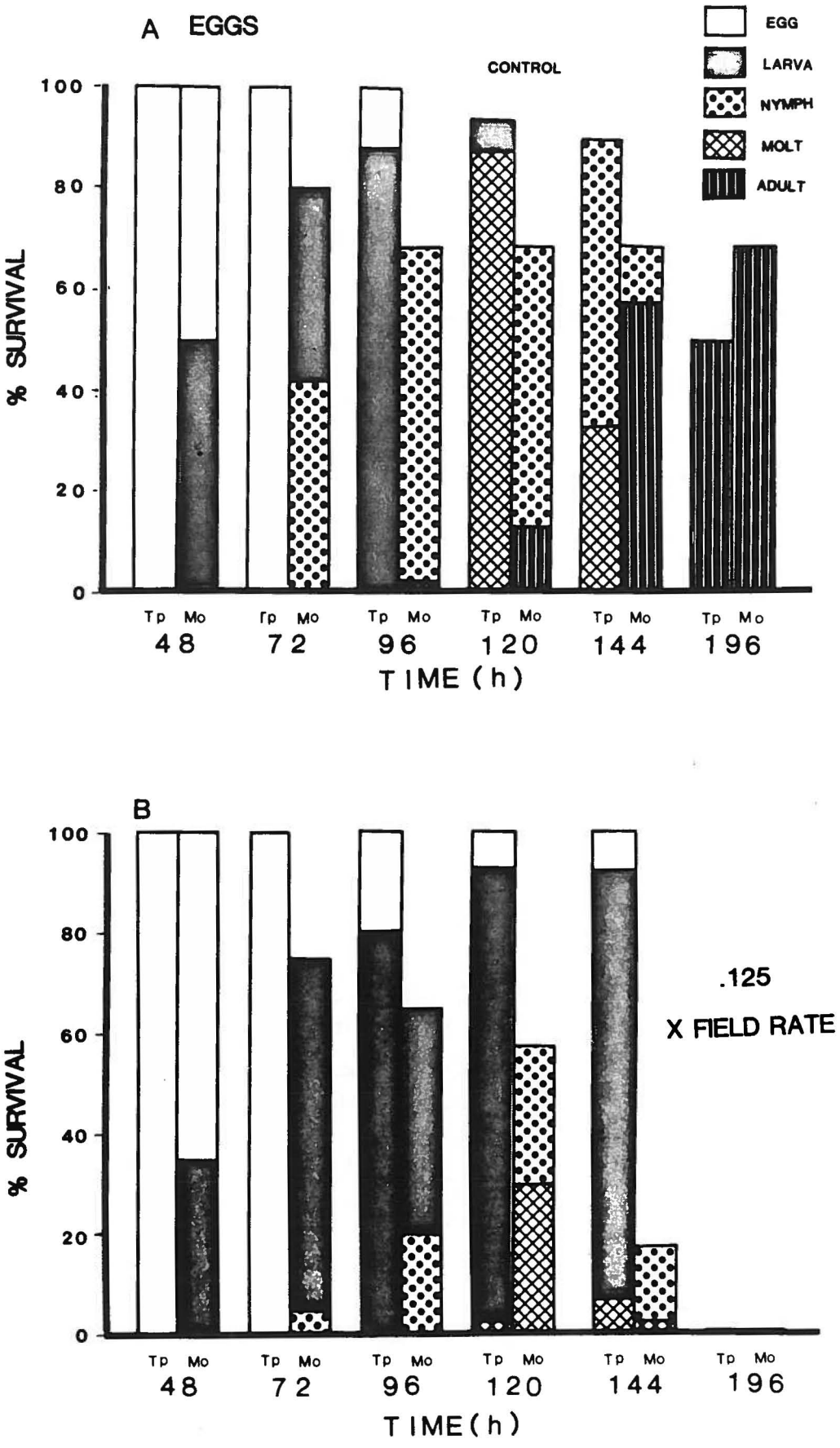
Tp Mo 0
Tp Mo .125
Tp Mo .25
Tp Mo .5
Tp Mo 1
Tp Mo 2
Tp Mo 4
X FIELD RATE

Figure 3


A EGGS
CONTROL
EGG
LARVA
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MOLT
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% SURVIVAL
100
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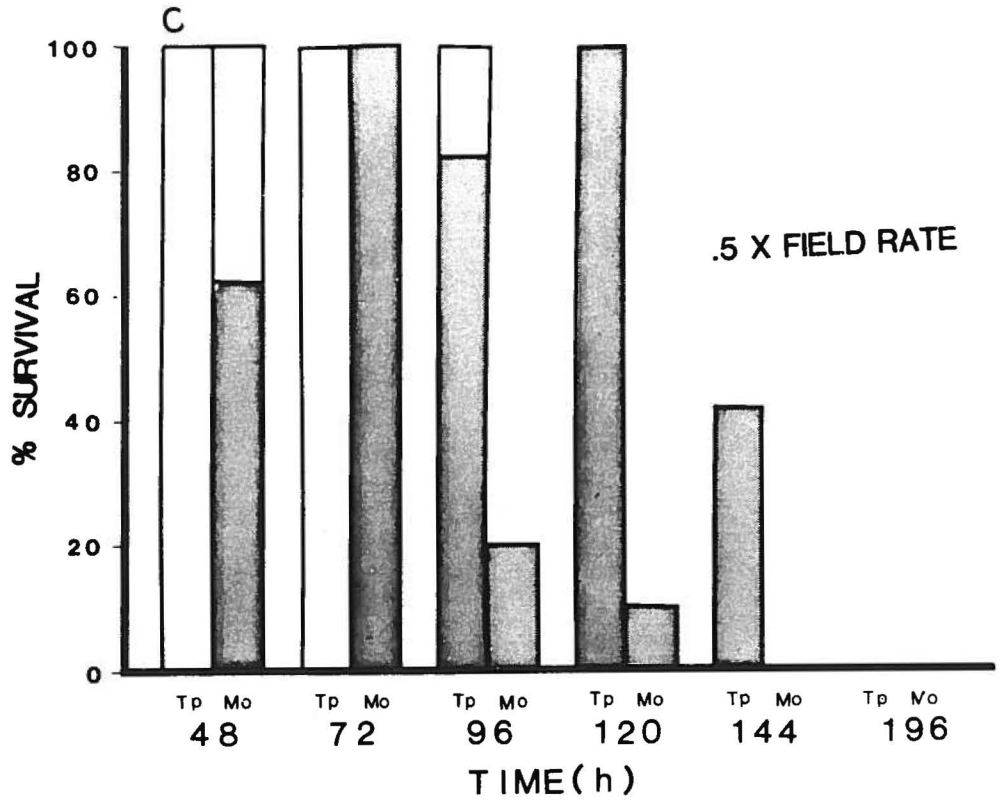
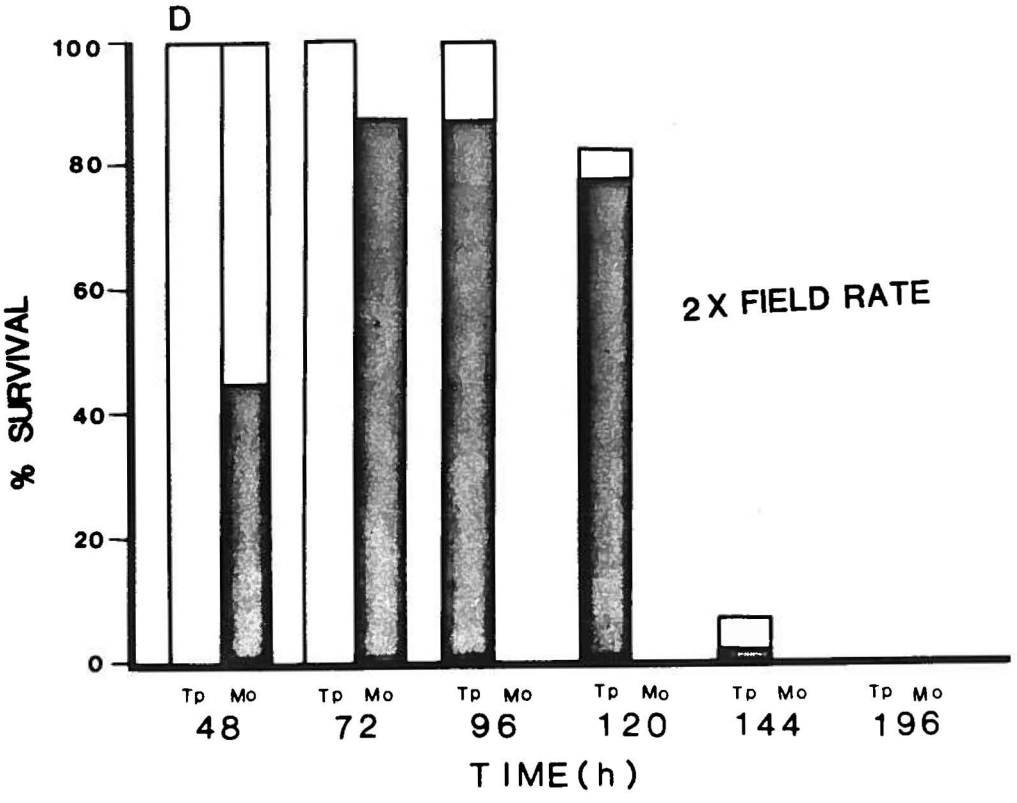
72
96
120
144
196
TIME (h)
B
.125
X FIELD RATE
% SURVIVAL
TIME(h)


C
100
80
60
40
20
0
% SURVIVAL
.5 X FIELD RATE
Tp Mo
48
72
96
120
144
196
TIME(h)


D
100
80
60
40
20
0
% SURVIVAL
2X FIELD RATE
Tp Mo
48
72
96
120
144
196
TIME(h)

Hoy 1985 Almond Board Annual Report

IV. Survey for Omite and Plictran Resistances in Pacific Spider Mites in Kern County and in Two-Spotted Spider Mites in Stanislaus--San Joaquin Counties during 1985

Kern County

During June 1985, we collected Pacific spider mites from Kern County in order to determine whether Omite and Plictran resistances are widespread. During 1984, we had looked at limited numbers of colonies of Pacific mite from Kern County, and the high LC_{50} values reported for those colonies could have been unique. We wanted to determine how widespread any potential resistance is. The survey was conducted by sampling from almond orchards near crossroads in Kern County in June 1985. No treatment history is available from the majority of the orchards. We simply stopped at orchards, examined them for spider mites and collected colonies for testing. Some orchards examined on that collecting trip had too few mites to initiate a colony. Colonies were initiated and reared on bean plants in the greenhouse until sufficient numbers of young females were available to conduct tests with a single dose of Plictran (3 lbs. 50WP/100 gallons water) and Omite (1.5 lbs. 30WP/100 gallons water). One hundred females were tested with each pesticide using the slide dip method. Females were held for 48 hrs at 27°C. The results are shown in Tables IV-1 and IV-2. Since the tests could not be conducted on a single date, control colonies (considered susceptible and resistant, respectively, to Omite and Plictran) were tested each time.

All colonies collected from Kern County and tested with Omite gave high rates of survival with the test dose, with % survival ranging from 30-54%, averaging 45%. The susceptible control colony collected from Glenn County in 1984 had survival rates ranging from 9-33% (Table IV-1). The resistant control colony's survival ranged from 43-58%. All Kern County colonies thus appear to have an increased ability to survive 1.5 lb. 30WP Omite/100 gallons water.

Table IV-1. Survival of T. pacificus females 48 hours after being treated with 1.5 lb. 30 WP Omite/100 gallons water.

	% survival of			
Colony source	Test colony	Resist. control	Susc. control	H_2O control of test colony
Kern Co.Hwy 5/Lerdo Hwy	42	43	9	90
Kern Co.Hwy 43/Hwy 58	41	49	24	90
Kern Co.Hwy 58/Heath Rd.	50	43	9	85
Kern Co.Beach Ave/Orange Ave	30	43	9	75
Kern Co.Merced Ave/Poplar Ave	52	49	24	90
Kern Co.Annin Ave/McCombs Ave	40	43	9	100
Kern Co.Whistler Rd/Wasco Pond Rd.	44	49	24	95
Kern Co.Whistler Rd/Mast Rd.	52	49	24	90
Kern Co.Browning Rd/Hwy 155	48	49	24	90
Kern Co.Whistler Rd/Hwy 99	54	58	33	95
Stanislaus Co.Hammett Rd/ Ciccarelli Rd.	22	30	3	85

Table IV-2. Survival of T. pacificus females 48 hours after being treated with 3 lb. 50 WP Plictran/100 gallons water.

	% survival of			
Colony source	Test colony	Resist. control	Susc. control	H_2O control of test colony
Kern Co.Hwy 5/Lerdo Hwy	52	64	28	95
Kern Co.Hwy43/Hwy 58	41	39	12	90
Kern Co.Hwy 58/ Heath Rd.	42	64	28	95
Kern Co.Beach Ave/Orange Ave	46	64	28	95
Kern Co.Merced Ave/Poplar Ave	66	64	28	95
Kern Co.Annin Ave/McCombs Ave	43	64	28	90
Kern Co.Whistler Rd/Wasco Pond Rd.	32	39	12	90
Kern Co.Whistler Rd/Mast Rd.	45	39	12	90
Kern Co.Browning Rd/Hwy 155	39	39	12	85
Kern Co.Whistler Rd/Hwy 99	32	48	14	95
Stanislaus Co.Hammett Rd/ Ciccarelli Rd.	29	48	14	90

Table IV-3. Dose response data for composite "Bakersfield" T. pacificus colony treated with Omite compared to susceptible (Chapla) and resistant (Bidart) colonies.

Colony and source	LC_{50} lbs 30 WP Omite/100 gal.	95% C.I.	LC_{90}	95% C.I.	Slope
Chapla almonds, Glenn County	.599	.505-.679	1.126	.998-1.316	4.67±.58
Bidart almonds Kern County	.906	.626-1.129	3.824	2.584-9.797	2.05±.46
Bakersfield colony Kern Co.	1.007	.779-1.228	3.747	2.592-8.324	2.25±.45

The same colonies were screened with 3 lb 50WP Plictran/100 gallons water, and again survival was generally close to that of the resistant control colony, ranging from 32-66% survival, averaging 41% survival. Resistant controls' survival ranged from 39-64% and susceptible controls' survival ranged from 12-28% (Table IV-2). The colony from Stanislaus County had a low survival rate of 29%.

The 10 Pacific mite colonies were then pooled, reared for several generations, and tested with Omite and Plictran to provide dose response data. As comparisons, a susceptible colony (Chapla, collected in 1984 from almonds in the Chico area), and a resistant colony (Bidart almonds, collected in Kern County in 1984) were also tested for comparison. The Omite LC_{50} values for the Chapla, Bidart, and pooled Bakersfield colonies are, 0.599, 0.906, and 1.007, respectively. The Chapla colony's dose response is statistically different than that of the Bidart and Bakersfield colonies, based on analysis by the POLO program. There is no significant difference in LC_{50} and LC_{90} values for the Bidart and Bakersfield colonies (Table IV-3).

The dose responses for Plictran are reported in Table IV-4. LC_{50} values for the Chapla, pooled Bakersfield colony collected in 1985, and the Bidart colonies are: 1.16, 2.59, and 2.67. The LC_{90} data are: 2.43, 11.39, and 5.86, respectively (Table IV-4). The dose response of the pooled Bakersfield colony is different than the Bidart colony (which was collected in 1984), and the higher LC_{90} value is noteworthy. It suggests that Plictran resistance has increased. Furthermore, it is clear that it is widespread in the Kern County area.

Stanislaus-San Joaquin Counties

The two-spotted spider mite (T.urticae) was collected from 7 sites in the Stockton-Modesto area in April 1985 and screened

Table IV-4. Dose response data for composite "Bakersfield" T. pacificus colony treated with Plictran compared to susceptible (Chapla) and resistant (Bidart) colonies.

Colony and Source	LC_{50} lbs 50 WP Plictran/100 gal	95% C.I.	LC_{90}	95% C.I.	Slope
Chapla almonds, Chico-Durham area (susceptible)	1.16	0.82-1.40	2.43	2.06-3.06	3.98
"Bakersfield" colony collected from __ almond orchards in Kern Co. in 1985	2.59	1.76-3.73	11.39	6.61-46.67	1.99
Bidart almonds Kern Co., collected in 1984	2.67	1.94-3.20	5.86	4.60-10.86	3.76

Data analysed by logit analysis using the POLO program.

with 1.5 lb. 30WP Omite/100 gallons and with 2 lbs 50WP Plictran/100 gallons using a slide dip technique. A susceptible T.urticae control colony and a resistant T.pacificus colony were tested each time, as well to serve as comparisons. T.urticae appears quite susceptible to Omite (Table IV-5). Little variability was observed in the responses of the colonies. (NOTE: We used T.pacificus as a resistant control colony because we had no T.urticae colony that was resistant to Omite.)

The results of screening T.urticae with Plictran are shown in Table IV-6. Survival of test colonies ranged from 12 to 41%. The resistant colony exhibited 47% survival and the susceptible control had 32% survival. In this case, both control colonies were T.urticae. In general the collected colonies were more susceptible to Plictran than our previously-collected susceptible colony. Only the first colony listed (Bluegum Avenue/Clark Rd.) appears close to the most tolerant control colony. Again, T.urticae from this area appears amenable to control by Plictran.

Table IV-5. Survival of T. urticae females 48 hours after being treated with 1.5 lb. 30 WP Omite/100 gallons water.

	% survival of			
Colony source	Test colony	Resist. control	Susc. control	H_2O control of test colony
Stanislaus co. Bluegum Ave/ Clark Rd.	3	30	3	90
Stanislaus Co.Rossmore Ave/ Hwy 132	8	30	3	87.5
Stanislaus Co.North Ave/ Dakota Ave	5	30	3	92.5
Stanislaus Co.Hammett Rd/ Ciccarelli Rd.	7	30	3	92.5
Stanislaus Co.Dakota Ave/ Bluegum Ave	8	30	3	87.5
Stanislaus Co.Beckwith Rd/ Standiford Rd.	7	30	3	95
San Joaquin Co.Manteca Rd/ Woodward Ave	6	30	3	90

Table IV-6. Survival of T. urticae females 48 hours after being treated with 2.0 lb. 50 WP Plictran/100 gallons water.

	% survival of			
Colony Source	Test colony	Resist. control	Susc. control	H_2O control of test colony
Stanislaus Co. Bluegum Av/ Clark Rd.	41	47	32	87.5
Stanislaus Co. Rossmore Av/ Hwy 132	26	47	32	87.5
Stanislaus Co. North Av/ Dakota Av.	26	47	32	90
Stanislaus Co. Hammett Rd/ Cicarelli Rd.	12	47	32	87.5
Stanislaus Co. Dakota Av/ Bluegum Av.	29	47	32	87.5
Stanislaus Co. Beckwith Rd/ Standiford Rd.	21	47	32	87.5
San Joaquin Co. Manteca Rd/ Woodward Av.	20	47	32	87.5

Conclusions

The two-spotted spider mite colonies (and the single Pacific mite colony) collected from the Stockton-Modesto area appear to be susceptible to both Omite and Plictran. This may be related to the fact that acaricide applications are lower in this area, in general, than they are in the Kern County region.

