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INTEGRATING PESTICIDES AND BIOCONTROL OF MITES

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I dedicate this paper to Marjorie Hoy, William Barnett and Donald Flaherty, my former colleagues at the University of California

Integrated Orchard Management

Galendromus occidentalis feeding on *Tetranychus pacificus* and *Tetranychus urticae* in California orchards

Use least disruptive insecticides for control of pest species
Monitor for spider mites
Monitor for predators (including phytoseiids)
Use economic thresholds
Consider predator prey ratios before spraying for mites
Apply lower than label rates of selective acaricides
Release insecticide resistant *G. occidentalis* when needed

Background

In the 1980s, California tree fruit and nut growers relied primarily on azinphosmethyl and other organophosphates for insect control.

High degree of tolerance present in native *G. occidentalis* populations to organophosphates.

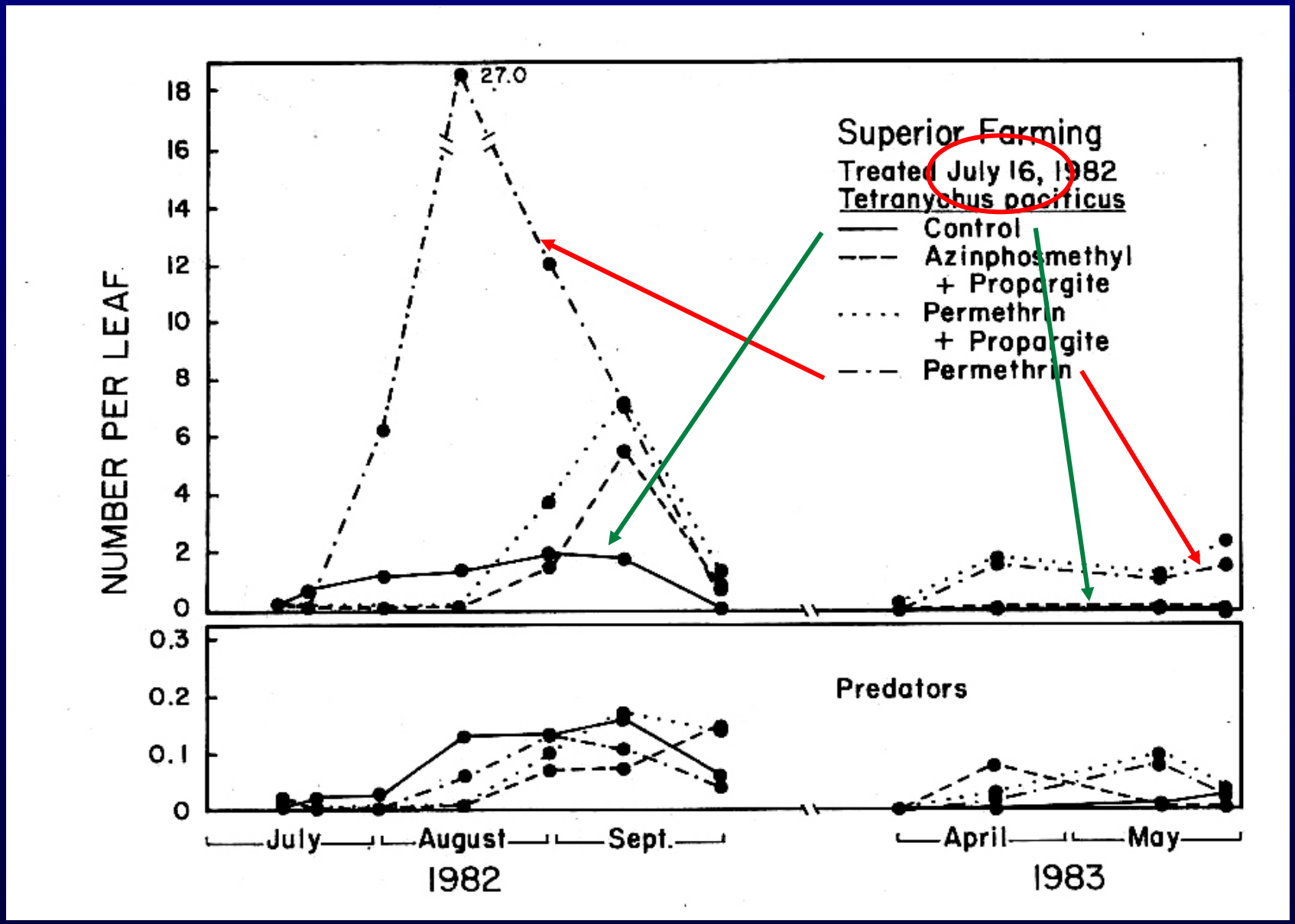
"Selective" acaricides available at that time included propargite, fenbutatin-oxide and cyhexatin which could be applied at lower than label rates to reduce densities of spider mites relative to predators.

Field observations of effect of registered insecticides on spider mite and *G. occidentalis* populations

