Pesticide Resistance in Citrus Pests

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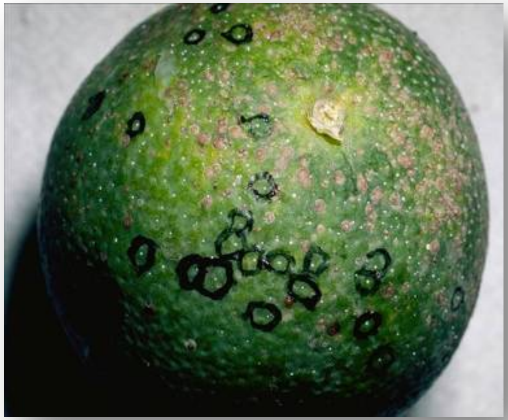
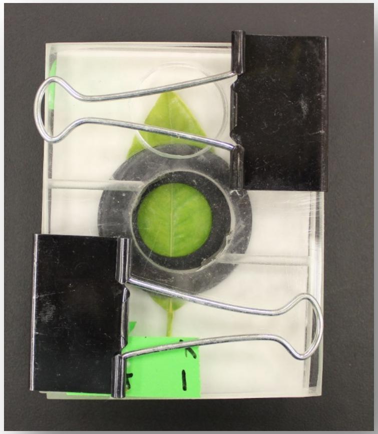
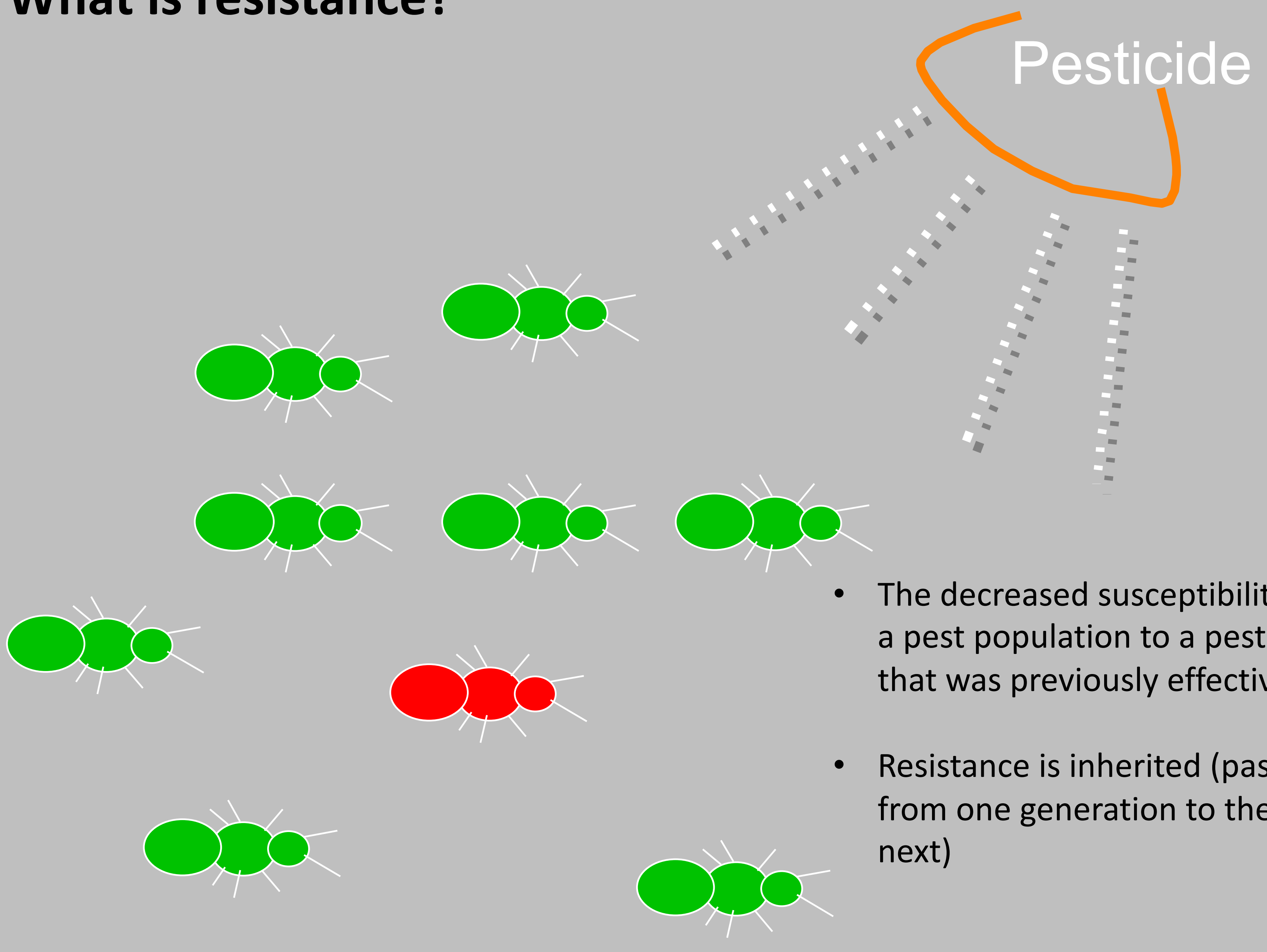


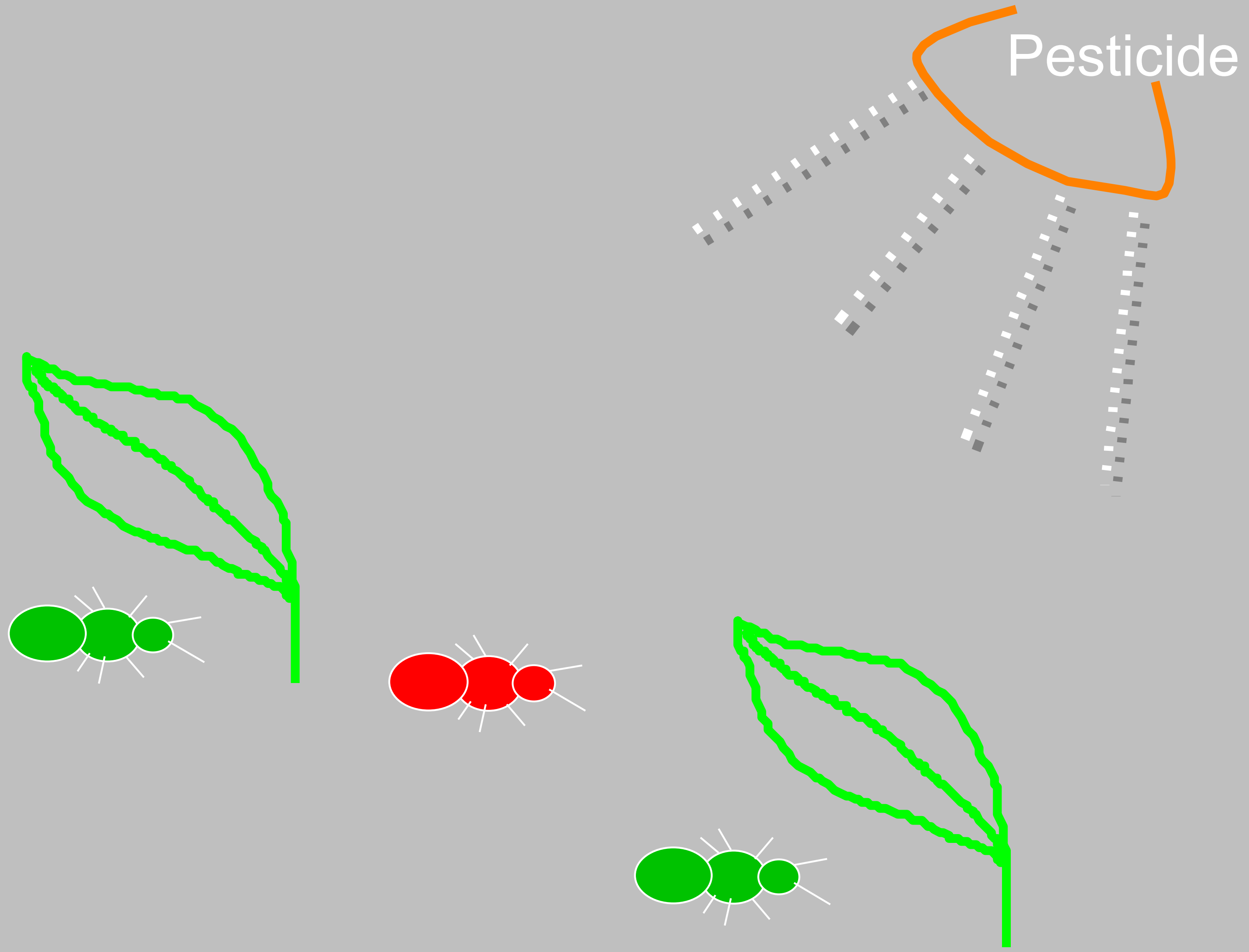


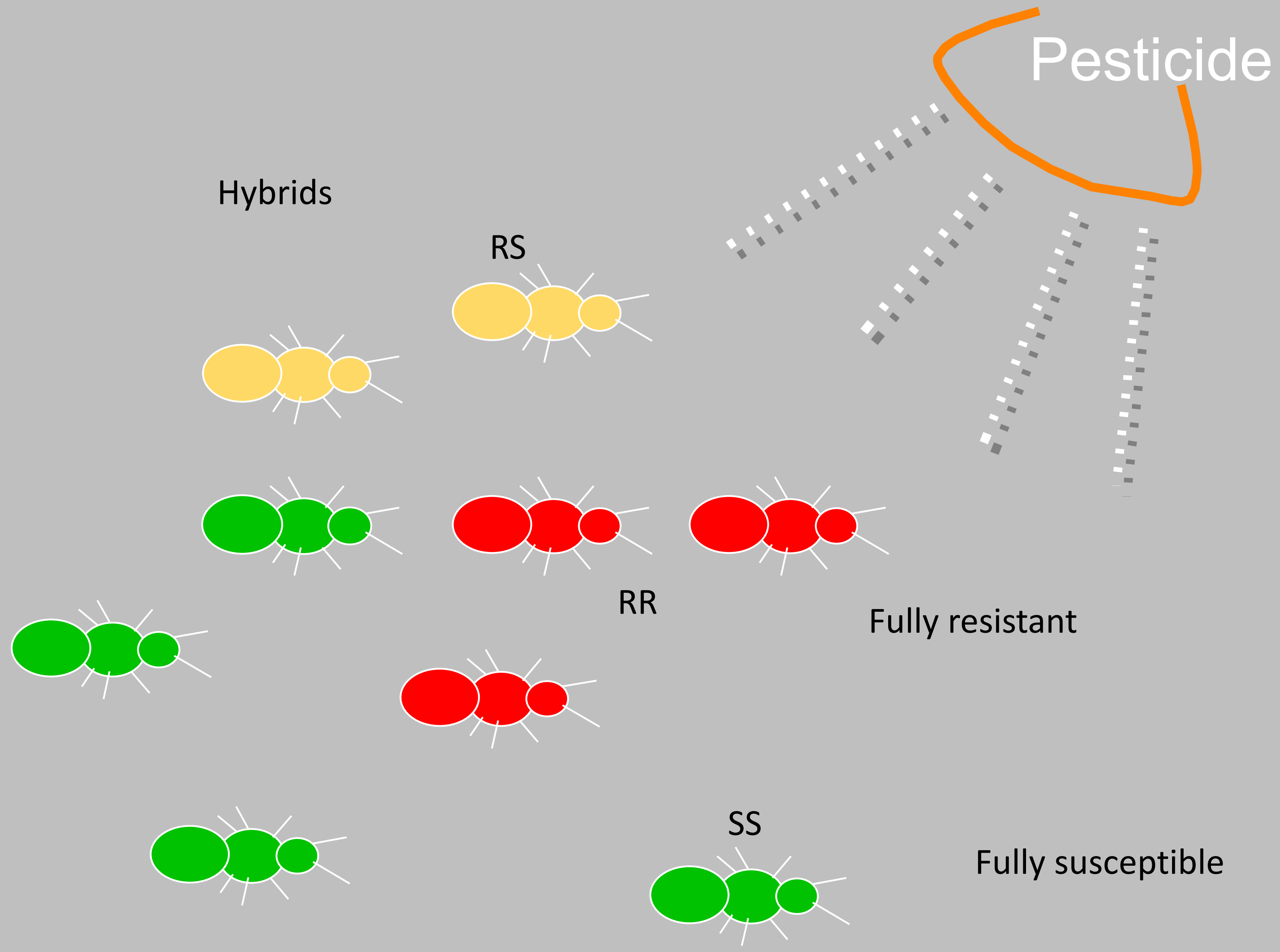
University *of* California
Agriculture and Natural Resources

What is resistance?