The Pacific mite colonies collected from Kern County give fairly consistent responses to both Omite and Plictran. All colonies resemble our "resistant" lab strains, and one colony (Whistler Rd./Hwy 99)) was provided by Dan Cahn and Darryl Castro from a site where a reported control failure occurred in the field. According to a conversation with them later, control was achieved when coverage was improved by slowing down the spray rig, adjusting the nozzles, etc. However, whether the explanation of better coverage leading to adequate control is sufficient is open to debate. By the time control was achieved, three applications of material had been applied, and thus residues from three applications had accumulated.

What does this data mean for the use of low rates of acaricides in the integrated mite management program? The integrated mite management program is predicated on 1) monitoring of predators and spider mites in order to adjust the predator-prey ratio. 2) Use of low rates to suppress the spider mites by ca. 50%, and 3) intervention early so that the predators have time to respond. It is my opinion that Omite and Plictran can still be used in the integrated mite management program if the above items are truly followed. First the orchards must be monitored. Secondly, M.occidentalis must be present and well distributed in the orchard. (Other generalist predators and other phytoseiid species were not considered in developing the integrated mite management program. Therefore, the grower or PCA should be sure of their identifications.)

These low rates of acaricides, if applied early, and properly, will still suppress spider mites. The key words are early and properly. In discussions with D. Cahn and D. Castro, they indicated that control was achieved by: making sure the applications went on early, adjusting the driving speed through the orchard (SLOW DOWN), increasing water volume and properly adjusting spray nozzles, and spraying on a non-windy day.

Omite and Plictran, in my opinion, will have a limited life if the integrated mite management program is NOT adopted. (It is also limited, although to a lesser degree, even if everyone adopts the integrated mite management program.) Relying on multiple applications using high rates of material will hasten the onset of high levels of resistance. Tank mixes are unlikely to provide much time, if any, because both Omite and Plictran resistances are present in Pacific mite populations. Likewise, alternation of materials will help, but only if the total numbers of applications and rates applied are reduced.

It is impossible to predict how long these materials will be useful. Studies now underway to understand mode of inheritance, fitness of the resistance allele(s) etc. will be important components in understanding the development of resistance.

V. Selecting for Omite and Plictran Resistances in T.pacificus

Bidart T.pacificus Colony

The Bidart T.pacificus colony was collected on June 27 1984 near Bakersfield. In 1984, it had an LC_{50} value of 0.753 (.632-852) lbs 30WP Omite/100 gallons water and an LC_{90} value of 1.582 (1.336-2.134), as determined by slide dip analysis. This was the highest dose response of any of the mite colonies tested with Omite during 1984. The same colony was also tested with Plictran using a slide dip, and the LC_{50} value was 2.669 (1.895-3.124) lbs 50 WP Plictran/100 gallons water; the LC_{90} was 3.958 (3.346-6.774) lbs 50WP/100 gallons. Numbers in parentheses are the 95% confidence limits, as calculated by POLO.

Thus, the Bidart colony had elevated dose responses for both Omite and Plictran compared to susceptible control colonies. This Bidart colony was then selected 3 times in the laboratory during March-May 1985, using 1 lb 30 WP Omite/100 gallons water (Table V-1). Survival after 48 hrs on bean leaves sprayed with Omite increased from 47% to 67% , suggesting selection had increased the resistance level. On July 1, a slide dip analysis was done of the selected (Bidart-3) colony and the Bidart base colony using 1.5 lb 30WP Omite/100 gallons water. Survival of 100 females of the selected colony (Bidart-3) was 34%, while survival of 100 females of the base colony was 45%. This test suggests that survival had not increased after 3 selections in the laboratory.We concluded that selection might be more effective if carried out in the greenhouse where sprays could be applied to bean plants so that all spider mite stages were exposed to Omite residues over their life span. Thus, the next 8 selections (selections 4-11, Table V-1) were carried out in the greenhouse using 0.1 to 1 lb 30WP Omite/100 gallons applied to flats of bean plants. Survival after each spray was estimated by determining the number of adult females alive on the bean leaves after one week (Table V-1). Then, on October 23,

a slide dip analysis was conducted using the Bidart base colony and the Bidart-11 selected colony. One hundred females were tested from each, and mortality assessed after 48 hrs; survival was not different. For the base colony, 37% of females survived and for the Bidart-11 colony, 38% survived. This suggests that the response to selection with Omite has plateaued. Mode of inheritance tests and a complete dose response test will be conducted soon.

Plictran Resistance in the Wasco T.pacificus Colony

The Wasco T.pacificus colony was collected at 46th and Palm June 27, 1984. A slide dip analysis in 1984 yielded a Plictran LC_{50} value of 3.05 lb 50WP/100 gallons water. A confidence limit was not calculated due to variability. The LC_{90} value was 7.09 (ditto for the confidence limit). This was the highest dose response to Plictran of the spider mite colonies tested in 1984.

This colony was then selected with Plictran 3 times in the laboratory (Table V-2) using 4 lb 50WP Plictran/100 gallons. Survival did not appear to increase.

The selection was continued in the greenhouse, where bean flats with the colony were sprayed periodically, using 0.2 to 3 lb 50WP Plictran/100 gallons. Survival did appear to increase with increasing doses of Plictran (Table V-2). On October 23, a slide dip was conducted using 100 females at a single dose (3 lb 50 WP Plictran/100 gallons). Survival of the Wasco-12 colony was 49% compared to 33% for the Wasco base colony. Selection will continue; a preliminary mode of inheritance test will be conducted, analyses of cross resistances will be made, and stability of the resistance and fitness attributes of the resistant strain will be evaluated as soon as possible.

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

Date selected and method 1985	Selection no.	Dose lbs 30 WP/100 gal.	% survival-48 hr. selected colony	% survival-48 hr. base colony
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
Greenhouse Spray - Bean flats				
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

*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%.

Table V-2. Selection for Plictran resistance using the Wasco colony of T. pacificus.

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

*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 $\leq$ 30%.

VII. Evaluation of Rovral and Asana as Selective Pesticides for M.occidentalis

Rovral is a broad spectrum fungicide being registered for use in almonds. Asana is a pyrethroid insecticide being evaluated for use in almonds. We conducted comparative toxicity tests with these pesticides to determine if they are toxic to the predator, M.occidentalis.

Effect of Rovral on T.pacificus and M.occidentalis

Rovral (iprodione) is a broad spectrum, contact fungicide, with action on both the spores and mycelium and is effective against brown rot blossom blight (Monilinia laxa) and shothole (Stigmina carpophila). The label recommends that Rovral be applied as an overall spray to obtain thorough coverage of bloom and foliage, using at least 0.25 lbs. Rovral/100 gallon, and a standard of 400 gallons per acre. Because this material is being registered for use in almonds, we tested it for toxicity to the predatory mite Metaseiulus occidentalis and the Pacific spider mite Tetranychus pacificus to determine toxicity to adult females of both species, as well as its impact on egg production by treated females. In addition, hatch success of eggs deposited by treated females was assessed.

Rovral (50 WP) was mixed fresh each test date using 6 test doses. The field rate of Rovral is assumed to be 0.3 g Rovral (50 WP)/liter water. Rates tested were 0, 0.125, 0.25, 0.5, 1 and 5 X the field rate. Five adult females were placed on each bean leaf disc, 10 discs/dose, and sprayed using a Crown Spra-Tool. Mortality and egg production were recorded after 48 and 96 hrs at 25-27^{o}C under continuous light. Eggs were removed as they were counted to increase accuracy. Successful egg hatch of eggs deposited by treated females was assessed by moving 5 eggs/disc to clean bean leaf discs (M.occidentalis) or by circling with black india ink eggs of T.pacificus and scoring them after 72-96 hr (M.occidentalis) or 96-120 hr (T.pacificus). The carbaryl-OP-sulfur resistant strain of M.occidentalis was tested and the Wasco colony of T.pacificus, which is tolerant of Plictran, was tested.

Rovral was not toxic to adult females of M.occidentalis or T.pacificus (Table 1). Egg production also was not altered on leaf discs sprayed with 0.125 to 5 X the field rate (Tabele 2). Finally, egg hatch of T.pacificus and M.occidentalis eggs was normal (Table 3). Thus, we have no evidence that Rovral is acaricidal to

either the Pacific spider mite or M.occidentalis. This suggests that Rovral will fit very nicely into an integrated pest management program for almonds.

Table 1. Survival of T. pacificus and M. occidentalis 48 h and 96 h after being sprayed with Rovral.

Dose x field rate	% survival after 48 h		% survival after 96 h	
	T. pacificus	M. occidentalis	T. pacificus	M. occidentalis
5	96	98	78	92
1	84	92	62	90
0.5	96	96	76	88
0.25	86	100	68	98
0.125	100	98	76	96
H_2O	98	100	84	98

Table 2. Rate of egg deposition by T. pacificus and M. occidentalis females sprayed with Rovral (Iprodione)

Species and doses tested (x field rate)	Mean eggs per disc per 5 females within 96 hrs (± S.D.)
T. pacificus	
0	101.9 (13.2)[1/]
0.125	116.5 (16.4)
0.25	96.1 (16.6)
0.5	105.0 (21.4)
1	104.3 (23.7)
2	118.1 (23.5)
M. occidentalis	
0	51.7 (4.4)[2/]
0.125	52.1 (6.5)
0.25	48.6 (3.4)
0.5	47.0 (7.3)
1	53.4 (8.2)
2	51.0 (3.9)

1/ No significant differences among means, ANOVA, $F^{s}_{54} = 1.939$, $P = 0.101$.

2/ No significant differences among means, ANOVA, $F^{s}_{54} = 1.631$, $P = 0.166$.

Table 3. Hatch of eggs deposited by females of T. pacificus and M. occidentalis after being sprayed with Rovral.

Rate tested x field rate*	% hatch of eggs deposited by females of	
	T. pacificus	M. occidentalis
5	88	96
1	92	86
0.5	92	94
0.25	90	86
0.125	90	94
H_2O	92	88

* field rate = 0.3 g 50 W/W Rovral/liter.

Toxicity of Asana (TM) HP Insecticide E (MO 70616) to
M.occidentalis and T.pacificus

Asana is a new insecticide for possible use in almonds. It is "quite closely related to PYDRIN Insecticide, but is used at only ¼ the ai/acre rate that you have used PYDRIN or permethrin in the past" (personal communication, Will Crites). Dosage rates for almonds...."would be in the range of 0.05-0.1 lb ai ASANA/acre..."

We tested adult females of 3 colonies of M.occidentalis and one colony of T. pacificus. Predator colonies tested included: Immature Selection #39, a colony selected for permethrin resistance which is polygenically determined; Block-11 Base colony, collected from an apple orchard in Washington with a moderate pyrethroid resistance level (which is probably different than that found in the Immature Selection colony); Block 11-3, which had been selected 3 times with permethrin for enhanced pyrethroid resistance. The Pacific mite colony was collected from Wasco, California from an almond orchard and is resistant to Plictran. Doses tested were 0, 0.25, 0.5, and 1 X the field rate (0.05 lb ai/acre, assuming 400 gallons applied/acre). Fifty adult females, 5/disc, were placed on bean leaf discs and sprayed with each dose tested. Survival was scored after 48 hrs at 25-27°C under continuous light. Females were scored as "alive" if they responded by moving an appendage after touching them with a fine camel's hair brush; they need not have been walking.

ASANA at the field rate is highly toxic to the Immature Selection #39 colony (survival = 2%), Block-11 Base colony (survival at 1 X = 0%; Block 11-3 Selected (survival at 1 X = 4%). However, it was not toxic to the T.pacificus colony tested, with survival averaging 72% at 1 X the field rate. At 0.5 and 0.25 X the field rate, substantial numbers of permethrin-resistant M.occidentalis survived. I don't know how the native strains of M.occidentalis would do at these rates, but it is probable that Asana would be highly

toxic to them.

It seems unlikely that ASANA can be selective to native populations of M.occidentalis, as the three colonies of M.occidentalis tested are moderately resistant to permethrin yet are seriously affected by this product at the field rate. Unless a higher level of resistance to this pyrethroid can be achieved, ASANA is likely to be disruptive to biological control of spider mites by M.occidentalis in California almond orchards.

Table 1. Effect of Asana[R] sprayed on 3 colonies of M. occidentalis and one colony of T. pacificus.

Doses x field rate	% survival of adult females			
	Imm.Sel.#35[1/]	Block-11 Base[1/]	Block-11-3[1/]	T. pacificus
0	92	94	88	96
0.25	50	24	58	80
0.5	22	2	40	80
1	2	0	4	72

1/ 50 ♀♀ tested at each dose, 5 ♀♀ per bean leaf disc using three M. occidentalis colonies moderately resistant to permethrin.

VIII. Publications

Grafton-Cardwell, E.E. and M.A. Hoy. 1983. Comparative toxicity of avermectin B_1 to the predator Metaseiulus occidentalis (Nesbitt) (Acari: Phytoseiidae) and the spider mites Tetranychus urticae Koch and Panonychus ulmi (Koch) (Acari: Tetranychidae). J. Econ. Entomol. 76:1216-1220. (Attached)

Hoy, M.A. and F.E. Cave. 1985. Laboratory evaluation of avermectin as a selective acaricide for use with Metaseiulus occidentalis (Nesbitt) (Acarina: Phytoseiidae). Exp. Applied Acarol.1:139-152. (Attached)

Headley, J.C. and M.A. Hoy (In press). The economics of integrated mite management in California almonds. Calif. Agric. (Jan. 1986 issue). (In section II)

Hoy, M.A., J.J.R. Groot, H.E. van de Baan. 1985. Influence of aerial dispersal on persistence and spread of pesticide-resistant Metaseiulus occidentalis in California almond orchards. Entomol. Exp. Appl. 37:17-31. (Attached)

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Comparative Toxicity of Avermectin B_1 to the Predator *Metaseiulus occidentalis* (Nesbitt) (Acari: Phytoseiidae) and the Spider Mites *Tetranychus urticae* Koch and *Panonychus ulmi* (Koch) (Acari: Tetranychidae)[1]

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ABSTRACT The relative toxicity of avermectin B_1 was assessed in the laboratory, using adult females of *Tetranychus uritcae* Koch, *Panonychus ulmi* (Koch), and *Metaseiulus occidentalis* (Nesbitt). Avermectin B_1 was less toxic to *M. occidentalis* than to the spider mites. However, at the proposed field rates (4, 8, and 16 ppm), few *M. occidentalis* survived and fecundity was reduced. Larvae of *M. occidentalis* were more susceptible to avermectin B_1 at 0.1, 4, 8, and 16 ppm, than adult females. Eggs of *M. occidentalis* hatched on leaf discs containing residues of avermectin B_1 applied at field rates, but none of the larvae survived to the nymphal stage. Larvae exposed to avermectin B_1 at 0.001, 0.01, and 0.1 ppm matured into adults and deposited eggs, although at 0.1 ppm survival, activity, and developmental rates were reduced. The differential toxicity of avermectin B_1 to this predator could be of practical importance in managing spider mite populations in the field, particularly if refuges exist or if resistant predator strains can be developed.

Management programs using *Metaseiulus (Typhlodromus) occidentalis* (Nesbitt) may require selective pesticides and rates which are more toxic to spider mites than to this predator. Resistance of spider mites to the selective acaricide cyhexatin (Plictran) has recently been demonstrated (Westigard and Hoyt, personal communication), suggesting that this acaricide may have a limited future. Avermectin B_1 is a mycelial extract of *Streptomycetes avermitilis* which acts as a gamma-aminobutyric acid (GABA) agonist (Fritz et al. 1979). In arthropods, this chemical most likely inhibits signal registration at neuromuscular junctions (Putter et al. 1981). Avermectin B_{1a} has been shown to be highly toxic to *Tetranychus urticae* Koch and several other tetranychid and eriophyid mites, and to many insect pests such as cabbage looper, *Trichoplusia ni* (Hübner), corn earworm, *Heliothis zea* (Boddie), and pea aphid, *Acyrthosiphon pisum* (Harris), as well as to nematodes (Egerton et al. 1979, Putter et al. 1981). We evaluated the selective toxicity of this new acaricide-insecticide-nematicide to the predacious mite *M. occidentalis* and two spider mites, *T. urticae* and *Panonychus ulmi* (Koch).

Materials and Methods

The WA strain of *M. occidentalis* was originally collected from a Wenatchee, Wash., apple orchard in 1977. The strain tested (WA-18) is resistant to organophosphorus (OP) insecticides and was also selected for permethrin resistance in the laboratory (Hoy and Knop 1981). Adult *T. urticae* came from an established greenhouse colony at the University of California, Berkeley, where the colony had been exposed to various pesticides in the past. Adult *P. ulmi* were freshly collected from a commercial apple orchard in Santa Cruz County, Calif. All tests were conducted at 24 to 27°C, 30 to 60% ambient relative humidity (RH), and an 18-h photophase. Five mites were used per leaf disc. Leaf discs were 2.1 cm in diameter. Abundant *T. urticae* eggs were provided on the discs as prey for *M. occidentalis*. A water-soluble liquid formulation of avermectin B_1 was used (not less than 80% avermectin B_{1a} and not more than 20% avermectin B_{1b}). Data (percent survival, mortality, or immobilized individuals) were analyzed by analysis of variance. Mean separation of percent survival at the concentrations tested was by Duncan's multiple range test ($P = 0.05$).

Test 1

Adult female *M. occidentalis*, *T. urticae*, and *P. ulmi* were exposed to almond leaf discs treated with avermectin B_1, and survival of the three mite species was compared. The almond leaf discs were dipped in aqueous solutions of avermectin B_1 or distilled water, allowed to dry, and then placed bottom side up on moist cotton (Hoy and Knop 1979). Forty to 80 mites were tested at each concentration, with 15 to 30 mites used for water controls. The two spider mite species were tested at concentrations of 0, 0.001, 0.01, and 4 ppm. *M. occidentalis* was tested with 0, 0.001, 0.01, 0.1, 4, 8, and 16 ppm. Survival (mites which moved when touched with a fine camel's-hair brush) and the number of mites absent from the leaf discs were scored for *T. urticae* and *P. ulmi* after 24, 72, and 120 h. By 168 h, the almond leaf discs had deteriorated due to feeding damage and these species could not be scored further. Discs containing *M. occidentalis* had no active stages of spider mites, so the discs persisted longer. Survival and the number absent from the leaf discs could be scored after 24, 72, 120, 168 and 240 h for *M. occidentalis*. The total number of eggs deposited by *M. occidentalis* females on avermectin B_1 residues was recorded at 72 h, and the data were analyzed by analysis of variance.

