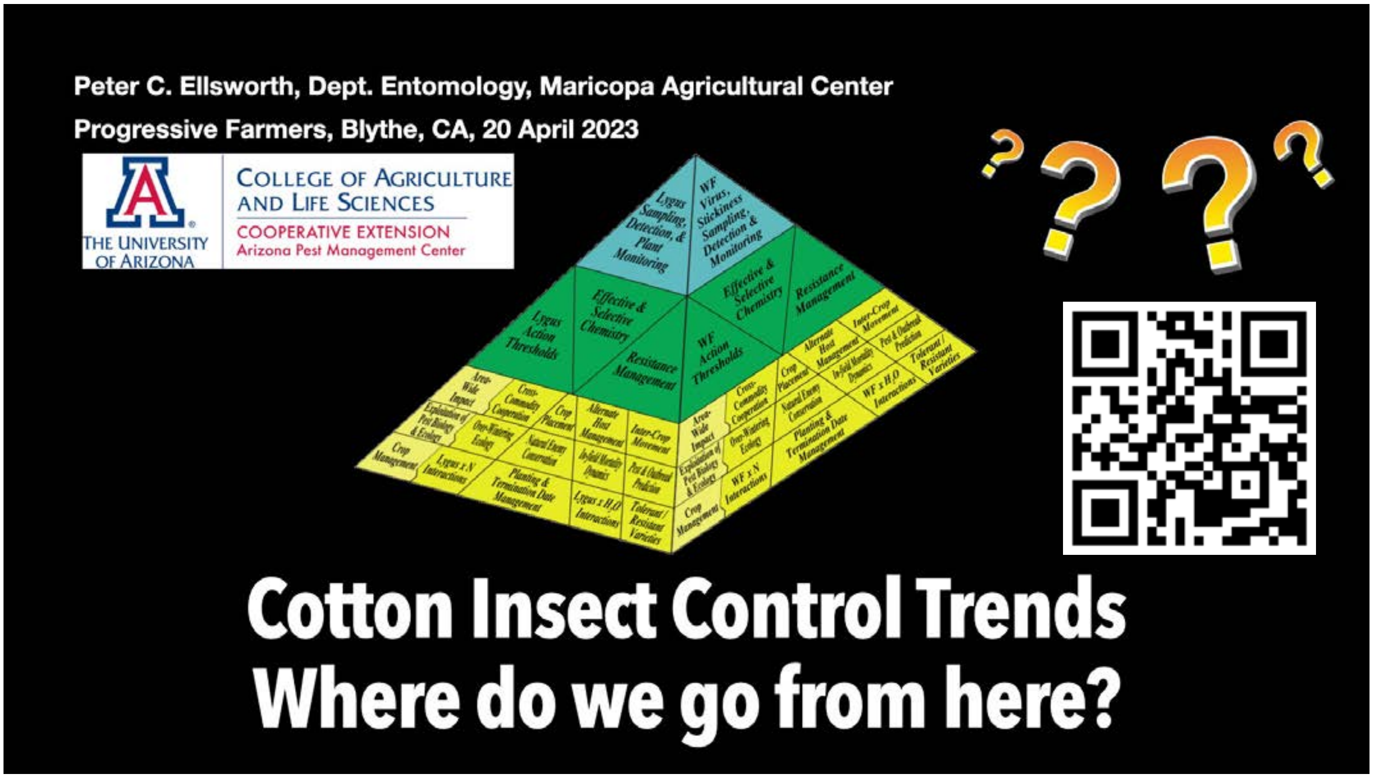
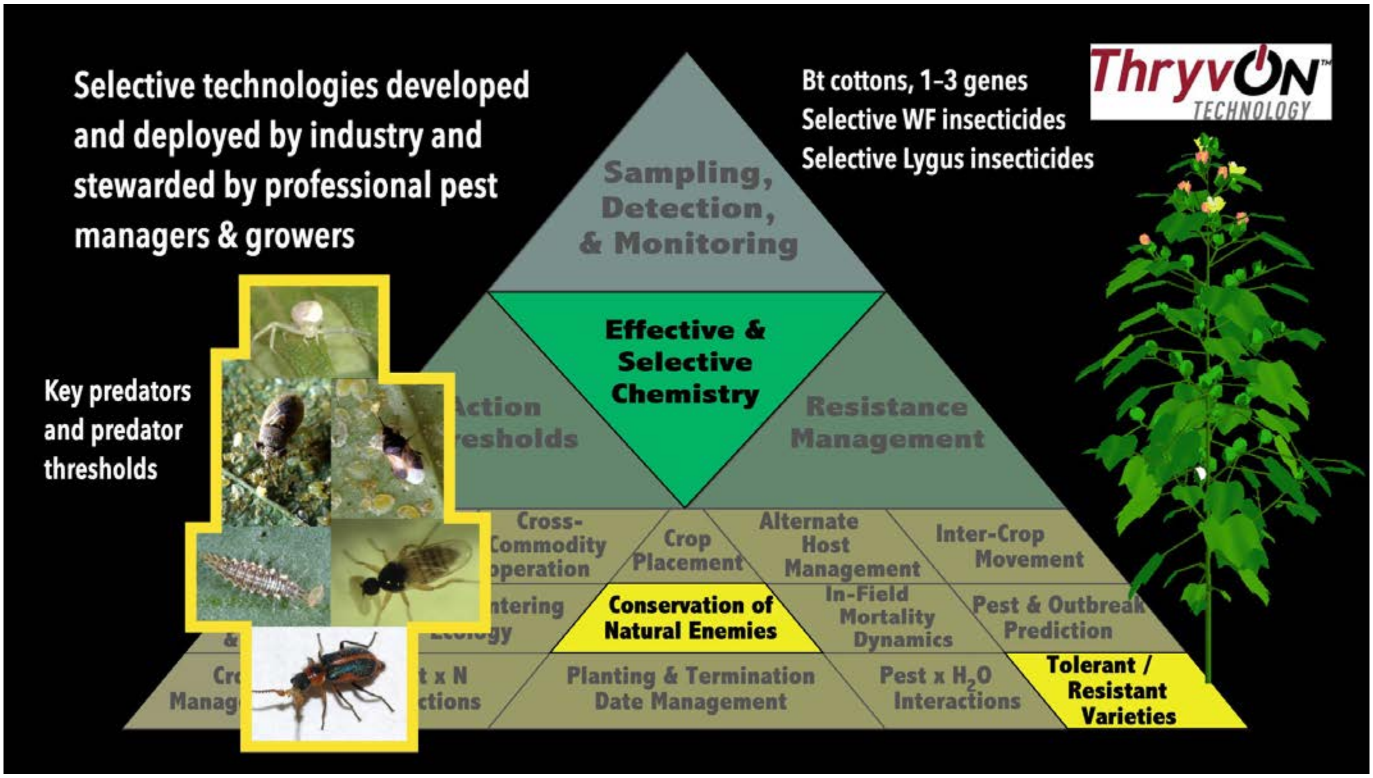
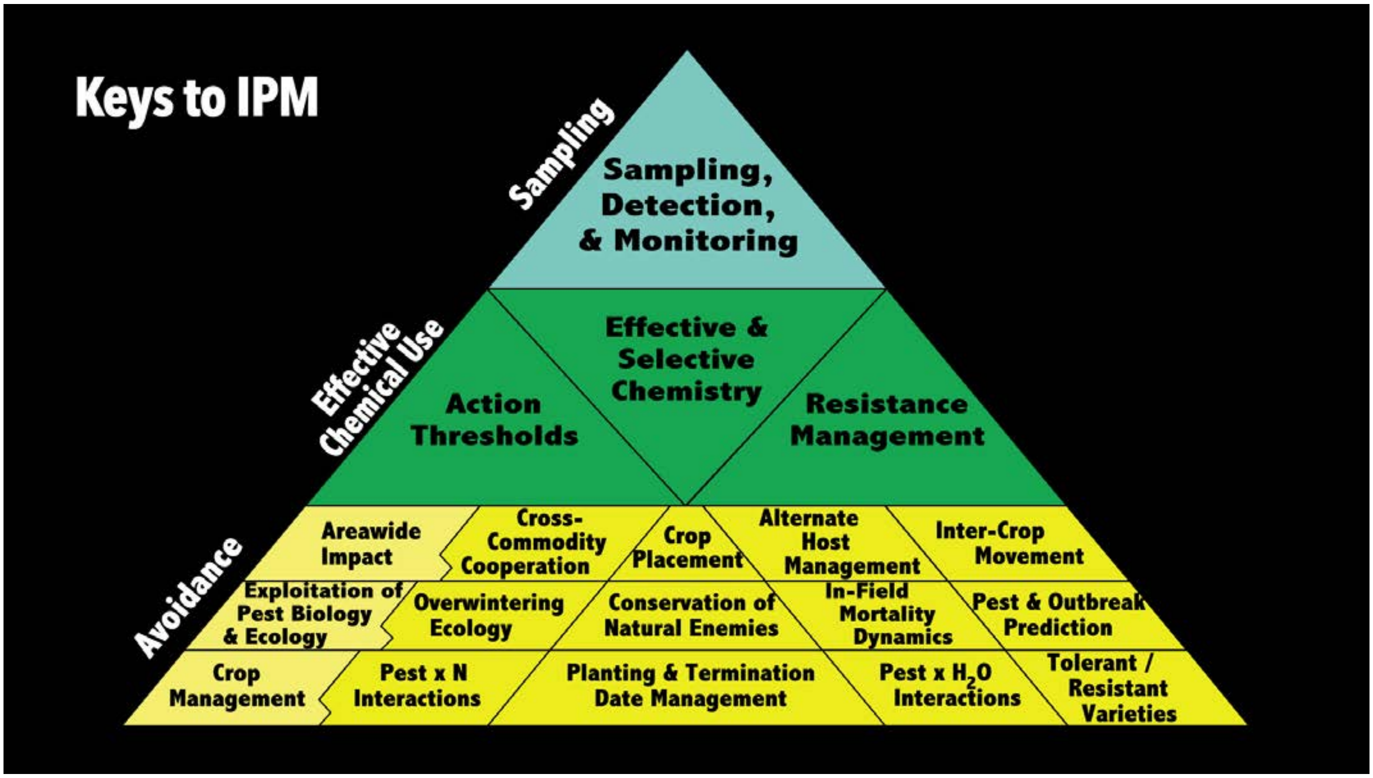


