Current status of insecticide resistance in Florida populations of Asian citrus psyllid and emerging management strategies

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Why does resistance develop?

- Lack of chemical diversity
- Excessive chemical use
- Lack of alternative IPM tactics
- Characteristics of the cropping system
- Genetics, physiology, behavior, and high breeding capacity of the target pest

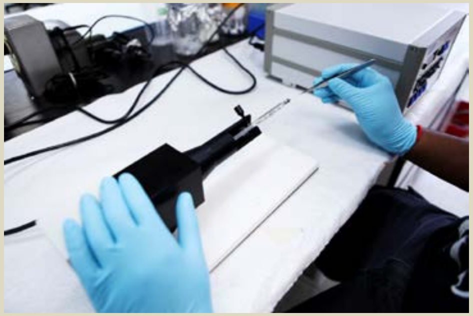
Citrus cropping system

- Neonicotinoids are part of the system from day 1
- Exit the nursery ‘hot’
- Treated with soil drenches when put in the ground (sometimes without rotation)
- Often receive neonicotinoids either by drench and/or foliar spray throughout lifespan

Physiology of the target pest

- Neonicotinoids are significantly more toxic to ACP by contact with cuticle than by ingestion through mouthparts

- The concentration of neonicotinoids that must be achieved within leaves that is required to kill ACP is much greater than what is needed by direct contact



Langdon et al. 2017, in press

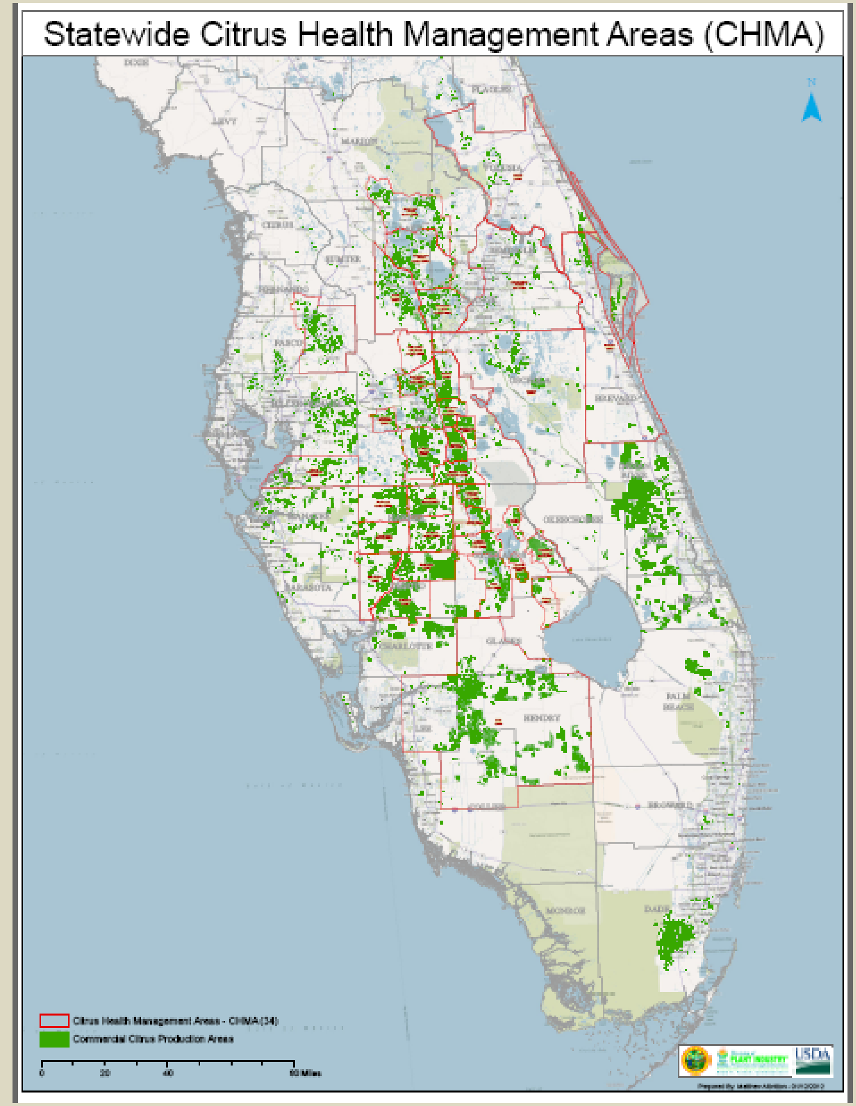
Citrus cropping system

- Under siege by insect-transmitted pathogen that kills trees
- Not contiguously grown, often close to urban landscape
- Under pressure from near 100% infection
- Secondary pests are still present and require attention
- Individual IPM tactics to control ACP will not prevent spread of HLB as stand-alone tools
- A muti-tactic system integrating all available strategies: chemical, biological, and cultural controls, as well as, disease tolerance and good horticultural practices are necessary for effective HLB management

Annual Survey to Monitor For Insecticide Resistance

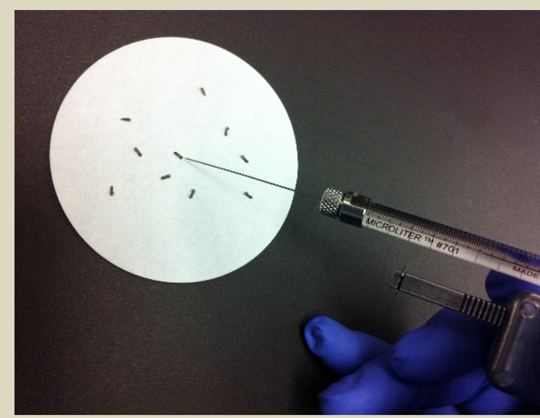
Four purposes:

1. Monitor for insecticide resistance in *D. citri* field populations
2. Study the changes that occur over time in the insecticidal response of *D. citri*
3. Determine the natural variation in *D. citri* insecticidal response
4. Refine spray schedules