Test 2

Survival and activity of *M. occidentalis* adults and newly hatched larvae on leaf discs treated with aver-

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Table 1. Susceptibility of adult females of *M. occidentalis*, *T. urticae*, and *P. ulmi* to avermectin B_1 on dipped almond leaf discs

Mite species and concn tested (ppm)	No. tested	% Survival (% absent from leaf disc) after[a]: 24 h	72 h	120 h	168 h	240 h
M. occidentalis						
16.0	40	95.0a (2.5)	42.5a (10.0)	17.5a (12.5)	(12.5)	(12.5)
8.0	40	82.5a (10.0)	47.5ab (27.5)	37.5a (27.5)	20.0a (27.5)	7.5a (30.0)
4.0	40	87.5a (5.0)	65.0bc (17.5)	32.5a (20.0)	(20.0)	10.0a (22.5)
0.1	40	87.5a (12.5)	75.0cd (15.0)	75.0b (15.0)	57.5b (15.0)	42.5b (17.5)
0.01	40	95.0a (5.0)	95.0de (5.0)	95.0b (5.0)	75.0b (10.0)	72.5c (10.0)
0.001	40	97.5a (2.5)	97.5e (2.5)	97.5b (2.5)	75.0b (9.5)	75.0c (9.5)
0.0	30	95.0a (5.0)	85.0cde (15.0)	85.0b (15.0)	65.0b (25.0)	50.0bc (25.0)
T. urticae						
4.0	40	5.0a (0.0)	0.0a (0.0)	0.0a (0.0)	—[b]	—[b]
0.01	40	85.0b (5.0)	57.5b (10.0)	42.5b (10.0)	—[b]	—[b]
0.001	40	85.0b (5.0)	70.0b (12.5)	67.5c (12.5)	—[b]	—[b]
0.0	15	100.0c (0.0)	100.0c (0.0)	100.0d (0.0)	—[b]	—[b]
P. ulmi						
4.0	80	0.0a (14.0)	0.0a (14.0)	0.0a (14.0)	—[b]	—[b]
0.01	60	66.5b (23.0)	23.0b (42.0)	7.5a (47.0)	—	—
0.001	80	86.0bc (9.0)	34.0c (39.0)	19.0b (41.0)	—	—
0.0	30	90.0c (7.0)	50.0c (33.0)	23.5b (40.0)	—	—

[a]Means for each species in the same column followed by the same letter do not differ at the 5% level, by Duncan's multiple range test.
[b]—, Almond leaf discs deteriorated and mites died.

mectin B_1 were compared. Pinto bean, *Phaseolus vulgaris* (L.), leaf discs were dipped into avermectin B_1 at 0, 0.001, 0.01, 0.1, 4, 8, and 16 ppm. Twenty to 25 mites were tested at each concentration. Survival was recorded after 48, 120, and 192 h. The surviving mites were divided into two classes—actively walking individuals and immobilized individuals.

Test 3

Eggs of *M. occidentalis*, 0 to 18 h old, were placed on pinto bean leaf discs treated with avermectin B_1 at 0, 0.001, 0.01, 0.1, 4, 8, and 16 ppm. Five eggs were placed on each of seven leaf discs at each concentration. Egg hatch and the survival, activity, and developmental rates of the subsequent life stages were evaluated after 96, 120, 144, 168, and 240 h.

Test 4

Adult female *M. occidentalis* were placed on treated pinto bean leaf discs for 48 h at rates of avermectin B_1 of 4, 8 and 16 ppm. Twenty mites were tested at each concentration. At 48 h, all actively walking adult females were removed from the treated discs and placed on untreated waxed paper discs with *T. urticae* eggs as food to see if they could deposit eggs after exposure to avermectin B_1.

Results and Discussion

Test 1

At 24 h, avermectin B_1 at 4 ppm was significantly less toxic ($P = 0.05$) to *M. occidentalis* than to *T. urticae* and *P. ulmi*. After 72 h, all rates of avermectin B_1 tested were significantly less toxic ($P < 0.01$) to *M. occidentalis* than to the two spider mite species. Survival was 65.0, 95.0, and 97.5% for *M. occidentalis*, 0.0, 57.5, and 70.0% for *T. urticae*, and 0.0, 23.0, and 34.0% for *P. ulmi* on residues of 4, 0.01, and 0.001 ppm, respectively (Table 1).

At 24 h, the concentration of avermectin B_1 had no effect on the survival of *M. occidentalis* (Table 1). At 72 h, however, the higher doses began to take effect; by 120 h, survival at 4, 8, and 16 ppm was significantly lower than at the other doses. Surviving *M. occidentalis* females appeared plump and healthy after 24 h on leaf

Table 2. Comparative fecundity of adult females of *M. occidentalis* after 72 h on almond leaf discs dipped in avermectin B_1

Determination	Avermectin B_1 concn (ppm)[a]						
	16.0	8.0	4.0	0.1	0.01	0.001	0.0
Mean no. of eggs/disc	2.60a	2.10a	1.90a	3.00a	13.20b	12.00b	15.50b
SD	0.92	1.64	1.31	1.41	6.50	5.95	3.62
Index of fecundity[b]	1.20a	0.80a	0.60a	0.80a	2.80b	2.50b	3.90c

[a]Means in the same row followed by the same letter do not differ at the 5% level, by Duncan's multiple range test.
[b]Index of fecundity = mean number of eggs per surviving female at 72 h.

discs at these rates, but they could not walk. Their legs were fully extended and stilt-like; when touched with a fine brush, they moved only slightly forward or backward. This type of paralysis of the legs has also been described for lepidopterous larvae (Putter et al. 1981). Survival of *M. occidentalis* females declined over time on the 4-, 8-, and 16-ppm residues until only 7.5 to 10% remained alive after 240 h. Because their legs were paralyzed and movements were limited, the predators did not feed. No *M. occidentalis* females left on the 4-, 8-, or 16-ppm residues recovered from their paralysis; they gradually became thinner, and most died within 240 h. Survival was not significantly different from water controls on 0.01- and 0.001-ppm residues, and those predators which survived could walk normally. On residues of 0.1 ppm, an intermediate response occurred in which survival was significantly lower than rates of 0.001 and 0.01 ppm and significantly higher than rates of 4, 8, and 16 ppm at 240 h. In addition, with avermectin B_1 at 0.1 ppm, some of the individuals could walk normally, whereas some were immobilized.

T. urticae females responded rapidly to avermectin B_1 (Table 1). After 24 h, only 5% remained alive on leaf discs treated with 4 ppm, and these individual exhibited the same stilt-like immobilization as *M. occidentalis* females. At 72 h and 120 h, all *T. urticae* females were dead on leaf discs treated with 4 ppm, and survival was significantly reduced ($P = 0.05$) on leaf discs treated with 0.01 and 0.001 ppm avermectin B_1 as compared with the water controls.

Female *P. ulmi* also exhibited an immediate response to avermectin B_1. At 24 h, all mites exposed to 4 ppm had died, and significantly fewer were alive on residues of 0.01 ppm than of 0.001 ppm or the water controls (Table 1). By 120 h, survival of *P. ulmi* females exposed to 0.01 ppm had decreased to only 7%. Females left on discs treated with 0.001 ppm did not have a significantly different survival rate from the water controls even after 120 h. Few *M. occidentalis* or *T. urticae* migrated from the almond leaf discs into the water-soaked cotton during the experiment. In contrast, after 72 h, 42, 39, and 33% of the *P. ulmi* adults had left the leaf discs, and after 120 h, 47, 41, and 40% had left the discs treated with 0.01, 0.001, and 0.0 ppm, respectively. This high level of activity was unexpected, since *P. ulmi* adults are normally tested for 24 to 48 h on almond leaf discs

Table 3. Survival and activity of adult females and larvae of *M. occidentalis* on bean leaf discs dipped in avermectin B_1

Stage and concn tested (ppm)	% In each class after[a]:								
	48 h			120 h			192 h		
	Active	Immobile	Dead	Active	Immobile	Dead	Active	Immobile	Dead
Adult females									
16.0	4a	88a	8a	0a	80a	20a	0a	68a	32ab
8.0	4a	96a	0a	0a	76a	24a	0a	48b	52a
4.0	8a	80a	12a	0a	68a	32a	0a	56ab	44ab
0.1	52b	36b	12a	44b	32b	24a	44b	27c	29bc
0.01	100c	0c	0a	96c	0c	4b	96c	0d	4d
0.001	100c	0c	0a	92c	0c	8b	92c	0d	8d
0.0	100c	0c	0a	96c	0c	4b	96c	0d	4d
Larvae									
16.0	—[b]	—	75a	0a	0a	100a	0a	0a	100a
8.0	—	—	70ab	0a	0a	100a	0a	0a	100a
4.0	—	—	75a	0a	0a	100a	0a	0a	100a
0.1	—	—	70ab	20ab	0a	80ab	20ab	0a	80ab
0.01	—	—	35bc	44bc	0a	56bc	40bc	0a	60bc
0.001	—	—	27c	60bc	0a	40bc	40bc	0a	60bc
0.0	—	—	7c	93c	0a	7c	53c	0a	47c

[a]Means for each life stage in a column followed by the same letter do not differ at the 5% level, by Duncan's multiple range test.
[b]—Impossible to distinguish between larvae immobilized due to molting and those immobilized by avermectin B_1 residues.

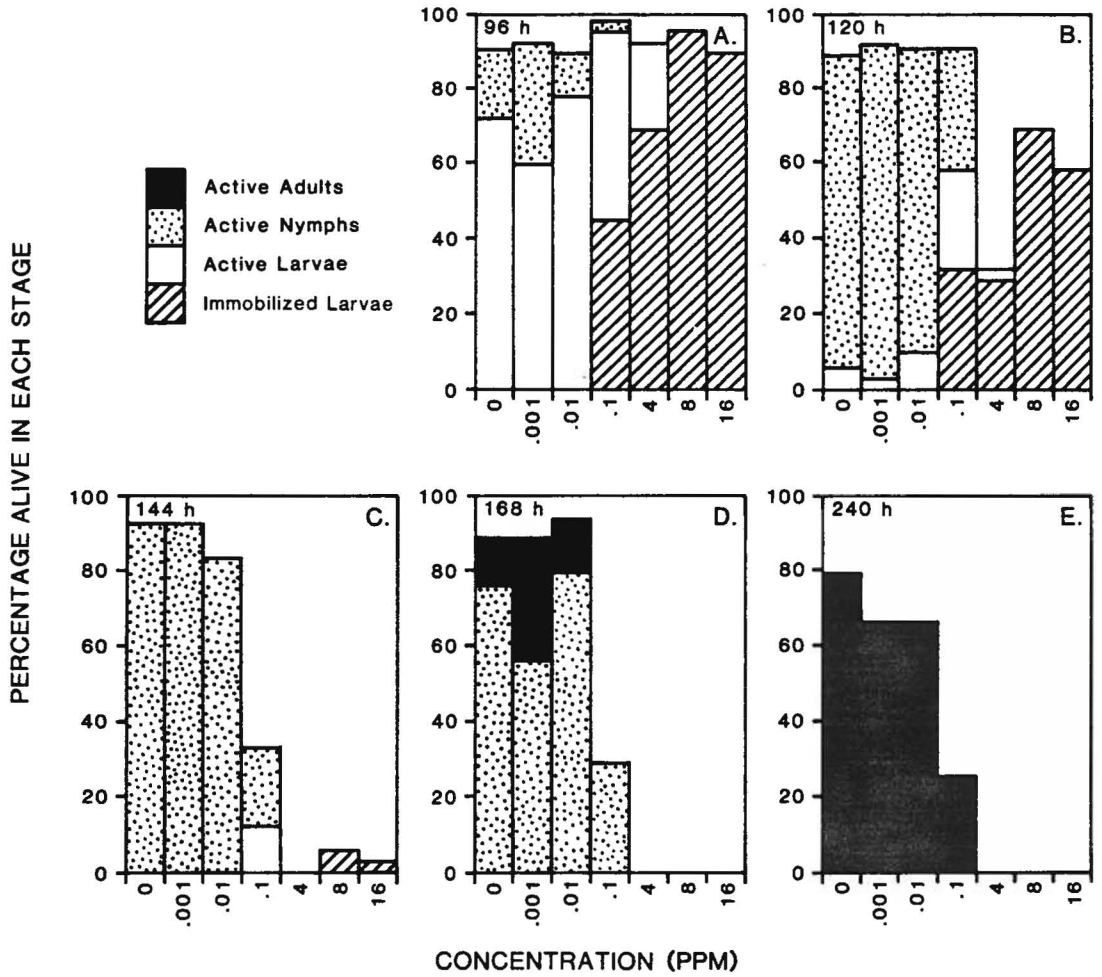

FIG. 1. Survival and developmental rates of *M. occidentalis* placed on avermectin B_1-treated bean leaf discs as eggs, as well as the percentage of larvae which became immobilized. The percentage of active and immobilized larvae, nymphs, and adults was recorded after 96, 120, 144, 168, and 240 h.

without significant losses. Since up to 40% of *P. ulmi* females on the water controls also ran into the water, we attributed this response to the non-settling behavior of *P. ulmi* after 72 h on the almond leaf discs rather than to a repellent effect of avermectin B_1.

Increasing concentrations of avermectin B_1 significantly decreased ($P < 0.01$) the fecundity of *M. occidentalis* females (Table 2). Females exposed to avermectin B_1 at 0.1, 4, 8, and 16 ppm for 72 h deposited only 3.0, 1.9, 2.1, and 2.6 eggs per disc, respectively, whereas those exposed to 0.0, 0.001, and 0.01 deposited 15.5, 12.0, and 13.2 eggs per disc (Table 2). The index of fecundity (mean number of eggs per surviving female after 72 h) was also significantly lower for *M. occidentalis* on rates of 0.1, 4, 8, and 16 ppm. The mean number of eggs deposited includes eggs deposited initially by females which succumbed to the pesticide and females which survived, so it overestimates the individual fecundity of surviving females.

Test 2

M. occidentalis adult females survived better ($P = 0.05$) than larvae after 48 h on leaf discs treated with avermectin B_1 at 0.1, 4, 8, and 16 ppm (Table 3). Females were quickly immobilized by rates of 0.1 to 16 ppm but showed no immobilization at rates of 0.01 and 0.001 ppm. As time passed, all of the females at 4, 8, and 16 ppm became immobilized or died, whereas 44% of the females at 0.1 ppm remained alive and active after 192 h. Females continued to survive as well on residues of 0.01 and 0.001 ppm as the water controls throughout the experiment.

M. occidentalis larvae placed on treated leaf discs remained inactive for a substantial period of time before molting to the protonymphal stage. Thus, it was difficult to determine whether they were immobilized or preparing to molt, and larvae were scored only for survival at 48 h (Table 3). All larvae exposed to avermectin B_1 at 4, 8, and 16 ppm died by 120 h. Larvae exposed to

residues of 0.1 ppm exhibited significantly lower ($P < 0.05$) survival than water controls throughout the experiment, whereas 0.01 and 0.001 ppm did not cause significantly different survival than the water controls.

Test 3

Avermectin B_1 did not affect the hatch of *M. occidentalis* eggs. Hatch varied from 83 to 97%, but there was no trend with increasing concentration. Figure 1 shows the activity, developmental rates, and survival of immatures which emerged from eggs placed on avermectin B_1 residues. At the highest concentrations (4, 8, and 16 ppm), all of the newly hatched larvae quickly became immobilized (Fig. 1a), and by 168 h all of these larvae had died (Fig. 1d), with none reaching the nymphal stage (Fig. 1c).

At the lowest concentrations tested (0.001 and 0.01 ppm), avermectin B_1 had no significant effect ($P = 0.05$) on the survival or developmental rate of larvae. At these rates larvae were active (Fig. 1a), and matured at the same rate as the water controls (Fig. 1a–e). At 0.1 ppm, however, some larvae became immobilized (Fig. 1a) and eventually died (Fig. 1c), reducing overall survival (Fig. 1e). *M. occidentalis* developed significantly more slowly ($P = 0.01$) on leaf discs treated with 0.1 ppm than mites on discs treated with 0.001 and 0.01 ppm. For example, larvae reared on residues of 0.001 and 0.01 ppm all became nymphs within 144 h, whereas >50% of the mites on 0.1-ppm residues were still larvae (Fig. 1c). At 168 h, ca. 15 to 35% of the *M. occidentalis* on residues of 0.001 and 0.01 ppm had reached the adult stage, whereas none of the mites on 0.1-ppm residues had become adults (Fig. 1d). Thus, the avermectin B_1 at the 0.1-ppm concentration elicited an intermediate response in survival, activity, and developmental rate by *M. occidentalis* when compared with the other concentrations tested.

Test 4

A few *M. occidentalis* adult females resumed oviposition after removal from avermectin B_1 residues. Of 60 females tested, only 10 were actively walking after 48 h (one, three, and six females on residues of 4, 8, and 16 ppm, respectively). Two of the 10 females deposited eggs 8 days after they were removed from the treated leaf discs to clean, waxed-paper discs. This suggests that, if spray coverage in the field were incomplete, or if refuges existed, some *M. occidentalis* females which escaped initial immobilization could survive and continue to deposit eggs. The immobilized mites which were left on the treated leaf discs did not recover by 192 h.

These laboratory tests demonstrate that avermectin B_1 is more toxic to the spider mites *T. urticae* and *P. ulmi* than to the phytoseiid *M. occidentalis*. Thus, field trials to determine whether this selectivity can be used for spider mite management are justified. Our experiments also demonstrate the differential effects of avermectin B_1 on the life stages of *M. occidentalis*. Egg hatch was not affected by any concentration of avermectin B_1 tested. Rates of 4, 8, or 16 ppm were extremely toxic to larvae placed on residues or larvae which hatched on these residues, whereas larvae exposed to residues of 0.01 or 0.001 ppm matured to the adult stage at rates comparable to water controls. Larvae exposed to 0.1 ppm exhibited intermediate developmental and survival rates. Adult females exhibited a higher survival rate than larvae on residues of 0.1 to 16 ppm, although many were immobilized and fecundity of active females was reduced. The ability of 2 of 10 females to deposit eggs when removed from avermectin B_1 residues suggests that refuges in the field may enhance survival of this predator.

Because several *M. occidentalis* females remained active after 48 h on discs treated with avermectin B_1 at 4 to 16 ppm, there may be genetic variability which could be useful in a selection program. *M. occidentalis* has been successfully selected in the laboratory for resistance to the carbamate insecticide carbaryl (Roush and Hoy 1981) and the pyrethroid permethrin (Hoy and Knop 1981). Possibly, laboratory or field selection of *M. occidentalis* for resistance to avermectin B_1 could be accomplished, improving the survival of the predator at field rates and therefore the selectivity of this compound.