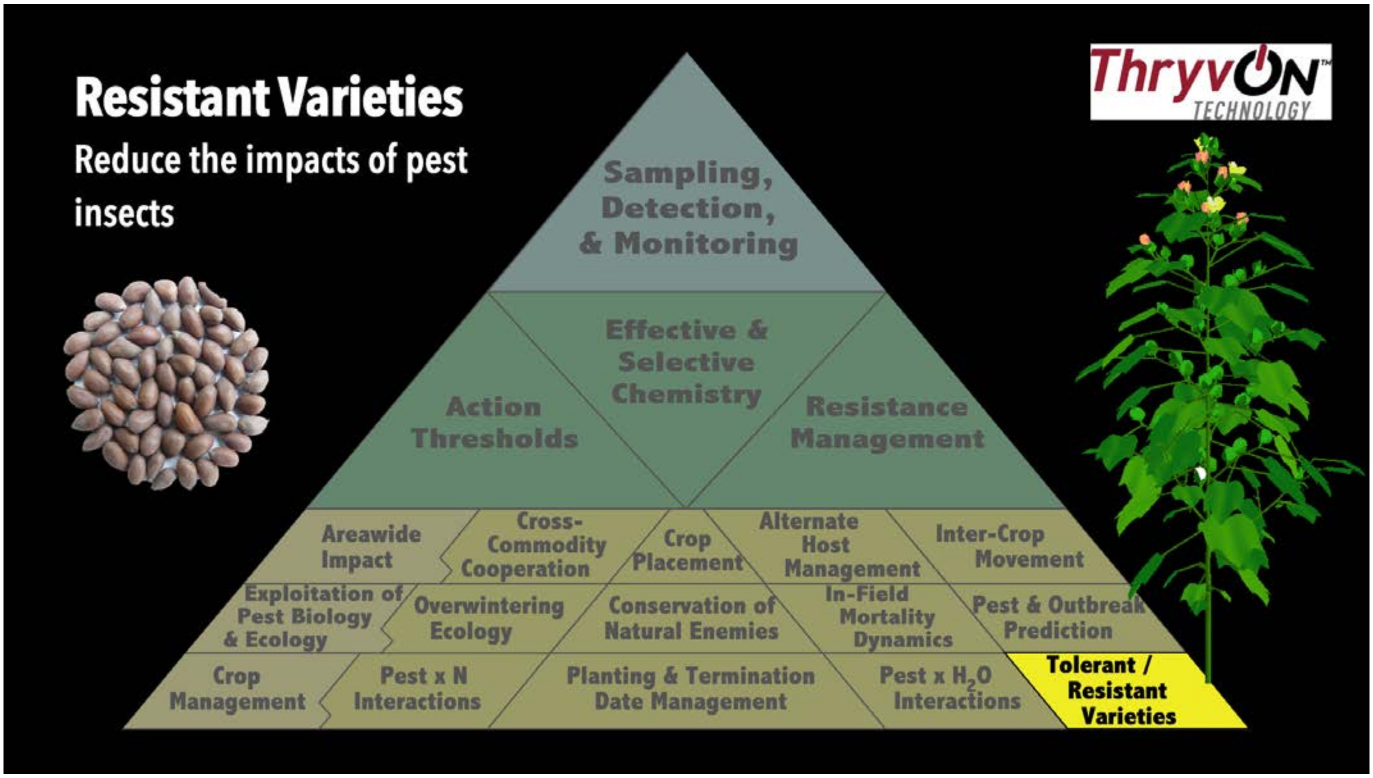
Progressive Farmers Meeting, Blythe, CA. 20 April 2023; 60 min with questions. 1 AZ and 1 CA CEU. 32 participants. Scan QR code to find copy of this document. Any recommendations, products, services, or organizations that are mentioned, shown, or indirectly implied in this publication do not imply endorsement by the USDA or the University of Arizona. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Extension Implementation Program and Biotechnology Risk Assessment Research Grant under award numbers 2021-70006-35385 and 2018-33522-28703, and grants from the Arizona Cotton Growers Association and Cotton Incorporated. A copy of this publication can be found at: http://hdl.handle.net/10150/668030.