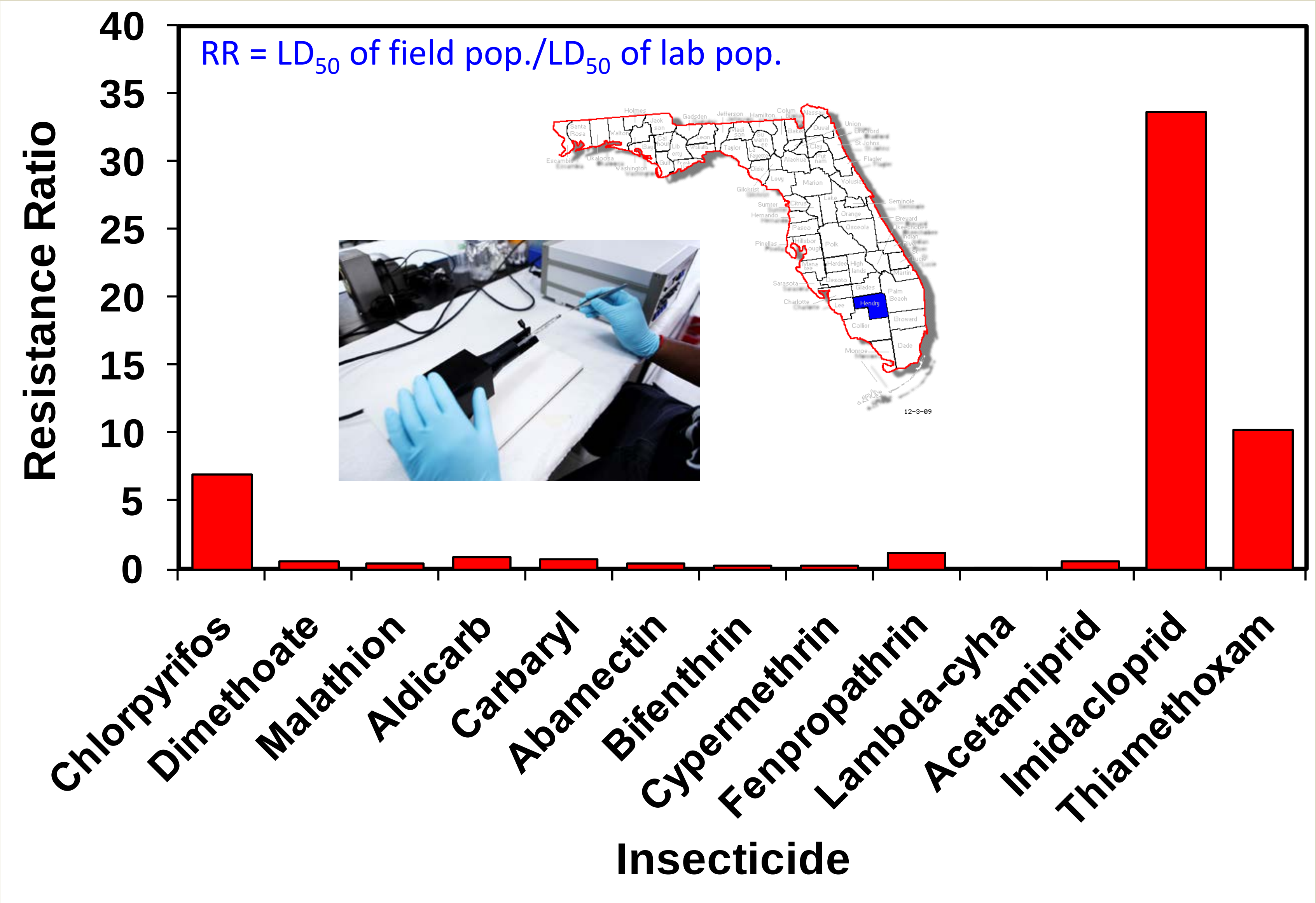


Procedure

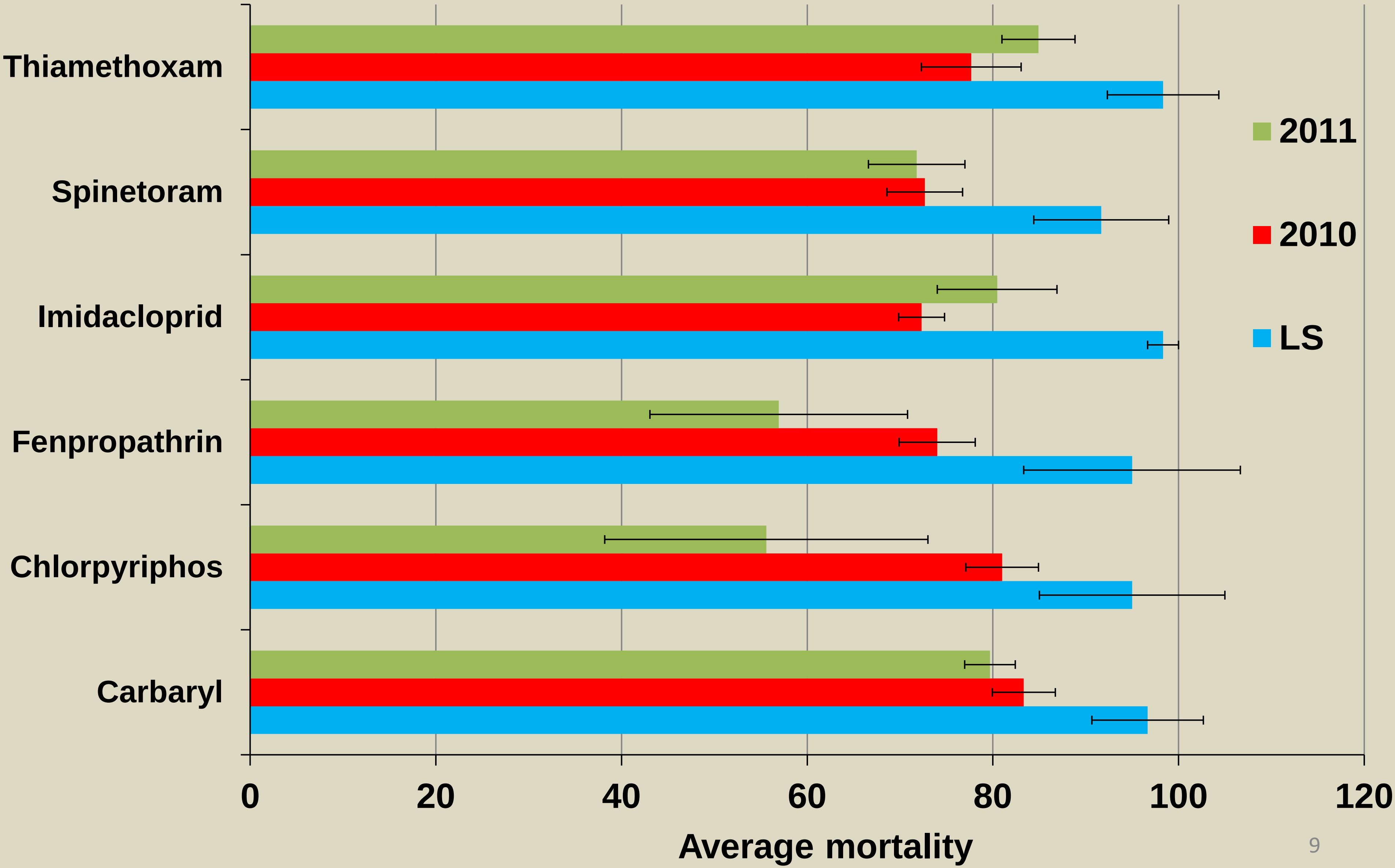
- 5000 insects are collected from the field by D-Vacuum
- Psyllids are brought back to the laboratory
- Topically treated with six different insecticides
- 500 insects/insecticide; 10 doses
- Score mortality 24 post-treatment
- Estimate LD_{50}, determine RR_{50}s and examine probit lines