- The decreased susceptibility of a pest population to a pesticide that was previously effective
- Resistance is inherited (passed from one generation to the next)


Pesticide


Pesticide
Hybrids
RS
RR
Fully resistant
SS
Fully susceptible

Insecticide resistance ≠ Insecticide tolerance

- **Tolerance** – natural ability of a population to withstand the toxic effect of an insecticide

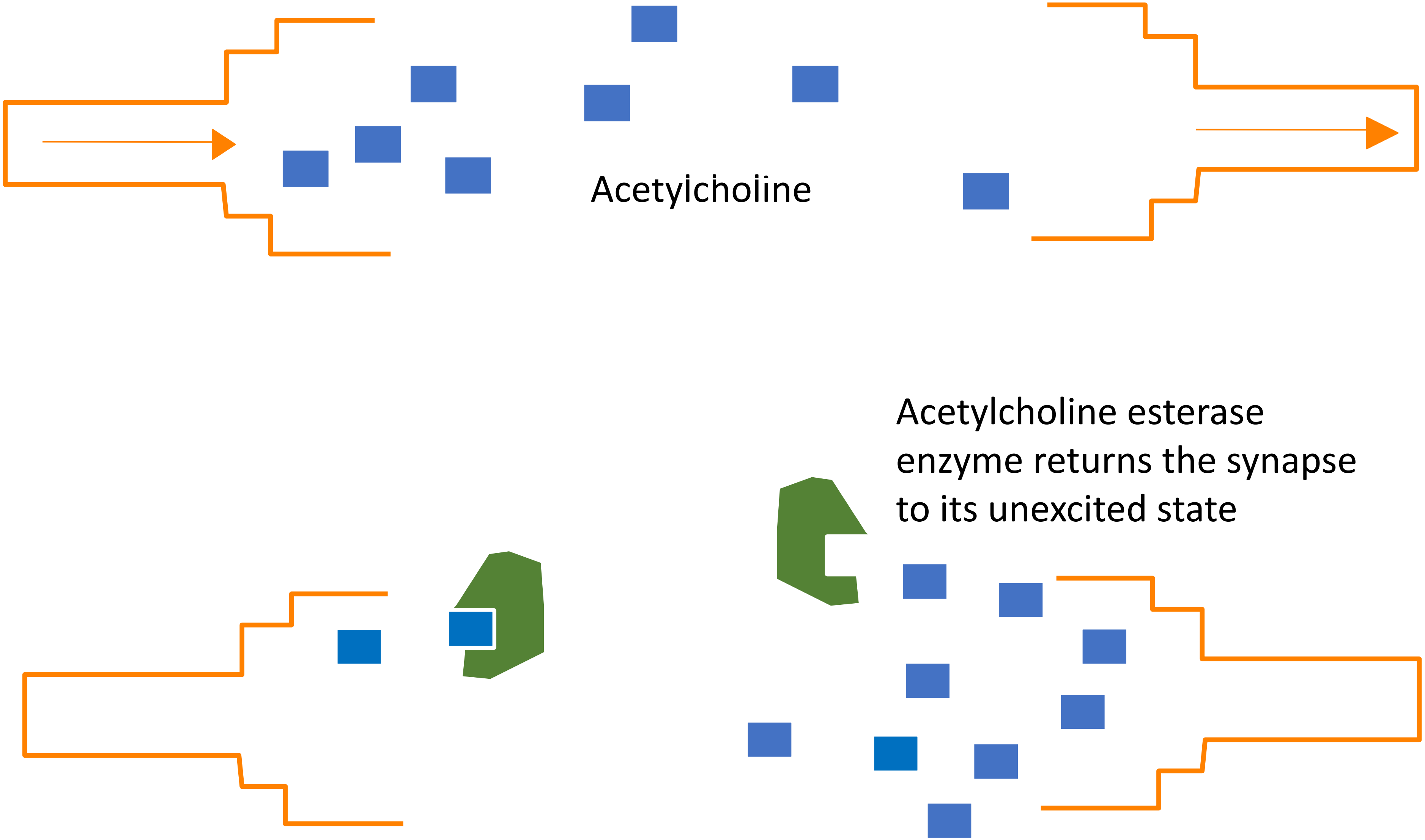
Example: Lacewings are highly tolerant of pyrethroids because they have really high natural levels of esterase enzymes.

- **Resistance** – increased survival over generations that it is genetically inherited

How do insects develop resistance?

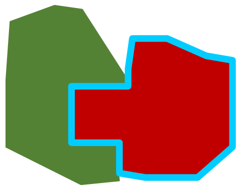
- Change their behavior
- Change their cuticle so that the pesticide can't penetrate as easily
- Increase the number of enzymes they have to detoxify the pesticide and maintain normal function
- Change the nature of the target site so that the pesticide can't bind to it

Normal Activity of a Nerve Synapse



How Pesticides Act on the Nerve Synapse

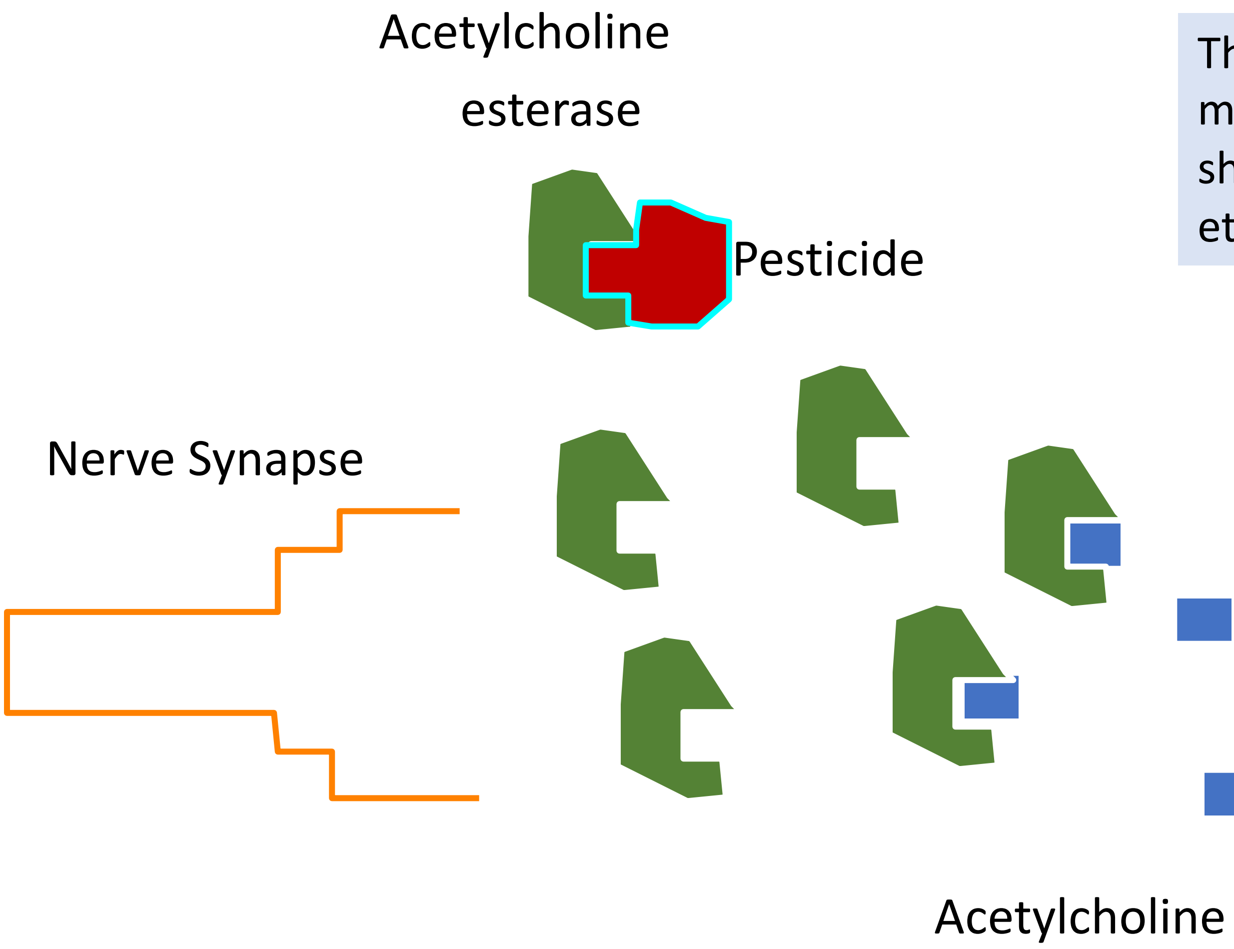
Acetylcholine esterase



Organophosphate and
Carbamate insecticides
bind with AchE and prevents
it from doing its job

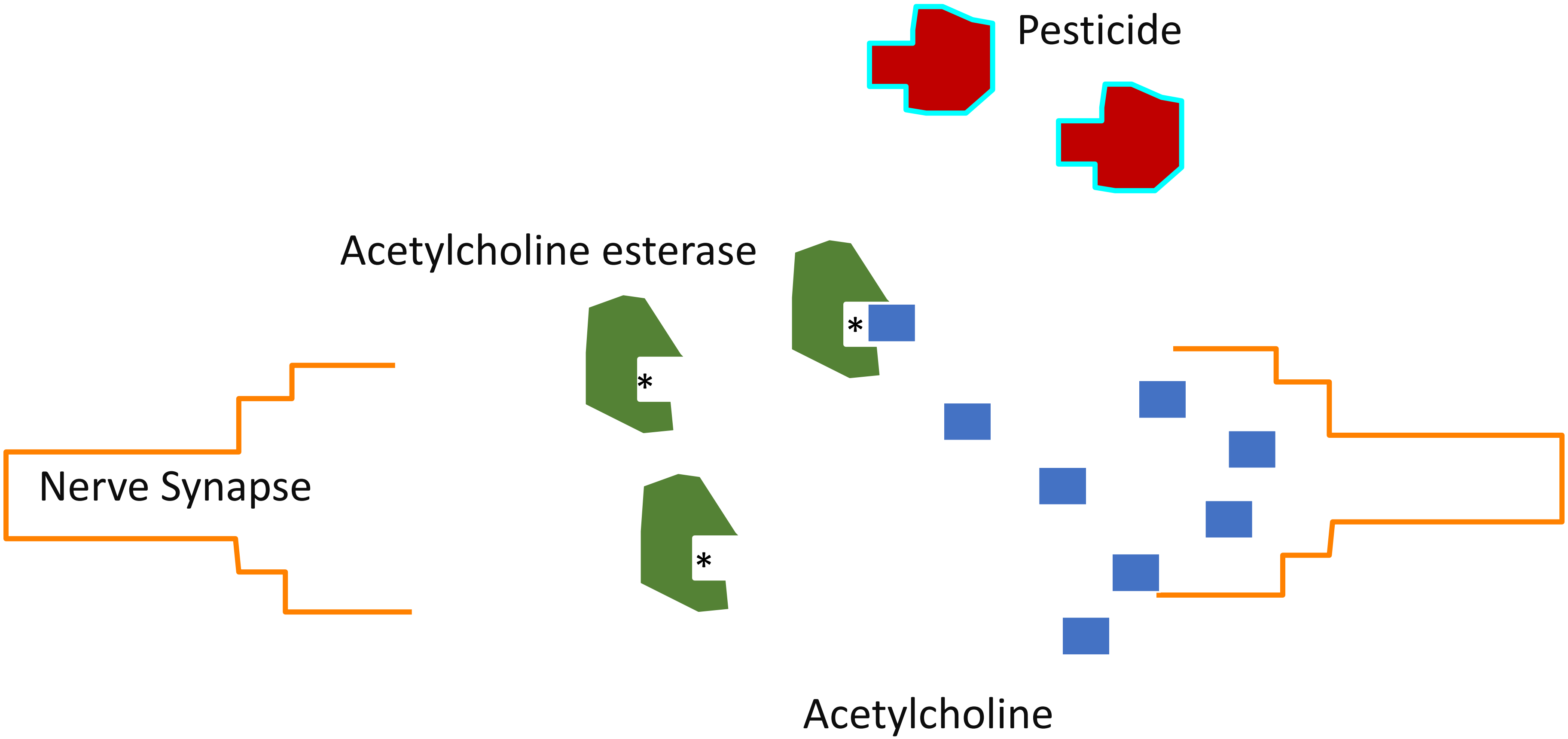
Acetylcholine can’t be restored
and the insect nervous system
remains in the excited state

One method of resistance: the insect makes more AchE



There is often a fitness cost for making more enzymes: shorter life, fewer eggs laid etc.