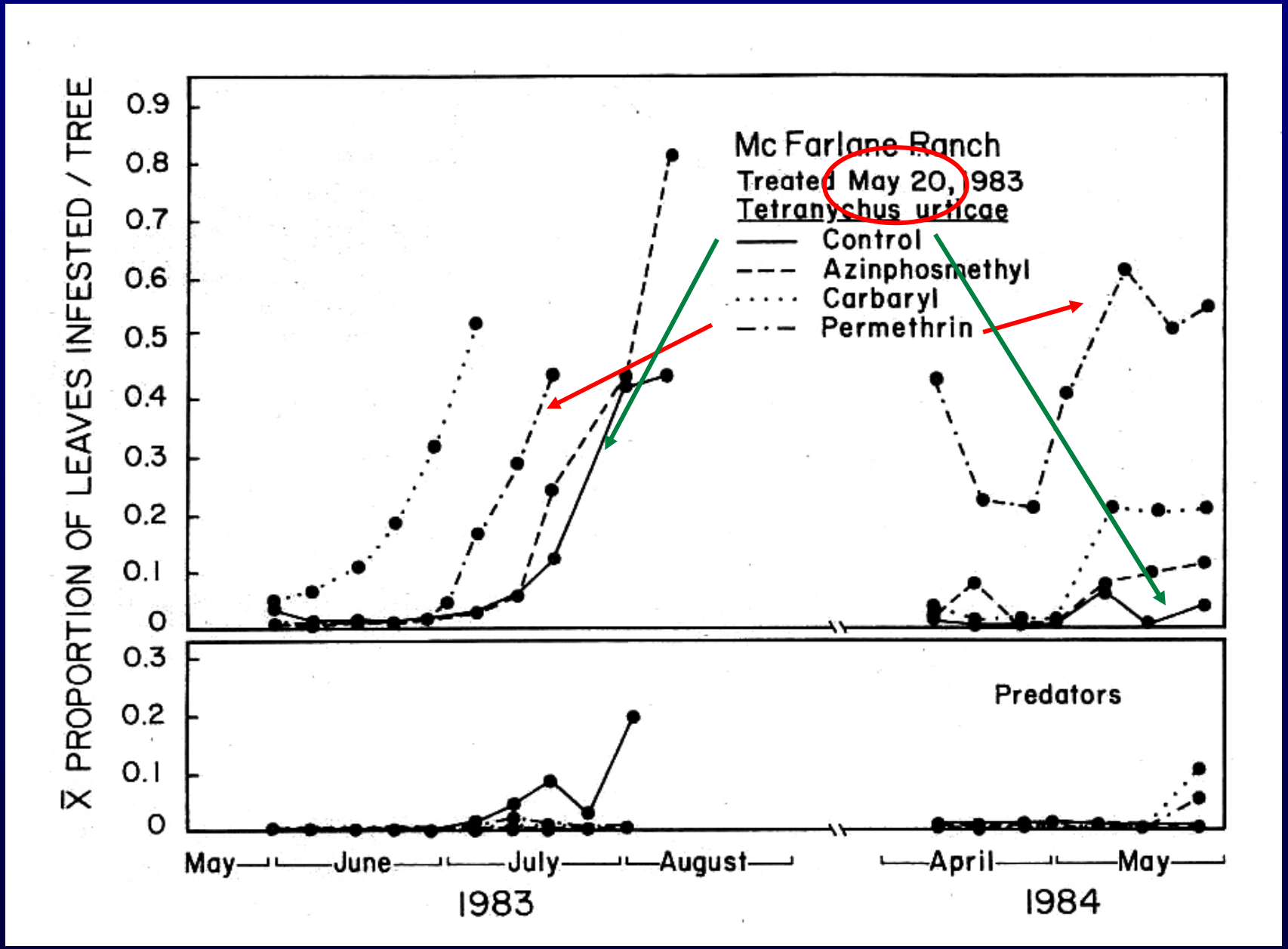
3 sites - Kern Co., Fresno Co., Butte Co.
3 insecticides - azinphosmethyl, carbaryl, permethrin
Weekly sampling for proportion of leaves infested

Bentley, W., F.G. Zalom, W.W. Barnett, and J.P. Sanderson. 1987. Population densities of *Tetranychus* spp. (Acari: Tetranychidae) after treatment with insecticides for *Amyelois transitella* (Lepidoptera: Pyralidae). J. Econ. Entomol. 80: 193-200.

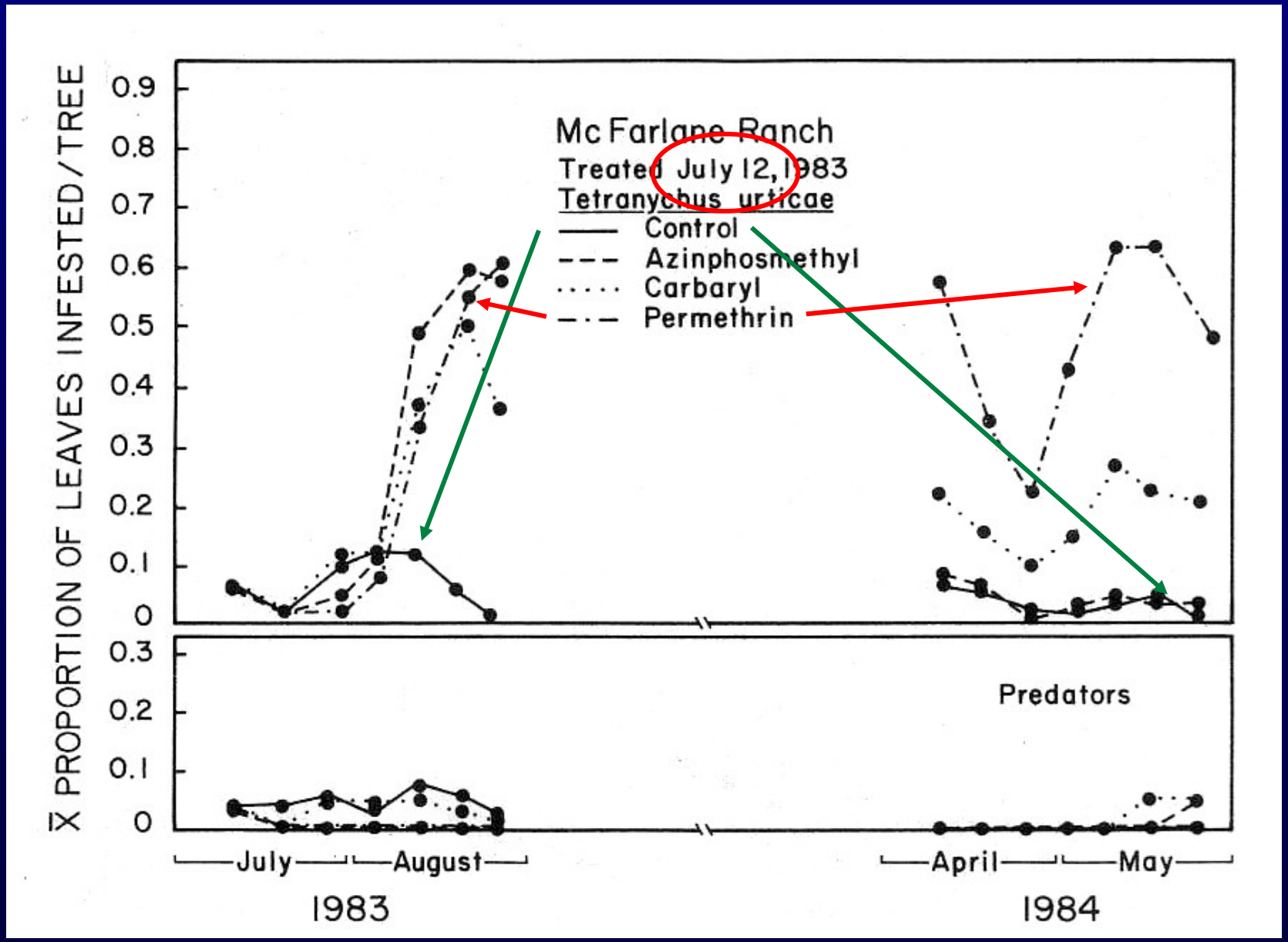
Mean number of *T.pacificus* and its predators per almond leaf