Insecticide susceptibility—2009

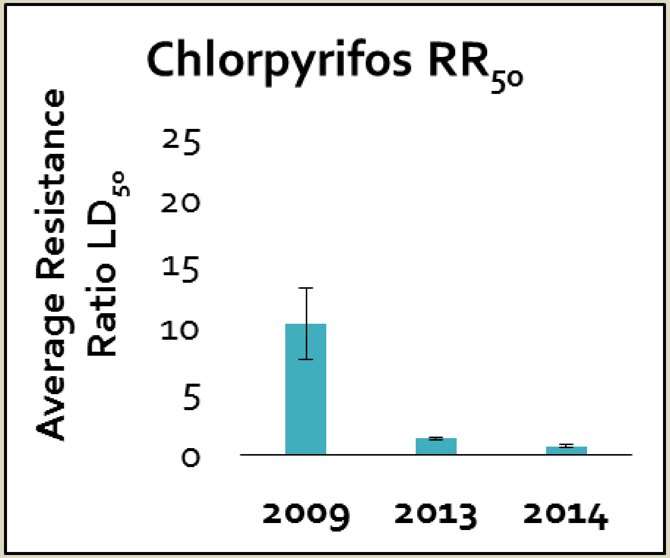


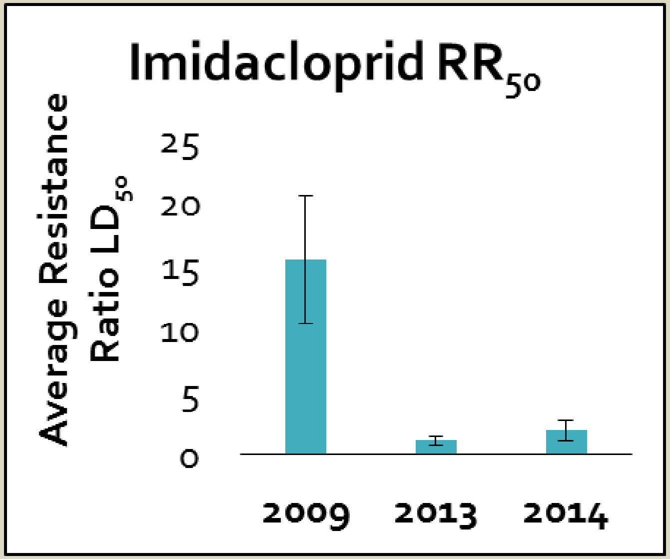
2010 & 2011 - Insecticide susceptibility of five field populations compared with laboratory susceptible population-LD_{95}



Average LD_{50} Resistant Ratios

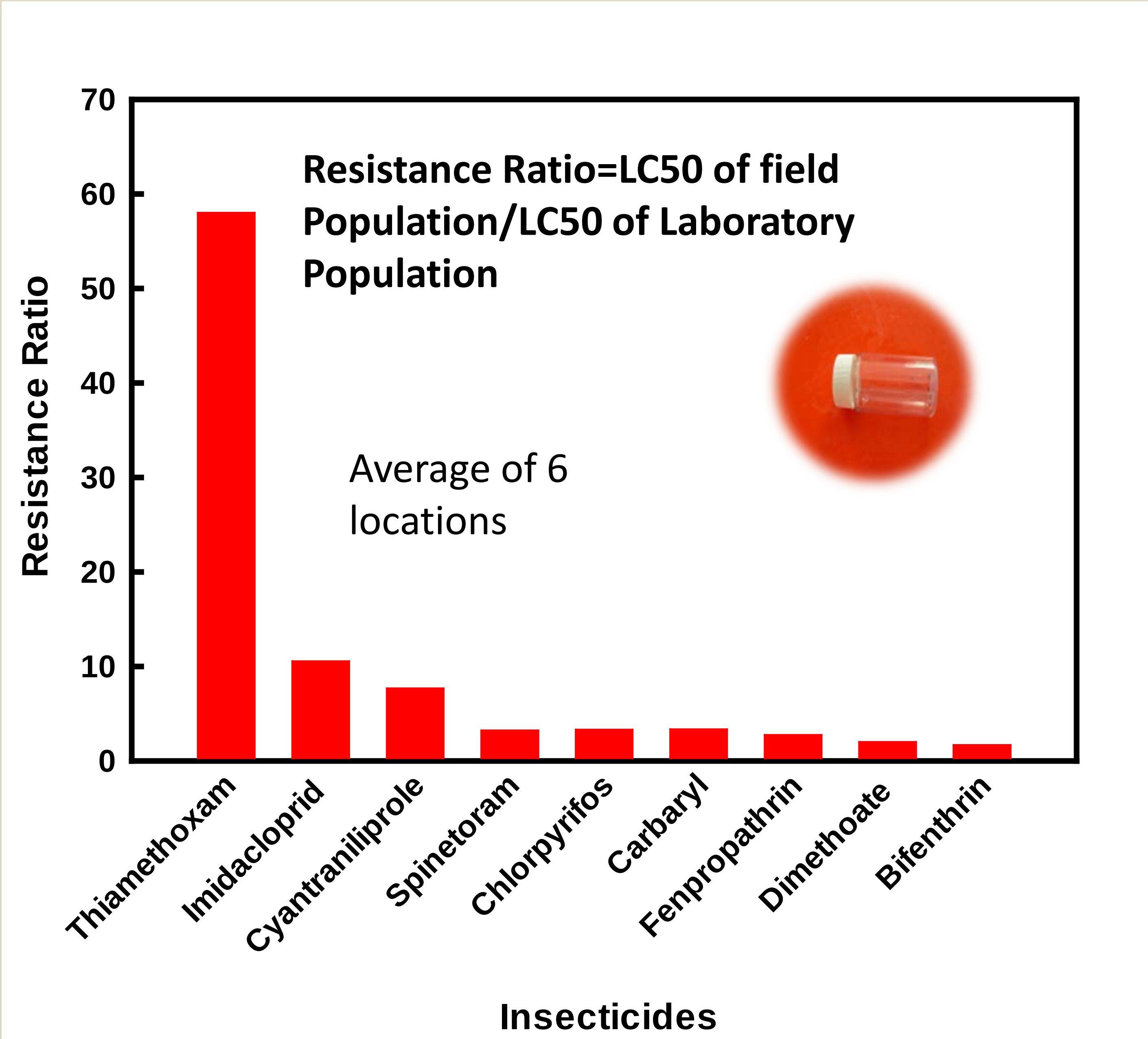
- RR_{50} = Field Population LD_{50} / Laboratory Strain LD_{50}
- 2009: ratios were on the rise for some major classes of insecticides
- 2013 and 2014 fell back to susceptible levels
  - Hypothesis: Improved spray regimes through CHMA were working