This is a graphical or symbolic outline of what I would like to cover in today's talk. The Arizona cotton IPM strategy has depended on the introduction and stewardship of multiple selective technologies like Bt cottons for lepidopteran control and selective insecticides that are specific to whiteflies or Lygus control. The system is entirely dependent on these technologies and their safety to natural enemies like predators that provide biological control of whiteflies and other pests. Recently, we introduced Predator Thresholds for determining the level of biological control provided by 6 groups of cotton predators. How does ThryvOn fit in this highly selective system? How to manage ThryvOn has become a very common question this year, now that it is completely commercialized and growers have made purchasing decisions outside of planted seed contracts.



But before we address these and other questions directly, we always need to step back and examine what it is we are trying to do in IPM. Sampling and Effective Chemical Use on a broad foundation of Avoidance and prevention tactics are our 3 fundamental keys to IPM. Our cotton IPM plan has developed over the years to what we see today, a very safe, efficient and economical strategy that is sustainable and beneficial to all.



Resistant varieties and ThryvOn cotton are cornerstone to the IPM program. Whether they are conventionally bred or products of genetic engineering, this is tantamount to building a less hospitable habitat for our pest insects. Some tolerant varieties in other crops like wheat or alfalfa reduce the numbers and/or impacts of the target pests, but they don't eliminate them all. So, what level of "tolerance" is needed to both support IPM programs and be of value both to the technology provider and the grower? That answer is not known, but consider how beneficial it would be if all pest problems were only "half as bad" as they otherwise would be. Indeed, when vaccine development was initiated for COVID-19, the level of protection sought by FDA and others was just 50%. Reflect back on the original Bollgard cottons. In many respects, we were "lucky". Cry1Ac conferred effective immunity of the cotton plant to pink bollworm. ThryvOn does not provide this level of protection. However, I think it does, in fact, reach that base level of protection that people seek in general.

COLLEGE OF AGRICULTURE AND LIFE SCIENCES
COOPERATIVE EXTENSION
Arizona Pest Management Center
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ThryvOn™ Cotton, Frequently Asked Questions

Peter C. Ellsworth, Isadora Bordini, Naomi Pier, University of Arizona

ThryvOn™ cotton is genetically engineered to resist injury by *Frankliniella* thrips and Lygus bugs. Expressed in all plant parts, the trait is derived from *Bacillus thuringiensis* (Bt), a common soil bacterium, producing a crystalline protein, Cry51Aa2, which is toxic to thrips and Lygus. In Arizona cotton the targets are Western Flower Thrips, *F. occidentalis*, and the Lygus bug, *L. hesperus*. While thrips are only an occasional minor pest, Lygus bugs are the number one yield-limiting pest of cotton. ThryvOn cotton provides a new IPM tool for growers.

1) What level of protection should I expect from ThryvOn?

ThryvOn cotton will reduce injury from western flower thrips and Lygus bugs, but will not eliminate all individuals from your fields. Fewer sprays and higher yields compared to non-ThryvOn cotton should be expected where Lygus pressures are high.

2) How does ThryvOn impact thrips in cotton?

While ThryvOn may not kill western flower thrips adults outright, the overall impact on the western flower thrips life cycle and population development in cotton is dramatic. Adult female thrips actively avoid laying eggs in ThryvOn cotton in favor of other hosts, including nearby fields or weeds within or adjacent to your field. Females lay 85% fewer eggs in ThryvOn cotton and only 7% of those survive to adulthood. Survivors are 20% smaller and live only half as long as thrips developing on non-ThryvOn cotton (Husseth et al. 2020).

3) How does ThryvOn impact Lygus in cotton?