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LABORATORY EVALUATION OF AVERMECTIN AS A SELECTIVE ACARICIDE FOR USE WITH *METASEIULUS OCCIDENTALIS* (NESBITT) (ACARINA: PHYTOSEIIDAE)

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ABSTRACT

Hoy, M.A. and Cave, F.E., 1985. Laboratory evaluation of avermectin for use with *Metaseiulus occidentalis* (Nesbitt) (Acarina: Phytoseiidae). *Exp. Appl. Acarol.*, 1: 139—152.

The suggestion that adding a light oil to avermectin B_1 would increase the toxicity of avermectin to spider mites and reduce its effect on predaceous mites was tested in laboratory trials with *Tetranychus urticae* Koch and *Metaseiulus occidentalis* (Nesbitt) on almond and bean foliage. No differences were found in the toxicity of avermectin + oil vs. avermectin alone at the doses tested for *T. urticae*; all (0.025, 0.5, 1, and 5 ppm) were highly toxic. Mortality of *M. occidentalis* females and larvae was not different on avermectin + oil vs. avermectin alone, but females produced more progeny on the avermectin + oil-treated foliage. At doses of 0.5 to 5 ppm, avermectin was sufficiently toxic to deplete predator populations in the field. Development of predator larvae on avermectin + oil and on avermectin alone was not different. Avermectin + oil on almond foliage aged outdoors was highly toxic after 96 h to *T. urticae* adults but *M. occidentalis* larvae survived well on residues by 96 h. *M. occidentalis* female survival and productivity were not different from the controls by 48 h. Hence a predator mite population might recover through larvae hatching onto residues. Avermectin + oil (3 ppm) residue on bean foliage held outdoors was still highly toxic to *T. urticae* after 33 days. In contrast, *M. occidentalis* females and larvae survived well on 48- to 96-hour-old residues. Neither predators nor spider mites placed on treated foliage (3 ppm) were able to reach untreated foliage in tests using bean plant seedlings with one leaf sprayed and one left unsprayed. Furthermore, when *M. occidentalis* females were exposed to 3 ppm avermectin for 300 s or longer, mortality was significant and the fecundity of females that had been exposed for as few as 30 s was reduced significantly. Thus, while avermectin is significantly more toxic to *T. urticae* than to *M. occidentalis*, its value as a selective acaricide will depend upon learning to use it at rates that will allow the retention of sufficient prey so that surviving predators can persist. Based on these laboratory tests, such selective doses are likely to lie below 1 ppm and can best be determined in field trials.

INTRODUCTION

Integrated pest management programs generally attempt to utilize biological control agents to the fullest extent possible. Natural enemies may some-

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times require assistance if economic damage is to be avoided, however. Selective acaricides are thus used in deciduous orchards and vineyards to assist the phytoseiid *Metaseiulus occidentalis* (Nesbitt) in controlling spider mites in western North America and in Australia. Propargite (Omite), cyhexatin (Plictran) and fenbutatin oxide (Vendex) are useful selective acaricides for such IPM programs (Jeppson et al., 1975).

The recent development of resistance to cyhexatin and propargite in *Tetranuchus urticae* (Koch) in apple and pear orchards in Australia (Edge and James 1982a, b), in Oregon (U.S.A.) pear orchards (P.H. Westigard and S.C. Hoyt, pers. commun., 1984) and in California (U.S.A.) strawberries (R.D. Nelson, pers. commun., 1984), pears (J. Joos, pers. commun., 1984), and almonds (M.A. Hoy, unpubl. information) suggest that these selective acaricides may have a limited future. The Australian strain resistant to cyhexatin is also resistant to fenbutatin oxide, azocyclotin and propargite (Edge and James, 1982a, b). Formetanate and cyhexatin resistance has been rumored to exist in *T. urticae* populations in the U.S.A., and Croft et al. (R.D. Nelson, pers. commun., 1984) recently determined the genetic basis of these types of resistance.

Because selective acaricides are so valuable in IPM programs, newly-developed acaricides should be evaluated for their selectivity as potential tools in IPM programs. Avermectin B_1, a mycelial extract of *Streptomyces avermitilis*, is a highly toxic insecticide—acaricide—nematicide (Putter et al., 1981). Grafton-Cardwell and Hoy (1983) compared the toxicity of avermectin B_1 to *M. occidentalis*, *T. urticae*, and *Panonychus ulmi* (Koch). They showed that avermectin is substantially more toxic to both spider mite species than to the predator but, at the proposed field rates (4, 8, 16 ppm), few predators survived and their fecundity was reduced. Predator larvae are more susceptible than females, although eggs are unaffected. They concluded that predators could persist in treated plots if refuges existed, or if lower doses were applied, and if predator eggs hatched after the residues became less toxic.

Recent field trials with avermectin suggested that the addition of a light oil could increase the toxicity of avermectin to spider mites and at the same time reduce its effect on phytoseiids (R.D. Brown, pers. commun., 1984). We therefore conducted laboratory trials with *M. occidentalis* and *T. urticae* to determine if the addition of oil to avermectin enhanced its selectivity. To determine the toxicity of residues exposed to UV light, we evaluated survival and fecundity of *M. occidentalis* and *T. urticae* females on treated almond and bean leaves held outdoors in sunlight. To determine if predators can reach unsprayed refuges, we tested the ability of females to move from sprayed to unsprayed leaves on bean plants. Finally, we determined the effect of short exposures to avermectin residues on survival and productivity of *M. occidentalis* females.

MATERIALS AND METHODS AND RESULTS

Colony sources

The mites used in this study came from established laboratory and greenhouse cultures. The *M. occidentalis* colony used is resistant to organophosphorus (OP) insecticides such as azinphosmethyl, diazinon, and phosmet and has undergone laboratory selection for carbaryl and sulfur resistance (carbaryl—OP—sulfur strain). The *T. urticae* colony came from an established greenhouse colony at the Oxford Tract of the University of California, Berkeley, and has a history of exposure to various pesticides.

Test conditions

Tests were conducted at 22—29° C, 50—65% RH, and under continuous fluorescent light. Abundant *T. urticae* were provided as prey on discs with *M. occidentalis.* The criterion for survival of both species was the ability to walk if touched lightly with a camel hair brush. Immobilized, obviously dead mites, and run-off mites were considered dead, as the immobilized mites were never observed to recover. This definition (including immobilized mites as dead) is different from that used by Grafton-Cardwell and Hoy (1983) where immobilized mites were scored as alive.

Survival, productivity and development: methods

The toxicity of avermectin mixed with an without oil on *M. occidentalis* and *T. urticae* was evaluated. Four dilutions of a water soluble formulation of avermectin B_1 (MK-936 0.15 EC) and a distilled water control were made both with and without oil (0.25% Sun Spray 6E) for a total of 10 treatments. Doses tested were 0 (distilled water control), 0.025, 0.5, 1.0 and 5.0 ppm a.i. avermectin B_1. Almond leaf discs, 1.75 cm in diameter, were dipped in the solutions, placed bottom side uppermost on moist cotton and dried for 45—60 min before placing mites on them (Hoy and Knop, 1979). Solutions were stirred continuously while leaf discs were dipped.

Survival of *M. occidentalis* and *T. urticae* females was evaluated for 10 treatments, using 50—60 females per treatment, 5 females per disc. The number of females walking, immobilized, dead and run-off was recorded after 24, 48, 72, 96, 120 and 168 h. *M. occidentalis* was also scored after 240 h. Productivity of predators was evaluated by recording the number of progeny (eggs, larvae and nymphs) on the treated discs after 72 h using 6—8 discs in each treatment. Survival of newly-hatched larvae of *M. occidentalis* was evaluated after 48, 120 and 192 h using 40 larvae (10 per disc) for each of the 10 treatments.

The effect of avermectin residues on the development of *M. occidentalis* was evaluated by placing 50 eggs (5 per disc) 0—24 h old, on treated almond

leaf discs for each treatment. The number of unhatched eggs, larvae, nymphs and adults, and their condition (mobile or immobilized) was recorded after 96, 120, 144, 168, 192 and 240 h.

Survival, productivity and development: results and discussion

Avermectin at 0.025, 0.5, 1.0 and 5.0 ppm with or without oil killed nearly all *T. urticae* females tested and therefore the enhancement of avermectin's toxicity by oil could not be demonstrated with these doses (Table 1). At the above rates, survival of *M. occidentalis* was 86, 54, 54, and 22%, respectively, on avermectin-treated foliage after 48 h. The avermectin + oil treatment was not significantly more toxic than avermectin alone to predator females after 48 h or 120 h (Table 1). Oil alone induced mortality of *T. urticae* females after 48 h; however, this mortality was almost entirely due to mites leaving the leaf discs. Survival of predator larvae on avermectin

TABLE 1

Survival of *M. occidentalis* and *T. urticae* adult females and *M. occidentalis* larvae on almond leaf discs dipped in avermectin with or without oil

Stage and species tested	Concentration (ppm)	Percentage survival[a] on avermectin after			
		48 h		120 h	
		Without oil	With oil	Without oil	With oil
Adult females					
M. occidentalis	0	96	86	76	65
	0.025	86	85	66	62
	0.5	54	56	36	42
	1.0	54	54	26	23
	5.0	22	14	0	4
T. urticae	0	98	74[b]	90	68
	0.025	0	2	0	0
	0.5	0	0	0	0
	1.0	0	0	—	—
	5.0	0	0	—	—
Larvae					
M. occidentalis	0	92	78	90	78
	0.025	70	75	62	72
	0.5	20	25[c]	15	38
	1.0	15	18	12	25
	5.0	8	0	0	0

[a]Survival was scored as the percent able to walk; immobilized mites were assumed dead. Fifty to sixty adult females were used in each treatment, 5 females per disc; 40 larvae were used in each treatment, 10 per disc.
[b]Survival differed significantly at 5% level according to group comparison *t*-test.
[c]These data are based on three replicates (total 30 larvae) rather than four.

+ oil was not different than on avermectin alone. Thus, avermectin + oil was not significantly less toxic to either adult or larval predators on these almond leaf discs.

Productivity of *M. occidentalis* females was significantly higher on avermectin + oil residues of 0.5 and 5.0 ppm than on avermectin alone (Table 2). This suggests that avermectin + oil might allow higher predator populations in the field. The increased productivity is due to the fact that females take longer to die on leaf discs treated with avermectin + oil than with avermectin only and continue to lay some eggs. As the avermectin rate increased, the number of progeny produced by the females declined (Table 2). Productivity of *T. urticae* was not reported because none survived at these rates.

Survival and developmental rates of larvae hatching from eggs placed on avermectin and avermectin + oil were not significantly different (Fig.1). There is no evidence that the addition of oil to avermectin reduces the toxicity of this material to immature stages of *M. occidentalis.*

TABLE 2

Productivity of *M. occidentalis* females after 72 h on almond leaf discs dipped in avermectin with or without oil

Avermectin dose (ppm)	Mean no. progeny per disc[a]	
	Without oil	With oil
0	42.8	33.8
0.025	17.8	30.2
0.5	4.7	10.3[b]
1.0	5.5	6.5
5.0	2.8	5.5[c]

[a]Five females were placed on each leaf disc, with 6—8 replicates per treatment.
[b]Means differ significantly at the 5% level according to a group comparison *t*-test.
[c]Means differ significantly at the 1% level according to a group comparison *t*-test.

Toxicity of aged residues: methods

To evaluate the toxicity of aged avermectin B_1 residues exposed to sunlight on *M. occidentalis* and *T. urticae*, two almond trees at the Oxford Tract (University of California, Berkeley) were sprayed with a hand held sprayer to the point of drip and leaves were removed 1, 24, 48, 96 or 168 h after treatment for testing. A NePlus variety tree was treated with 3 ppm a.i. avermectin in 0.25% oil (Sun Spray 6E), equivalent to 0.3 g a.i./100 liters water. The control tree, a Nonpareil variety almond, was sprayed only with a 0.25% oil solution. Leaves were left on the trees for exposure to ambient weather conditions and leaf discs 1.75 cm in diameter were cut from the treated leaves and placed bottom side uppermost on wet cotton. A total of 50 females of *M. occidentalis* and *T. urticae* were placed on the oil only

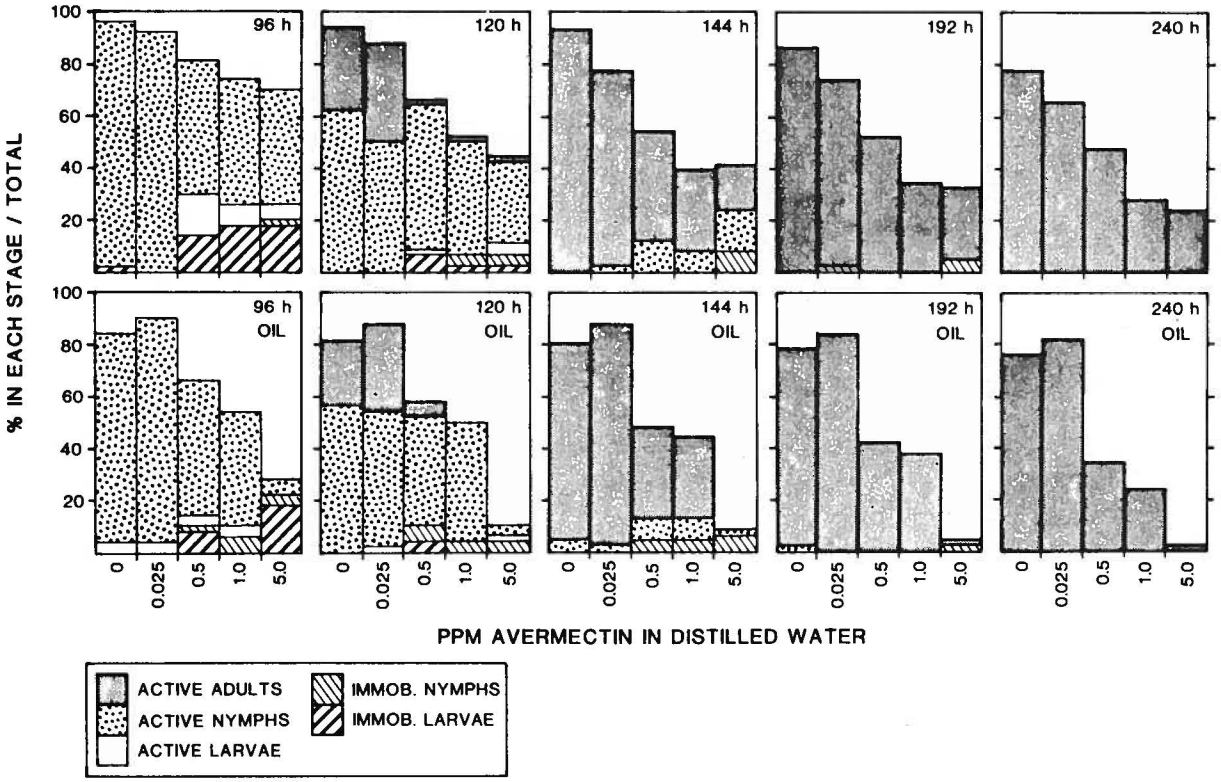

Fig. 1. Comparison of survival and post-embryonic development rates of *M. occidentalis* hatching from 50 eggs placed on leaf discs treated with avermectin and with avermectin + oil, each evaluated after 96, 120, 144, 192 and 240 hours.

or avermectin + oil-treated discs, 5 females per disc. Fifty larvae of *M. occidentalis* were tested, using 10 per disc. The numbers of individuals walking, immobilized, dead and run-off were counted after 120 h. To evaluate the effect of aged residues on productivity, the number of progeny (eggs, larvae and nymphs) on each disc were counted.

The toxicity of avermectin residues on pinto bean plants (*Phaseolus vulgaris*) exposed to sunlight was also evaluated. Four sets of pinto beans received one of the following: avermectin, avermectin + oil, water, or water + oil. Avermectin was applied at the rate of 3 ppm a.i., and oil at the rate of 0.25% of Sun Spray 6E. Plants were sprayed to the point of drip after dicotyledon leaves were expanded but before trifoliate leaves had opened. The beans were sprouted in a greenhouse, then moved and left outside for treatment and exposure to sunlight. Plants received full sun during the first 24 h after treatment but were placed in coarse netted cages after leaves showed evidence of sunburn. During rainy weather, plants were kept in plastic covered cages to prevent loss of residues. Survival and productivity of *M. occidentalis* and *T. urticae* females, and survival of *M. occidentalis* larvae was evaluated on residues aged 1, 24, 48, 96 and 168 h. In addition, the survival and productivity of *T. urticae* females was recorded on residues 432 and 792 h old. Fifty females or larvae were tested with each treatment and scored after 120 h.

Toxicity of aged residues: results and discussion

The avermectin + oil residues remained highly toxic to *T. urticae* females 96 h after they were applied to an almond tree at Oxford Tract (Table 3). In contrast, survival of *M. occidentalis* females was 42, 84, 64, and 56% on residues aged 1, 24, 48 and 96 h, respectively, which was not different from the water controls. Similarly, *M. occidentalis* larvae exhibited survival rates of 48, 66, 70, and 92% on 3 ppm avermectin + oil residues aged 1, 24, 48 and 96 h. Thus, these residues lose their toxicity to these predator larvae relatively rapidly and should allow survival of those predators that had escaped the spray application in untreated refuges or because they were in the egg stage. Progeny production of the predator females increased on older residues so that by 48 and 96 h there was no significant difference in the number produced by females on avermectin + oil and on water + oil (Table 3). Thus, while progeny production is reduced significantly on residues aged 24 h or less, it is higher on older residues (and not different from the water controls) and could allow recovery of the predator population.

When this test was repeated on pinto bean plants similar results were obtained (Table 4). By 48 h, 3 ppm avermectin + oil was not significantly more toxic than water + oil to *M. occidentalis* females. Productivity of *M. occidentalis* females was generally reduced on the avermectin residues less than 96 h old. *M. occidentalis* larvae survived about equally well as the water controls after the avermectin residues (with and without oil) were 96 h old.

TABLE 3

Survival and productivity of *M. occidentalis* and *T. urticae* females and survival of *M. occidentalis* larvae after 120 h on residues 1, 24, 48 or 96 h old on 0 or 3 ppm avermectin plus oil applied to almond foliage

Species and stage	Residue age at start of test (h)	Percentage survival on discs[a]		Mean progeny per disc	
		3 ppm + oil	0 ppm + oil	3 ppm + oil	0 ppm + oil
Adult females					
M. occidentalis	1	42	62	19.3	43.9[b]
	24	84	84	47.7	67.3[b]
	48	64	70	40.8	53.3
	96	56	56	36.0	40.9
T. urticae	1	0	90[b]	2.9	186.6[b]
	24	0	94[b]	4.6	198.8[b]
	48	2	92[b]	11.7	208.5[b]
	96	24	84[b]	58.0	187.1[b]
Larvae					
M. occidentalis	1	48	96[b]		
	24	66	96[b]		
	48	70	92[b]		
	96	92	92		

[a]Fifty females were tested on each treatment at each residue age using 5 females per disc. Fifty larvae were tested using 10 larvae per disc. Tests were scored 120 h after being set up. Survival was the percentage of individuals able to walk; immobilized mites were assumed dead.
[b]Difference between treatment and water control means is significant at 5% level, group comparison *t*-test.