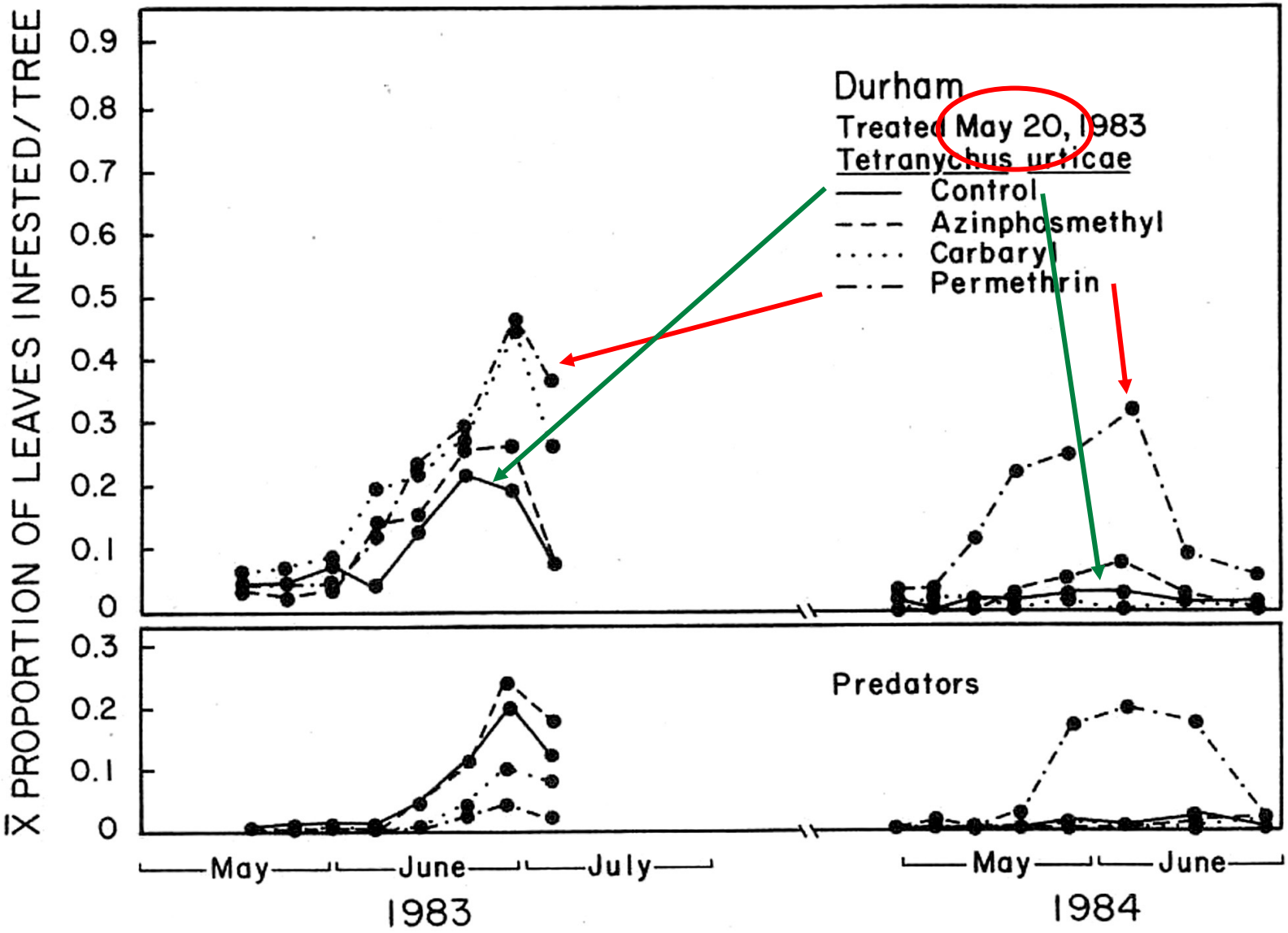
Mean number of *T.urticae* and its predators per almond leaf



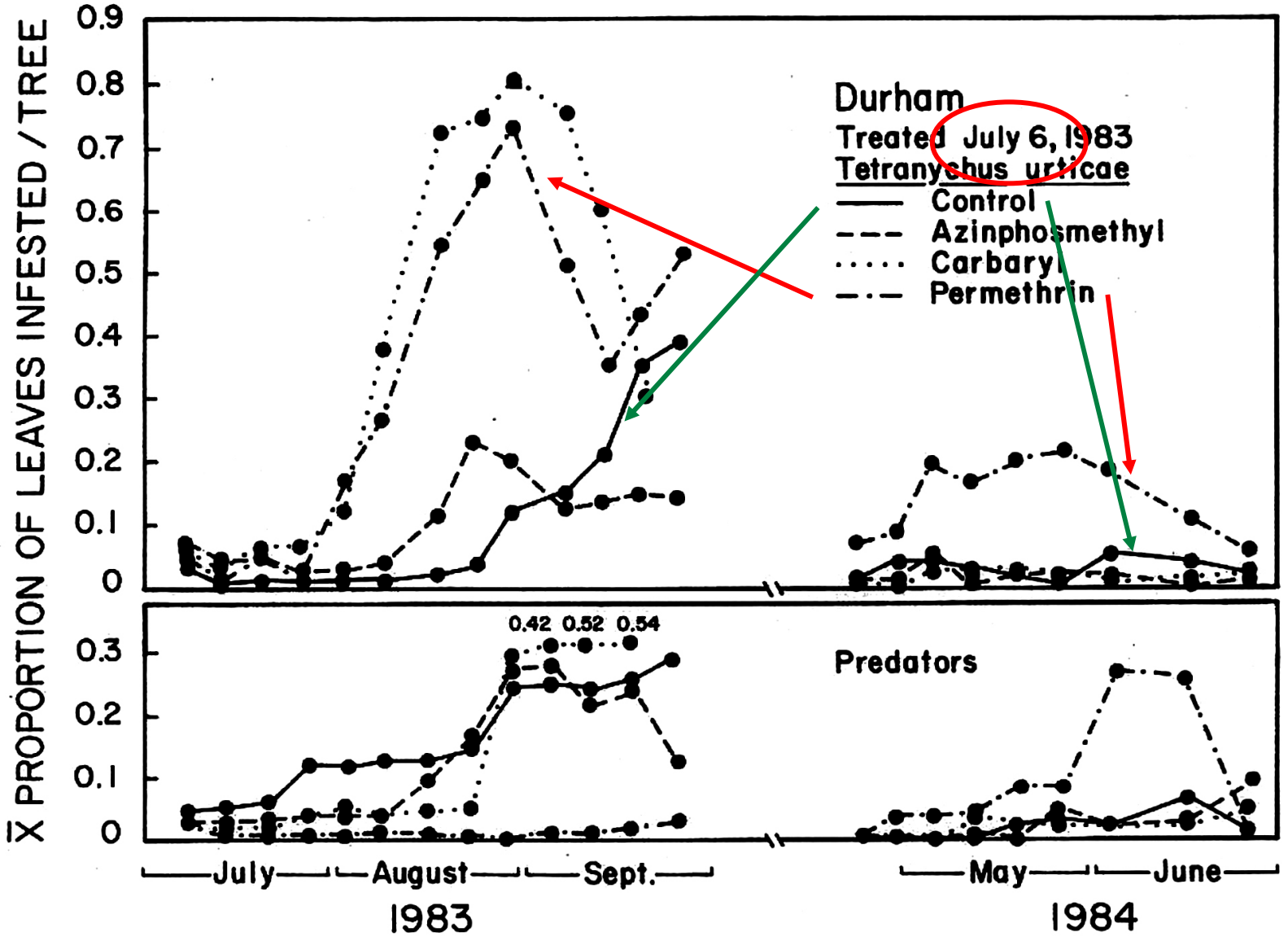
Mean number of *T.urticae* and its predators per almond leaf