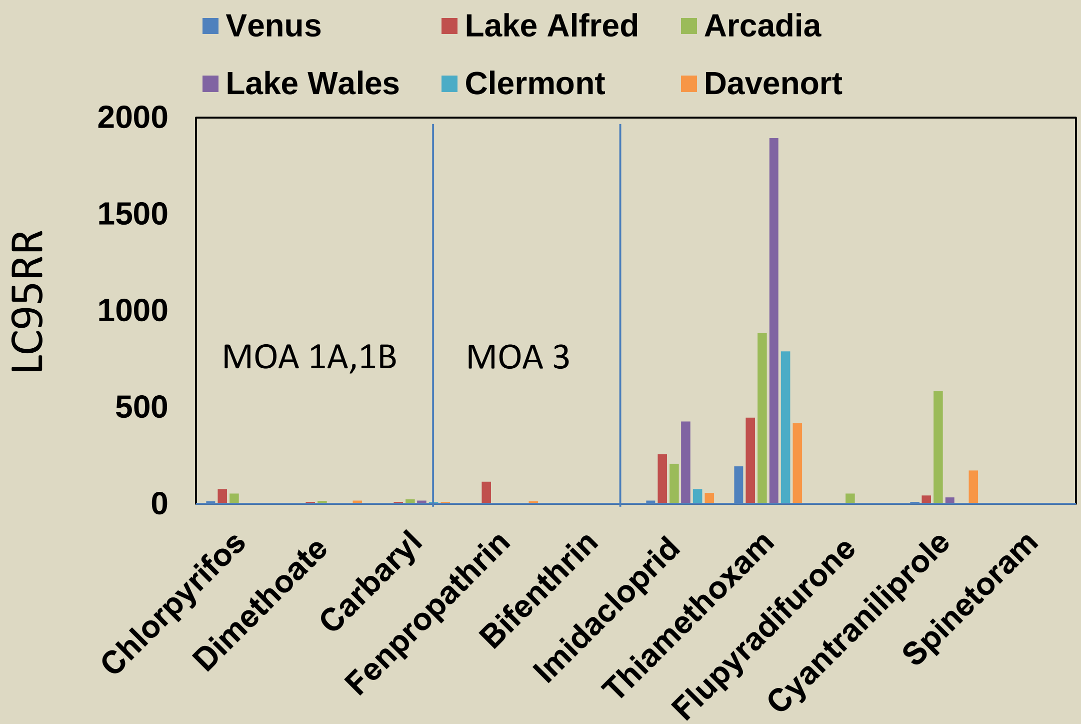
*Average of RR_{50} from all sites surveyed