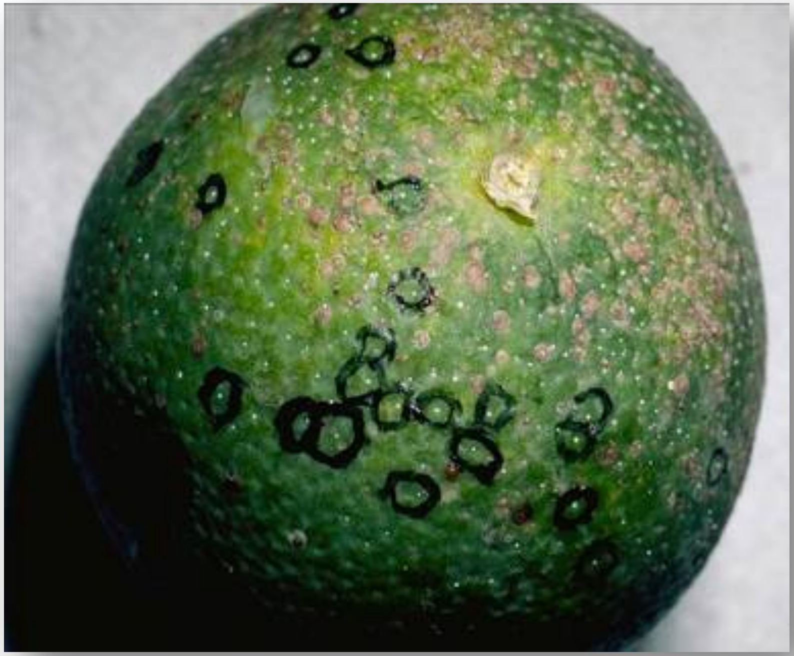
Second method of resistance: the insect changes the nature of the binding area for AchE and the pesticide can't attach (decreased target site sensitivity)



How do we measure resistance?

California red scale organophosphate resistance monitoring

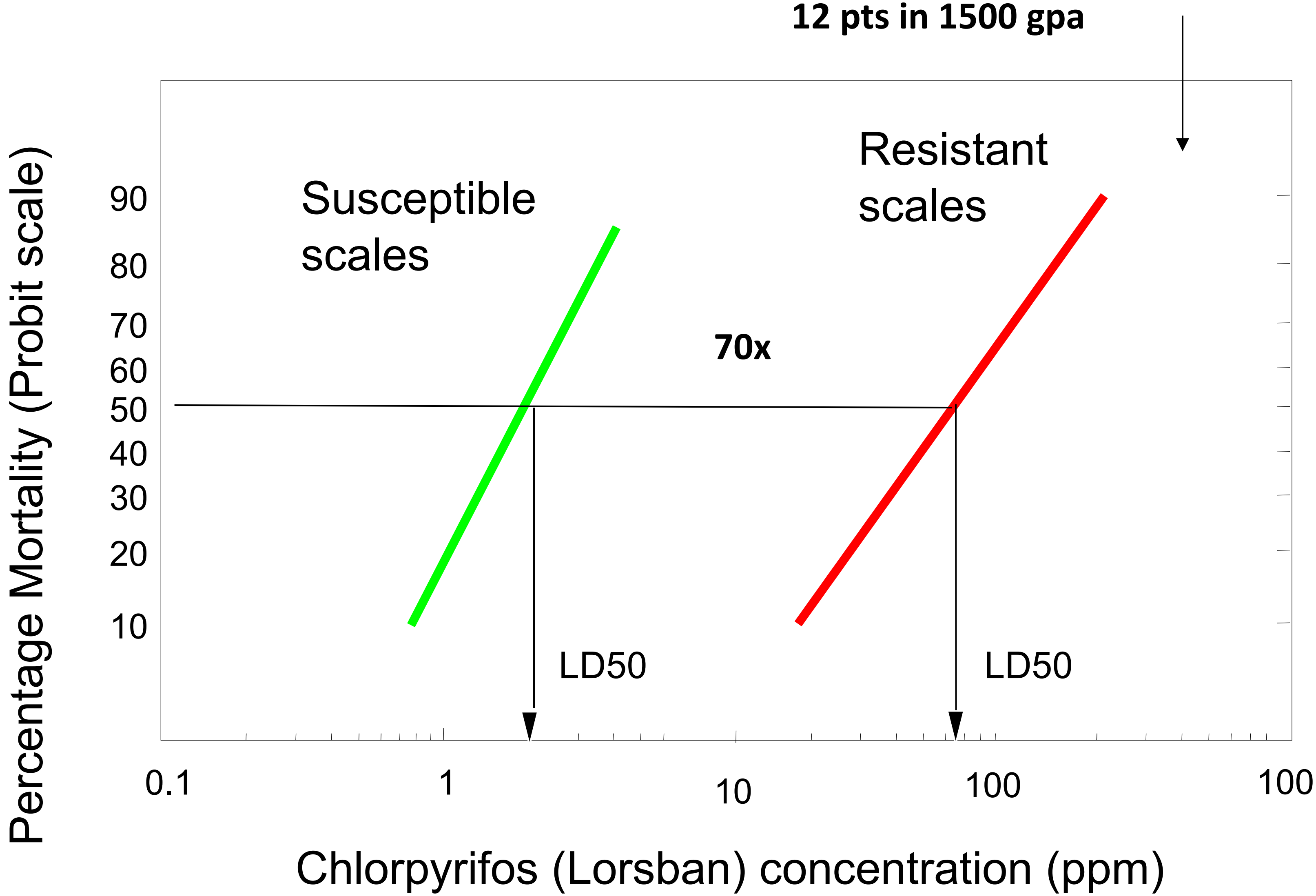
- Circle the 1st instar scales
- Dip the fruit
- Wait 14 days for the scales to molt to 2nd instars

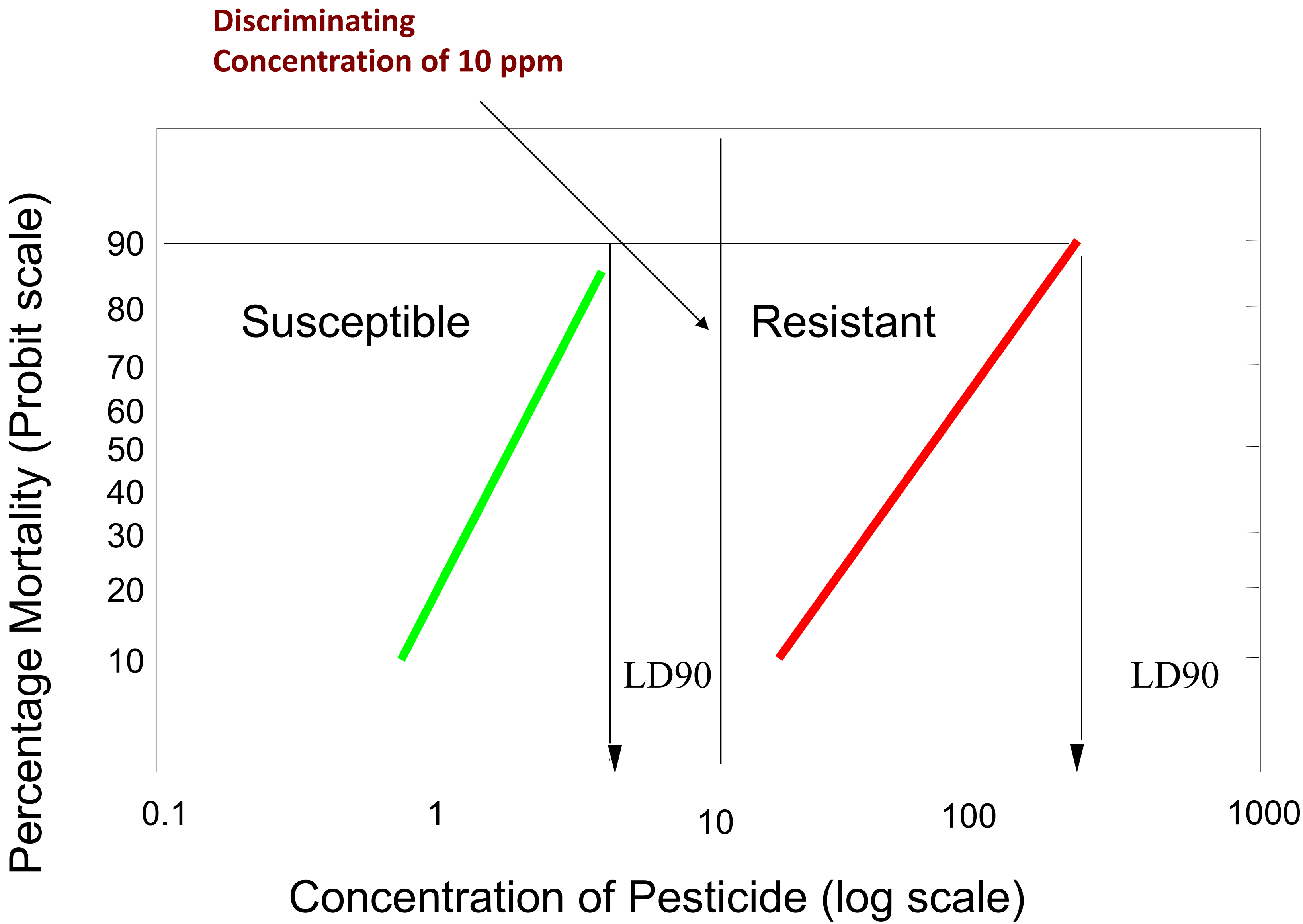


Log concentrations of insecticide:
1, 3.16, 5.62, 10, 31.6, 56.2, 100, 316, 562 ppm chlorpyrifos (Lorsban)

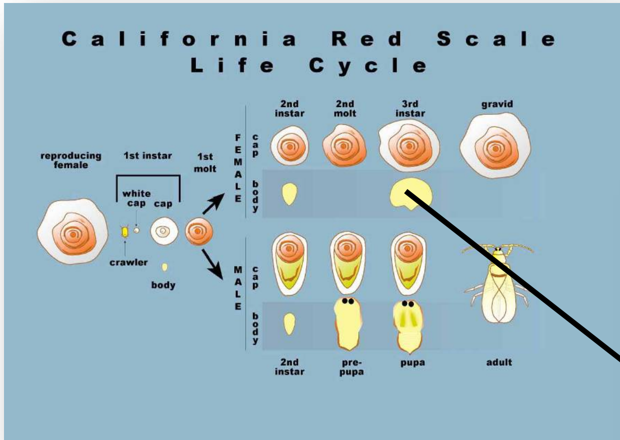
California red scale

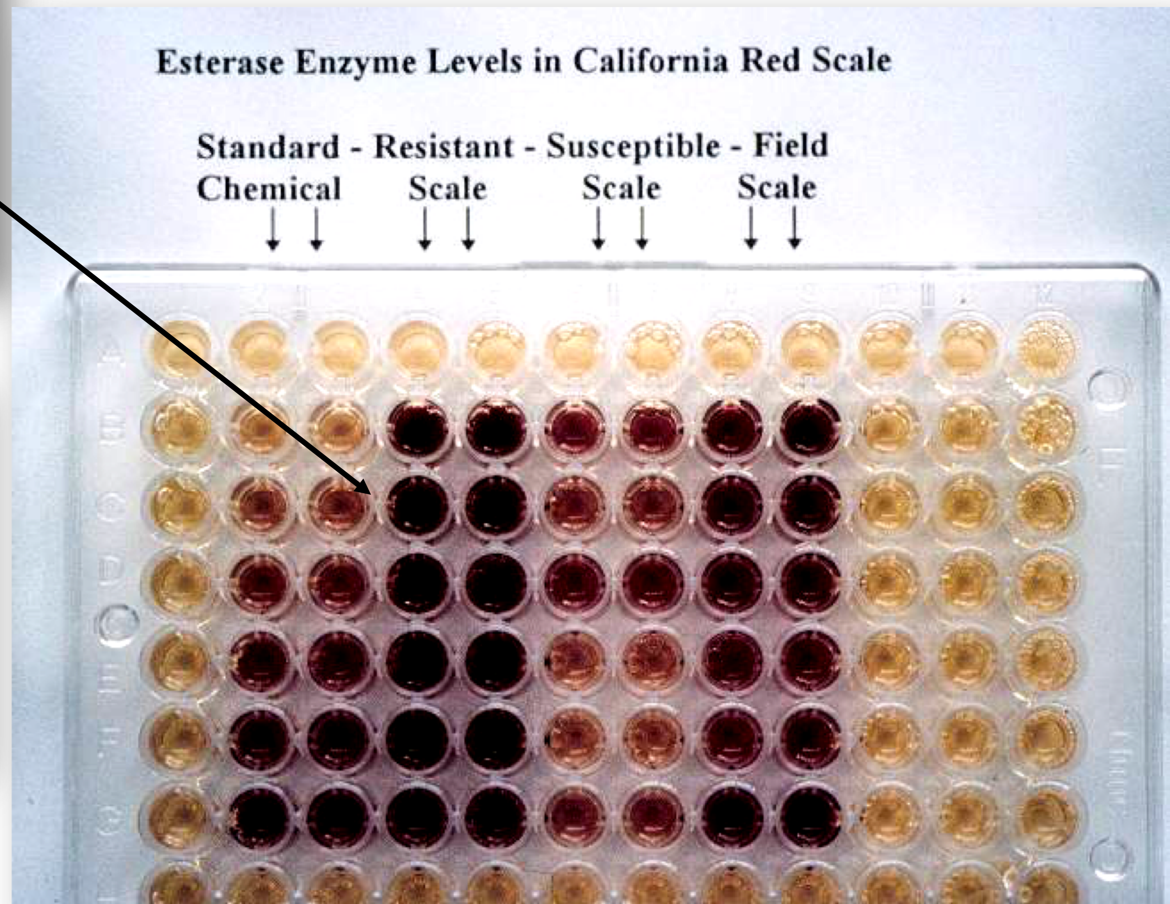
Lorsban field rate = 500 ppm
12 pts in 1500 gpa