Mean number of *T.urticae* and its predators per almond leaf



Mean number of *T.urticae* and its predators per almond leaf



Zalom, F. G., M. W. Stimmann, T. S. Arndt, D. B. Walsh, C. Pickel, and W. H. Krueger. 2001. Analysis of permethrin (*cis*- and *trans*- isomers) and esfenvalerate on almond twigs and effects of residues on the predator mite *Galendromus occidentalis* (Acari: Phytoseiidae). Environ. Entomol. 30: 70-75.

Pyrethroid bark residues - Methods

- Orchard was never previously treated
- Eight single tree replicates applied by handgun sprayer; randomized complete block design
- Untreated buffer trees between each treatment replicate
- Rates: esfenvalerate - 0.1 lbs ai per acre
  permethrin - 0.4 lbs ai per acre

Pyrethroid bark residues - Methods

Treatments

1. Esfenvalerate dormant spray only
2. Permethrin dormant spray only
3. Esfenvalerate dormant spray and hull-split spray
4. Permethrin dormant spray and hull-split spray
5. Esfenvalerate hull-split spray only
6. Permethrin hull-split spray only
7. Untreated

Dormant spray - February 3, 1995
Hull split spray - July 21, 1995

Pyrethroid bark residues - Methods

- Field samples (~ 4 cm) were cut from the trees and placed in washed canning jars
- Pruning implements washed with water and detergent between treatments and replicates
- Samples taken in February (just after dormant spraying), in July (just after hull-split spraying) and in August (at harvest, one month after hull-split spraying)
- Samples stored at -20°C until residue analysis
- Samples for bioassays used immediately

Pyrethroid bark residues - Residues

Residue analysis

- Twig surface area measured
- Twig sonicated in hexane to extract
- 1 µl aliquots were injected into the GC

Pyrethroid bark residues - Bioassays

- Twigs cut into 3.0 - 4.0 cm lengths, then cut in half lengthwise
- Five cut twigs of a single treatment placed onto moistened filter paper
- One replicate = 4 dishes (20 twigs in all)
- Four replicates of each treatment
- Two female *G. occidentalis* per twig
- *G. occidentalis* came from a colony established from field collections in the Sacramento Valley
- Predator survival evaluated 24 and 48 hrs after being transferred

Pyrethroid residues on field treated almond twigs from dormant season application

Esfenvalerate sample	ng/mm^2 esfenvalerate	ng/mm^2 total permethrin
2/3/95	0.84 ± 0.12	1.72 ± 0.49
7/21/95	0.28 ± 0.08	0.40 ± 0.27
	0.12 ± 0.04	0.26 ± 0.18

Application date 2/3/1995

Mean □ SD; each value = 4 samples run in duplicate

Percent survival of *Galendromus occidentalis* on pyrethroid treated almond twigs

Pesticide and timing	Percent survival corrected for control mortality	
	24 hrs[a/]	48 hrs[b/]
Untreate d	100.0	
	19.6	
	53.6	

Treatements applied 2/3/1995
Bark samples collected 8/24/95
Treatment means followed by the same letter do not differ significantly ($p<0.05$) when compared by Fishers protected LSD.
[a/] $F = 8.85$, df = 8, $p<0.0001$
[b/] $F = 8.355$, df = 8, $P<0.0001$

Conclusion:

- Measurable pyrethroid residues were found on field twig samples seven months after the pesticide application
- Pyrethroid residues declined considerably in the months following application
- Pyrethroid residues still caused significant mortality to the beneficial mite, *Galendromus occidentalis*, for almost 7 months after application

Walsh, D. B., F. G. Zalom and M. Stimmann. 1998. Effects of pyrethroid insecticide residues on almond leaves on the biology of the western orchard predator mite *Galendromus occidentalis* (Nesbitt) (Acari: Phytoseiidae). Acta Horticulturae 470: 539-546.

Pyrethroid leaf residues - methods

- Almond trees treated with esfenvalerate or permethrin on June 21, 1996
- Leaves from previously untreated trees dipped into a serial dilution, 25 leaf disks removed, and returned for extraction and residue analysis.
- Duplicate set of leaf disks treated and collected as described were used for *G. occidentalis* bioassays
- 5 gravid females transferred to each disk with *T. urticae* eggs as food
- Recorded number dead, alive, runoffs and eggs

Results of bioassays indicating repellency, mortality, survivorship, and fecundity 72 h after *G. occidentalis* were placed on leaf disks with various residue levels of esfenvalerate and on untreated leaf disks

Percent of field concentration *Esfenvalerate*	*df* =	Repelled ± SE	Dead ± SE
			31.337**
			1.448
			2.00 ± 0.44[2]
			2.00 ± 0.47[2]
			3.30 ± 0.45[2]
			3.60 ± 0.33[2]
			4.10 ± 0.38[2]
			4.30 ± 0.30[2]
			4.30 ± 0.40[2]
			0.25 ± 0.10

** significant *F*-value for treatment effect at $p<0.01$

[1, 2] Significant at $p<0.05$ or $p<0.01$ from control in pairwise *t*-tests

Results of bioassays indicating repellency, mortality, survivorship, and fecundity 72 h after *G. occidentalis* were placed on leaf disks with various residue levels of permethrin and on untreated leaf disks

Percent of field concentration *Permethrin*	*df* =	Repelled ± SE	Dead ± SE
			34.044**
			0.942
0		0.20 ± 0.13	
0.6		0.60 ± 0.22	
0.3		0.30 ± 0.15	
1.0		1.00 ± 0.26 [1]	
2.8		2.80 ± 0.51 [2]	
4.2		4.20 ± 0.42 [2]	
4.2		4.20 ± 0.33 [2]	
0.25		0.25 ± 0.10	

** significant *F*-value for treatment effect at $p<0.01$

[1, 2] Significant at $p<0.05$ or $p<0.01$ from control in pairwise *t*-tests

Pyrethroid insecticide residues (*n*g/mm^2) from leaf disks treated in serial dilution in Nov., 1996, and from field-collected leaves in Nov., 1996, 5 months after treatment with maximum label rates in June, 1996.