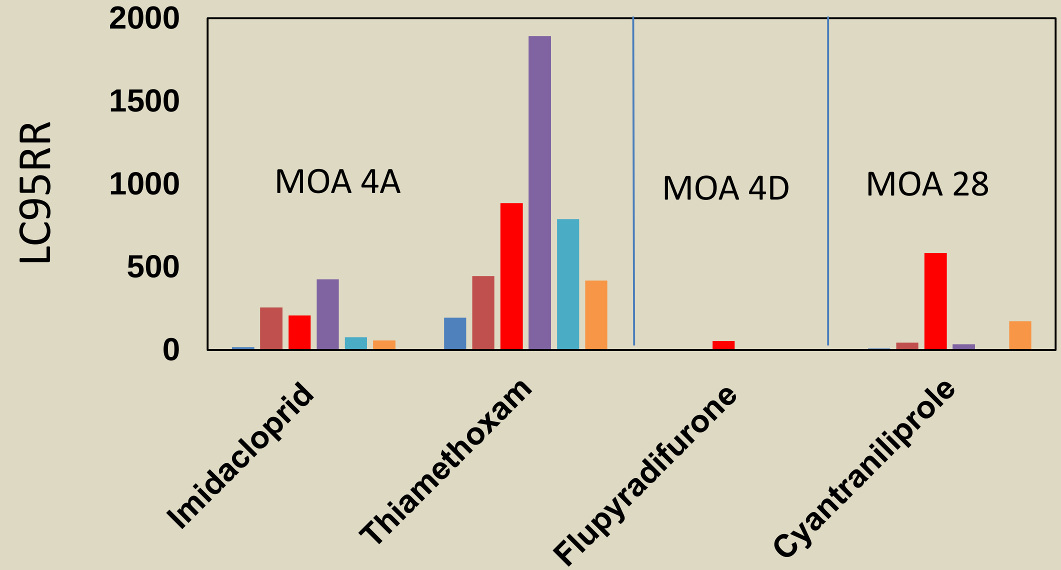
Insecticide susceptibility—2017



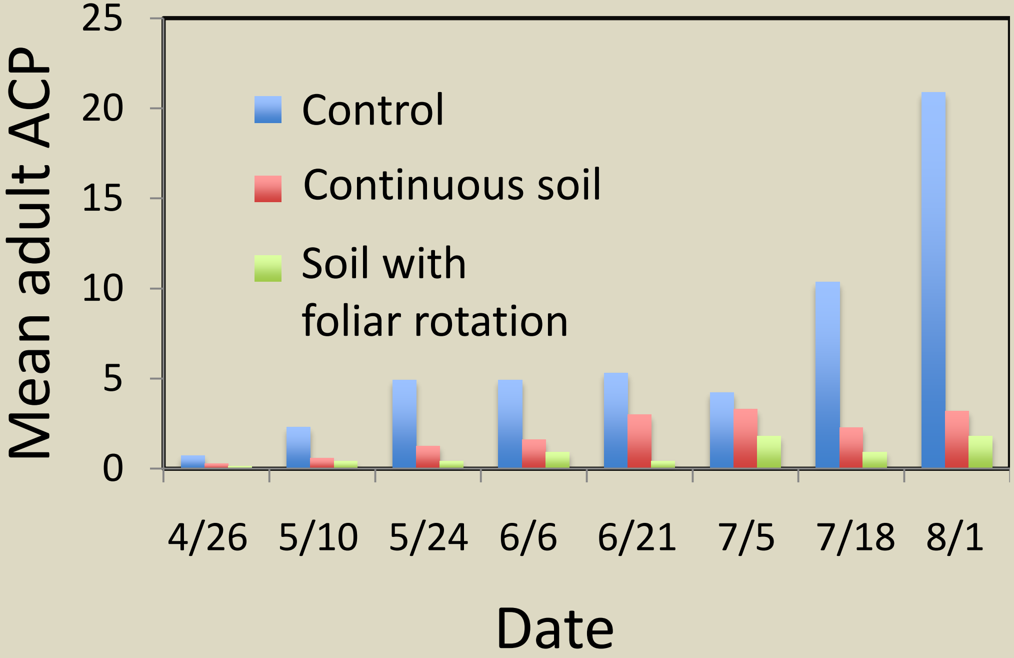
2017 Resistance monitoring in 6 locations in Florida (LD95s)

MOA	Class	Site of action
1	OPs & carbamate	AChE inhibitors Nerve action
3	pyrethroid	Sodium channel Nerve action
4A	Neonicoti-noid	Nicotinic AChR modulator Nerve action
4D	butenolide	Nicotinic AChR modulator Nerve action
28	diamide	Ryanodine receptor modulator nerves/muscles





How bad can resistance get and how fast can it show up?



Treatments	HLB infected
Control	**3.8%**
Soil drench neonic	**11.3%**
Soil drench + rotation	**0%**

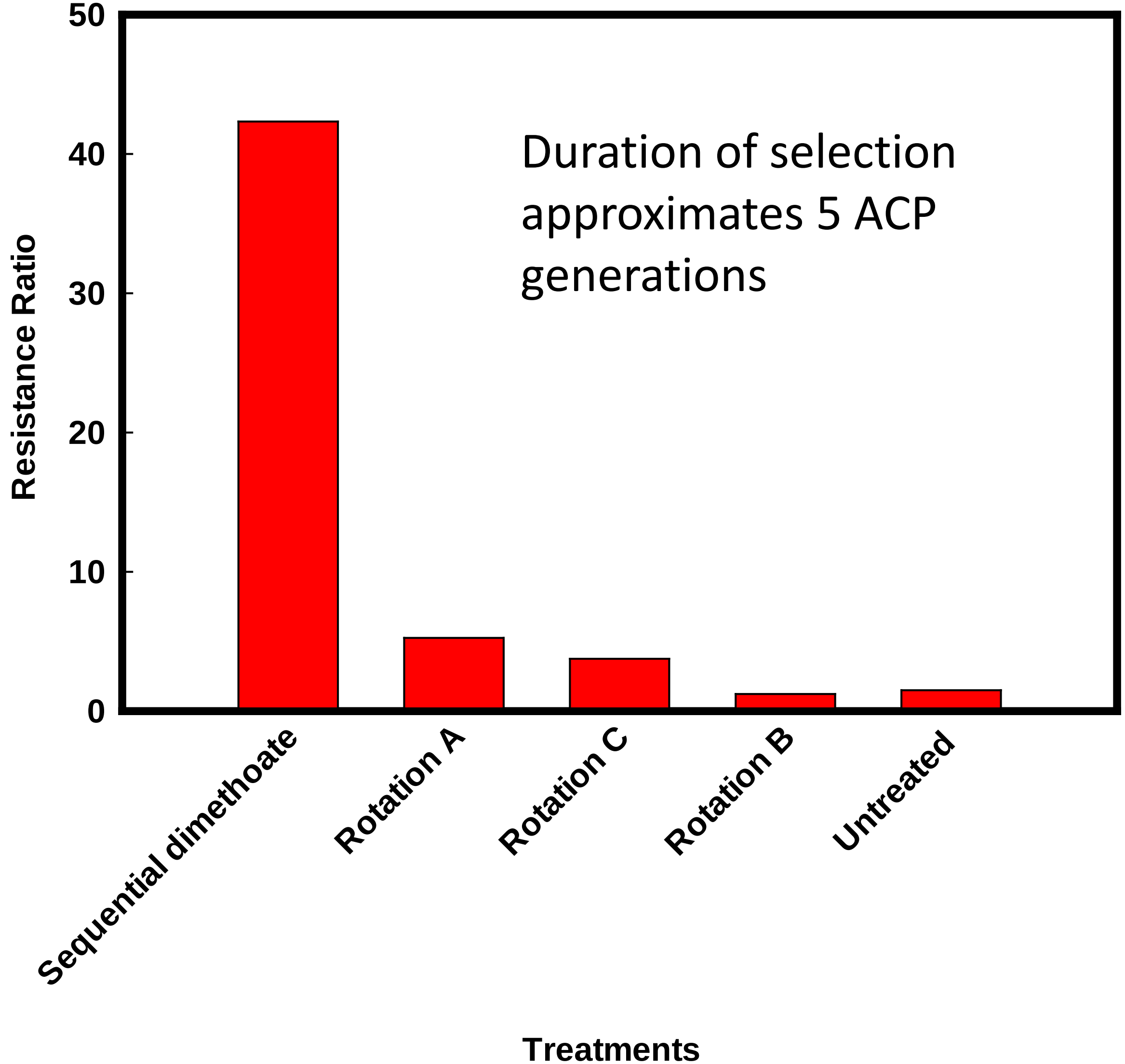
- Resistance Ratio (RR) of ACP in soil drench only treatment

RR = 93.4 to 126.0

Kim and Rogers, in preparation

Rotation is effective

Susceptibility of ACP following 5 consecutive dimethoate sprays versus various insecticide rotations