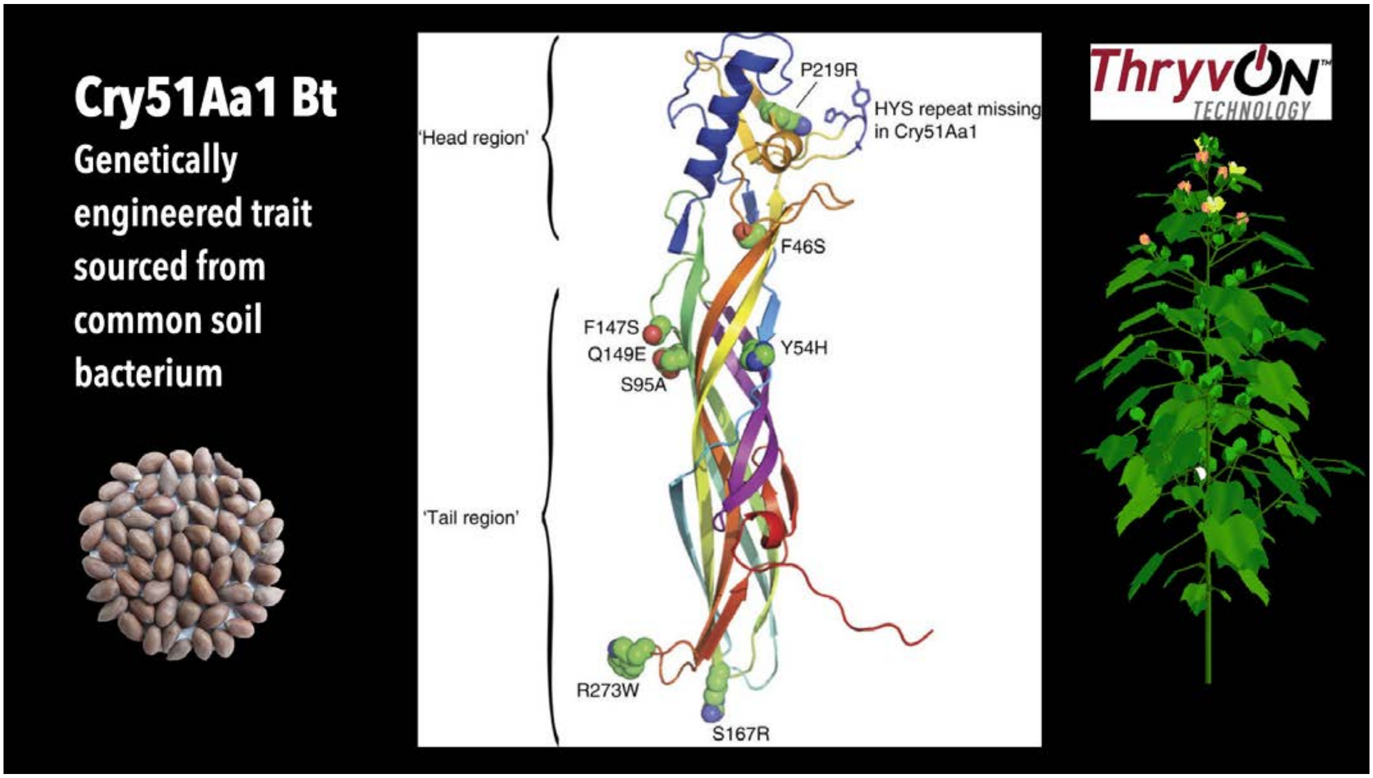
The ThryvOn protein is toxic to Lygus bugs and will kill young nymphs and reduce the weight and size of those that survive. While Lygus adults that develop in or migrate to ThryvOn cotton may survive, the overall impact of ThryvOn on Lygus reduces their populations (Figure 1). Over time these lower numbers and reduced feeding lead to less impact on the crop. Because ThryvOn cotton does not kill all Lygus in the crop, some Lygus bugs will still be present in the field.

4) Do I need to spray for Lygus in ThryvOn cotton?

ThryvOn cotton is not immune to all Lygus or the damage they might cause. Even sick, slower-developing nymphs can feed on squares and cause square shed. Under higher pest pressures, Lygus sprays may still be needed. ThryvOn cotton will give PCAs and growers more time to determine if Lygus presence is associated with any fruiting site losses, allowing for timely sprays when necessary. Use fully selective Lygus insecticides like Carbine® or Transform® when needed (Bordini et al.

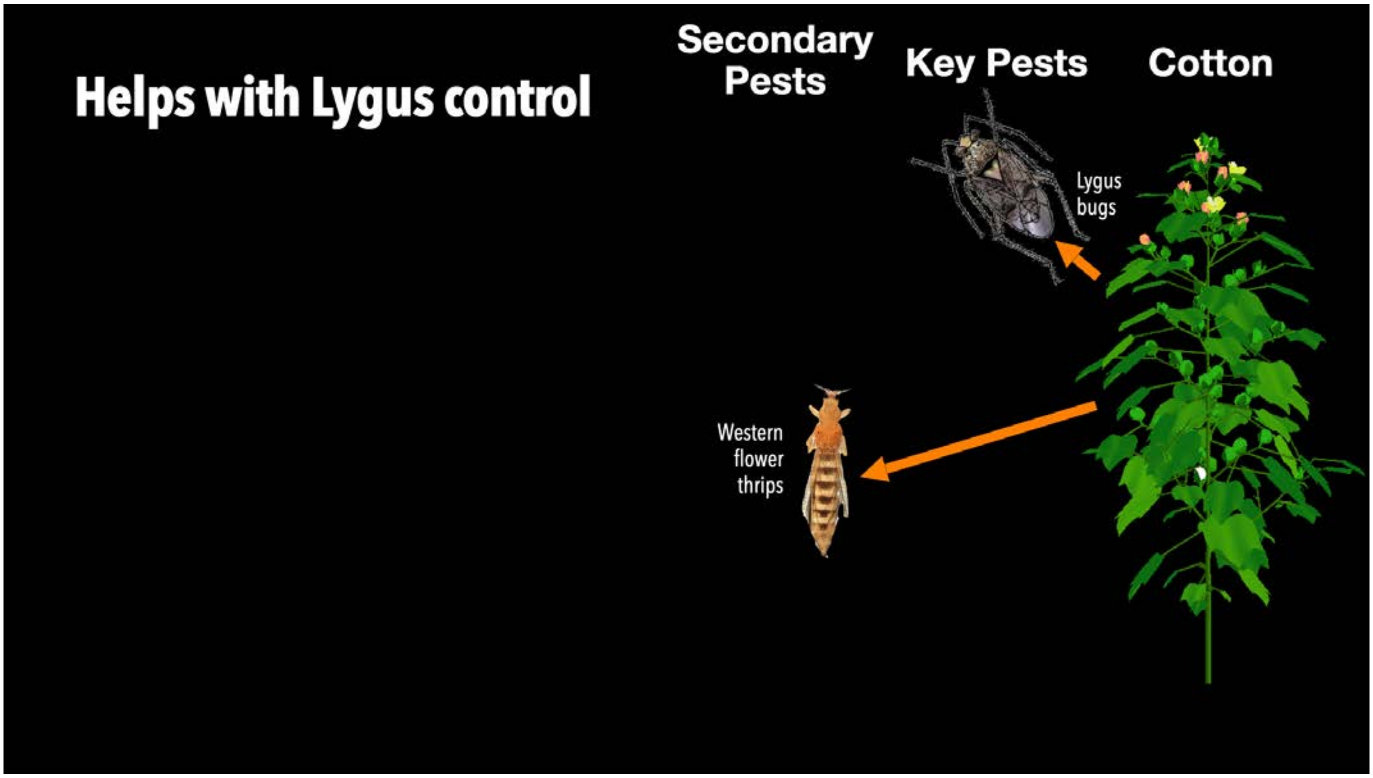
Figure 1. ThryvOn cotton (T, orange) provided additional protection from Lygus nymphs over time (gray hashed area) in comparison to non-ThryvOn control cotton (C, blue) and extended the time to the standard Lygus threshold by 7 days, delaying the need for a Carbine spray (arrows) in a 2019 field study (Ellsworth, unpublished).