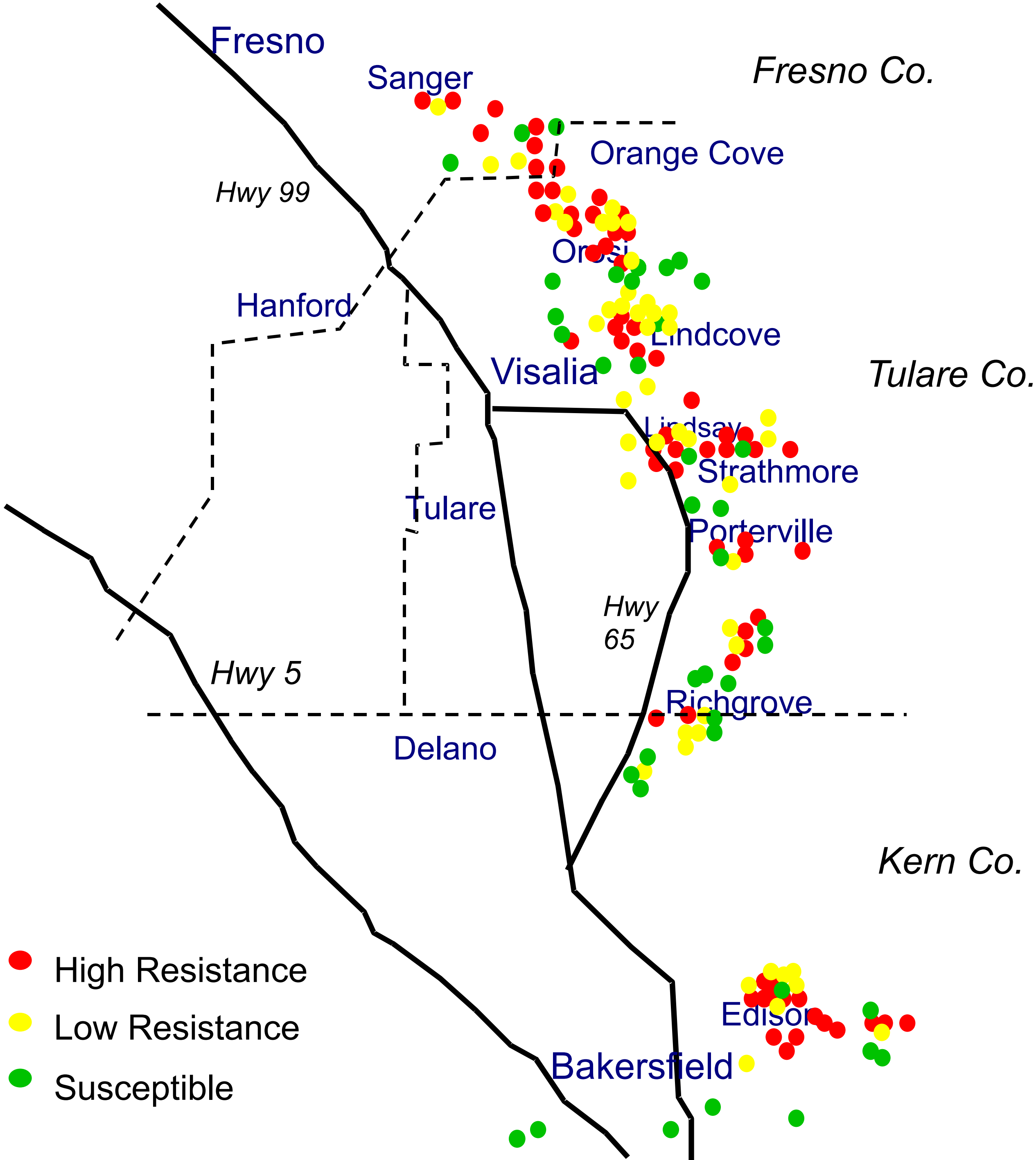

Discriminating
Concentration of 10 ppm
Percentage Mortality (Probit scale)
90
80
70
60
50
40
30
20
10
Susceptible
Resistant
LD90
LD90
0.1
1
10
100
1000
Concentration of Pesticide (log scale)

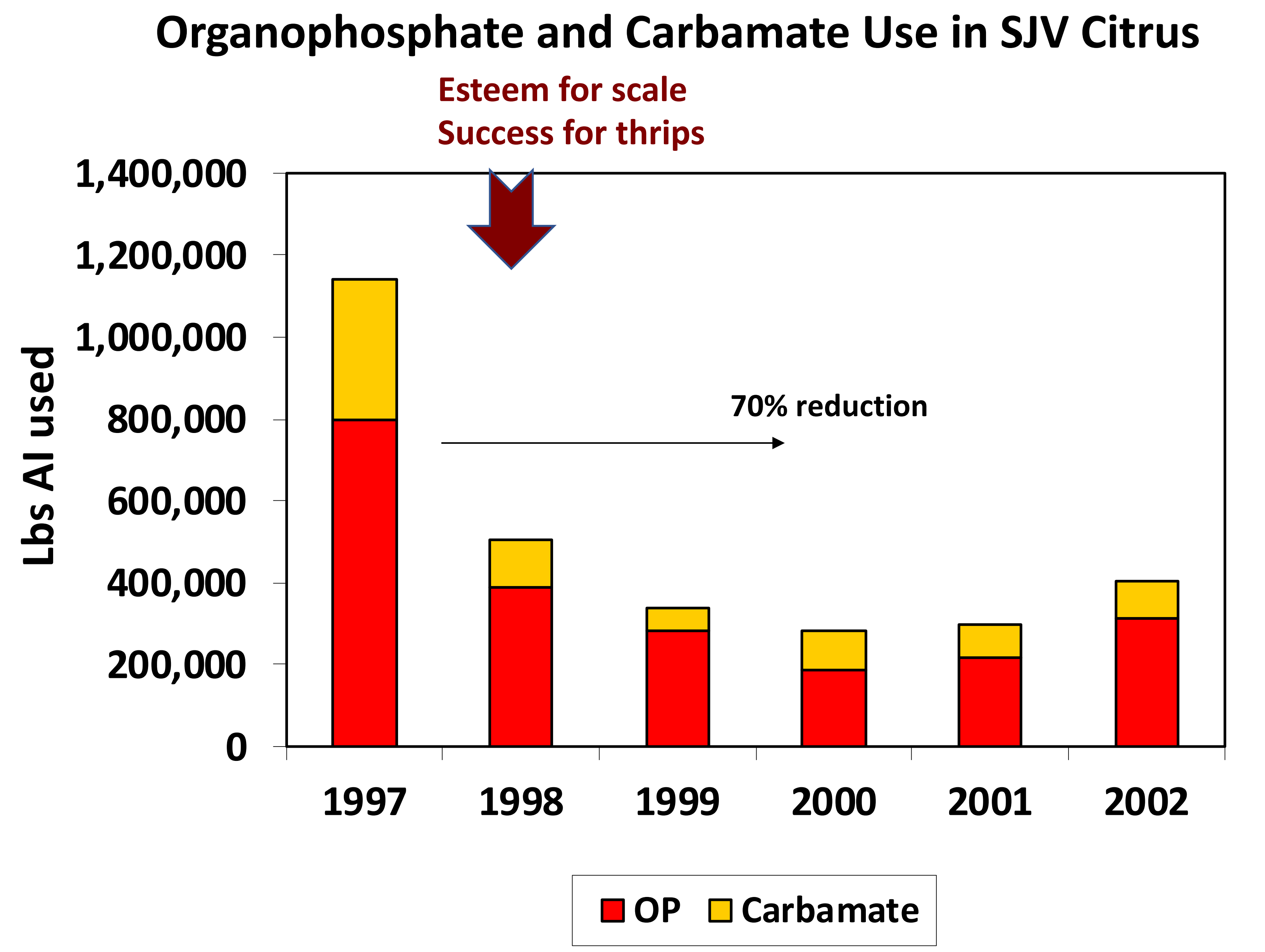
California red scale uses esterase enzymes to resist organophosphates and carbamates. Scales with **high esterase enzyme activity** have resistance.





California Red Scale Response to Organophosphate Insecticides 1993-1997




Organophosphate and Carbamate Use in SJV Citrus
Esteem for scale
Success for thrips
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Lbs AI used
70% reduction
1997
1998
1999
2000
2001
2002
OP
Carbamate

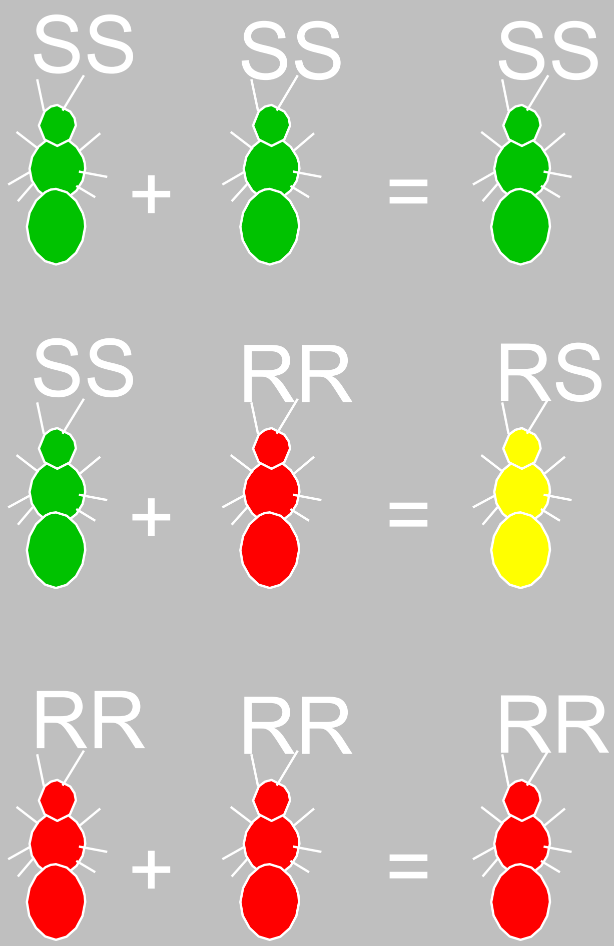
Does resistance go away in red scale if you stop using OPs?

If a block has a population of red scale that is fairly uniformly resistant to organophosphates and carbamates, resistance does not usually decline during the following years (We have sampled some orchards for 7 years).

Why not?