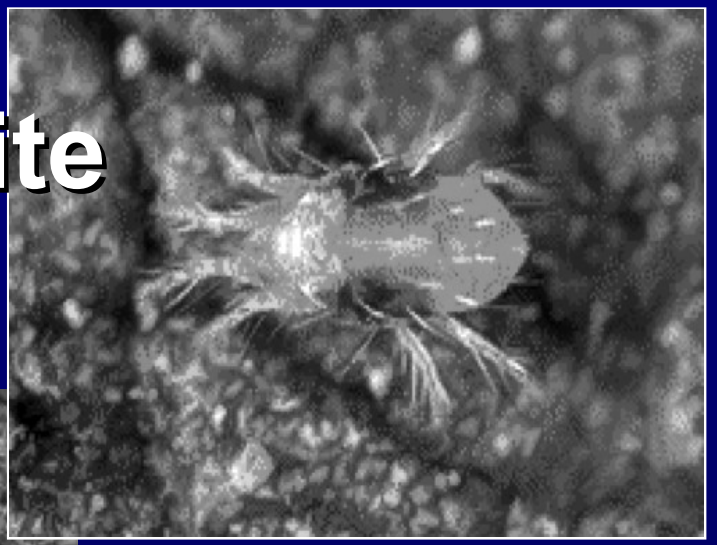
Percent Field Rate	Residue (*n*g/mm^2) Esfenvalerate	Residue (*n*g/mm^2) Permethrin[1]
0.000	0.000	0.000
0.195	0.006	0.009
0.39	0.018	0.010
0.78	0.057	0.017
1.56	0.086	0.039
6.25	0.630	0.808
25.0	4.505	6.337
100.0	5.261	14.590
Field November	0.987	0.127

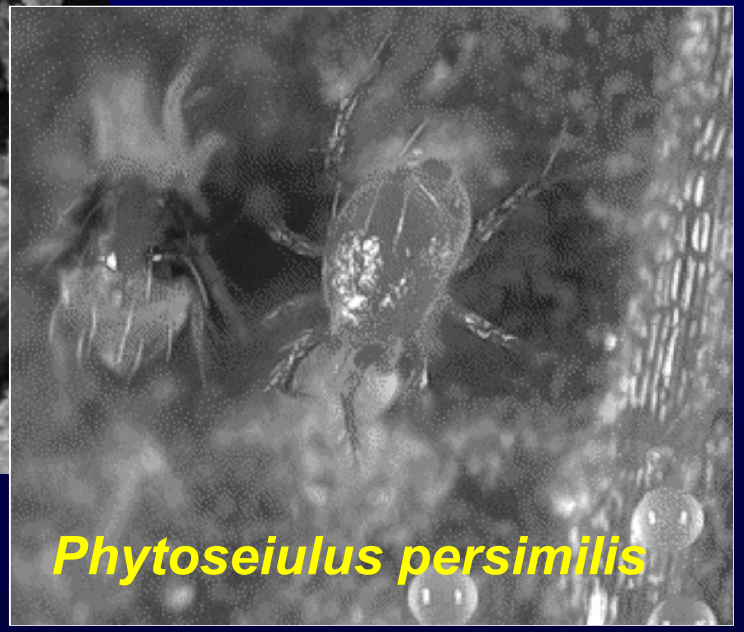
[1] Permethrin = *cis*- and *trans*- permethrin combined

Some Acaricides Registered In California?

Kelthane (dicofol)
Vendex (fenbutatin-oxide)
Omite (propargite)
Apollo (clofentezine)
Agrimek (abamectin)
Pyrimite/Nexter (pyridaben)
Savey/Onager/Hexygon (hexythiazox)
Acramite (bifenazate)
Zeal (etoxizole)
Kanemite (acequinocyl)
Oberon/Envidor (spiromesifen/spirodiclofen)
Fujimite (fenpyroximate)
Ecotrol (rosemary oil + peppermint oil)

Two spotted spider mite





Phytoseiulus persimilis

Pacific spider mite

Some recent literature on impacts of pesticides (primarily focusing on acaricides) on Phytoseiids:

Effects of Abamectin on *P. persimilis*:

Cote, K.W, Lewis, E.E. and Schultz, P.B., 2002. Compatibility of acaricide residues with *Phytoseiulus persimilis* and their effects on *Tetranychus urticae*. Hortscience. 37: 906-909 -

➡ No mortality after 24 h

Zhang. Z. and Sanderson, J.P., 1990. Relative toxicity of abamectin to the predatory mite *Phytoseiulus persimilis* (Acari: Phytoseiidae) and twospotted spider mite (Acari: Tetranychidae). J. Econ. Entomol. 83: 1783-1790 -

➡ Found sublethal effect from residues from a 4 ppm application reduced egg-laying by as much as 50%. Feeding on treated *T. urticae* reduced egg production.

Some recent literature on impacts of pesticides (primarily focusing on acaricides) on Phytoseiids:

Effects of Abamectin on *P. persimilis*:

Oomen, P.A., Romeijn G. and Wiegers, G.L., 1991. Side-effects of 100 acaricides on the predatory mite *Phytoseiulus persimilis*, collected and evaluated according to the EPPO guideline. Bul. European Mediter. Plant Protect. Org. (OEPP/EPPO). 21: 701-712 -

Malezieux, S., Lapchin, L., Pralavorio, M., Moulin, J.C. and Fournier, D., 1992. Toxicity of pesticide residues to a beneficial arthropod, *Phytoseiulus persimilis* (Acari: Phytoseiidae). J. Econ. Entomol. 85: 2077-2081 -

Shipp, J.L., Wang K. and Ferguson, G., 2000. Residual toxicity of avermectin b1 and pyridaben to eight commercially produced beneficial arthropod species used for control in greenhouse pests. Biol. Control. 17: 125-131 -

➡ No significant effect on survival

Some recent literature on impacts of pesticides (primarily focusing on acaricides) on Phytoseiids:

Effects of Bifenazate:

Dekeyser, M.A., McDonald, P.T., Angle Jr. G.W. and Moore, R.C., 1996. D-2341 – A novel agent to control spider mites. pp. 487-492, In: *Proceedings, 1996 British Crop Protection Conference Pests and Diseases*. British Crop Protection Council, Brighton, England -

➡ Bifenazate was harmless to *G. occidentalis*

James, D. G. 2002. Selectivity of the acaricide, bifenazate, and aphicide, pymetrozine, to spider mite predators in Washington hops. Intl. Jour. Acar. 28: 175-179 -

➡ In bioassays, bifenazate at the full field rate was moderately toxic to *G. occidentalis, N. fallacis,* and *A. andersoni* and 2 coccinellid species (37 81% mortality), but less toxic at half and quarter rates (0 44% and 0-11%, respectively)

Some recent literature on impacts of pesticides (primarily focusing on acaricides) on Phytoseiids:

Effects of Bifenazate, Acequinocyl and Etoxazole:

Kim, S.S. and Seo, S.G., 2001. Relative toxicity of some acaricides to the predatory mite, *Amblyseius womersleyi* and the twospotted spider mite, *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae). Appl. Entomol. Zool. 36: 509-514 -

➡ In contact bioassays, acequinocyl and bifenazate did not affect survival, fecundity or sterility of *A. womersleyi*, but etoxazole affected immature development

Kim, S.S. and Yoo, S.S., 2002. Comparative toxicity of some acaricides to the predatory mite, *Phytoseiulus persimilis* and the twospotted spider mite, *Tetranychus urticae*. BioControl. 47: 563-573 -

➡ Similar results as from previous study, but with *P. persimilis*

Measures of Pesticide Toxicity

Acute toxicity - percent mortality
LD50 or LC50 - dose response
Sublethal effects - fecundity, sterility, immature development
Total effects -
Persistence -
Behavioral modification -

Direct and sublethal effects of acaricides on *Galendromus occidentalis* and *Phytoseiulus persimilis* - implications for conservation and augmentation

Primary Investigator
Dr. Francisco Javier Sáenz-de-Cabezón Irigaray

Predator mite bioassays - *products & rates*

Active ingredient, trade name, formulation and concentration (ppm) of acaricides evaluated.

Active ingredient	Trade name	% a.i. and formulation	Concentration (ppm)
Fenpyroximate	Fujimite	5 SC	62.5
Etoxazole	Zeal	72 WP	24.12
Acequinocyl	Kanemite	15 SC	158.0
Bifenazate	Acramite	50 WS	112.75
Spiromesifen	Oberon	23 SC	76.20

Amount of solution applied was 10.6±0.53 µl/cm2.
The chemicals evaluated were mixed with distilled water

Bioassay methods - direct contact

30 adult *G. occidentalis* females were sprayed

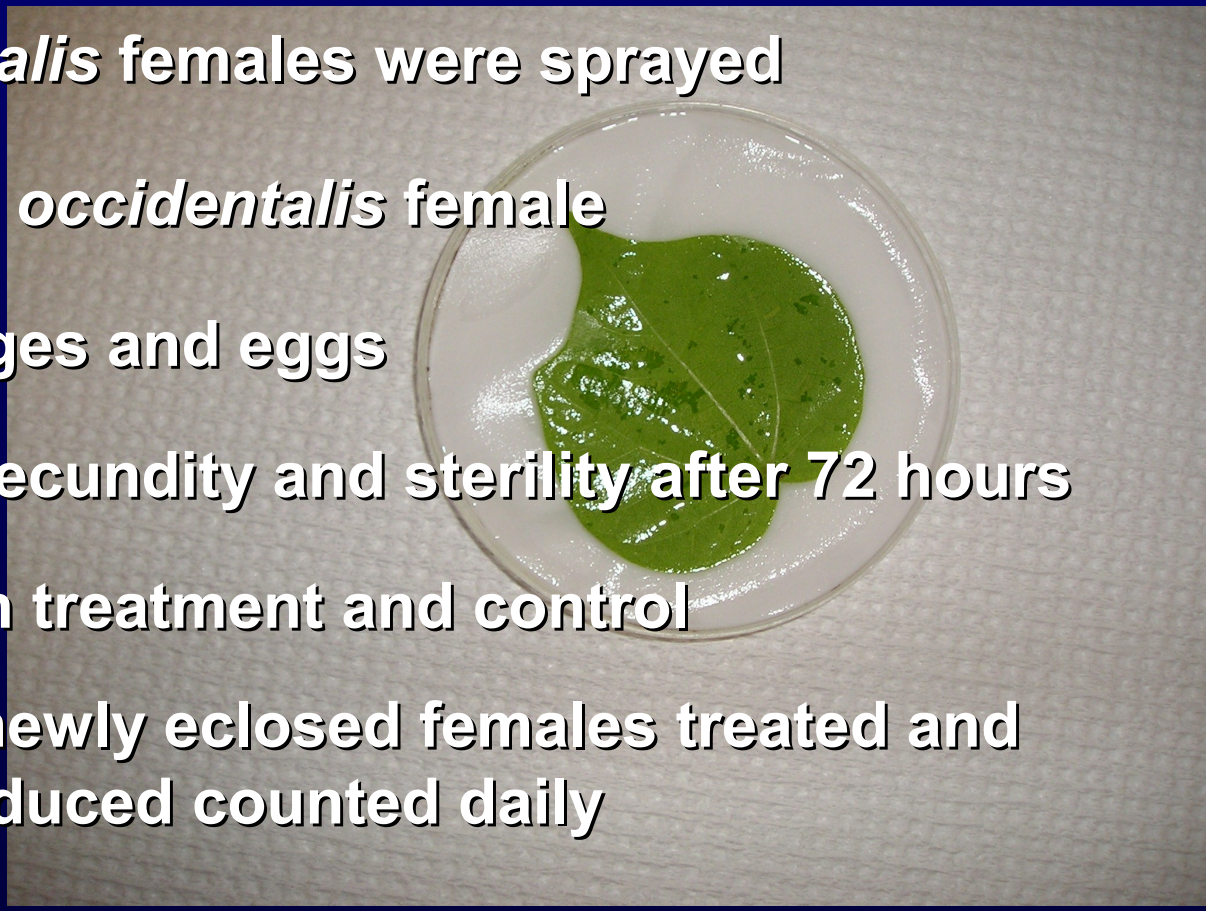
One treated adult *G. occidentalis* female

T. urticae active stages and eggs

Evaluate mortality, fecundity and sterility after 72 hours

20 replicates of each treatment and control

Separate cohort of newly eclosed females treated and number of eggs produced counted daily



Statistical methods

Mortality, fecundity and sterility analyzed by ANOVA with means separated by LSD ($p < 0.05$)

Total effects of pesticides - *E***

E (%) = 100% - (100% - M) x R

Where

M = Abbott corrected mortality (Abbott, 1925)

R = reproduction per treated female (eggs/female x % sterility) / reproduction per untreated female