As ThryvOn rolls out commercially, there are a number of frequently asked questions. We put together some of these in this short publication that you can find at the QR code shown and at this URL: http://hdl.handle.net/10150/659845

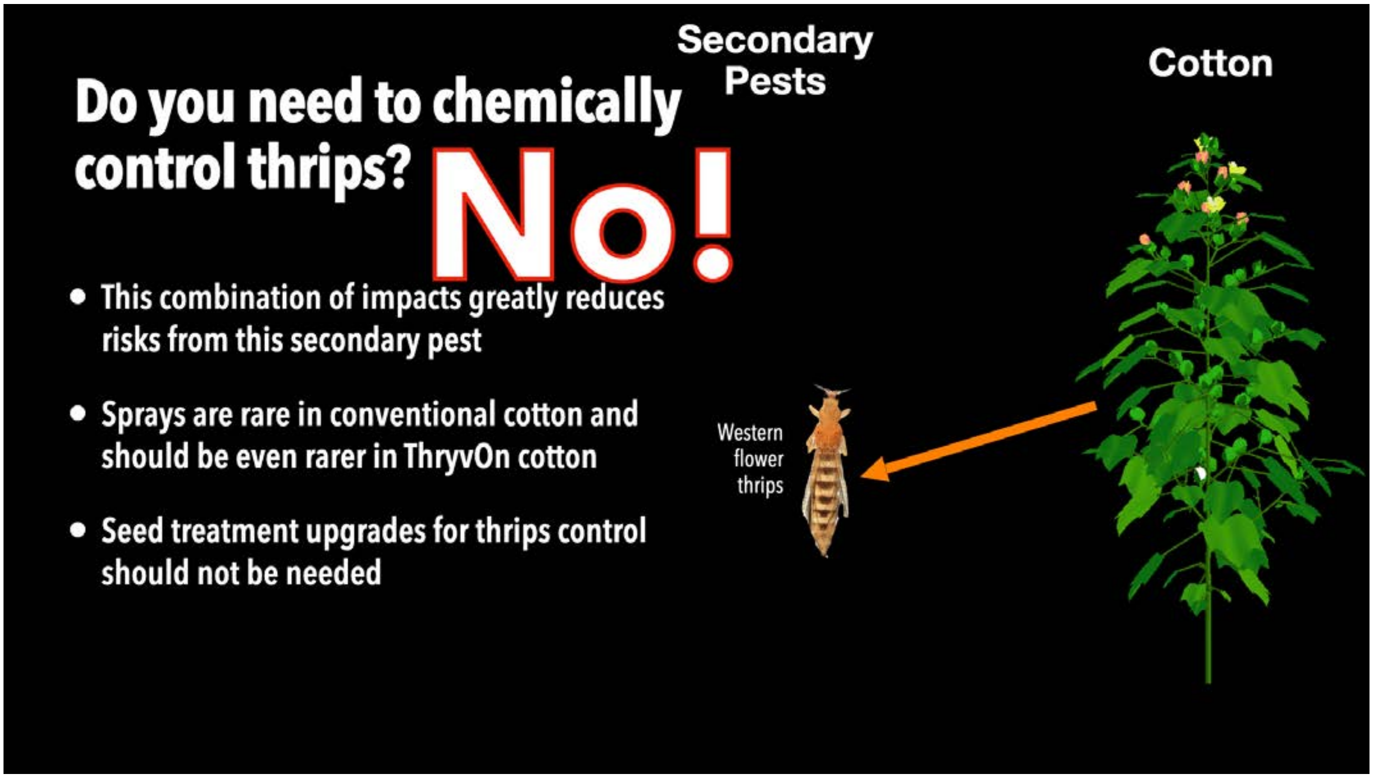


ThryvOn cotton is based on the isolation and optimization of a genetic trait sourced from a common soil bacterium that we call Bt. You know Bt cotton as previously only relevant in lepidopteran / caterpillar control. This Bt has a different spectrum activity but the same safety characteristics as the lep-targeting Bt traits. Much of our early work was to establish this safety profile for the technology.

What are the targets of the ThryvOn trait in cotton? Thrips in the Frankliniella genus and Lygus bugs.



ThryvOn helps in the control of Lygus, our #1 yield-limiting and key pest of cotton, as well as in the control of Western Flower Thrips, which generally does not require specific management in Arizona and is a secondary pest.