1. **Probably the resistance is genetically dominant**
2. **Scales don't move much, so once you have resistance, there are few if any susceptible scales in neighboring orchards that make it to your orchard, interbreed with the resistant individuals, and so reduce resistance.**
3. **Growers continue to use OPs for citricola scale control which continues to eliminate susceptible red scales and maintain OP resistance.**

Dominance versus recessiveness

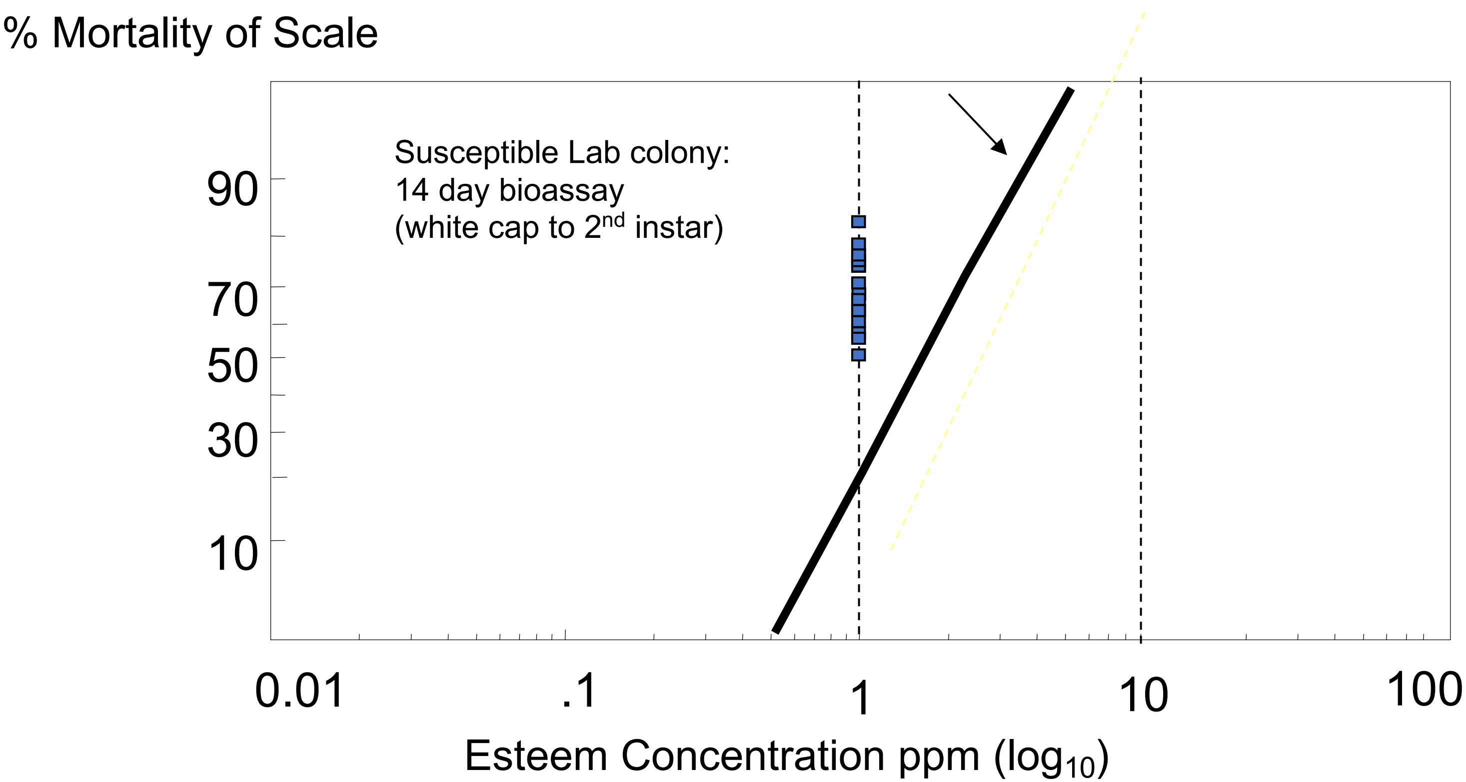


Heterozygote:
- Dominant acts like R
- Recessive acts like S or intermediate

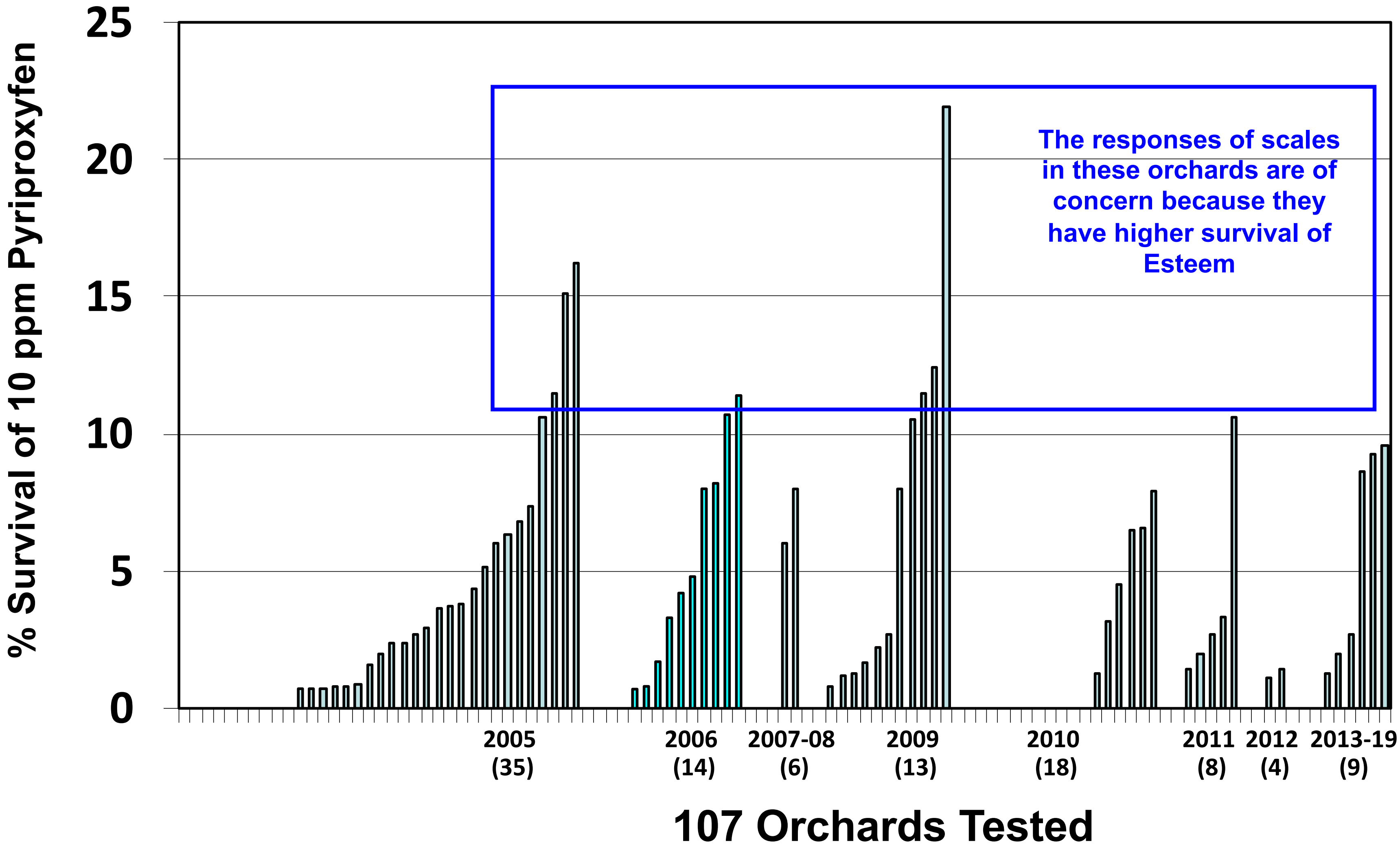
Esteem Bioassay

Collect fruit from commercial citrus orchards, circle 1st instars and after dipping in 10 ppm see how many can molt to the 2nd instar after 14 days.

Esteem field rate = 70 ppm
16 oz in 1500 gpa



California red scale response to Esteem



- Nothing higher than 22% survival
- No trend towards higher survival in recent years
- Suggests that resistance is not dominant and/or the bioassay is just not revealing it

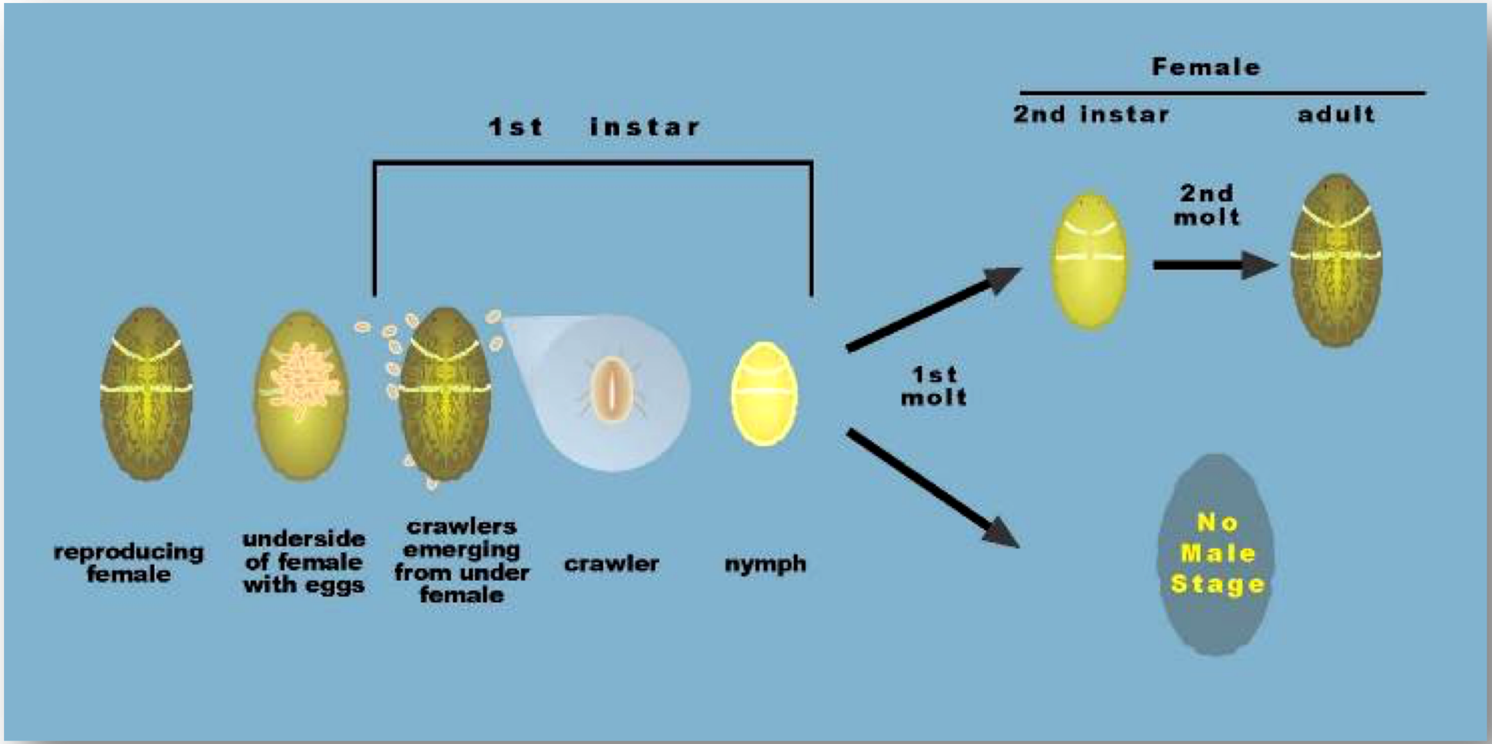
How do you know when you have a resistance problem?