In contrast, *T. urticae* adults were all killed by avermectin residues with oil up to 792 h (33 days) later. Only 6% of adult females survived on the avermectin residue lacking oil after 792 h (Table 4). Thus, despite the fact that the residues were exposed to sunlight, significant reduction in the toxicity of the avermectin (3 ppm with or without oil) was not observed on pinto bean foliage. Productivity of *T. urticae* females on 3 ppm avermectin + oil was significantly lower than on 3 ppm avermectin alone for residues aged 24, 48, 96, 168, 432 and 792 h, suggesting that oil enhanced the effects of avermectin to *T. urticae* females. The survival of the predators on the residues older than 48 h would be dependent upon availability of prey and thus is dependent upon significant refuges existing which would permit the survival of both predators and prey.

Effects of short exposures: methods

The effect of avermectin on *M. occidentalis* exposed to residues for short periods of time was evaluated. Pinto bean leaf discs, 1.27 cm in diameter,

TABLE 4

Survival and productivity of *M. occidentalis* and *T. urticae* females and survival of *M. occidentalis* larvae after 120 h on aged avermectin residues on pinto bean plants

Species and stage	Residue age at start of test (h)	Percentage survival on discs[a]				Mean progeny per disc			
		With oil		Without oil		With oil		Without oil	
		3 ppm	water	3 ppm	water	3 ppm	water	3 ppm	water
Adult females									
M. occidentalis	1	0	98[b]	8	100[b]	4.8	74.8[b]	8.9	73.4[b]
	24	36	94[b]	12	90[b]	39.1	76.1[b]	18.7	72.7[b]
	48	84	96	80	98	62.8	69.0	59.1	71.1[b]
	96	88	94	88	94	53.3	72.8[b]	61.5	70.5
	168	86	92	92	98	58.4	67.5	68.6	73.0
T. urticae	1	0	72[b]	0	68[b]	2.2	221.6[b]	3.9	226.0[b]
	24	0	88[b]	0	80[b]	1.0	242.3[b]	2.4[c]	259.3[b]
	48	0	88[b]	0	74[b]	1.6	204.1[b]	3.3[c]	209.2[b]
	96	0	98[b]	0	86[b]	3.0	321.1[b]	5.6[c]	278.6[b]
	168	0	56[b]	0	68[b]	4.3	285.6[b]	10.5[c]	266.7[b]
	432	0	20[b]	0	46[b]	4.6	191.3[b]	42.4[c]	231.6[b]
	792	0	78[b]	6	70[b]	8.1	199.5[b]	40.3[c]	176.7[b]
Larvae									
M. occidentalis	1	30	92[b]	14	92[b]				
	24	32	94[b]	46	90[b]				
	48	42	94[b]	74	92				
	96	84	86	88	88				
	168	72	86	100	96				

[a] Survival was the percent of individuals able to walk; immobilized mites were assumed dead; fifty adult females were used in each treatment, 5 females per disc; 50 larvae were used in each treatment, 10 per disc.
[b] Means differ significantly at 5% level, group comparison *t*-test, from the water controls.
[c] Mean progeny differ at 5% level, group comparison *t*-test, for females on 3 ppm avermectin + oil vs. 3 ppm avermectin alone.

were dipped in a solution of 3 ppm avermectin, placed bottom side uppermost on moist cotton, and dried for 30 min. Control discs were dipped in water only. Gravid females one to two days old (30 per treatment) were placed on the discs for 0, 5, 20, 30, 60, 300, 600 or 1800 s. After exposure, each female was transferred to an untreated leaf disc with spider mite prey. The number of females walking, immobilized, dead or run-off was recorded after 24 and 120 h. Productivity was measured after 120 h by counting the number of eggs, larvae and nymphs on each disc. All controls were scored for survival after 24 and 120 h, but productivity was measured only for the 60 s exposure set of controls.

Effects of short exposures: results and discussion

M. occidentalis females exposed to 3 ppm avermectin residues for 60 s or less exhibited survival rates comparable to water controls, although their fecundity was reduced significantly after 30 s of exposures (Table 5). Exposure of females for 5 min reduced survival from 87 to 30% and these females produced an average of only 3.5 progeny compared to 11.4 progeny produced by females on the water controls during 120 h. Thus, it appears that even brief exposures (5 min) to avermectin residues negatively affect survival and productivity of *M. occidentalis* females.

TABLE 5

Effects of short exposures to 3 ppm avermectin residues on survival and fecundity of *M. occidentalis* females[a]

Exposure interval (seconds)	Percentage survival after 120 h after testing with		Mean progeny per female after 120 h after testing with[c]	
	Avermectin (3 ppm)	Water	Avermectin (3 ppm)	Water
5	80.0	93.3	10.8 ab	
20	86.7	80.0	11.8 a	
30	80.0	73.3	9.4 b	
60	66.7	93.3	9.0 b	11.4 a
300	30.0	86.7[b]	3.5 c	
600	6.7	76.7[b]	1.4 d	
1800	0	90.0[b]	0.7 d	

[a]Females tested for specified time period then transferred to untreated discs with prey.
[b]Number of survivors on treated vs. control discs differs significantly at 5% level by Chi-square analysis.
[c]Means followed by different letters are significantly different at 5% level by Duncan's multiple range test.

Residue detection by predators: methods

The ability of *M. occidentalis* to detect and avoid avermectin residues was evaluated. Leaf discs 1.75 cm in diameter were cut from pinto bean leaves so that the midvein divided the disc in two. One-half of each leaf disc was marked with a dot of India ink to identify the side predators were placed on at the start of the test. Three sets of 10 discs were set up: one had the unmarked disc halves treated with 3 ppm of avermectin. One set had both halves treated with 3 ppm of avermectin and the other set was untreated. Avermectin was applied to the leaf disc half with a small camel hair brush. To insure predator activity during the test, discs had no prey. Fifty 1 to 2-day-old gravid females were tested on each treatment, using five females per disc. The number of females located on each side of the leaf disc and their condition (walking, immobilized, dead or run-off) after 2 and 24 h, the number and position of predator eggs after 24 h, and the number, position and condition of all progeny after 120 h was recorded.

Residue detection by predators: results and discussion

There is no evidence that *M. occidentalis* females can detect avermectin residues and avoid them. Insignificant differences in the location of females were found after 2 and 24 h on leaf disc halves with avermectin residues vs. untreated leaf disc halves. There were no differences in the location of females on the two control conditions (untreated : untreated and treated : treated). There were significant differences in the number of progeny produced by females on the two controls; females on untreated : untreated leaf discs produced 41 : 40 eggs and 45 : 36 immature progeny, respectively. In contrast, females on treated : treated discs produced only 5 : 3 eggs and 6 : 2 immatures after 120 h. Egg production on treated : untreated disc halves was 6 : 24, which is significantly different. Thus, females tended to deposit eggs on untreated disc halves, suggesting that some form of discrimination may occur. However, the number of progeny found on the treated: untreated disc halves was 22 : 8, again a significant difference, but in the opposite direction. This is probably due to the fact that active larvae moved on to the avermectin residues and died, thereby accumulating on the treated leaf disc half.

Refuge seeking in spider mites and predators: methods

The ability of spider mites and predators to move from a treated to an untreated leaf on the same plant was evaluated. Pinto bean plants with newly-expanded dicotyledon leaves were placed individually in water-filled vials. The apical stem of each plant was removed and vaseline applied to the main stem below the dicotyledon petioles to confine the mites to these leaflets. One leaflet of each plant was left untreated by enclosing it in plastic food

wrap while both sides of the other leaflet were sprayed using an aerosal propellant (Spray-Tool®). Treated leaflets were marked with a felt tip pen and sprayed with: avermectin, avermectin + oil, water, or water + oil, at the rates of 3 ppm a.i. avermectin and 0.25% Sun Spray 6E oil. Test mites (5 females per plant) were placed on the upper surface of the treated leaflet, held at 24—27°C under continuous light, and scored after 24 h by recording their position (upper/lower surface of treated/untreated leaflet) and condition (walking, immobilized, dead, or missing).

Refuge seeking in spider mites and predators: results and discussion

When *M. occidentalis* or *T. urticae* females were placed on the top of an avermectin-treated leaf, only a few were able to move to the untreated leaf (Table 6), indicating that predators and spider mites are unlikely to find an untreated refuge. These mites did not often move from their "release" leaf when the leaves were treated with oil or water only.

These data, along with the fact that residues are toxic to predators within 5 min (Table 5) suggest that predators are unlikely to aggregate in untreated refuges in the field.

TABLE 6

Refuge seeking by *T. urticae* and *M. occidentalis* females on pinto bean seedlings[a]

Test comparisons and leaf surface		Number alive at each site	
		M. occidentalis	*T. urticae*
3 ppm + oil : untreated	top	0 : 0	0 : 0
	bottom	1 : 0	0 : 0
oil : untreated	top	8 : 0	10 : 0
	bottom	38 : 1	37 : 3
3 ppm : untreated	top	0 : 0	2 : 0
	bottom	5 : 0	0 : 3
water : untreated	top	18 : 0	24 : 1
	bottom	29 : 1	22 : 1

[a]Test females (5 per plant; 10 replicates) were placed on the top surface of a treated dicotyledon leaf and their location was scored after 24 h.

GENERAL CONCLUSIONS

Laboratory toxicity test results can rarely be translated directly into predictions of field results. Nevertheless, avermectin + oil does not appear to be substantially less toxic to *M. occidentalis* than avermectin alone at

the rates tested. Differences in productivity of females on avermectin + oil do suggest that predator populations might be enhanced in the field by the addition of oil since these residues are relatively harmless to *M. occidentalis* larvae and adults after 48 h. Thus, eggs deposited at the time the plants are sprayed would be able to hatch 48 h later and the progeny could survive on the residues. The difficulty with this scenario, however, is the fact that all rates tested in the laboratory are so toxic to *T. urticae* that sufficient prey might not be available to maintain predators under field conditions. The high toxicity to *T. urticae* of residues on bean foliage (3 ppm) aged 33 days in sunlight suggests that these obligatory predators would starve or disperse from the orchard.

Therefore, field trials with avermectin (and avermectin + oil) are necessary to determine what rates can be used selectively in specific crops and different climatic areas. If predators are absent in the crop system, the standard rates would be indicated. However, if *M. occidentalis* is present and well distributed in the crop, and yet requires assistance to maintain spider mites below the injury level, then these laboratory tests suggest that rates lower than 1 ppm are likely to be required. Field trials using such low rates should be conducted in large blocks to determine how best to maintain some prey for this predator. Currently, lower-than-label rates of propargite, cyhexatin, and hexakis are used in California almond orchards to manage spider mites when *M. occidentalis* is unable to provide timely control (Hoy et al., 1984). Unpublished small plot field trials conducted by J.P. Sanderson and M.M. Barnes with avermectin in almonds suggest that avermectin can suppress spider mites without eliminating *M. occidentalis* (M.M. Barnes, pers. commun., 1984). These data need confirmation in commercial sized orchards where the effects of commercial application methods and aerial movements of both predators and spider mites can be incorporated into the evaluations.

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Influence of aerial dispersal on persistence and spread of pesticide-resistant *Metaseiulus occidentalis* in California almond orchards

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Keywords: aerial dispersal, *Metaseiulus occidentalis*, Acarina, Phytoseiidae, Tetranychidae, spider mites, pesticide resistance, almonds, biological control, genetic improvement, carbaryl, western predatory mite, European red mite, two-spotted spider mite, Pacific mite

Abstract

Aerial dispersal of the phytoseiid *Metaseiulus occidentalis* (Nesbitt) was evaluated as a component in managing pesticide-resistant populations established in California almond orchards. Peak dispersal occurred in late July and early August during 1982 and 1983. Most predators (and spider mites) left the orchards on the prevailing winds from the northwest. Within the orchard, the prevailing winds had less influence, and dispersal was usually random. Both spider mites and predators dispersed randomly with regard to height from the almond trees, but data obtained during one 24-h interval suggest they do not disperse randomly throughout the day. Most aerial movements occurred between 16–22 h when relative humidity and wind speeds increased and temperatures decreased. Spider mites and predators were trapped on panels located 200 m from the orchard. A survey of carbaryl resistance levels in *M. occidentalis* collected from almond orchards surrounding the release sites indicates that carbaryl-resistant *M. occidentalis* dispersed at least 800 m between 1981–83. However, growers wishing to use the resistant strains should release them in their orchards as natural dispersal appears to be too slow. Migration of native *M. occidentalis* into the release sites appeared to be sufficiently rare that dilution of carbaryl-resistant populations was minimal during a 2–4 year period.

Introduction

Spider mites, and their phytoseiid predators that occur in deciduous crops, live in habitats that are discontinuous and seasonally transient. Thus, they must move from senescent foliage each fall to overwintering sites. They may also move from exhausted resources to new resources during the growing season. Both spider mites and their phytoseiid predators can walk from leaf to leaf or along the trunks of trees. Bernstein (1983, 1984) reviewed dispersal behavior of *Phytoseiulus persimilis* and showed that females could walk 319.5 meters per day. However, very rapid movements from orchard to orchard or from tree to tree have been observed. Apparently both spider mites and phytoseiids have adopted aerial movements as a long distance dispersal mechanism (Boykin & Campbell, 1984; Brandenburg & Kennedy, 1982; Field, 1981; Fleschner *et al.*, 1956; Hoelscher, 1967; Hoy, 1982; Johnson & Croft, 1976, 1981; Mitchell, 1970; Pedgley, 1982; Stabler, 1913).

Experiments were conducted in 2 almond orchards in California during 1982 and 1983 to answer the following questions: 1) Do spider mites and *Metaseiulus occidentalis* disperse aerially throughout the growing season? 2) Do spider mites and *M. occidentalis* disperse inside almond orchards from tree to tree via the prevailing winds from the northwest? 3) Do these mites enter and leave almond orchards randomly with regard to the four compass directions? 4) Is there a relationship

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between the number of *M. occidentalis* and spider mites on foliage and the number dispersing aerially? 5) Do spider mites and *M. occidentalis* disperse throughout the day? 6) Do predators and spider mites disperse primarily from the tops of almond trees? 7) How far can spider mites and predators disperse from almond orchards? 8) How do aerial movements of susceptible native *M. occidentalis* influence persistence of carbaryl resistance after the resistant strain has been established?

Materials and methods

Field plots. Experiments were conducted during 1982 and 1983 in 2 commercial almond orchards near Livingston, California in the San Joaquin Valley of California, U.S.A. The Livingston-I site is 5.7 hectares (14 acres) with Mono, Yosemite, and Mission varieties planted in a 1:2:1 pattern, with trees 4.6 m and rows 7.6 m apart. *M. occidentalis* resistant to organophosphorus (OP) and carbaryl insecticides (Roush and Hoy, 1981) were released on 9 June 1981 into every third tree in every third row, by placing 350 ♀♀/release tree. During 1982, the grower applied carbaryl (4.5 kg 80 WP Sevin/ha) on May 14 and propargite on June 19 (1.3 kg 30 WP Omite/ha) by air blast sprayer. On August 4, he applied cyhexatin (0.6 kg 30 WP Plictran/ha) by aircraft. During 1983, he applied no insecticides during the growing season, but applied 0.6 kg 30 WP propargite/ha by air blast sprayer on June 9.

The Livingston-III orchard consists of 18.2 ha (45 acres) of Mission, Nonpareil, and NePlus trees in a 1:2:1 spacing with trees 7.3 × 7.3 m apart. *M. occidentalis* resistant to carbaryl, OP, and sulfur pesticides (Hoy, in press) were released on 28 May 1982, using 2 different release patterns; 900 ♀♀/tree were released into every third tree in every third row in half the block (150 000 ♀♀), while 100 ♀♀ were released into every tree in the other half of the block, using another 150 000 ♀♀. On 14 May and 15 July 1982, the grower applied carbaryl using 4.5 kg 80 WP/ha and 6.8 kg 80 WP/ha, respectively, with an air blast sprayer. On 15 July, the grower included 1.1 kg 30 WP propargite/ha with the carbaryl. During 1983, this block received no insecticides during the growing season, and the grower applied 1.1 kg 30 WP propargite/ha on 10 June.

Foliage samples. During both years, foliage counts of spider mites and predators were obtained ca. weekly by removing 10 leaves/tree from the bottom half of each of 5 marked trees in 4–6 sites in the orchard (Fig. 1). The foliage was refrigerated, brushed with a mite brushing machine, and active stages of spider mites and *M. occidentalis* were counted under a dissecting microscope.

Aerial sampling methods – 1982

Movements into and out of orchards. Vertically-oriented clear plexiglass panels (76 × 175 mm) were placed on towers 7.6 meters outside the 2 orchards to estimate the relative densities of mites moving into and out of the 2 orchards throughout the season in the 4 compass directions. Towers were placed on all 4 sides of the orchards, except none was placed on the north side of the Livingston-III block (Fig. 1). Panels were located 1.9, 3.9, and 5.8 m above ground level. Two panels at each height were directed toward and 2 away from the orchard, respectively. Each tower thus held 12 panels. Trees were estimated to be 8–9 m tall; thus the panels did not reach the canopy top. Panels were covered with a thin film of gear box oil (SAE 90) on one side only and replaced every week or 2 weeks. Mites trapped on the panels were counted using a dissecting microscope. After counting, the panels were washed and reused. Panels were continously present from May 5 until September 1 outside the Livingston-I site and from May 26 until August 11 outside the Livingston-III orchard.

Movements inside the orchards. Mite movement within the orchard was monitored over the season by hanging panels between rows with a rope and pulley system so that the grower could take his farm equipment down the rows. Panels were changed each week or 2 weeks and examined as described above. Two sets of 4 panels each were ca. 4.8 and 2.8 m above ground level, and were oriented so that all 4 compass directions were sampled at mid- and lower-canopy heights.