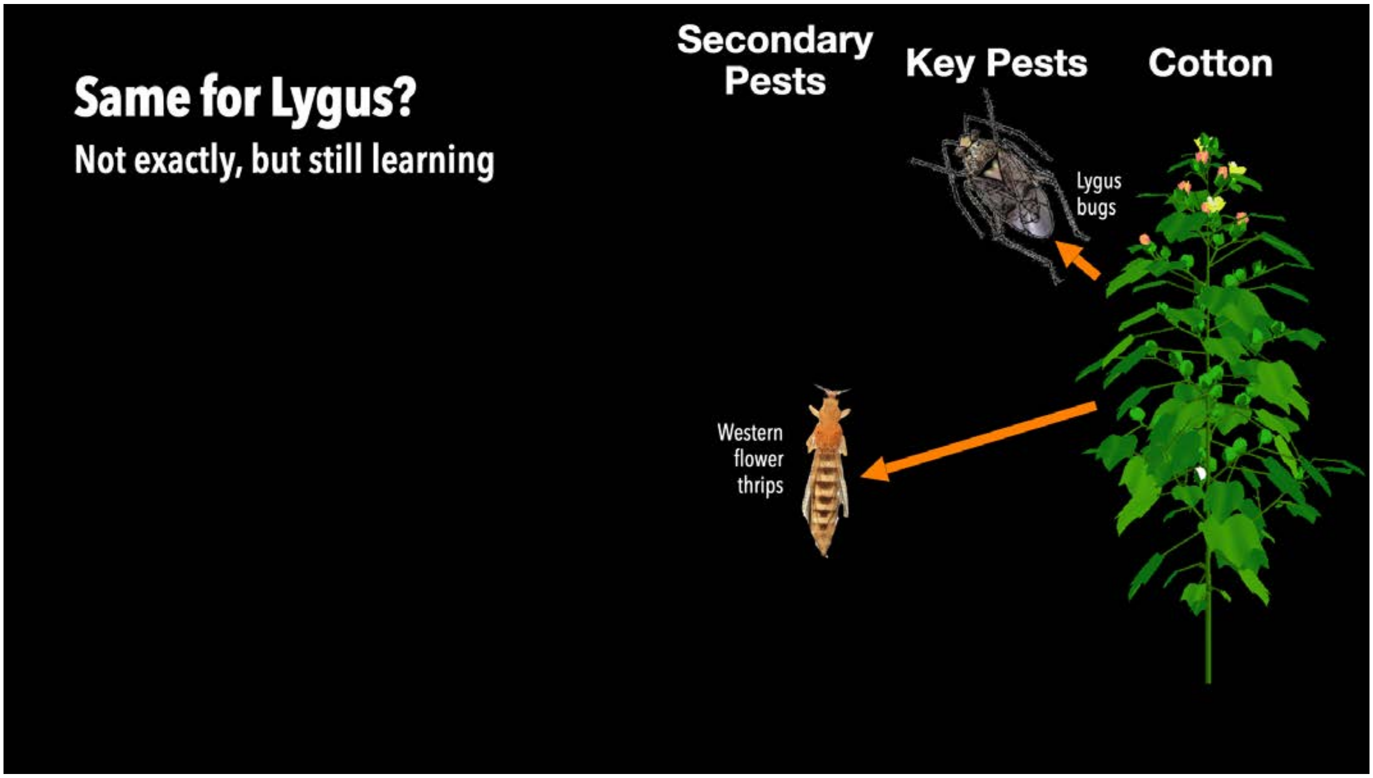


When I first constructed this slide two years ago, it contained some nuance and dithering. So let me answer the question directly, "No!", growers of ThryvOn will not need to chemically control or otherwise manage thrips. ThryvOn is that good on Western Flower Thrips. It is rare to find complete scientific consensus among cotton entomologists belt wide, but on this we are in complete agreement. No seed treatments, no in-furrow sprays, no foliar sprays are needed on ThryvOn cotton for thrips control.

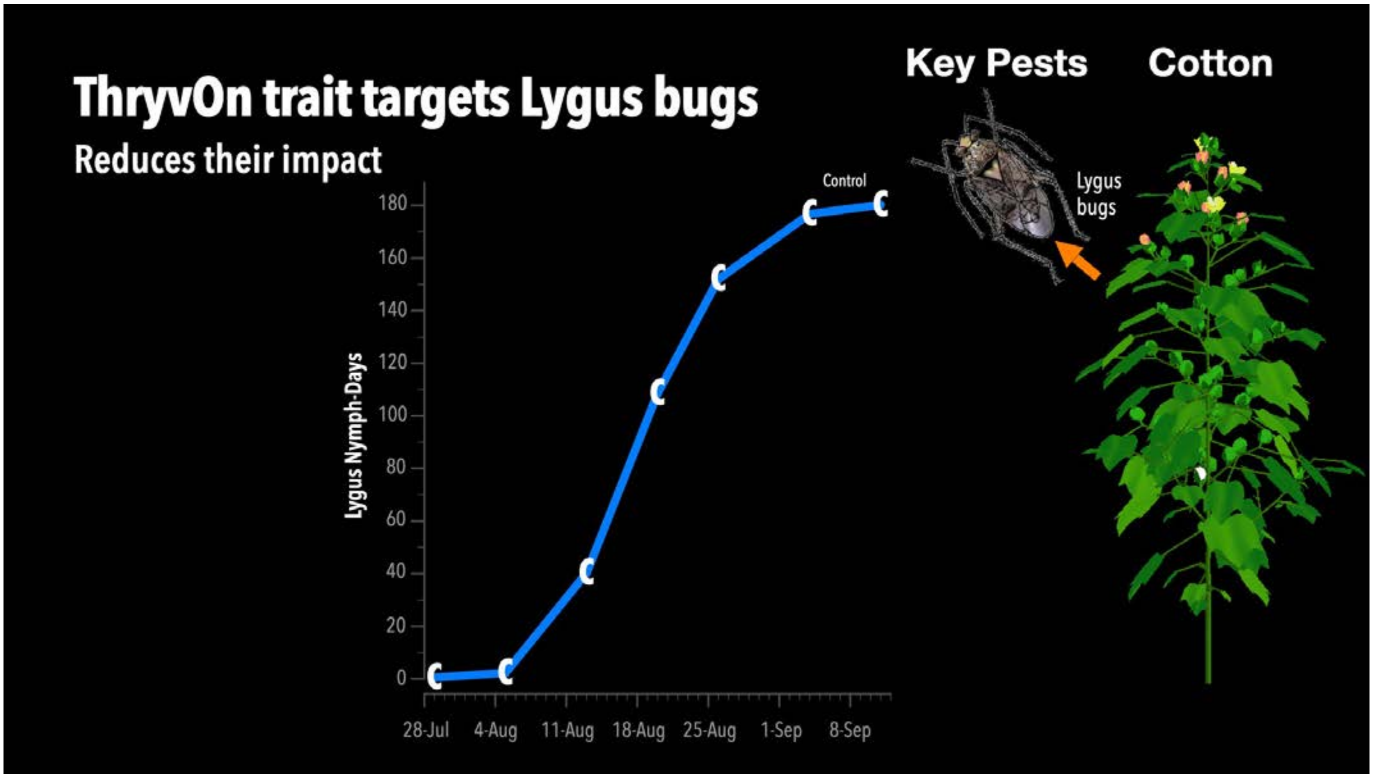
Dr. Scott Graham, Extension Entomologist at Auburn University, shared with me this dramatic slide that shows ThryvOn's efficacy in one of the worst thrips years they have ever had. I told him that he'll be sharing this slide with producers 30 years from now, because it is unlikely he'll ever see such heavy pressure as this again.

On the left is the ThryvOn variety and on the right is the closest genetics in a non-ThryvOn variety. The effects of thrips feeding, notably by a different species of thrips than we have here in cotton, is dramatic and devastating. ThryvOn provided outstanding control.