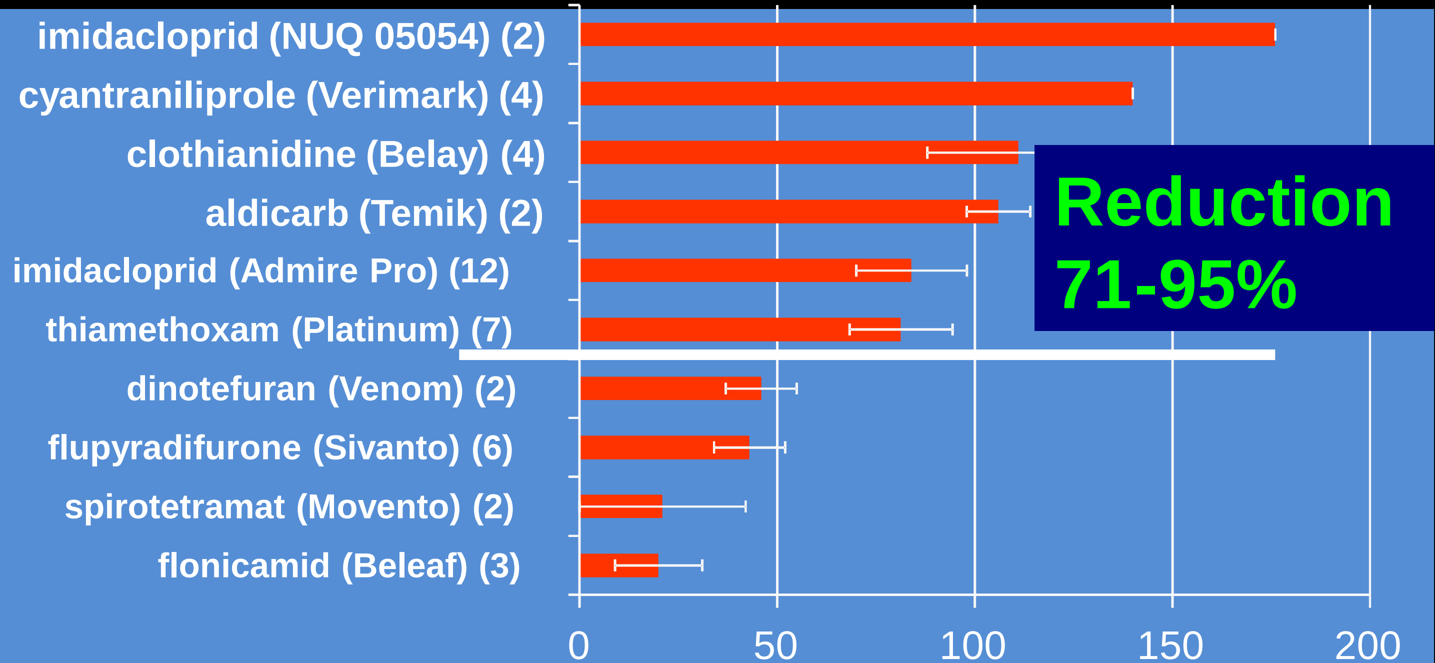


Rotation A: organophosphate, microbial, synthetic pyrethroid, insect growth regulator and neonicotinoid;
Rotation B: neonicotinoid, synthetic pyrethroid, microbial, organophosphates and insect growth regulator;
Rotation C: microbial, insect growth regulator, organophosphate, neonicotinoid and synthetic pyrethroid;
Sequential dimethoate: 5 sprays with dimethoate (Resistance Ratio=LC50 of field Pop/LC50 of Laboratory Pop).

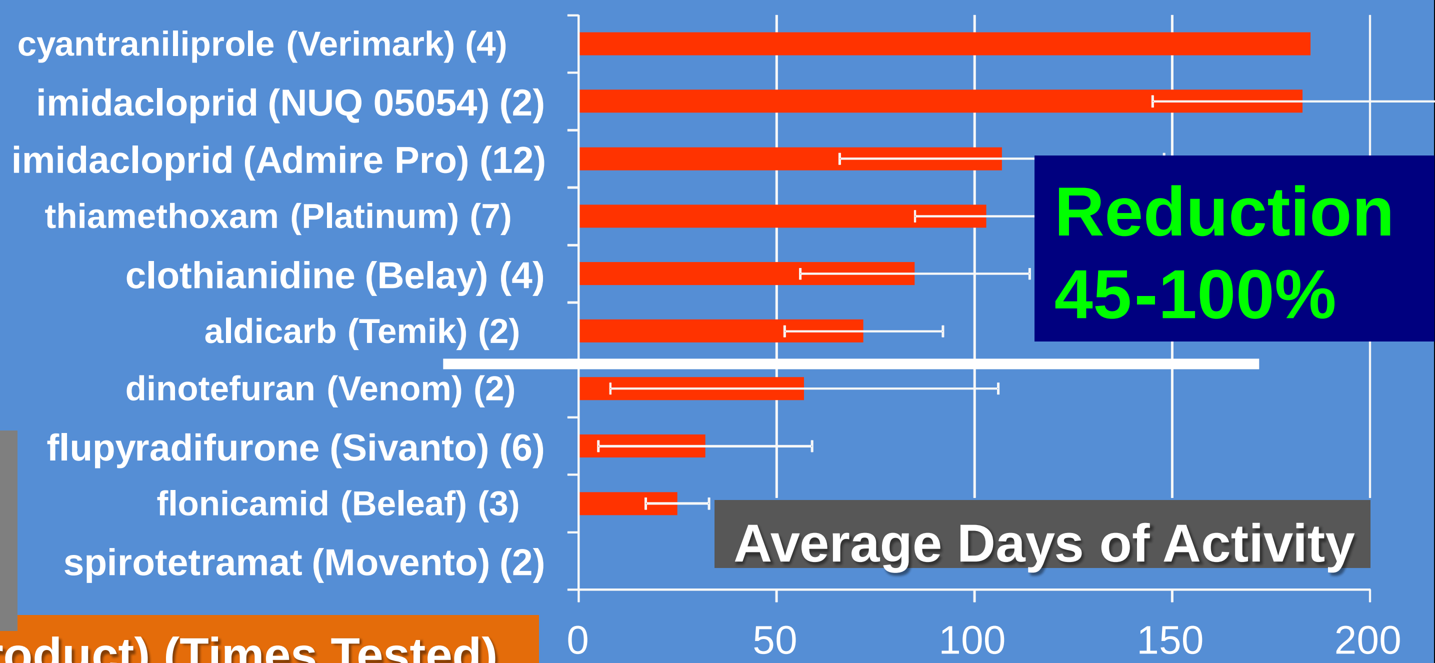
Chemical Control of ACP in Young Trees – Limited Options, Rotate MOA