The mean number of spider mites (active stages only) and *M. occidentalis* on foliage was compared to the number of mites captured on the plexiglass panels located inside the 2 orchards. To compare

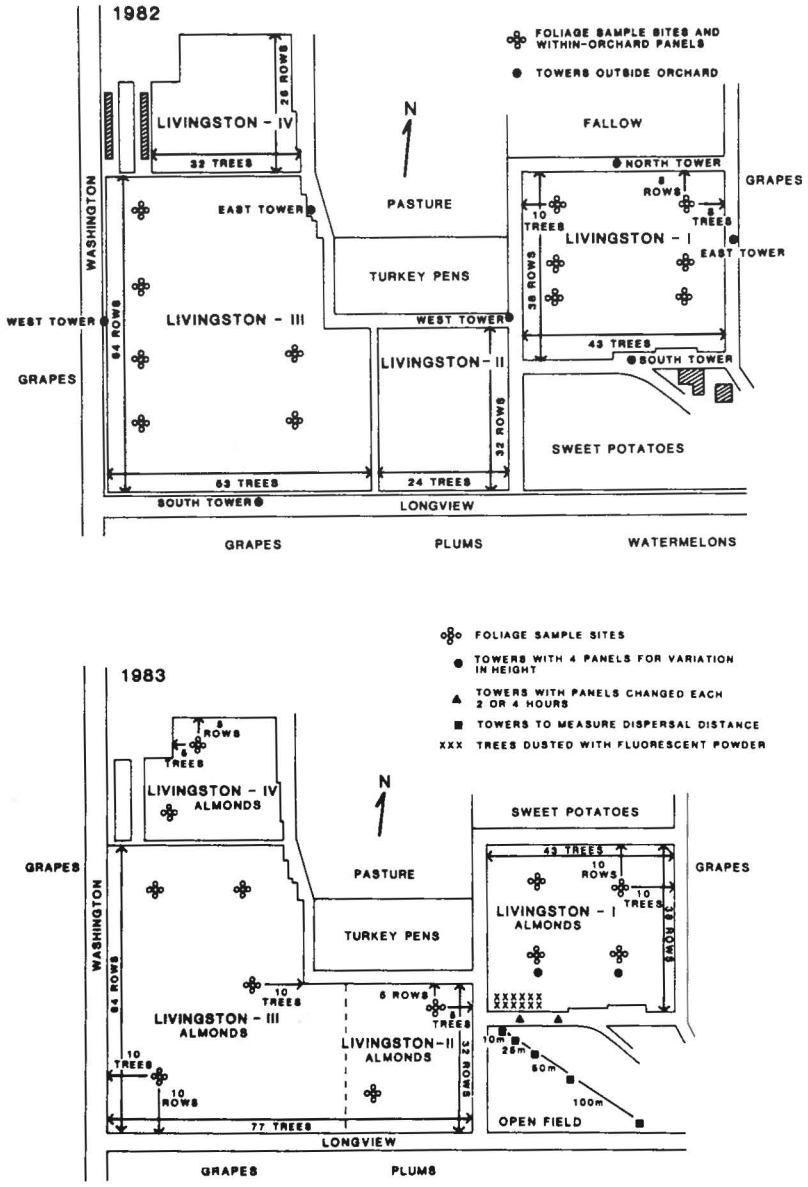

Fig. 1. Map of Livingston-I and Livingston-III almond orchards and surrounding area with foliage sample sites, and panel locations within and without the 2 orchards in 1982 (top) and 1983 (bottom).

the mean number of mites on foliage with those on the panels, the number on the panel was divided by 7.5, as this is the approximate ratio between an almond leaf and the panel.

Aerial sampling methods - 1983

Greased panels were placed inside and outside the Livingston-I orchard during July 18–25 and July 25–August 1. Clear perspex sheets (122 × 49.5 cm (0.604 m^2)) were nailed to wooden frames and coated with a thin film of gear box oil (SAE 140) on one side only using a 15.2 cm rubber roller (Printmaster). Panels of the same size were used once in each of the 3 experiments described below, as after removal they were cut into 40 strips each 3 × 49.5 cm and spider mites and predators were counted using a dissecting microscope.

Diurnal patterns of dispersal. To learn if mites disperse randomly during the day, a panel was placed on each of 2 towers 6.1 m tall. The towers were located 8 m south of the first row of trees (Fig. 1); a panel extended down 1.22 m from the top of the tower with the greased side oriented towards the orchard. Panels were replaced every 2 h for 24 h during July 18–19 and every 4 h for 48 h during July 25–27. Every time the panels were changed, weather data (temperature, relative humidity, wind speed, and wind direction) were collected.

Variability in numbers collected at different heights. During 1982, the panels suspended at 2 heights within the orchard did not sample the canopy top. Since dispersing spider mites and scale insects are positively phototropic and negatively geotropic (Washburn & Washburn, 1984), we wondered if *M. occidentalis* dispersed from the tree tops. To test this, 4 perspex panels were placed 2.8, 4.6, 7.3, and 10.8 m above ground level on each of 2 towers inside the Livingston-I orchard. The towers were located between 2 rows of trees (Fig. 1). The panel located 7.3 m above ground level was near and the panel 10.8 m above ground was above the canopy. Panels were oriented so that the greased surface faced northwest (in the direction of the prevailing winds), were left in the orchard for 7 days, and replaced once for a second week of trapping.

Dispersal distance. Two rows of 5 trees in the southwest corner of the Livingston-I orchard were dusted with fluorescent powder according to the method described by Brandenburg & Kennedy (1982). Dust (0.9 kg) was applied twice, once a week, using a 2-stroke powder duster. Spider mites and *M. occidentalis* trapped on the greased panels during the subsequent week were examined for the dust using an UV light. Because the mites were inadequately marked the panels were cut in strips and the mites were counted under dissecting microscope. Mites were trapped on 5 panels, each placed vertically 6.1 m above the ground on a tower, with the panel extending downward 122 cm. The 5 towers were placed in a diagonal line across an open field and were 15, 25, 50, 100, and 200 m southeast of the dusted trees (Fig. 1).

Survey for carbaryl resistance in surrounding almond orchards. Almond orchards surrounding the Livingston release sites (Fig. 1) were examined during July 19–26, 1983 for *M. occidentalis* to obtain colonies that could be tested for their carbaryl resistance levels. Since native *M. occidentalis* colonies characteristically exhibit no carbaryl resistance, the presence of even low levels of carbaryl resistance in these colonies would support the hypothesis that the resistant strain has dispersed from the release sites into surrounding orchards (Hoy, 1982; Roush, 1979; Roush & Hoy, 1981; Hoy, unpubl.). Fifteen colonies were obtained from sites within a radius of 4827 m (3 miles) with founding numbers ranging from 3 to 26, averaging 10 individuals. The colonies were kept until 40–50 gravid ♀♀ could be tested, 5/disc, on pinto bean leaf discs (*Phaseolus vulgaris*), sprayed with 2.4 g a.i. carbaryl/l distilled water. The carbaryl-OP resistant laboratory colony and a carbaryl-susceptible laboratory colony (WA-33 or Immature Selection-37) were tested at the same time as controls. Susceptible colonies, whether freshly collected from the field or maintained in the laboratory, typically have 0–4% survival rates at this test dose, while the resistant colony typically has a 70–85% survival rate. In addition, 20 ♀♀ from each colony were tested with water as a check of handling mortality or disease.

Survival of M. occidentalis *at high temperatures.* Previous laboratory and field studies indicated that hungry, newly-mated *M. occidentalis* females are the primary dispersants (Field, 1981; Hoy, 1982, unpubl.) Dispersing predator ♀♀ must survive high temperatures and low relative humidities in the San Joaquin Valley during July and August, and we wondered how long they could survive these harsh conditions. Female deutonymphs of the carbaryl-OP-sulfur resistant colony were individually isolated with a ♂ on senescing pinto bean leaf discs densely populated with *T. urticae* as prey. As soon as the ♀♀ mated, they were moved to a paraffin-coated paper disc without prey for 24 h at 25 °C and 60–70% R.H. Five hungry ♀♀ were slide-mounted ventral side up on sticky tape using the method developed for toxicity tests (described by Hoy & Knop, 1979), and placed into a temperature cabinet (Percival I-30 B) and held 12, 24, 36, and 48 h at

30°C and 6 h at 35° and 40°C. Each temperature and duration was replicated 4 or 5 times (20 or 25 ♀♀ total) for each temperature and duration tested. Equal numbers of ♀♀ were used as controls at each temperature and duration but placed into boxes with 80–90% R.H. The proportion surviving was recorded at the end of each test interval, as once the ♀♀ were placed in the desiccator it was not opened until time to score.

Results and discussion

Movements out of orchards in 1982. Three species of spider mites were trapped on panels outside the 2 orchards in 1982. They were *Tetranychus pacificus* (relative abundance = ca. 60%), *T. urticae* (10%), and *Panonychus ulmi* (30%).

Both spider mites and *M. occidentalis* left the Livingston-I orchard primarily on the south and east sides of the orchard throughout the season (Table 1). Ca. 92% of the spider mites and 94% of the predators were trapped on panels outside the Livingston-I orchard on the south and east towers. Similarly, 96 and 82% of the spider mites and *M. occidentalis*, respectively, were trapped on the panels located on the south and east towers outside the Livingston-III orchard (Table 2). During the summer the prevailing winds in this area of the San Joaquin Valley are from the northwest; thus, it appears that much of the aerial dispersal of both spider mites and *M. occidentalis* out of these 2 orchards is via the prevailing winds. More than 80% of the spider mites and predators trapped on the greased panels were adult ♀♀. There were no consistent statistical differences in the numbers of mites

Table 1. Spider mites and *M. occidentalis* leaving the Livingston-I orchard, 1982.

Date panels placed on towers 1982	Mean spider mites (S.D.) trapped/panel located on the				Mean M. occidentalis (S.D.) trapped/panel located on the			
	North	South	East	West	North	South	East	West
		side of the orchard[1]				side of the orchard[1]		
May 5	0 (0)	-	-	-	0 (0)	-	-	-
11	0.3 (0.8)	-	-	0	0 (0)	-	-	-
19	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
June 2	0 (0)	0.2 (0.4)	0 (0)	0.2 (0.4)	0 (0)	0 (0)	0 (0)	0 (0)
16	0.2 (0.4)	0.2 (0.4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
July 7[2]	0.5b (0.8)	2.5a (2.4)	0.5b (0.8)	0.2b (0.4)	0 (0)	0.2 (0.4)	0 (0)	0 (0)
14[2]	3.2b (0.9)	73.3a (42.0)	8.7b (3.6)	8.7b (2.7)	0.8 (0.9)	1.3 (1.4)	0.3 (0.5)	0 (0)
28[2]	-	104.8a (36.2)	7.7b (4.4)	6.8b (2.1)	-	2.8a (2.0)	0.8b (0.4)	0.5b (0.8)
Aug. 4[2]	1.5b (1.4)	100.7a (76.3)	5.3b (2.1)	3.0b (2.8)	0.2b (0.4)	5.3a (3.8)	2.0b (1.4)	0.2b (0.4)
11[2]	0.3 (0.5)	9.0 (3.1)	10.3 (12.5)	0.2 (0.4)	0b (0)	9.8a (1.5)	10.7a (13.4)	0.2b (0.4)
20[2]	0b (0)	4.00a (2.5)	0.8b (2.1)	0b (0)	0b (0)	1.0a (0.7)	0.2b (0.4)	0b (0)

[1] Mites trapped on 6 panels (175 x 75 mm) facing the orchard on towers at each site.
[2] Means significantly different at the 5% level when tested with one way ANOVA.

Table 2. Spider mites and *M. occidentalis* leaving the Livingston III-orchard.

Date panels placed on towers 1982	Mean spider mites (S.D.) trapped/ panel located on the South side of the orchard[1]	East	West	Mean M. occidentalis (S.D.) trapped/ panel located on the South side of the orchard[1]	East	West
May 26	0.3 (0.8)	0.3 (0.8)	0 (0)	0 (0)	0 (0)	0 (0)
June 2	0.2 (0.4)	0.2 (0.4)	0 (0)	0 (0)	0 (0)	0 (0)
16	0.3 (0.5)	0.3 (0.5)	0.2 (0.4)	0 (0)	0 (0)	0 (0)
23[2,3]	8.0a (2.1)	2.2b (2.1)	0.8b (1.5)	0.2 (0.4)	0 (0)	0 (0)
July 1[2]	34.2a (30.9)	6.8b (3.3)	1.0b (0.6)	0 (0)	0.2 (0.4)	0 (0)
7[2]	58.0a (43.2)	19.2b (9.7)	1.7b (2.2)	0 (0)	0 (0)	0 (0)
14[2]	61.2a (32.3)	78.7a (28.4)	4.3b (3.8)	6.7a (3.9)	2.0b (2.3)	0b (0)
21[2]	66.3b (42.1)	196.0a (47.0)	2.8b (2.5)	13.3ab (8.7)	7.0ab (3.5)	0.2bc (0.4)
28[2]	29.8b (24.6)	693.0a (324.2)	27.0b (16.0)	22.2b (17.1)	101.5a (21.4)	5.2b (4.1)
Aug. 11	0.8 (1.5)	1.0 (1.0)	0.8 (1.2)	0.5 (0.5)	2.3 (1.8)	0 (0)

[1] Mites were trapped on 6 panels (175 x 75 mm) facing the orchard on towers at each site.
[2] Means significantly different at the 5% level when tested with one way ANOVA.
[3] Spider mite means of June 23 were transformed to log (n + 1) due to a lack of homogeneity of variances.

trapped on the panels at the 3 heights on the towers outside the orchard, so the data are pooled in Tables 1 and 2.

The correlation coefficient for the number of spider mites on foliage (all active stages) vs. the number trapped on the panels (primarily adult females) is 0.609 (S.E. = 25.93, $P \leqslant 0.001$) for the Livingston-I orchard and 0.308 (S.E. = 10.00, $P \leqslant 0.001$) for the Livingston-III orchard. Few spider mites were trapped until after early July (Tables 1, 2, Fig. 2). The fact that aerial dispersal peaked in July in both orchards, even though spider mite densities were different, suggests that factors other than density may also influence aerial dispersal. One such factor could be the almond tree physiology. For example, hullsplit typically occurs during the first week of July in San Joaquin Valley almonds and this major event could be associated with substantial physiological changes in the foliage.

Dispersal of *M. occidentalis* was correlated with the density of active stages of predators on the foliage in the Livingston-I almond orchard ($r = 0.619$, S.E. = 1.6). Peak density of ♀♀ on the panels lagged behind the peak density on the foliage by about one week (Table 1). The correlation between the numbers of predators on foliage and on the panels was lower in the Livingston-III orchard ($r = 0.067$, S.E. = 1.487). Little dispersal occurred in this orchard until July 21, whereas densities on the foliage were high during late June and early July (Table 2). The lag in the numbers of predators trapped on panels could be due in part to the fact that nymphs as well as adults were sampled on foliage while ♀♀ primarily were trapped on the panels.

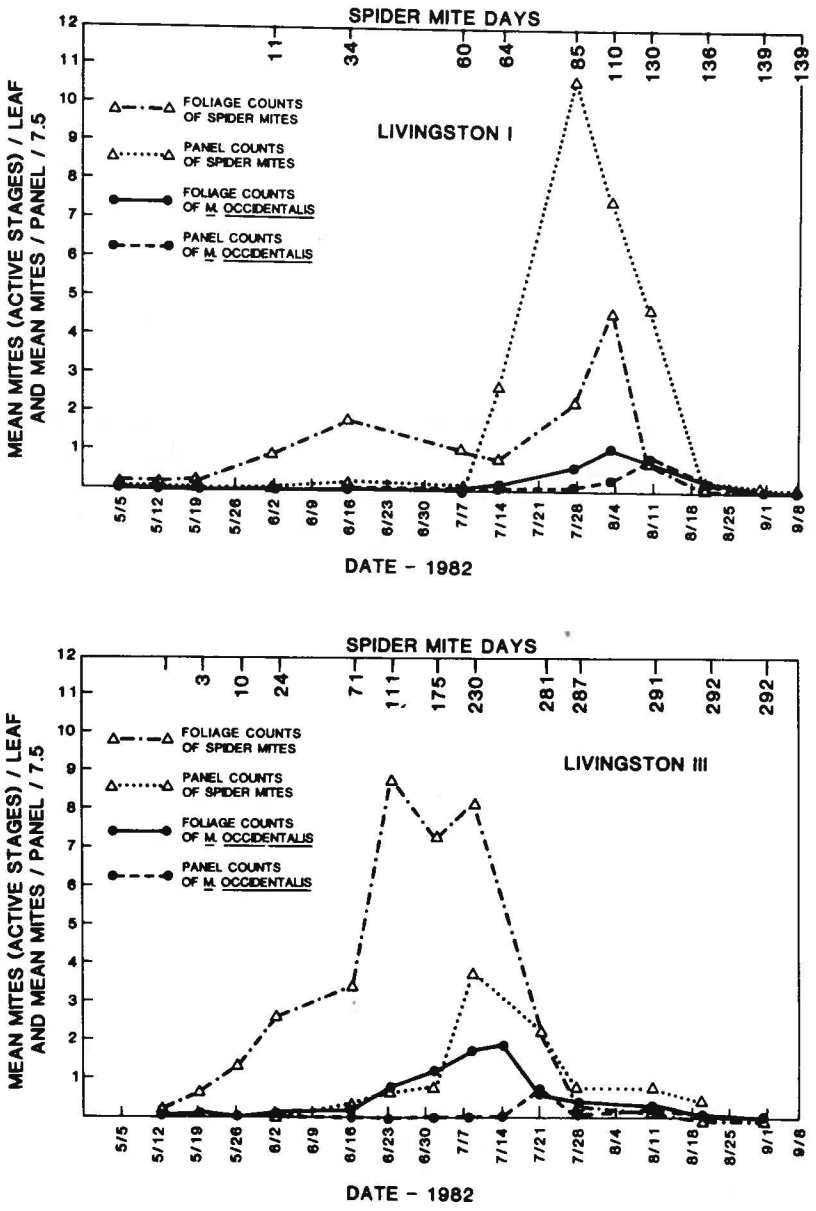

Fig. 2. Comparison of mean number spider mites and *M. occidentalis* on foliage (active stages) and on greased panels (primarily females) in the Livingston-I (top) and III (bottom) orchards during 1982. No. mites on panels divided by 7.5 to correspond to almond leaf area.

Large numbers of spider mites left the 2 orchards during 1982 (Tables 1, 2). To obtain a conservative estimate of the number of spider mites and predators leaving each side of the orchard over the season, we assumed a) that the number of mites trapped on the small panels (76 × 175 mm) were directly proportional to the number leaving the surface area of the side of the orchard and 5) that the number leaving the top of the orchard was negligible (which is unlikely). If these assumptions are followed then about 170 million spider mites left the Livingston-I orchard over the season on the south side of this 5.7 ha orchard, which measured 196.6 × 3.7 m in length and height, and 30 million

left on the east side of the orchard, for a total of 200 million spider mites. Using the same assumptions, an estimated 230 and 1100 million spider mites left the south and east sides, respectively, of the 18.2 ha Livingston-III orchard during 1982. These numbers could be sufficiently high to have an impact on certain surrounding orchards and vineyards if even 10% of the dispersing spider mites colonize a new site successfully. Thus, orchards or vineyards lacking predators and having low numbers of spider mites could be inoculated with spider mites.