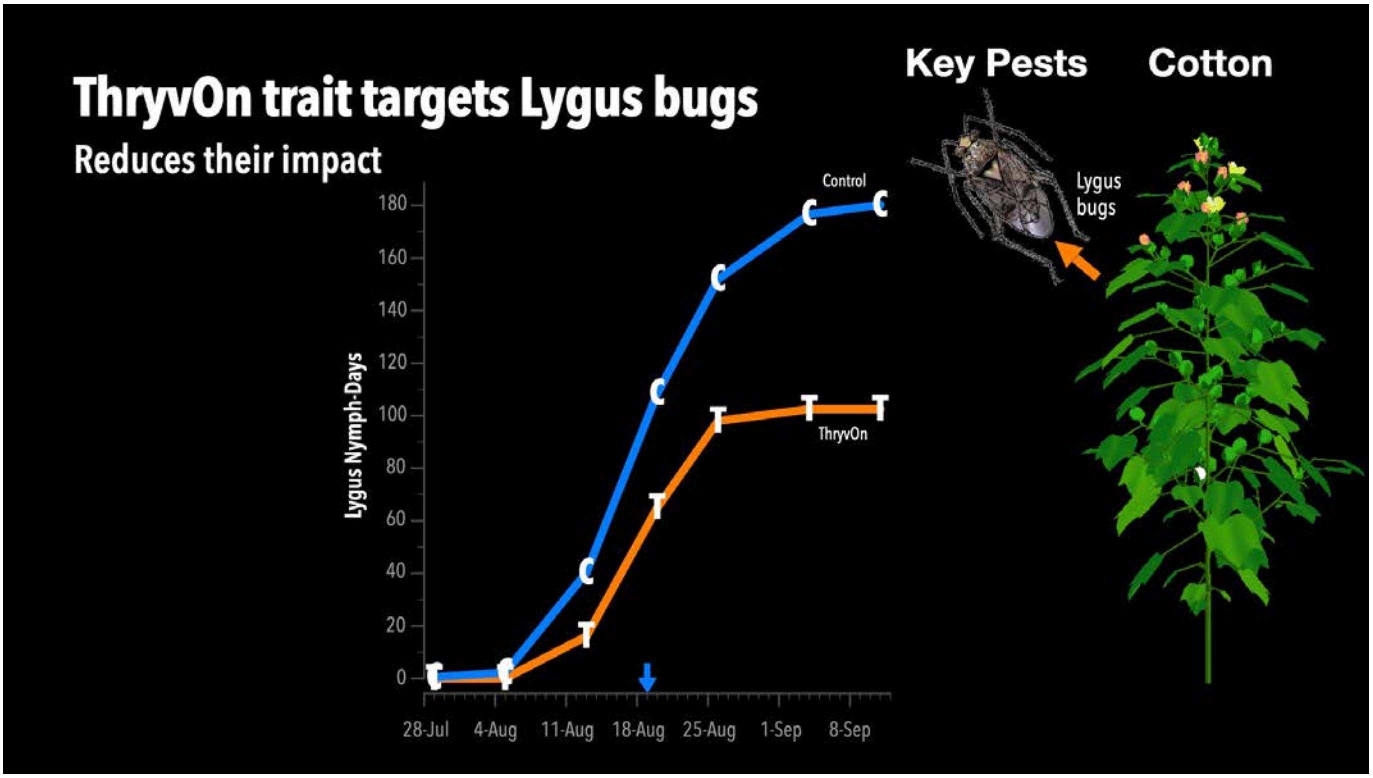
Do you remember Ron Popeil and his catch-phrase? Set it and forget it. That's pretty much the way you can think of ThryvOn cotton for thrips control.



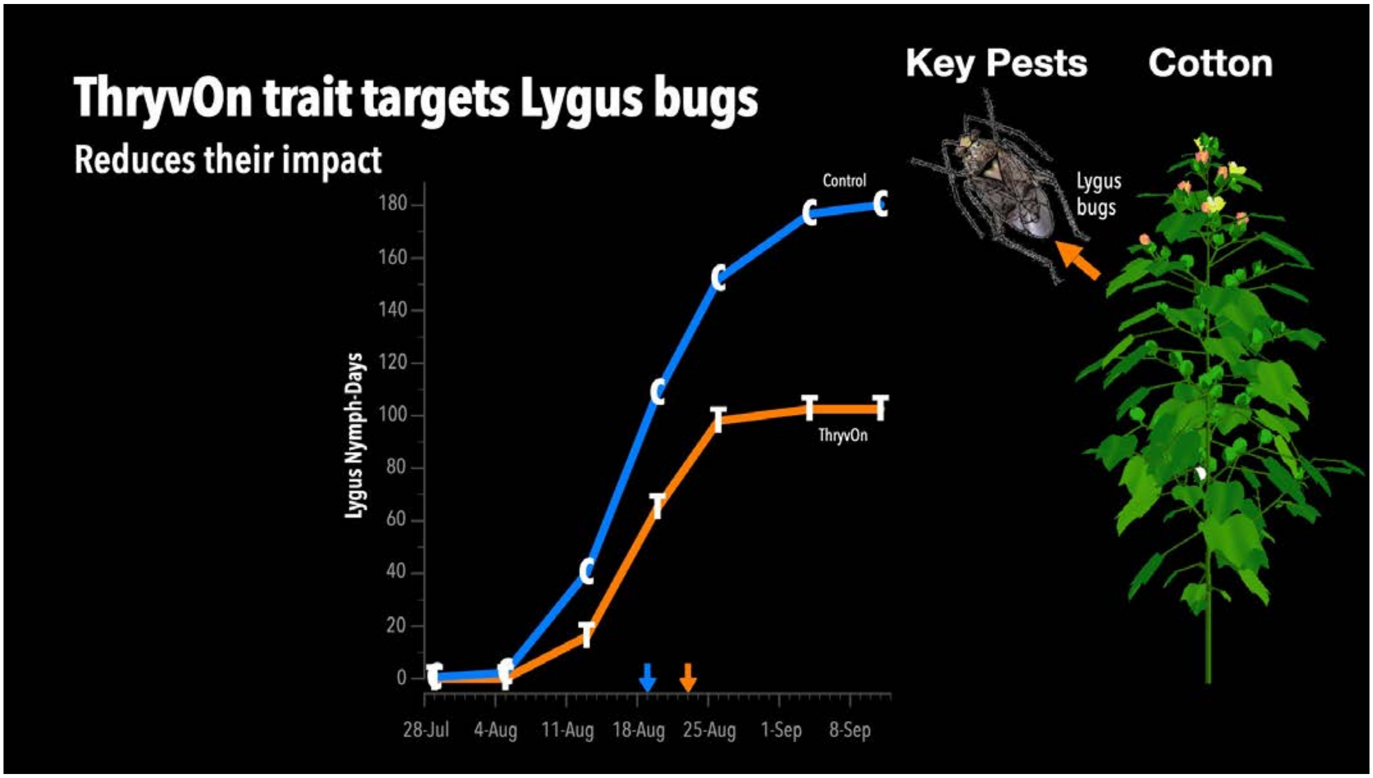
Is that the same for Lygus? Absolutely not and that's important, because growers and Pest Control Advisors will have to be scouting and watching this cotton closely whenever Lygus become abundant.