- **Laboratory tests**. The line shifts to the right and it takes much higher concentrations to kill them

However, the levels of resistance in the laboratory are just an indicator because the lab rate is not exactly what is happening in the field (dipping the insect versus spraying an orchard)

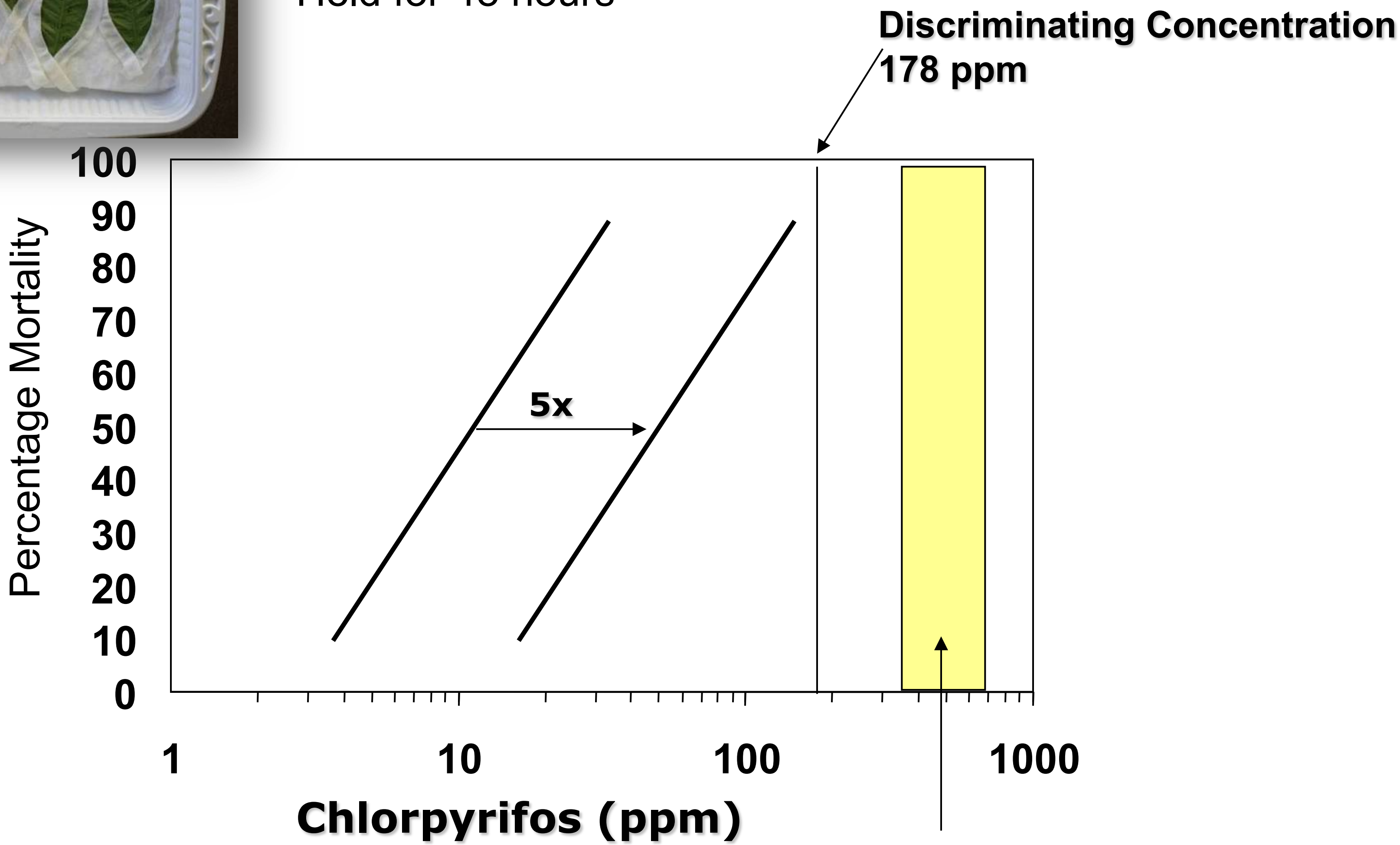
- **Field** applied treatments work for a shorter and shorter period of time or don't work at all

Citricola Scale Lifecycle



Response of Citricola Scale to Lorsban

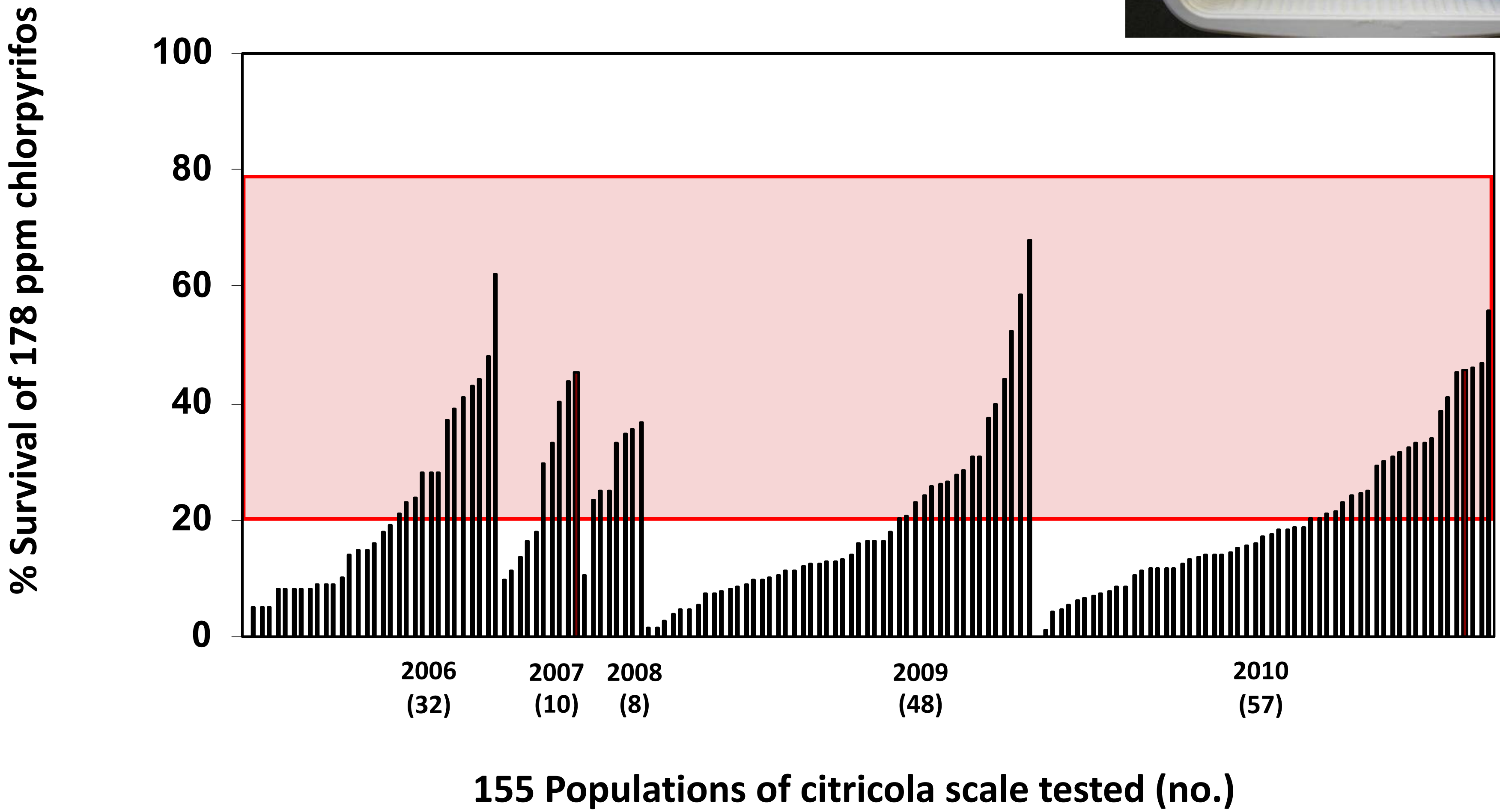
Citricola scale infested leaves
Dipped in 178 ppm chlorpyrifos
Held for 48 hours



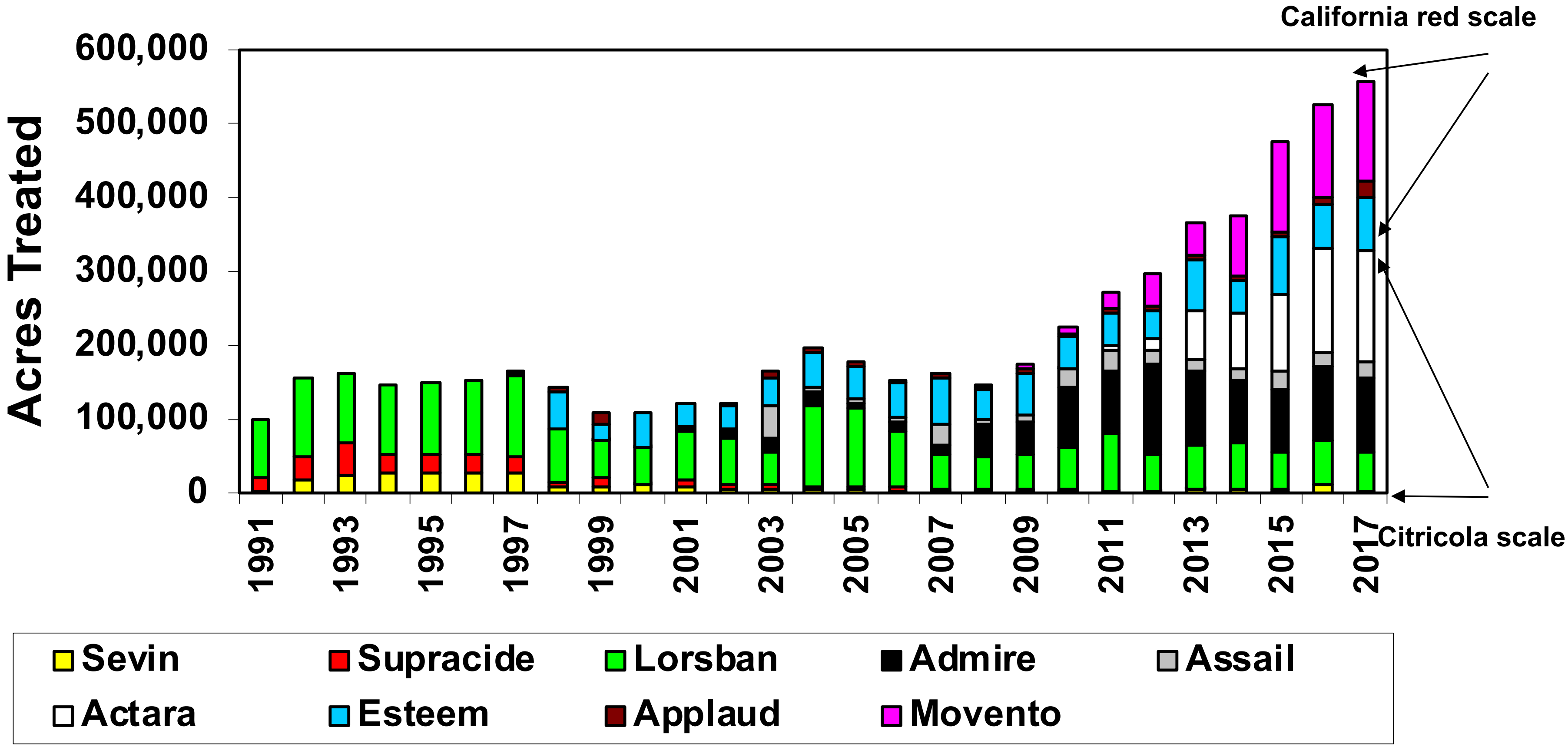
Field rate: 3-6 lb AI chlorpyrifos in 1000 gpa

Citricola scale

41% of populations with organophosphate resistance (20-75% survival) after > 50 years of exposure to OPs

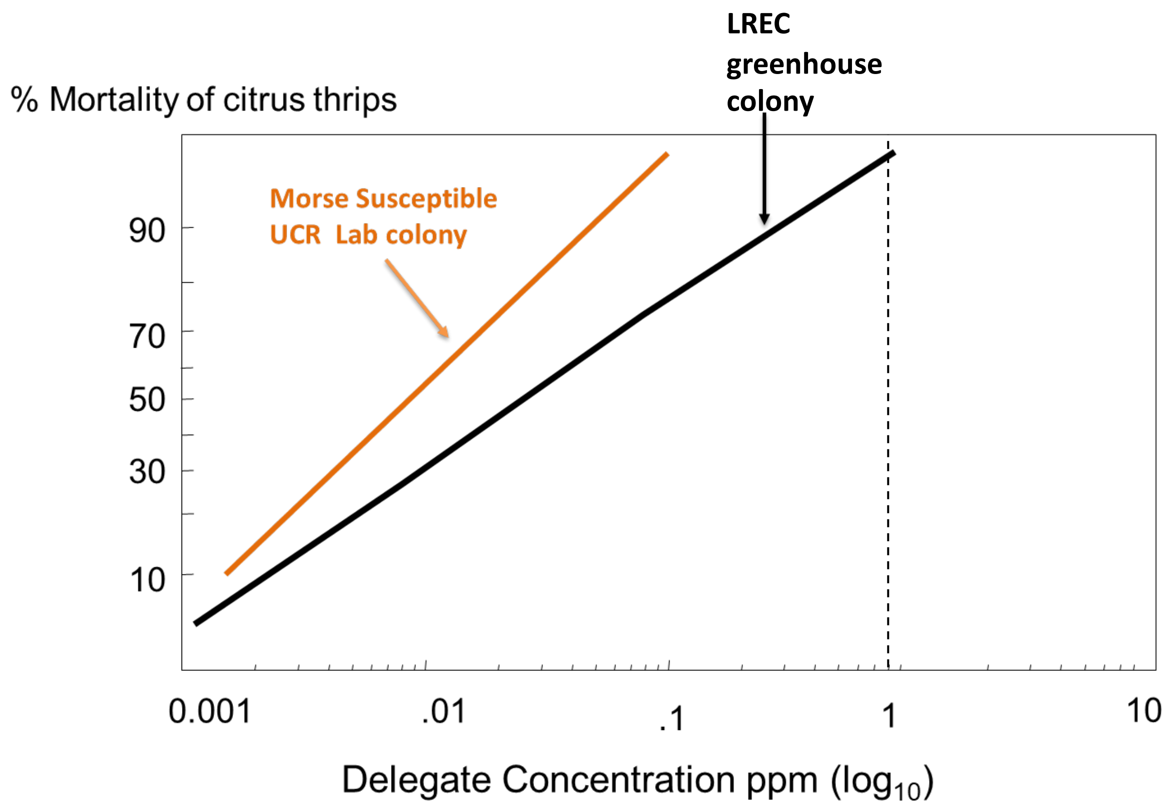


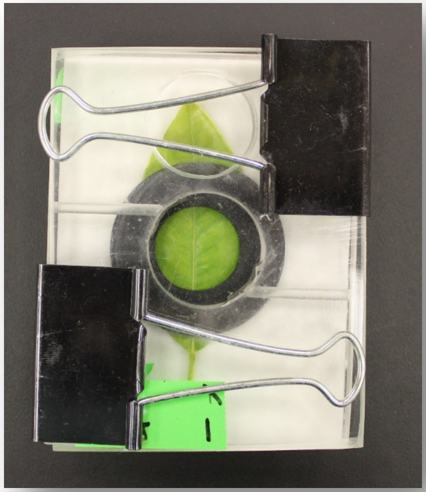
Insecticides Used for Scale Control in the San Joaquin Valley