These numbers are low estimates of spider mite dispersal, since it is not unusual for San Joaquin Valley almond orchards to have peak densities reaching 30–40/leaf in contrast to the peak of 9–11 in these 2 sites. Stabler (1913) showed that spider mites dispersed at least 200 m from almond orchards and he 'established the fact that red spiders are blown sufficient distances by the wind to make an infested orchard a menace to orchards within a reasonable distance.' Likewise, Brandenburg & Kennedy (1982) showed that 'Large populations of spider mites in field corn were found responsible for subsequent infestations in peanuts,' when these fields were adjacent.

However, it is likely that 200 or even 1100 million spider mites is only a small proportion of the total number of spider mites in many orchards or vineyards under normal circumstances. If we conservatively assume that over the season each leaf has only one spider mite, estimate that each almond tree has about 0.5 million leaves, there are 75 trees/acre, then an almond orchard might conservatively have 37.5 million spider mites/acre over a season. Under many circumstances the arrival of additional spider mites would probably be unnoticed. However, aerial inoculation might be very important if the mites coming into the orchard have a unique pesticide resistance, or if the orchard lacks predators and/or has very low densities of spider mites due to pesticide applications.

Using the same assumptions regarding aerial movements, approximately 8.1 and 8.3 million *M. occidentalis* left the south and east sides of the Livingston-I orchard over the season, respectively. Similarly, about 40 and 97 million predators left the larger Livingston-III orchard during 1982. These predators could provide an inoculum for surrounding orchards or vineyards if survival is high and the dispersal distances achieved are sufficient. Again, however, the impact on the recipient orchard will depend upon the relative densities of the resident predator population. If the orchard lacks predators, immigration of the resistant strain could be significant. If the recipient orchard has high densities of susceptible native predators then the gene frequency of the resistance gene would remain very small unless relevant pesticides were used as a selective agent.

Movements into the orchards in 1982. The panels with the greased surfaces facing away from the orchard nearly always trapped significantly fewer mites than the traps facing the orchard on the same dates during 1982. Thus, there appears to be 2.5 to 28-fold difference in the number of *M. occidentalis* entering and leaving the Livingston-I orchard over the season. The total number of *M. occidentalis* presumably entering the orchard that was trapped on the 6 panels facing away from the south side of the Livingston-I orchard was 22; 2 were trapped on panels facing west, none on panels facing north, and 3 were trapped on panels facing east over the season. In contrast, a total of 103, 5, 6, and 84 females were trapped on panels facing toward the south, west, north, and east sides of the orchard, respectively, and presumably represent the proportion leaving the orchard. These data suggest that relatively few pesticide-susceptible *M. occidentalis* entered the Livingston-I orchard. Similar results were obtained with the Livingston-III orchard, where the number leaving apparently outnumbered the number entering by ratios of 3.8 to 8.4. *M. occidentalis* were trapped on panels facing away from the orchard on the south, west, and east of Livingston-III in the following numbers: 71, 39, and 68, suggesting these mites were entering the orchard. In contrast, 276, 163, and 569 predators left this orchard over the 1982 season and were trapped on the panels on the south, west, and east sides of the orchard, respectively.

There is however, a correlation between the number of predators trapped on the panels facing toward and away from the orchard at each of the tower sites (compass directions). Thus, if high densities left the orchard on the south side of the orchard, comparably high numbers were trapped on panels facing away from the orchard. These traps were used to estimate the number of predators entering the orchard. If the mites disperse primarily

on the prevailing winds, then proportionally more should have been trapped on the panels facing north and west. This suggests that the traps facing away from the orchard actually measure the relative densities of predators in the air at the time, and the number impinging on the panels facing away from the orchard are not a reliable estimator of the number actually coming into the orchard. We suspect that eddy effects allowed outgoing predators (and spider mites) to be trapped on the panels facing away from the orchard, thus overestimating the numbers entering the orchard from distant orchards or vineyards.

Movements inside the orchards. The traps suspended between 2 rows of trees within the 2 Living-

Table 3. Movement of spider mites and *M. occidentalis* with the Livingston-I almond orchard during 1982.

Date panels placed on towers 1982	Mean spider mites (S.D.) trapped/panel facing				Mean M. occidentalis (S.D.) trapped/ panel facing			
	North	South	East	West[1]	North	South	East	West[1]
Apr. 22	-	-	0 (0)	0 (0)	-	-	0 (0)	0 (0)
28	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
May 5	0.3 (1.0)	0.9 (3.2)	0.1 (0.3)	0.1 (0.5)	0 (0)	0 (0)	0 (0)	0 (0)
11	0 (0)	0 (0)	0 (0.2)	0 (0.2)	0 (0)	0 (0)	0 (0)	0 (0)
19	0 (0)	0 (0.2)	0 (0.2)	0 (0.2)	0.1 (0.3)	0 (0.2)	0 (0)	0 (0)
June 2	2.2 (1.9)	2.7 (4.0)	1.7 (1.7)	2.2 (1.5)	0 (0)	0 (0)	0 (0)	0 (0)
16	1.8 (2.2)	1.4 (1.8)	0.8 (1.2)	1.3 (1.4)	0 (0)	0 (0)	0 (0)	0 (0)
July 7[2]	23.0 (22.6)	16.3 (19.3)	19.5 (22.9)	24.6 (28.1)	0.4ab (1.1)	0.2ab (0.8)	0b (0.9)	0.7a (0.9)
14[2]	66.2 (83.3)	63.4 (90.5)	66.3 (101.3)	80.3 (116.8)	0.7ab (1.1)	0.3b (0.9)	0.2b (1.0)	1.0a (1.1)
28[3]	58.5 (80.2)	48.3 (43.8)	50.5 (67.1)	75.0 (108.7)	3.0 (3.4)	2.5 (2.8)	2.5 (3.0)	2.7 (3.1)
Aug. 4[2,3]	44.5 (56.4)	25.6 (21.1)	32.7 (25.0)	44.1 (57.0)	8.1a (6.7)	5.8c (5.5)	6.5bc (6.8)	7.0ab (6.7)
11[2,3]	2.0a (1.9)	1.0b (1.1)	1.6ab (1.9)	1.8ab (2.1)	3.6a (3.1)	1.3b (2.5)	1.3b (2.1)	4.0a (3.2)
20[3]	1.8 (4.3)	0.3 (0.8)	0.4 (1.0)	1.8 (4.3)	0.6 (1.3)	0.3 (1.0)	0.3 (0.8)	0.3 (0.9)
Sept. 1[3]	0.4 (1.0)	0.2 (0.5)	0.2 (0.5)	0.3 (0.7)	0 (0.2)	0 (0.2)	0 (0.2)	0.1 (0.3)

[1] Mites were trapped on 16 panels (175 x 75 mm) at each of 6 sites; at each site, 4 panels each faced north, south, east and west.
[2] Means significantly different at the 5% level when tested with a one way ANOVA.
[3] Spider mite counts during July 28-Sept. 1 were tested using log (n + 1) transformation due to lack of homogeneity of variance.

ston orchards during 1982 were located at 2 heights and oriented to trap mites coming from all 4 compass directions. Unlike the results with the traps located on towers outside the orchard, consistent differences in the number of mites trapped on panels oriented north, south, east, or west did not occur (Tables 3 & 4). Some significant differences were found on certain sample dates, however, which suggests that the prevailing winds from the northwest sometimes do influence the movement of mites inside the orchard. However, it appears that wind turbulence within the orchard is more important than the prevailing wind direction, and both spider mite and predator movements within the orchard were relatively uniform. No consistent differences were found in numbers of mites trapped at the 2 heights within the orchard, so the data are pooled in Tables 3 & 4.

Diurnal patterns of dispersal. Neither spider mites (*P. ulmi* and *T. pacificus*) nor *M. occidentalis* dispersed uniformly throughout the day, based on the sampling conducted during 18–19 July 1983 (Fig. 3). During 1983, most of the spider mites sampled were *P. ulmi*, with only a few *T. pacificus* collected. Most dispersal occurred during the 16–22 h interval. Temperatures declined from 30 to 22.5 °C, relative humidity increased from 30 to 46%, and average wind speed increased (Fig. 3). A similar pattern was observed during the second sampling interval (July 25–27), but the absolute number of mites trapped were very low, so they are not graphed. Because so few were trapped during the second week, we have too few replicates to determine if the dispersal pattern observed is typical.

There were no gross, order of magnitude, differences in the numbers of *P. ulmi* and *M. occidentalis*

Table 4. Movement of spider mites and *M. occidentalis* within Livingston-III almond orchard.

Date panels placed on towers 1982	Mean spider mites (S.D.) trapped/panel facing				Mean M. occidentalis (S.D.) trapped/panel facing			
	North	South	East	West[1]	North	South	East	West[1]
May 26	0 (0)	0 (0)	0.2 (0.5)	0.1 (0.3)	0 (0)	0 (0)	0 (0)	0 (0)
June 2	2.7 (3.4)	1.5 (2.3)	1.7 (2.2)	2.0 (2.6)	0 (0)	0 (0.1)	0 (0)	0 (0)
16	5.0 (3.7)	4.6 (5.2)	5.1 (5.0)	6.0 (5.1)	0 (0.1)	0 (0.1)	0 (0)	0 (0)
23	5.8 (4.9)	5.2 (5.7)	5.8 (5.5)	7.7 (6.5)	0 (0)	0.2 (0.4)	0.2 (0.6)	0.2 (0.4)
July 1	32.5 (26.0)	28.1 (21.9)	26.8 (15.9)	29.3 (20.4)	1.0 (1.5)	0.3 (0.5)	0.5 (0.9)	1.0 (1.5)
7	-	-	-	-	1.5 (2.5)	0.4 (0.6)	0.5 (0.6)	0.7 (0.9)
14	15.3 (16.5)	15.7 (16.1)	20.3 (23.4)	23.4 (24.2)	2.5 (2.9)	3.1 (3.4)	2.0 (2.4)	3.4 (2.6)
21	7.9 (9.5)	5.9 (11.7)	4.5 (5.2)	7.1 (8.6)	1.5 (1.5)	0.9 (1.4)	0.6 (1.3)	1.7 (1.9)
28	7.5 (8.4)	4.9 (7.3)	5.2 (6.6)	7.4 (8.5)	3.7 (3.4)	4.0 (5.7)	3.1 (3.8)	2.7 (2.5)
Aug. 11[2]	0.4 (0.6)	8.5b (0.7)	0.5b (1.2)	1.3a (1.7)	0.5 (0.8)	0.3 (0.5)	0.4 (0.7)	0.6 (1.3)

[1] Mites were trapped on 16 panels (175 x 75 mm) at each of 6 sites; at each site, 4 panels each faced north, south, east and west.
[2] Means significantly different at the 5% level when tested with a one way ANOVA.

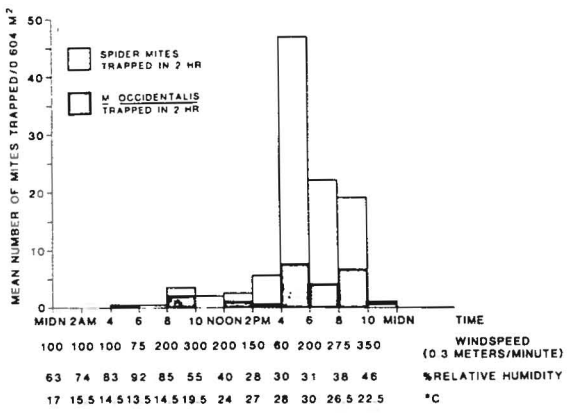

Fig. 3. Dispersal of spider mites and *M. occidentalis* every 2 h during July 18–19, 1983 outside the Livingston-I almond orchard.

trapped at 2.75, 4.6, 7.3 or 10.8 m within the orchard (Table 5). This suggests that traps located at any height within the orchard are equally good estimates of *relative* dispersal densities. Thus there is no evidence that exceptionally large numbers of mites disperse out of the top of the almond tree. The two towers (east and west, Fig. 1) were expected to provide comparable data. However, the numbers of spider mites and predators trapped on the east tower was significantly greater than the number trapped on the west tower for both of the weeks sampled (Table 5).

Dispersal distance. Fluorescent dust was found on the greased panels 15, 25, 50, 100, and 200 m from the dusted trees. However, the dust particles were not associated with either spider mites or predators. The reasons for this are unknown as preliminary laboratory trials showed that predators could be so marked. Substantial numbers of spider mites and *M. occidentalis* were found 200 m away from the dusted site (Table 6), although we cannot be sure these mites came from the Livingston-I orchard. However, it is likely that the mites either came from the Livingston-I or II orchards, since these are the closest mite sources in the area (Fig. 1). Even if the mites came from the Livingston-II orchard, the nearest almond tree is at least 200 m away. Thus, these predators can move at least 200 m with prevailing winds of ca. 100–200 m/minute (Fig. 3). In fact, there is no apparent decline in the numbers of mites trapped on the most distant tower.

Survey for carbaryl resistance in surrounding almond orchards. Four of 15 colonies of *M. occidentalis* collected from almond orchards surrounding the Livingston release sites exhibited a measurable level of carbaryl resistance, suggesting that the released strain had successfully dispersed and established in these sites. Eleven colonies exhibited 0% survival when tested with 2.4 g carbaryl a.i./liter water. This is typical of native populations of *M. occidentalis* tested to date from California almond, apple, and pear orchards and vineyards (Roush, 1979; Roush & Hoy, 1981; Hoy, 1982). The colonies that exhibited 6, 6, 14, and 34% survival are south and east of the release orchards, as might be expected if aerial movements occur primarily with the prevailing winds from the northwest, and were collected ca. 800 m from the nearest release site. Resistant and susceptible laboratory colonies had 80 and 0% survival rates.

Table 5. Comparison of numbers of mites trapped at four heights within the Livingston-I almond orchard, 1983.

Date and tower location	Total number of mites on panels (m above ground)							
	2.75		4.6		7.3		10.8	
	SM	MO[1]	SM	MO	SM	MO	SM	MO
July 18–25								
East tower	224	70	178	30	302	95	408	67
West tower	132	28	222	38	283	72	188	42
July 25–Aug. 1								
East tower	166	14	168	28	662	64	320	40
West tower	10	0	11	3	5	2	15	3

[1]SM = total no. of spider mites/panel (0.604 m²); MO = total no. of *M. occidentalis*/panel.

Table 6. Spider mites and *M. occidentalis* trapped on panels south and east of fluorescent-dusted trees in the Livingston-I almond orchard, 1983.

Interval sampled	Distance (m) from dusted trees									
	15		25		50		100		200	
	SM[1]	MO	SM	MO	SM	MO	SM	MO	SM	MO
July 18–25	84	30	98	37	40	17	32	21	27	8
July 25–Aug. 1	41	23	34	11	26	15	18	7	64	19

[1]SM = total no. spider mites/panel (0.604 m^2); MO = total no. of *M. occidentalis*/panel.

Survial of M. occidentalis *at high temperatures.* Hungry, mated *M. occidentalis* females can survive for 6 h at 35 °C at 30% R.H., and more than 45% survive for 24 h at 30 °C and 30% R.H. (Table 7). This seems to be sufficiently long that aerial movements can result in successful colonization of nearby orchards and vineyards. These temperatures and relative humidity conditions are similar to those experienced during the July 1983 field experiments (Fig. 3).

General discussion

During 1981–83, large numbers of *M. occidentalis* and spider mites dispersed during July and early August, both within and out of the 2 almond orchards (Tables 1–4; Hoy, 1982). Aerial dispersal thus appears to provide a mechanism for between-tree, between-row, and longer range movements of both predator and prey in almonds. Stabler (1913) first observed aerial movements of spider mites in California almonds, and Fleschner *et al.* (1956), Boykin & Campbell (1983), Brandenburg & Kennedy (1982), and others have described large scale aerial movements of spider mites in other crops. Recognizing that such movements occur is important in pest management programs. Orchard 'hot spots' can serve as the infestation foci for the entire orchard, making spot treatments of spider mites highly justified, particularly when predator densities are low. Large scale aerial movements of spider mites could also explain the rapid infestations seen in several almond orchards in the tops of trees during July and August when densities during the preceding 2 weeks were exceptionally low (M. Hoy, unpubl.). These rapid population increases are attributable in part to the very high reproductive rate exhibited by spider mites in hot, dry conditions but they are probably due, in some cases, to immigration of large numbers of spider mites into the orchard from neighboring orchards with outbreak populations.

Table 7. Survival of hungry, newly-mated females of *M. occidentalis* at high temperatures at 30 and 80% R.H.

Test duration (hours)	Temp. ° C	Mean % survival at 30% R.H.[1]	(S.D.)	Mean % survival at 80% R.H.	(S.D.)
12	30	70	(26)	95	(10)
24	30	45	(20)	90	(12)
36	30	16	(26)	100	(0)
48	30	0	-	93	(12)
6	35	100	(0)	100	(0)
6	40	0	-	90	(12)

[1]Relative humidity controlled with saturated calcium chloride in a 3.75 l desiccator; 20 or 25 ♀♀ tested under each condition; desiccators were unopened until the test was complete.

Aerial movements of both spider mites and *M. occidentalis* are correlated with the densities of each on the foliage, but factors other than density may influence dispersal rate. Perhaps the tree's physiological status has an important role, as dispersal of spider mites occurred shortly after hull split in 2 almond orchards during 1982 and 1983. Whether unique temperature, relative humidity, or wind conditions occurred at this time is unknown. All of these factors are known to influence arthropod dispersal (Pedgley, 1982; Wellington, 1983).

M. occidentalis appears to have a dispersal strategy similar to that of spider mites. Spider mites are aerial planktors, having a low probability of reaching a new resource (Mitchell, 1970). To enhance colonization rate, both spider mites and *M. occi-*

dentalis compensate by having ♂♂ smaller than, and less abundant than, ♀♀ and thereby invest less biomass in the sex that does not disperse. Both spider mite and *M. occidentallis* ♀♀ mate very shortly after their emergence as adults, making the success of any subsequent colonization more likely. In the case of this parahaploid predator, immediate mating is particularly necessary as unmated ♀♀ cannot produce progeny (Hoy, 1979), a contrast to the situation in which unmated arrhenotokous spider mites can produce sons. Mitchell (1970) suggested that prior to dispersal spider mite reproduction would be stimulated so that a rapid increase in ♀♀ occurred within a short interval. Whether *M. occidentalis* alters its sex ratio or its reproductive rate prior to dispersal is unknown, but their reproductive rate in the presence of abundant prey is sufficiently high that rapid increases in the standing crop of ♀♀ occur rapidly. It is likely that, because *M. occidentalis* is an obligate predator, the absolute numbers of predator dispersants are always substantially lower than the number of spider mite dispersants from any particular site. This hypothesis is supported by the relative numbers of predators and spider mites trapped on panels during 3 years of sampling (Tables 1–4; Hoy, 1982).

In San Joaquin Valley almond orchards, movement out of the orchard appears to be primarily via prevaling winds from the northwest. Within the almond orchard, dispersal of spider mites and predators appears to be less dependent upon prevailing winds and more uniform, presumably due to complex wind patterns within the orchard. These movements within the orchard explain how pesticide-resistant predators released into a few trees within the orchard can spread throughout the orchard within a few weeks (Hoy, 1982; Pedgley, 1982).