** *From* Overmeer and Van Zon. 1982. Entomophaga. 27, 357-364

Predator mite bioassays - *direct contact*

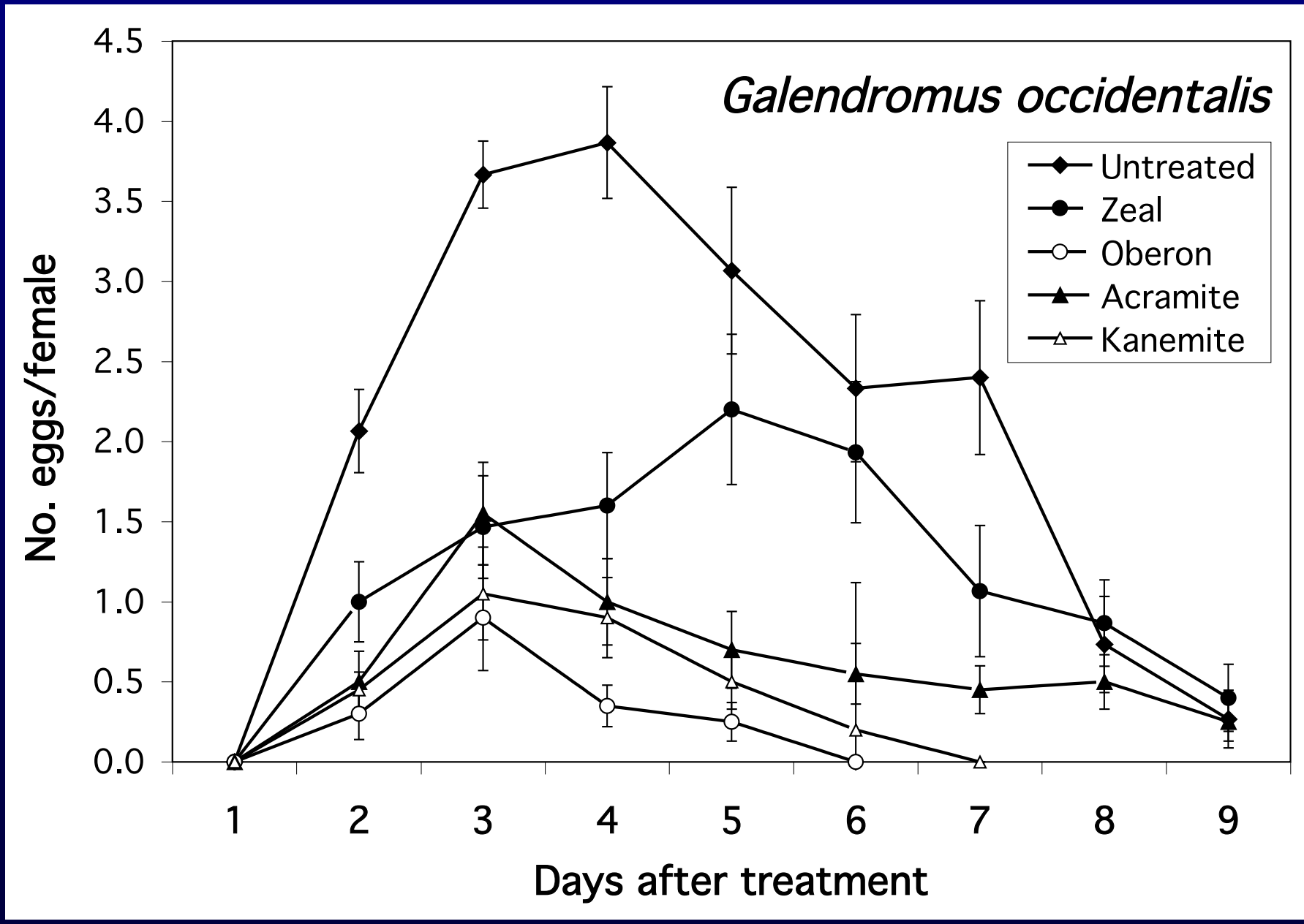
G. occidentalis **survival, fecundity and sterility resulting from exposure of adult females to direct contact spray with label rates of five different acaricides.**

Active ingredient	Contact spray			
	% Survival	Total eggs/ female	Sterility (% hatch)	*E*
Control	100□0a	12.4□0.8a	100□0a	-
Acequinocyl	100□0a	9.2□0.6b	96.0□4.9a	28.5
Bifenazate	100□0a	9.4□0.5b	92.3□3.4a	30.2
Etoxazole	98.3□2.2a	9.4□0.7b	0□0b	100
Spiromesifen	98.3□2.2a	8.6□0.5b	96.1□4.0a	34.0
Fenpyroximate	0□0b	0□0c	0□0b	100

Means followed by the same letter are significantly different at $p<0.05$ by LSD.

Exposure to residues?

Daily fecundity of newly eclosed treated *G. occidentalis*



Bioassay methods - residues

Leaf disks were air-dried after spraying

One adult *G. occidentalis* female

T. urticae active stages and eggs

Mortality, fecundity and Sterility after 72 hours

20 replicates of each treatment and control

Predator mite bioassays - *residues*

G. occidentalis **survival, fecundity and sterility resulting from exposure of adult females to leaf surface residues of label rates of five different acaricides.**

Active ingredient	Surface residue			
	% Survival	Eggs laid	Sterility	*E*
Control	98.3□2.2a	11.2□1.0a	100□0a	-
Acequinocyl	93.4□3.0a	9.6□0.5a	92.2□4.9a	25.1
Bifenazate	95.1□2.7a	9.6□0.9a	96.0□4.0a	20.1
Etoxazole	93.4□3.0a	9.0□0.5a	0□0b	100
Spiromesifen	91.7□3.2a	5.0□0.7b	92.6□4.3a	61.7
Fenpyroximate	0□0b	0□0c	0□0b	100

Means followed by the same letter are significantly different at $p<0.05$ by LSD.

Predator mite bioassays - *total effects*

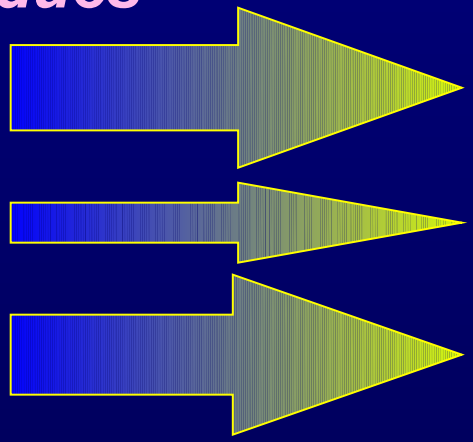
Total effects of pesticides (*E*)

Active ingredient	Surface treatment	Contact treatment	
Acequinocyl	25.1	28.5	
Bifenazate	20.1	30.2	*Primary cause?*
Etoxazole	100	100 ←	Reduced sterility
Spiromesifen	61.7	34.0 ←	Reduced fecundity
Fenpyroximate	100	100 ←	Increased mortality

IOBC Classifications - (Sterk et al., 1999)

Leaf surface residues

Acequinocyl
Bifenazate
Spiromesifen
Etoxazole
Fenpyroximate



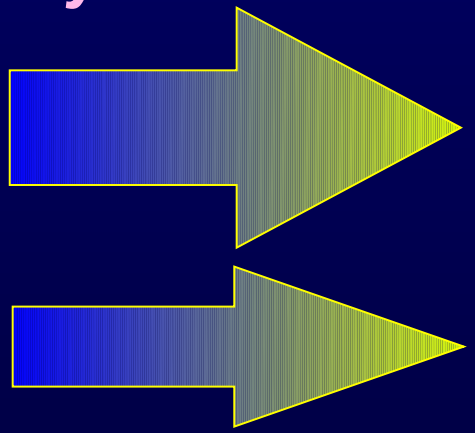
Harmless (class 1)