Citrus thrips resistance to Delgate

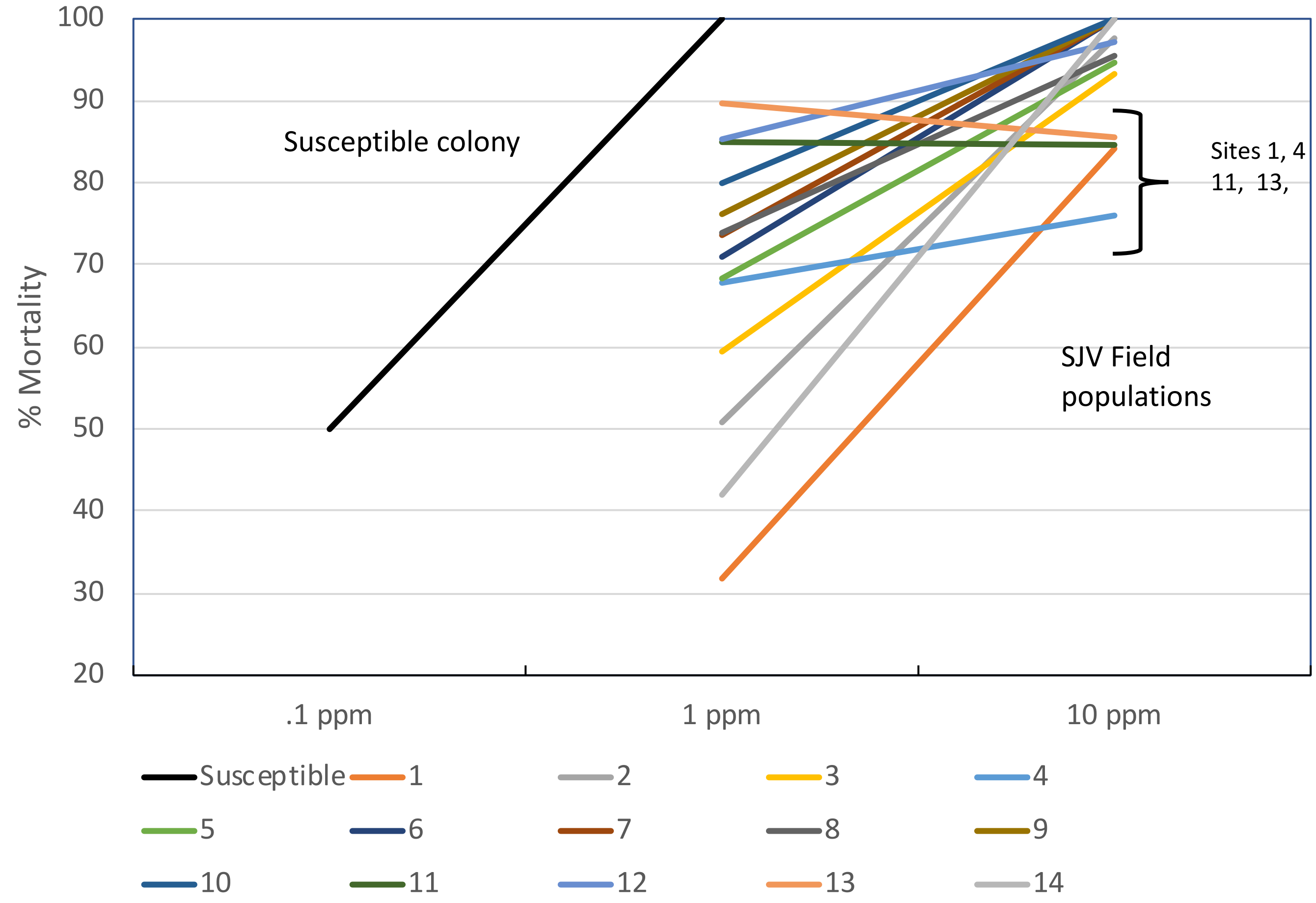
- Delegate (spinetoram) field rate: 45-56 ppm
  - 6 oz in 200-250 GPA
- 48 hour bioassay of field collected adult thrips
- Discriminating concentration of 1 ppm



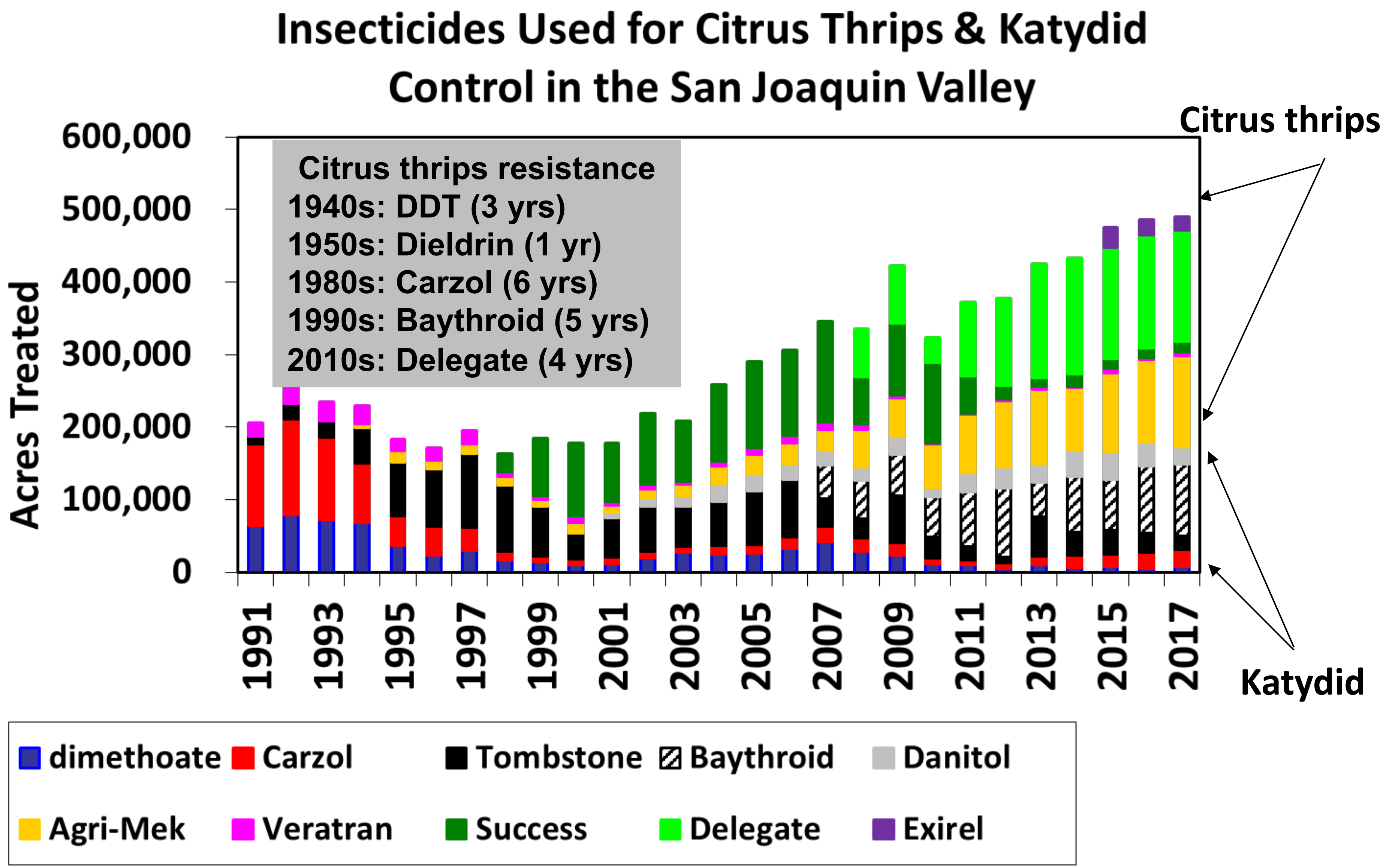


2019 Citrus thrips adult % mortality response to 1 and 10 ppm Delegate

- 14 Field populations are showing 50-90% mortality of 1 ppm (resistance!)
- Sites 1, 4, 11 and 13 are concerning because they show <80% mortality at 10 ppm (High levels!)



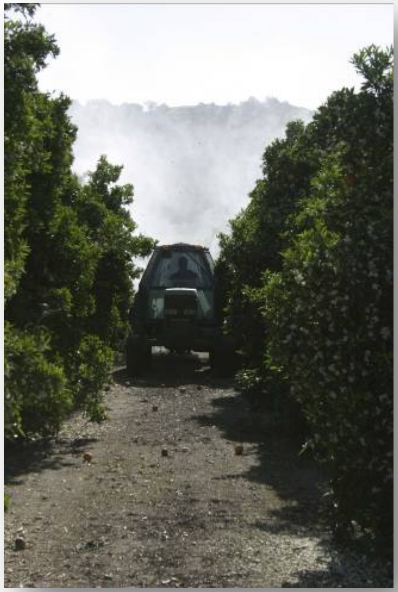
Break for Quiz questions



Insecticides Used for Citrus Thrips & Katydid Control in the San Joaquin Valley
Citrus thrips resistance
1940s: DDT (3 yrs)
1950s: Dieldrin (1 yr)
1980s: Carzol (6 yrs)
1990s: Baythroid (5 yrs)
2010s: Delegate (4 yrs)
Acres Treated
600,000
500,000
400,000
300,000
200,000
100,000
0
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
Citrus thrips
Katydid
dimethoate
Carzol
Tombstone
Baythroid
Danitol
Agri-Mek
Veratran
Success
Delegate
Exirel

Rate of Insecticide Resistance Development

- are resistance alleles dominant or recessive
- how many genes are involved
- number of generations for pest
- population mobility and interbreeding with susceptible insects
- persistence of pesticide residues
- frequency of treatment**



Organophosphate/carbamate resistance history in citrus

	Citrus thrips (dimethoate, Carzol)	California red scale (Lorsban, Supracide, Sevin)	Citricola scale (Lorsban)
Resistance documented	1980s	1990s	2000s
Generations per year	7-8	4	1
Mobility	Highly	Crawlers and males	crawlers

Can resistance develop to organically approved products?

Bacillus thuringiensis (Bt): leafminer, diamondback moth, beet army worm, European corn borer, Indian meal moth, pink bollworm

Azadirachtin: ??

Spinosad (Success): leafminer, diamond back moth, beet army worm, Colorado potato beetle

Oils: ??

Sulfur: predatory mites

Pheromones: ??

Pyrethrum: blue tick, house flies

Cryolite: walnut husk fly

The one advantage of organics, is they are so short-lived its not a strong selection pressure. So you see resistance only where they are sprayed very frequently.

Cross Resistance

Within the same chemical class, the insect has a mechanism of resistance that protects it against any chemical in that group, because the pesticide attacks the same point.