Soil Applications

Adult



Nymph

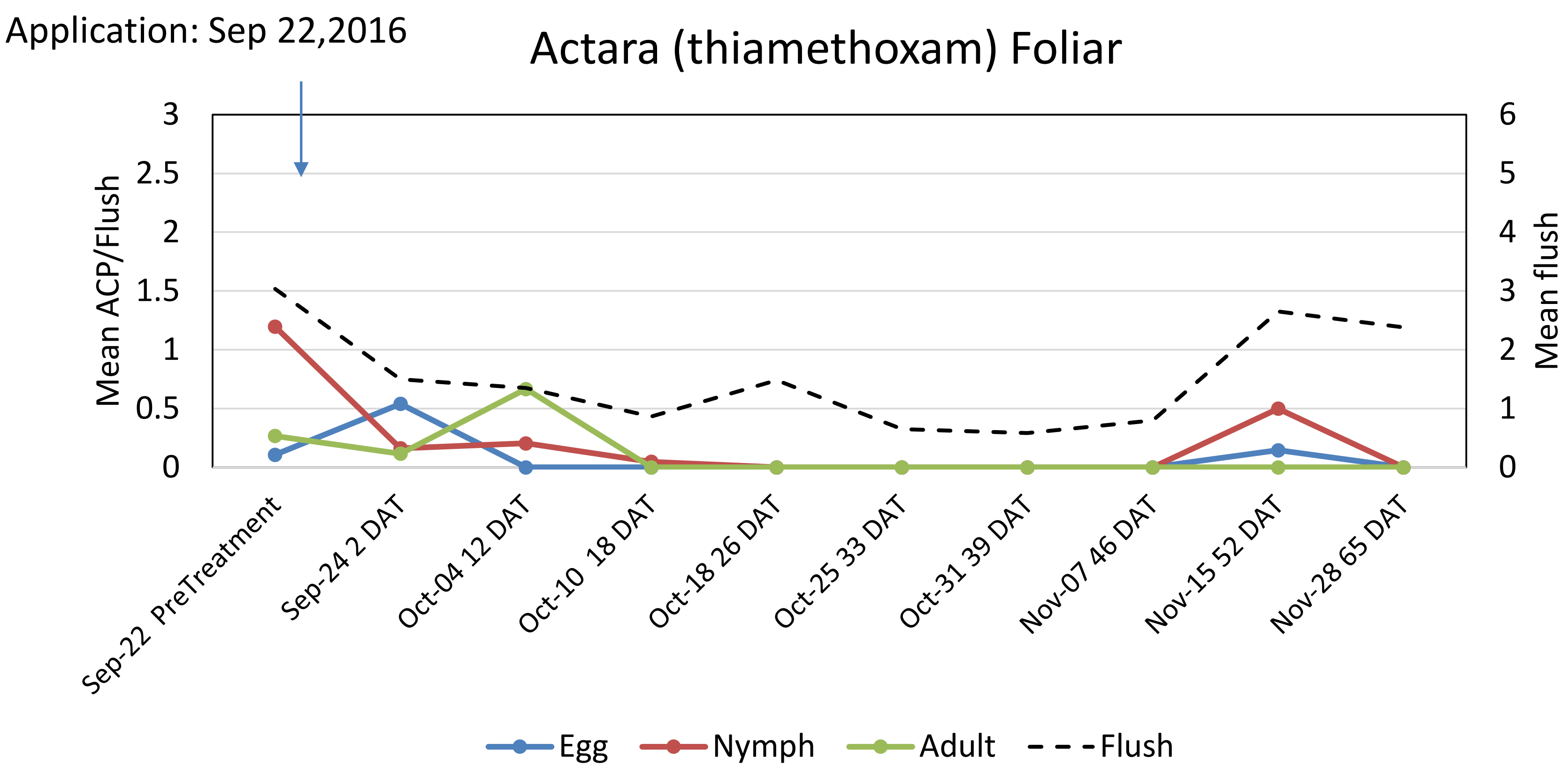


Qureshi et al. 2014. PLoS ONE. 9 (12) e112331. doi:10.1371/journal.pone.0112331

Active Ingredient (Product) (Times Tested)

Persistence of neonicotinoids in California is very good – both foliar and systemic. Ventura California thiamethoxam insecticide treatment