There is no evidence that the majority of either spider mites or *M. occidentalis* moves to the tops of trees prior to dispersing; the numbers of spider mites and predators trapped on panels at 4 heights within the orchard did not differ. Dispersal of both spider mites and *M. occidentalis* during one 24-h interval did occur when weather conditions were optimal for survival; i.e. temperature decreased, relative humidity increased, and wind speed was low to moderate. Whether spider mites and *M. occidentalis* commonly disperse during late afternoon through early evening is unknown, but these conditions are common in the San Joaquin Valley during the summer, and dispersal at this time would have great selective value.

Large numbers of spider mites and lesser numbers of *M. occidentalis* dispersed out of the Livingston-I and III orchards over the 1982 and 1983 seasons. Despite this, almond orchards in a 0.5 mile radius surrounding the sites where the carbaryl-OP resistant *M. occidentalis* were released had no, or only low to moderate levels of, carbaryl resistance. Even assuming that the predators survived the requisite number of mins/h in the hot, dry air to arrive at a suitable host plant, a number of other conditions must be suitable if establishment is to occur. A colonizing predator must find prey; it must not suffer application of inappropriate pesticides (the carbaryl-OP or carbaryl-OP-sulfur resistant strains are susceptible to pyrethroid insecticides), and it must compete successfully with any native phytoseiid predators in the orchard. Even though acaricides such as cyhexatin or propargite are selective, full application rates of these could result in such low levels of prey, at least for several weeks, that starvation could occur particularly since *M. occidentalis* does not feed on pollen or nectar. Therefore, if an almond grower would like to establish the pesticide-resistant strains of *M. occidentalis* in his orchard, he should not rely on natural spread, as it appears to be too slow. Mass rearing and release is feasible, and is a more reliable method of establishment (Hoy *et al.*, 1982 a, b).

Conversely, movements of susceptible native *M. occidentalis* into these release sites appear to be sufficiently low that the pesticide-resistant strains should persist for at least several years. The ambiguity in the trap information (i.e., the correlation between high densities on panels facing both into and out of the south and east sides of the orchards) makes it difficult to estimate the number of predators coming into the orchard accurately, but the number must be very low in relation to the density already present. Other field data support this; the carbaryl-OP resistant strain was released into a Bakersfield orchard in 1979 and the carbaryl resistance level has not changed despite the fact that carbaryl was applied only once (in 1980) after the predators were released and the orchard is surrounded on 3 sides by almond orchards where the carbaryl-OP resistant strain was never released (Hoy, 1982; Hoy *et al.*, 1984). Carbaryl was not

applied during 1983 in the Livingston-I or III almond orchards, yet the resistance levels of the predators remain high to moderate. Thus, *available evidence* supports the hypothesis that dilution of the resistant strains, once established in the orchard, will not occur in significant amounts over a 1-4 year interval, which is the longest period these resistant strains have been evaluated. Persistence of the resistant strains, barring application of inappropriate pesticides, is sufficiently good that releases should be considered to provide permanent establishments.

Acknowledgments

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Résumé

Influence de la dispersion aérienne sur la persistance et la diffusion de Metaseiulus occidentalis *résistants aux insecticides dans les vergers d'amandiers en Californie*

La dispersion aérienne du phytoseïdae, *M. occidentalis* (Nesbitt), a été estimée comme élément de la lutte contre les populations résistantes aux insecticides établies dans les vergers de Californie. La dispersion maximale s'est produite fin juillet et début août en 1982 et 1983. La plupart des prédateurs (et des acariens) quittent les vergers avec les vents dominants du nordouest. Dans le verger, les vents dominants sont moins importants et la dispersion est généralement au hasard. Tant les acariens que les prédateurs se dispersaient au hasard par rapport à la taille des amandiers, mais les relevés sur 24 heures laissent supposer qu'il n'y a pas une distribution aléatoire pendant la journée. La plupart des mouvements aériens se produisirent entre 16 et 22 heures quand HR et vitesse du vent augmentaient et température diminuait. Les acariens et prédateurs ont été piégés sur des panneaux à 200 m du verger. Le contrôle des niveaux de résistance au carbaryl de *M. occidentalis*, récoltés dans les vergers d'amandiers entourant le point de lâcher, montre que les individus résistants se sont dispersés à au moins 800 m de 1981 à 1983. Cependant, les arboriculteurs souhaitant utiliser des souches résistantes devront les lâcher dans les vergers, car la dispersion naturelle est trop lente. La migration de *M. occidentalis* indigènes dans les lieux de lâcher est apparue suffisamment rare pour que la dilution des souches résistantes au carbaryl soit minime pendant 2 à 4 ans.

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19 December 1985

Dear Bob,

Enclosed is a draft manuscript that I did not include in my Almond Board Report. The MS is preliminary, as we are continuing some of our work. However, you can see why we are excited about both Apollo and Savey as potential acaricides for almond integrated mite management. I am hoping that these products can be registered quickly. They will fit into an IPM program well because they are essentially nontoxic to M.occidentalis and are also going to allow the predators to feed on dead eggs and actives. It will be important to use these products early in the season, but I believe that they are really important to almond IPM. In contrast, Thuringiensin and avermectin are much more toxic to both spider mites and M.occidentalis and it will require much more effort to learn how to use them selectively in the field.

Please call me if you have questions or want to discuss any aspects of my report or proposal. Thanks for a nice dinner in Fresno, and I look forward to a continuing joint effort.

Sincerely,

Marjorie

DRAFT

Selectivity of the Acaricides Clofentezine and Hexythiazox[1] to the Phytoseiid Predator *Metaseiulus occidentalis* (Nesbitt)

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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. Toxicity of both clofentezine and hexythiazox was very low to adult females, larvae and eggs of the predator. 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 hrs old) of T. pacificus and T. urticae Koch. However, both clofentezine and hexythiazox are less toxic to eggs of T. pacificus 49-72 hrs old than to younger eggs.

Footnotes

1/ Acarina: Phytoseiidae

INTRODUCTION

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 aimed at reducing 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 are in need of assistance, low rates of selective acaricides such as propargite and cyhexatin have been used to adjust these ratios, thereby reducing grower's costs (Headley and Hoy, in press; Hoy in press; Hoy 1984; Hoy et al. 1984). The useful life of these long-used selective acaricides could be limited if resistance develops 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 (Savy) are both ovicides; neither is considered to be an adulticide. Both are considered effective against several spider mite species, providing effective residual control. Preliminary field data from almonds and peaches suggest both might be selective for the western predatory mite, Metaseiulus occidentalis (Nesbitt) (R. Rice, Personal Communication; W.W. Barnett, Personal Communication). This paper compares the toxicity of these ovicides to M.occidentalis and to the Pacific spider mite, T.pacificus, a key pest of almonds in California. We tested eggs of T.urticae (Koch) and T.pacificus with clofentezine to determine whether this acaricide is equally toxic to eggs of these

two species and compared the toxicity of clofentezine and hexythiazox to different aged eggs of T. pacificus.

MATERIALS AND METHODS

Acaricides Tested

Clofentezine (Apollo), a tetrazine compound was obtained from Nor-Am Chemical Company in a 50% aqueous based flowable-suspension concentrate (SC) formulation. Application rates expected for use in almonds are 2-4 oz ai/acre, assuming 400 gallons are applied per acre (3.75-7.5 g ai/100 liters water assuming 1514 liters are applied her 0.404 hectare). The field rate was thus assumed to be 4 oz ai/100 gallon water (7.5 g ai/100 liters water), and rates 0.125, 0.25, 0.5, 1, 2 and 4 X 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 1.75-3.5 oz ai/acre, assuming 400 gallons are applied per acre (3.28-6.56 g ai/100 liters water). The field rate for these tests was thus assumed to be 3.5 oz ai/400 gallon water (6.56 g ai/100 liters water) per acre (0.404 hectare), and rates 0.125, 0.25, 0.5, 1, and 2 X the proposed field rate were tested.

All tests were conducted using freshly-prepared solutions in distilled water, at 25-27^0 C, 38-58 % relative humidity, 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, California in June 1984 and reared on bean plants (Phaseolus vulgaris (L)) in the greenhouse. It is resistant to cyhexatin (Hoy & Conley, unpublished). The T.urticae colony tested is a greenhouse colony that has been exposed to various pesticides in the past.

Adult females

Gravid M.occidentalis females were placed, 5 per bean leaf disc, on 10 bean leaf discs 2.1 cm in diameter for each dose. Each disc received a surplus of all stages of T.pacificus as prey before being sprayed with 0, 0.125, 0.25, 0.5, 1, and 2 X the proposed field rate of clofentezine or hexythiazox. Gravid T.pacificus females were tested in a similar way. The undersurface of the bean leaf discs containing the mites were sprayed to drip using a Crown Spray-Tool^{R}. Survival was recorded after 48 and 96 hrs. Fecundity was assessed by counting the number of eggs on each leaf disc after 48 hrs. Comparisons of the survival of T.pacificus and M.occidentalis at each rate was compared using a t-test. Survival and fecundity were analyzed using analysis of variance (ANOVA) and Duncan's multiple range test (Duncan 1955).

Larvae

Larvae of M.occidentalis were placed, 5 per bean leaf disc,

on 10 discs which had T.pacificus eggs sprayed with water or 1 X the field rate of clofentezine or hexythiazox. To obtain eggs of known age, T.pacificus females had been placed on the discs for 24 hrs and then removed. After the eggs were sprayed, M.occidentalis larvae were added. The number of larvae becoming adults after 96 hrs was determined and ANOVA was conducted to determine if larval survival differed from the water controls. In addition, the new adults were monitored after 144 hrs to be sure the females could deposit eggs.

Eggs

Adult females of T.pacificus and M.occidentalis were placed on bean leaf discs, allowed to deposit eggs for 24 hrs, and removed. The number of eggs were then adjusted to consist of 10 per disc on 10 discs for each rate tested. All stages of T.pacificus were added to discs with eggs of M.occidentalis and the mites and discs were then sprayed with 0, 0.125, 0.25, 0.5, 1, and 2 X the proposed field rates of clofentezine or hexythiazox. Clofentezine was also tested at 4 X the proposed field rate. Egg hatch and development to adulthood were assessed after 48, 96, and 144 hrs by recording the number of eggs, larvae, nymphs, and adults. Comparisons of the survival of T.pacificus and M.occidentalis at each rate were made using ANOVA and Duncan's multiple range test.

Comparative toxicity of clofentezine to T.urticae and T.pacificus eggs

Eggs of T.pacificus and T.urticae 0-24 hrs old were tested with 0, 0.5, 1 and 2 X the proposed field rate of clofentezine to determine if differences in sensitivity among these two species

exist. At each dose, 50 eggs were tested. The number of larvae and nymphs or adults on each disc was recorded after 192 hrs. 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 discs and removed after different times in order to obtain eggs 0-12, 13-24, 25-48 and 49-72 hrs old at 25-27°C. Eggs were removed to leave 10 eggs/disc, and 5 discs each were sprayed at the same time with water or 1 X the field rate of clofentezine or hexythiazox. The number of eggs that hatched and the number of larvae or nymphs was assessed after 144 hrs. ANOVA and Duncan's multiple range test were used to determine if there were differences in hatch and development compared to 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 females of T.pacificus and M.occidentalis. Survival after 96 hrs at 0, 0.125, 0.25, 0.5, 1 or 2 X the field rate of hexythiazox was 94, 90, 84, 88, 84, 86 % for M.occidentalis and 96, 78, 80, 78, 78, 72 % for T.pacificus, respectively. None are different. Survival of M.occidentalis females 96 hrs after treatment with clofentezine was

82.9, 82.9, 76.4, 82.9 and 65.8 % at 0, 0.25, 0.5, 1 and 2X the field rate and for T.pacificus, survival at these rates was 72.9, 75.7, 76.9, 70.0, and 71.4 %, respectively. None are different.

Egg deposition by hexythiazox-treated M.occidentalis females was influenced (Table 1). The number of eggs deposited by M.occidentalis females within 48 hrs ranged from a mean of 15.3 (±2.83) on leaf discs treated with water alone to 20.2 (± 5.05) for females treated with 2 X the field rate of hexythiazox. These differences are significant at the 5 % level (Table 1). The apparent increase in egg deposition by M.occidentalis females at all rates tested above 0.125 X the field rate is unexpected; we have no explanation for it. The number of eggs deposited by T.pacificus females averaged 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 of this enhanced egg deposition, we assessed the ability of these eggs deposited on dried residues to hatch after 192 hrs (Table 1). Hatch was dramatically reduced on discs treated with all rates of hexythiazox compared to the water controls. Thus, the residual activity of hexythiazox is substantial.

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 2 X the field rate. Egg deposition by clofentezine-treated T.pacificus females was not affected, averaging 58.6 (±14.6) to 61.2 (±20.7).

Effects on Eggs of M.occidentalis and T.pacificus

There were no significant effects of hexyathiazox or clofentezine on hatch of M.occidentalis eggs at any of the rates tested (Table 2). Once hatched, larvae successfully developed to nymphs and adults on the treated leaf discs; no significant differences in developmental success were observed at the rates tested.

Hexythiazox and clofentezine are toxic to eggs of T.pacificus (Table 2). At 0.5, 1 and 2X the field rates of hexythiazox, no eggs hatched. Hatch and development to the nymphal stage (26%) was observed at the 0.125 X field rate, but this was significantly reduced compared to that of the water control (80%). At the 0.25 X rate of hexiathiazox, 2% of the eggs successfully hatched and larvae reached the nymphal stage.

Clofentezine appears to be somewhat less toxic to T.pacificus eggs. After 96 hrs, 57, 37, 51, 42, 10 and 5% of the eggs had successfully hatched at the rates tested. T. pacificus nymphs were present within 144 hrs even at the 1, 2, and 4 X field rates (Table 2).

Comparative toxicity of clofentezine to T.pacificus and T.urticae eggs

No significant differences in sensitivity were found in eggs of T.pacificus and T.urticae at any of the rates tested. The number of nymphs and adults present after 192 hrs were not different (t-test). For T.pacificus, 82, 66, 20 and 30 % of the 50 eggs tested at each dose (0,0.5,1 and 2 X 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 on larvae of M.occidentalis reared on treated eggs

Larvae of M.occidentalis that were fed eggs of T.pacificus treated with water or 1 X the field rate of clofentezine or hexythiazox developed normally on this diet of killed eggs. After 96 hrs, 90, 92 and 90 % of the larvae tested on water, 1 X clofentezine, or 1 X hexythiazox, respecively, 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 and thus may be able to prevent resurgances of spider mite populations.

Toxicity to different aged eggs of T.pacificus

Clofentezine and hexythiazox are more toxic to young eggs of T.pacificus than they are to eggs 49-72 hrs old. Eggs (1-12 hrs old) treated with water or 1 X the field rate of clofentezine or hexythiazox yielded 66, 20 and 8 % nymphs within 144 hrs (Table 3). Eggs treated when 49-72 hrs old had equivalent numbers of nymphs after 144 hrs compared to the water control. Thus, both hexythiazox and clofentezine appear less toxic to eggs of T.pacificus that are near the time of hatch; this, too, would provide prey for M.occidentalis and could assist in maintaining populations of this predator in almond orchards.

RConclusions

Both hexythiazox and clofentezine are selective ovicides effective against T.urticae and T.pacificus and nearly nontoxic to the predatory mite M. occidentalis. The fact that these ovicides are not toxic to older eggs or active stages of spider mites means that long term retention of these predators may be possible since not all prey will be eliminated from the almond orchard. As such, these ovicides are particularly useful in an integrated mite management program where acaricides are applied only to adjust the predator:spider mite ratios.

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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 (x field rate) and species	Mean eggs deposited by 5 ♀♀ per disc within 48 hrs[1/] (± S.D.)		Mean eggs hatched (S.D.) per disc after 192 hrs[1/]	
	clofentezine	hexythiazox	clofentezine	hexythiazox
M. occidentalis				
0	16.7 (4.9)a	15.2 (2.8)a	-[2/]	-[2/]
0.125	-[2/]	15.4 (3.4)a	-	-
0.25	11.4 (4.7)bc	20.8 (2.8)b	-	-
0.5	8.8 (5.2)c	21.0 (5.0)b	-	-
1	13.3 (5.8)ab	20.1 (2.9)b	-	-
2	9.6 (6.3)bc	20.2 (5.0)b	-	-
T. pacificus				
0	58.6 (14.6)	23.7 (4.8)a	-	19.8 (4.5)a
0.125	-[2/]	21.0 (6.6)a	-	15.4 (5.7)b
0.25	57.6 (11.5)	20.5 (4.5)a	-	15.0 (5.9)b
0.5	53.2 (15.7)	27.7 (10.0)ab	-	9.7 (4.5)c
1	55.4 (18.0)	29.0 (7.4)ab	-	3.7 (3.7)d
2	61.2 (20.7)	32.9 (14.0)b	-	2.3 (1.8)d

1/ Means in each column for each species are significantly different (ANOVA) at $p \leq 0.05$, using Duncan's Multiple Range test if followed by different letters.

2/ Data not collected.

Table 2. Effects of clofentezine and hexythiazox on eggs (0 - 24 hrs old) of M. occidentalis and T. pacificus.

Doses (x field rate) and species	% hatched eggs after 96 hrs		% nymphs + adults after 144 hrs	
	clofentezine	hexythiazox	clofentezine	hexythiazox
M. occidentalis				
0	88	88	80	76
0.125	- [1/]	91	-	79
0.25	92	89	78	86
0.5	89	96	83	77
1	87	92	78	82
2	88	88	82	74
4	82	-	65	-
T. pacificus				
0	57 a [2/]	75 a	86 a	80 a
0.125	-	25 b	-	26 b
0.25	37 b	1.0 c	66 b	2.0 c
0.5	51 ab	0 c	72 b	0 c
1	42 ab	0 c	50 c	0 c
2	10 c	0 c	12 d	0 c
4	5 c	-	6 d	-

1/ Data not obtained.

2/ Letters after the number in each column for each species are significantly different ($p \leq 0.05$) using Duncan's Multiple Range test.

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

Age of eggs treated and pesticides (x field rate)	% larvae or nymphs within 144 hrs after treatment[a/]
0-12 hrs	
water control	66 a
clofentezine (1 x)	20 b
hexythiazox	8 b
13-24 hrs	
water	86 a
clofentezine (1 x)	30 b
hexythiazox (1 x)	14 b
25-48 hrs	
water	88 a
clofentezine (1 x)	84 a
hexythiazox (1 x)	64 b
49-72 hrs	
water	92
clofentezine (1 x)	74
hexythiazox (1 x)	72

a/ Numbers followed by the same letters within an age class of eggs are not significantly different ($p \leq 0.05$) (Duncan's (1955) multiple range test).