Mode of Action Group	Insecticides used for citrus thrips control
Group 1A/1B Carb/OP acetylcholine esterase inhibitor	Dimethoate, Carzol
Group 3 pyrethroid Sodium channel modulator	Danitol, Baythroid, Mustang
Group 4d butenolide Nicotinic acetylcholine receptor agonists	Sivanto
Group 5 spinosyn Nicotinic acetylcholine receptor allosteric activators	Success, Entrust, Delegate
Group 6 avermectin chloride channel activators	Agri-Mek and generics
Group 28 ryanoid Ryanodine receptor modulators	Exirel
Group ? botanical	Veratran

Multiple Resistance (Super bugs)

Insects can use one or more different mechanisms of resistance to protect themselves against many different insecticide classes at the same time

+ Reduced penetration of the cuticle
+ increased enzyme activity
+ reduced nerve sensitivity

Example: Asian citrus psyllid in Florida, treated 9-12 times/yr

	MOA grp 1	MOA grp 3	MOA grp 4
ACP resistance	OPs/Carbamates	Pyrethroids	neonicotinoids

Insecticide Mode of Action Classification:

A key to effective insecticide resistance management

Insecticide Resistance Action Committee

IRAC website: www.irac-online.org

Introduction

IRAC promotes the use of a Mode of Action (MoA) classification of insecticides as the basis for effective and sustainable insecticide resistance management (IRM). Insecticides are allocated to specific groups based on their target site. Reviewed and re-issued periodically, the IRAC MoA classification list provides farmers, growers, advisors, extension staff, consultants and crop protection professionals with a guide to the selection of insecticides or acaricides in IRM programs. Effective IRM of this type preserves the utility and diversity of available insecticides and acaricides. A selection of MoA groups is shown below.

Effective IRM strategies: Alternations or sequences of MoA

All effective insecticide (and acaricide) resistance management (IRM) strategies seek to minimise the selection for resistance from any one type of insecticide or acaricide. In practice, alternations, sequences or rotations of compounds from different MoA groups provide sustainable and effective IRM. This ensures that selection from compounds in the same MoA group is minimised. Applications are often arranged into MoA spray windows or blocks that are defined by the stage of crop development and the biology of the pest(s) of concern. Local expert advice should always be followed with regard to spray windows and timings. Several sprays of a compound may be possible within each spray window but it is generally essential to ensure that successive generations of the pest are not treated with compounds from the same MoA group. Metabolic resistance mechanisms may give cross-resistance between MoA groups, and where this is known to occur, the above advice must be modified accordingly.

Moulting & Metamorphosis

Group 18 Ecdysone agonist / disruptor
Diacylhydrazines (e.g. Tebufenozide)
Group 7 Juvenile hormone mimics
JH analogues, Fenoxycarb, Pyriproxyfen, etc

Midgut

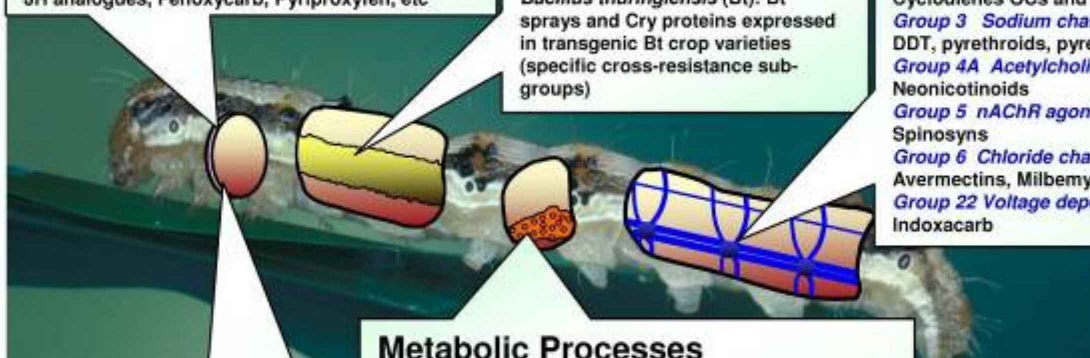
Group 11 Microbial disruptors of insect midgut membranes
Toxins produced by the bacterium *Bacillus thuringiensis* (Bt): Bt sprays and Cry proteins expressed in transgenic Bt crop varieties (specific cross-resistance sub-groups)

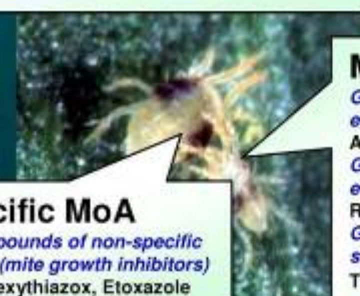
Nervous System

Groups 1A & B Acetylcholinesterase (AChE) inhibitors
Carbamates and Organophosphates
Group 2 GABA-gated chloride channel antagonists
Cyclodienes OCs and Phenylpyrazoles (Fiproles)
Group 3 Sodium channel modulators
DDT, pyrethroids, pyrethrins
Group 4A Acetylcholine receptor (nAChR) agonists
Neonicotinoids
Group 5 nAChR agonists (Allosteric) [not group 4A]
Spinosyns
Group 6 Chloride channel activators
Avermectins, Milbemycins
Group 22 Voltage dependent sodium channel blocker
Indoxacarb

Non-specific MoA

Group 9 Compounds of non-specific mode of action (selective feeding blockers)
Pymetrozine, Flonicamid, etc.





Cuticle Synthesis

Groups 15 and 16 Inhibitors of chitin biosynthesis
Benzoylureas (Lepidoptera and others), Buprofezin (Homoptera)

Metabolic Processes

Many groups acting on a wide range of metabolic processes including:
Group 12 Inhibitors of oxidative phosphorylation, disruptors of ATP
Diafenthiuron & Organotin miticides
Group 12 Uncouplers of oxidative phosphorylation via disruption of H proton gradient - Chlorfenapyr

Non-specific MoA

Group 10 Compounds of non-specific mode of action (mite growth inhibitors)
Clofentezine, Hexythiazox, Etoxazole

Metabolic processes

Group 20 Mitochondrial complex III electron transport inhibitors
Acequinocyl, Fluacrypyrim, etc
Group 21 Mitochondrial complex I electron transport inhibitors
Rotenone, METI acaricides
Group 23 Inhibitors of lipid synthesis
Tetronic acid derivatives

v4, October 2005

UC IPM Guidelines for Citrus – Mode of action group number

SELECTIVE

A. SABADILLA#
(Veratran D) 10–15 lb
1–2 gallons molasses or
RANGE OF ACTIVITY: Pests: narrow (citrus thrips); Natural enemies: predatory thrips
PERSISTENCE: Pests: short; Natural enemies: short
COMMENTS: For use on all varieties. Acidify water in the spray tank to a pH of 4.5 before adding predaceous mite *Euseius tularensis* are present. Sabadilla is a short residual stomach poison; tin feed well on bait and it degrades with time. Use higher rates with more dilute applications. Do n wind velocity so as to achieve outside coverage. Don't apply during periods of heavy dew, fog, o

B. SPINETORAM
(Delegate WG) 4–6
RANGE OF ACTIVITY: Pests: narrow (thrips, orangeworms, katydids); Natural enemies: predator
PERSISTENCE: Pests: intermediate; Natural enemies: intermediate
RESISTANCE: Some citrus thrips populations in Kern County.
MODE-OF-ACTION GROUP NUMBER[1]: 5
. . . PLUS . . .
NARROW RANGE OIL
(415)
RANGE OF ACTIVITY: Pests: broad (unprotected stages of insects and mites); Natural enemies:
PERSISTENCE: Pests: short; Natural enemies: short
MODE OF ACTION: Improves translaminar movement and insecticide persistence.
COMMENTS: For use on all varieties. Do not apply to citrus nurseries or to citrus in greenhouses application to coincide with early to mid-hatch (see the thresholds listed above). To avoid potent (less than 1 inch in diameter) on a day when the ambient temperature has or is expected to exc reduced wind velocity so as to achieve outside coverage. Repeated applications will result in citr and spinosad) more than twice a year. Do not apply more than a total of 12 oz/acre per crop.

C. ABAMECTIN
(Agri-Mek SC) 2.25–4.
RANGE OF ACTIVITY: Pests: intermediate (citrus thrips, mites, leafminers); Natural enemies: pr
PERSISTENCE: Pests: intermediate; Natural enemies: intermediate
MODE-OF-ACTION GROUP NUMBER[1]: 6
. . . PLUS . . .
NARROW RANGE OIL
(415)
MODE OF ACTION: Improves translaminar movement and insecticide persistence.
RANGE OF ACTIVITY: Pests: broad (unprotected stages of insects and mites); Natural enemies:
PERSISTENCE: Pests: short; Natural enemies: short
COMMENTS: For use on all varieties. Apply in 50–250 gal water/acre. Do not apply in citrus nurs apply to small fruit (less than 1 inch in diameter) on a day when the ambient temperature has o substantial numbers of predators such as the predaceous mite, *Euseius tularensis,* are present. reduced wind velocity so as to achieve outside coverage. Repeated applications will result in citr formulations. **Regulations affect use for the San Joaquin Valley from May 1 to October 3**

D. CYANTRANILIPROLE
(Exirel) 20.5
RANGE OF ACTIVITY: Pests: aphids, leafminer, psyllids, sharpshooters, thrips; Natural enemies:
PERSISTENCE: Pests: intermediate; Natural enemies: none
MODE-OF-ACTION GROUP NUMBER[1]: 28
. . . PLUS . . .
NARROW RANGE OIL
(415)
RANGE OF ACTIVITY: Pests: broad (unprotected stages of insects and mites); Natural enemies:
PERSISTENCE: Pests: short; Natural enemies: short
MODE OF ACTION: Improves translaminar movement and insecticide persistence.
COMMENTS: Do not make ground applications within 25 feet or air applications within 50 feet of by air in a minimum of 10 gallons/acre.

DuPont™ Exirel®

INSECT CONTROL
WITH THE ACTIVE INGREDIENT CYAZYPYR®

GROUP	28	INSECTICIDE

For foliar applications to brassica, bulb, cucurbit, fruiting, leafy, legume (except soybean), root and tuberous and corm vegetables; commercially grown greenhouse cucumber, eggplant, pepper and tomato; cotton, oil seed crops; strawberries; bushberries; peanuts; citrus, pome, and stone fruits; tree nuts; and tobacco for pest management of sucking and chewing insects that can vector certain plant diseases, aiding in optimization of the crop's potential.

Active Ingredient	***By Weight***
Cyantraniliprole 3-bromo-1-(3-chloro-2-pyridinyl)-N-[4-cyano-2-methyl-6-[(methylamino)carbonyl]phenyl]-1H-pyrazole-5-carboxamide	10.20%
Other Ingredients	89.80%
TOTAL	100.00%

EXIREL® is a suspoemulsion (oil in water emulsion). SHAKE WELL BEFORE USING.

Contains 0.83 lb. active ingredient per gallon.

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Phone: 1-800-441-7515 (Toll Free)

Not for sale, sale into, distribution and/or use in Nassau and Suffolk counties of New York State.

KEEP OUT OF REACH OF CHILDREN

CAUTION

Si usted no entiende la etiqueta, busque a alguien para que se la explique a usted en detalle. (If you do not understand the label, find someone to explain it to you in detail.)

FIRST AID

IF ON SKIN: Take off contaminated clothing. Rinse skin immediately with plenty of water for 15-20 minutes. Call a poison control center or doctor for treatment advice.
IF IN EYES: Hold eye open and rinse slowly and gently with water for 15-20 minutes. Remove contact lenses, if present, after the first 5 minutes, then continue rinsing. Call a poison control center or doctor for treatment advice.
For questions regarding emergency medical treatment, you may contact 1-800-441-3637 for information.

PRECAUTIONARY STATEMENTS

HAZARDS TO HUMANS AND DOMESTIC ANIMALS

CAUTION! Causes moderate eye irritation. Avoid contact with eyes, skin or clothing. Prolonged or frequently repeated skin contact may cause allergic reactions in some individuals.

PERSONAL PROTECTIVE EQUIPMENT

Applicators and other handlers must wear:
Long-sleeved shirt and long pants.
Chemical resistant gloves Category A (such as butyl rubber, natural rubber, neoprene rubber, or nitrile rubber), all > 14 mils.
Shoes plus socks.

How can you slow resistance? Practice IPM

Use pesticides as a last resort

1. Keep trees healthy, pruned and watered
2. Remove shiners
3. Utilize pheromone disruption
4. Release natural enemies
5. Use soft pesticides to allow natural enemies to survive and assist
6. Wait to treat until pests have reached treatment thresholds
7. Rotate between chemicals that have different modes of action