Slightly harmful (class 2)

Harmful (class 4)

Direct contact spray

Acequinocyl
Bifenazate
Spiromesifen
Etoxazole
Fenpyroximate



Harmless (class 1)

Harmful (class 4)

Bioassay methods - rate of increase

Leaf disks were air-dried after spraying

One adult *G. occidentalis* female

T. urticae active stages and eggs

Mortality, fecundity and sterility after 7 days

20 replicates of each treatment and control

Statistical methods

Mortality, fecundity and sterility analyzed by ANOVA with means separated by LSD ($p < 0.05$)

Instantaneous rate of increase r_i (Walthall & Stark 1997)

$$r_i = \ln(N_t/N_0)/t$$

Where

N_t = final number of animals

N_0 = initial number of animals

t = change in time

Predator mite bioassays - *rate of increase*

Intrinsic rate of increase of *G. occidentalis* population following exposure of newly exposed females to label rates of five different acaricides.

Treatment	Instantaneous rate of increase (r_i)	
Control	0.342±0.002	a
Etoxazole	-0.863±0.000	c
	-0.052±0.106	b
	-0.863±0.000	c
	-0.463±0.112	b
	-0.522±0.106	b

Means followed by the same letter are significantly different at $p<0.05$ by LSD.

Predator mite residual bioassays - *products & rates*

Active ingredient, trade name, formulation and concentration (ppm) of acaricides evaluated.

Active ingredient	Product	% a.i. and formulation	Concentration (ppm)
Fenpyroximate	Fujimite	5 SC	
		72 WP	
		15 SC	
		50 WS	
		23 SC	
		15 EC	

Amount of solution applied was 10.6±0.53 µl/cm2.
The chemicals evaluated were mixed with distilled water

Bioassay methods - *exposure to residues*

Strawberry plants grown and treated in the field, experiment conducted during June, 2005

Acaricides applied at 100 ml per plant to runoff

Five 20 mm leaf disks per Petri dish arena

Three adult female *G. occidentalis* per disk

T. urticae active stages and eggs transferred as food

Evaluate mortality and fecundity after 3 d (sterility 6 d)

Five replicates of each treatment and control

Procedures repeated with treated leaflets removed from the plants at 3, 6, 10, 14, 17, 24, 30 and 37 days after application

IOBC Persistence Categories

Based on persistence - days after treatment that total effects are greater than 30%

A = short lived (<5 d)
B = slightly persistent (5-15 d)
C = moderately persistent (16-30 d)
D = persistent (>30 d)

Mean ± SD percent *G. occidentalis* and *P. persimilis* female mortality 72 h after exposure strawberry leaflets treated with the labeled dose of formulated products.

Treatment	Mean ± SD % mortality									
	G. occidentalis					*P. persimilis*				
	Days after treatment					Days after treatment				
	3	6	10	>14	IOBC	3	6	10	>14	IOBC
Control	0 a	0 a	0 a	0 a	A	0 a	0 a	0 a	0 a	A
Bifenazate	0 a	0 a	0 a	0 a	A	0 a	0 a	0 a	0 a	A
Etoxazole	26.4±6.6 b	0 a	0 a	0 a	A	0 a	0 a	0 a	0 a	A
Spiromesifen	0 a	0 a	0 a	0 a	A	0 a	0 a	0 a	0 a	A
Abamectin	33.0±10.4 b	0 a	0 a	0 a	A	26.4±12.3 b	26.4±12.3 b	0 a	0 a	A
Fenpyroximate	100 c	100 b	100 b	100 b	D	100 c	100 c	100 b	100 b	D
Acequinocyl	100 c	0 a	0 a	0 a	A	100 c	0 a	0 a	0 a	A

Within columns means (±SD) followed by the same letter do not differ significantly at p=0.05 by LSD.
IOBC categories: A = short lived (<5 d), B = slightly persistent (5-15 d), C = moderately persistent (16-30 d), D = persistent (>30 d)

Mean ± SD *G. occidentalis* fecundity (eggs/female/day) recorded 72 h after exposure to strawberry leaflets treated with the labeled dose of formulated products.

Treatment	Days after treatment				
	3	6	10	14	17
					2.0±0.05ab
					2.3±0.03a
					2.3±0.10a
					2.1±0.07ab
					2.1±0.10ab
					0.2±0.05c
					1.9±0.15b

Within columns means (±SD) followed by the same letter do not differ significantly at p=0.05 by LSD.

Mean ± SD *G. occidentalis* sterility recorded 72 h after exposure to strawberry leaflets treated with the labeled dose of formulated products.

Treatment	Days after treatment				
	3	6	10	14	17
					100±0.00 a
					44.4±4.21 b
					0.0±0.00 c
					99.1±0.90 a
					99.1±0.90 a
					0.0±0.00 c
					99.0±0.96 a

Within columns means (±SD) followed by the same letter do not differ significantly at p=0.05 by LSD.

Mean ± SD *P. persimilis* fecundity (eggs/female/day) recorded 72 h after exposure to strawberry leaflets treated with the labeled dose of formulated products.

Treatment	Days after treatment				
	3	6	10	14	17
					3.8±0.32a
					4.4±0.20a
					4.4±0.18a
					4.1±0.18a
					4.1±0.24a
					1.3±0.11b
					4.4±0.18a

Within columns means (±SD) followed by the same letter do not differ significantly at p=0.05 by LSD.

Mean ± SD *P. persimilis* sterility recorded 72 h after exposure to strawberry leaflets treated with the labeled dose of formulated products.

	Days after treatment				
Treatment	3	6	10	14	17
					97.4±1.34a
					62.5±3.40c
					0.0±0.00d
					76.7±5.30b
					97.0±0.91a
					0.0±0.00d
					99.0±0.60a

Within columns means (±SD) followed by the same letter do not differ significantly at p=0.05 by LSD.

Total effects (*E*) of acaricide residues on *G. occidentalis* recorded 72 h after exposure to strawberry leaflets treated with the labeled dose of formulated products.

	Days after treatment				
Treatment	3	6	10	14	17
					0
					100
					0
					0
					100
					6

IOBC categories: A = short lived (<5 d), B = slightly persistent (5-15 d), C = moderately persistent (16-30 d), D = persistent (>30 d)

Total effects (*E*) of acaricide residues on *P.persimilis* recorded 72 h after exposure to strawberry leaflets treated with the labeled dose of formulated products.

Treatment	Days after treatment 3	6	10	14	17
					26
					100
					12
					3
					100
					0

IOBC categories: A = short lived (<5 d), B = slightly persistent (5-15 d), C = moderately persistent (16-30 d), D = persistent (>30 d)

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INTEGRATING PESTICIDES AND BIOCONTROL OF MITES

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