This mirrors the types of results we observed with neonics 10 years ago



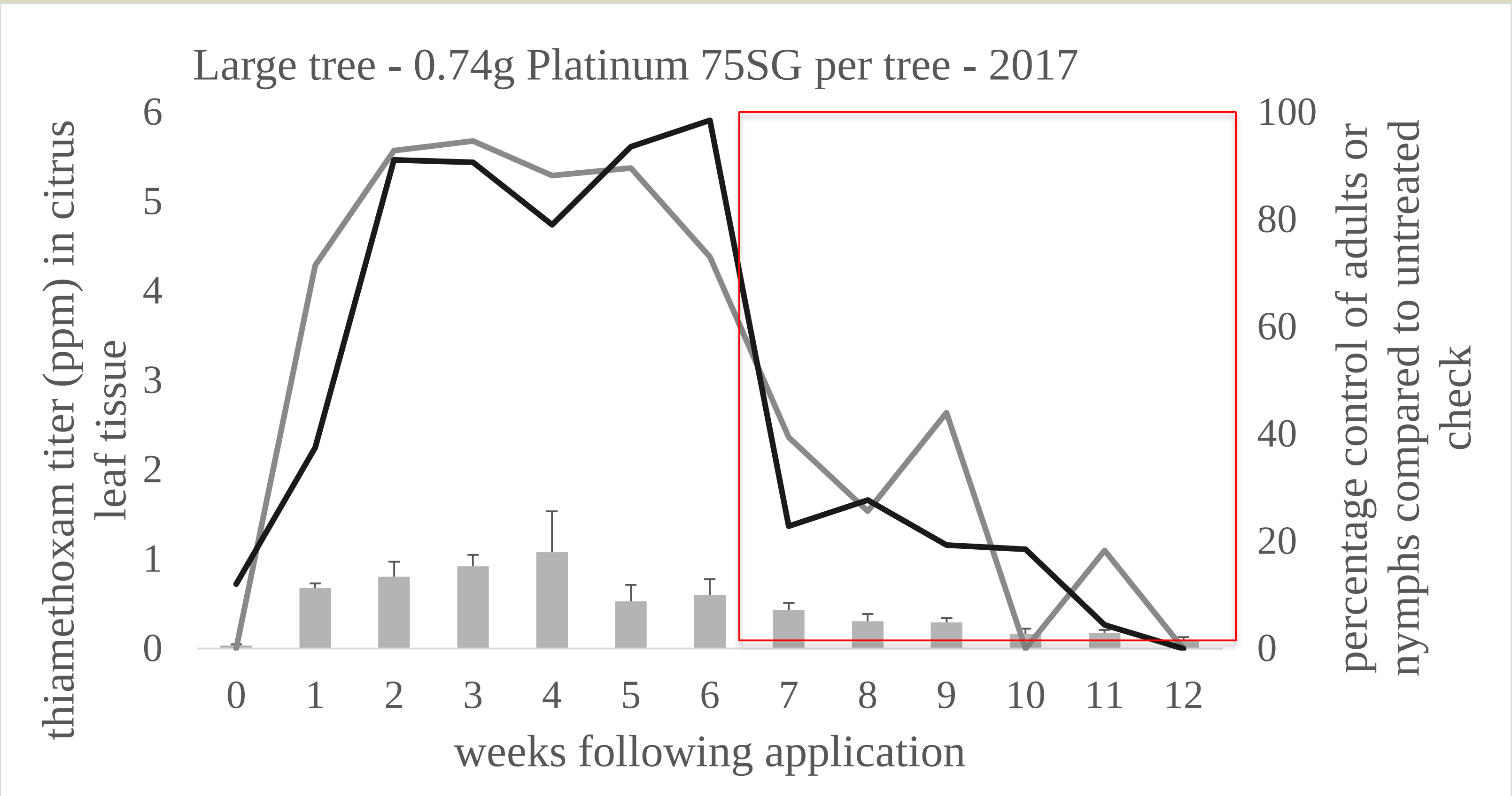
5.5 OZ/A + 1% Supreme Spray 440

1 GA/100GA

Grafton-Cardwell, CA

Sub-lethal concentrations of neonicotinoids persist long after treatments are effective against ACP—causes selection pressure

18 month old trees



Langdon et al. 2017, in review

Seek to use IPM principles where possible

- Manage tree health with best horticultural practices
- Incorporate cultural control where possible: reflective mulches, spray timing targeting dormant weather ACP
- Ensure effective chemical use-Apply label rates without cutting, rotate modes of action, maximize coverage
- If possible, scout for pests (including secondary pests) to understand need for application

Diversify Chemical Use

<u>Multiple targets</u>
Adults/nymphs
Secondary pests

<u>Rotation</u>

<u>Reduce Frequency</u>
and use selective MOAs
when possible

<u>Cost</u>

Dormant or Border

Growing season/whole block

Months	Nov-Dec	Jan	Feb-Mar	Apr	May - June	July - Aug	Sep-Oct
Products	OP[13] (e.g. Imidan, Dimethoate, chlorpyrifos)	Pyrethroid[14] (Mustang Danitol Baythroid)	*Sivanto[9] *Movento[1] *Portal[2] *Micromite[4] *Intrepid[5] Exirel[6]	OIL[7] Portal[2] Micromite[4] Exirel[6] Apta[8] Sivanto[9]	Movento[1] Delegate[10] Abamectin[11] Knack[12] Exirel[6] Apta[8] Sivanto[9]	Oil[7] Sivanto[9] Apta[8] OP[13]	Movento[1] Delegate[10] Apta[8] Sivanto[9]
Pests	ACP Weevils	ACP Weevils	ACP Mites Leafminer Weevils Scales Aphids	ACP Mites Leafminer Weevils Aphids	ACP Rustmite Leafminer Scales	ACP	ACP Rustmite Leafminer

ACP[+++1,6.8,9,13,14] ACP[++2,10] ACP[+4,7,11] Leafminer[4,5,6,10] Rustmite[1,4,7,8,11] Scales[1,12] Aphids[9] Mealybugs[1]

P. Stansly

Diversifying Chemical Use may require use of IGRs, nymph-targeting materials, and not expecting to see **0** living ACP following application

Treatment	May	June	July	September	October
Rotation A	dimethoate	abamectin + thiamethoxam	fenpropathrin + abamectin	diflubenzuron	imidacloprid
Rotation B	imidacloprid abamectin +	fenpropathrin	abamectin + thiamethoxam	dimethoate	diflubenzuron
Rotation C	thiamethoxam	diflubenzuron	dimethoate	imidacloprid	fenpropathrin

Consequences of single product use

- Product failure-causing resistance in Europe to neonicotinoid insecticides for whitefly occurred where both foliar sprays and soil drenches were made in concert

- Also, neonicotinoids were not rotated in that case because no other options existed at the time in that cropping system

Current consequences of resistance

- Current levels of resistance to neonicotinoids were high to alarming at all locations surveyed thus far
- Preliminary investigations indicate that <u>at least 6 months</u> of completely ceasing selection pressure will be required for ACP populations to fall back to susceptible levels
- After populations reverse to susceptibility, they may remain forever ‘primed’ to becoming resistant faster than was required initially, making rigorous resistance management a top priority into the future

How should neonicotinoids be used for young tree protection in the face of resistance?

- Soil applications do not deliver sufficient neonicotinoid toxicant into the plant to kill resistant or semi-resistant ACP—application failures are occurring now

- Sub-lethal concentrations of neonicotinoids persist in non-bearing citrus trees during the period when ACP are not effectively controlled, further exacerbating resistance selection

How should neonicotinoids be used for young tree protection in the face of resistance?

- Moving forward, growers choosing to continue use of soil-applied neonics should closely monitor their groves to ensure the soil applications are still providing effective control
- In the European whitefly example that mirrored our current situation with ACP, soil applications of neonicotinoids were suspended with replacement by foliar sprays only, which bought more time for growers and allowed crop protection from the virus-spreading vector

How should neonicotinoids be used for young tree protection in the face of resistance?

- If control failures are observed after applications of soil-applied neonicotinoids, we recommend using neonicotinoids only as foliar sprays <u>**in new plantings**</u> along with a rigorous rotation with other foliar-applied chemistries

- A rotation of at least 5 modes of action in sequence has been shown to effectively prevent development of resistance

If you were doing young tree care without soil application of neonicotinoids:

- Foliar sprays may serve as replacements for soil drenches as warranted
- Insecticide alternatives such as Surround reduce ACP numbers and help prevent pathogen inoculation
- Reflective mulches further reduce ACP populations

Tree size	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Non-bearing trees Resent -5 year < 3’-9’	FS-1	FS-2	FS-3	FS-4	FS-5	FS-1	FS-2	FS-3	FS-4	F-5S	FS-1	FS-2
	Season-long Reflective mulch											
FS= Foliar Insecticide Spray; Green shaded areas indicate opportunity for Kaolin clay application. Rate 25 lbs/100 gal of water works well. Can cover more than an acre. Can interfere with translaminar insecticides*												

Conclusions:

- ACP in Florida show neonicotinoid resistance in numerous locations and regions
- Neonicotinoids exhibit far greater contact toxicity to adult ACP than toxicity by ingestion
- Soil application of neonicotinoids causes persistent sub-lethal dosages of active ingredient in plants that exacerbates resistance
- ACP control in young trees is still possible but might be best achieved using only foliar-based insecticide applications, making sure to rotate modes of action with every application. Further research is needed to evaluate this strategy
- Insecticide resistance can be effectively managed by rotating 5 modes of action in sequence

Funding: CRDF