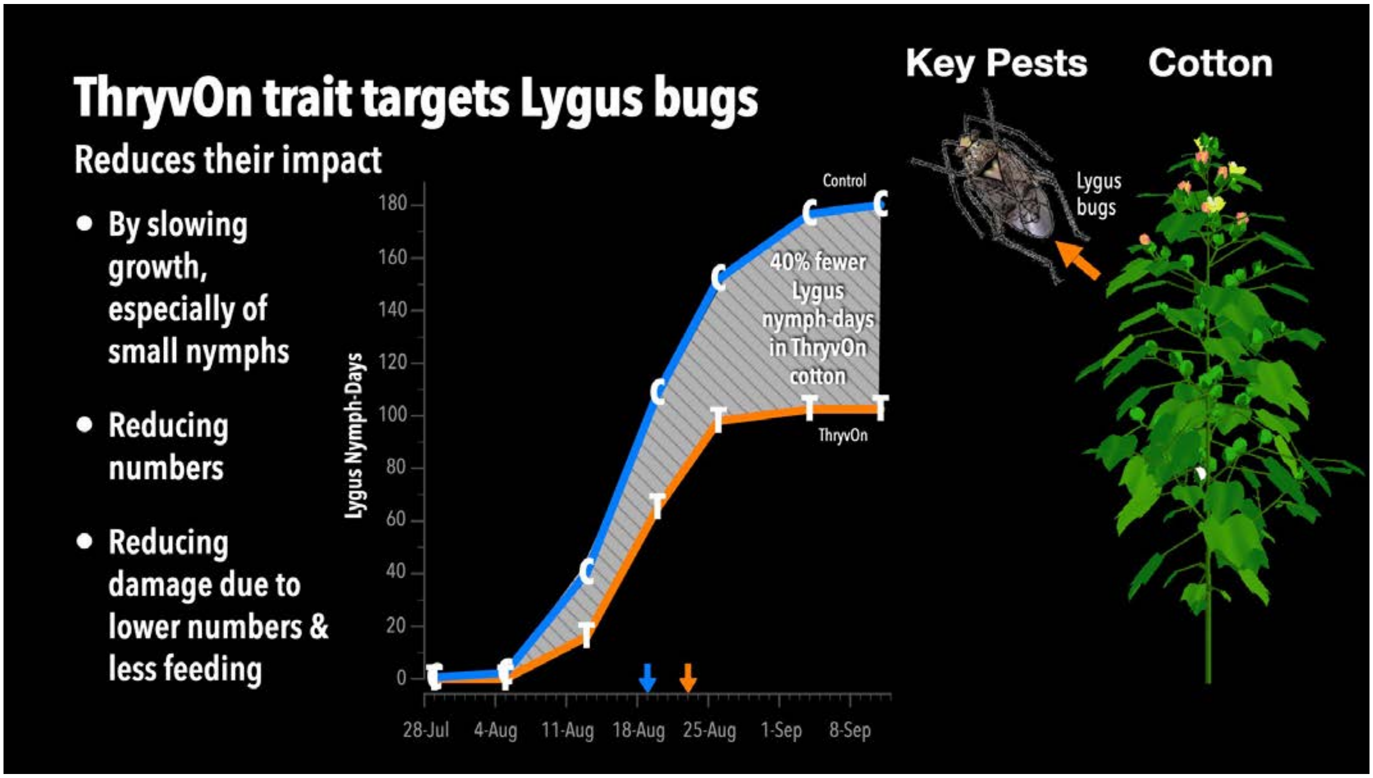
ThryvOn reduces the impact of Lygus in cotton quite well, but not perfectly nor completely. This is not like original Bollgard on pink bollworm. In this trial, we quantify Lygus impact in nymph-days, which accumulate over the season just like heat units through time.



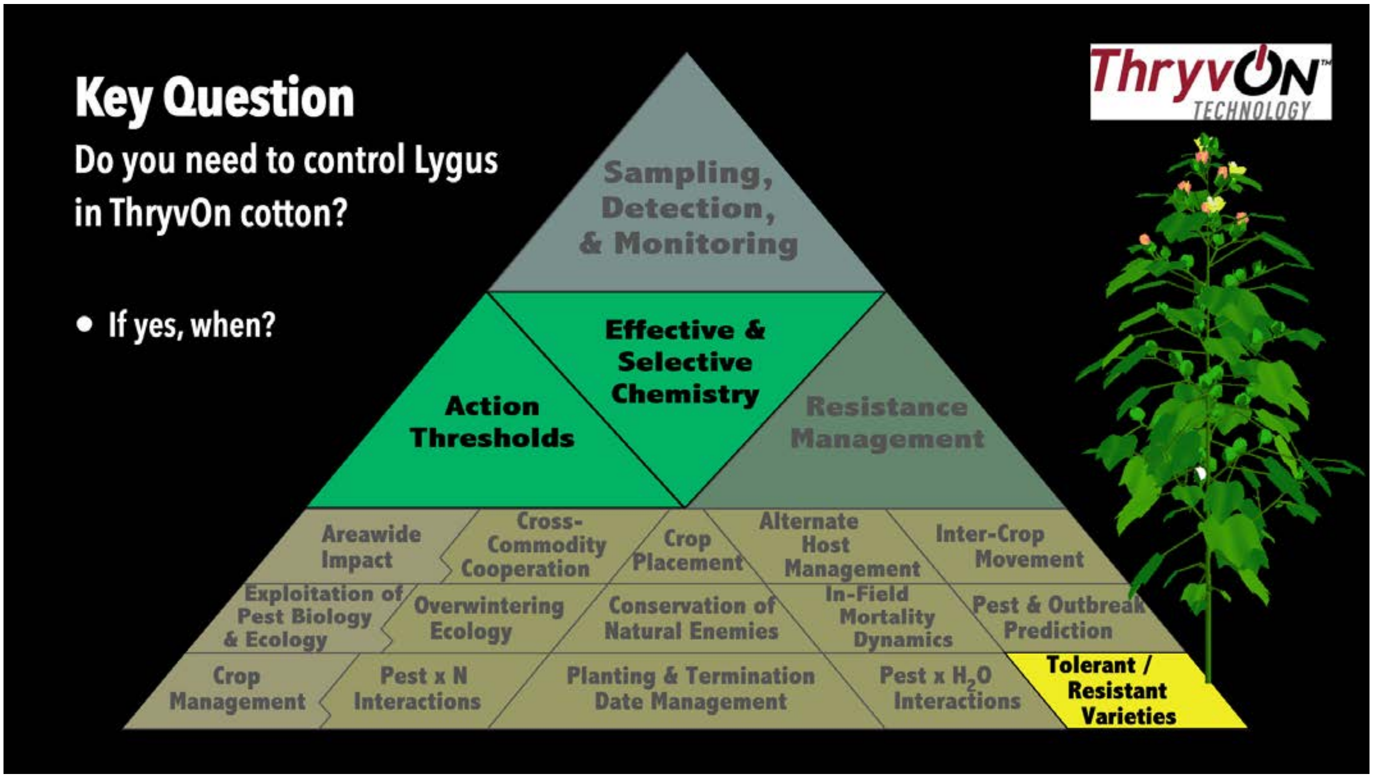
We reached the standard Lygus threshold in the control line (C) and sprayed with Carbine. But the ThryvOn supported far fewer Lygus nymph-days than the control.



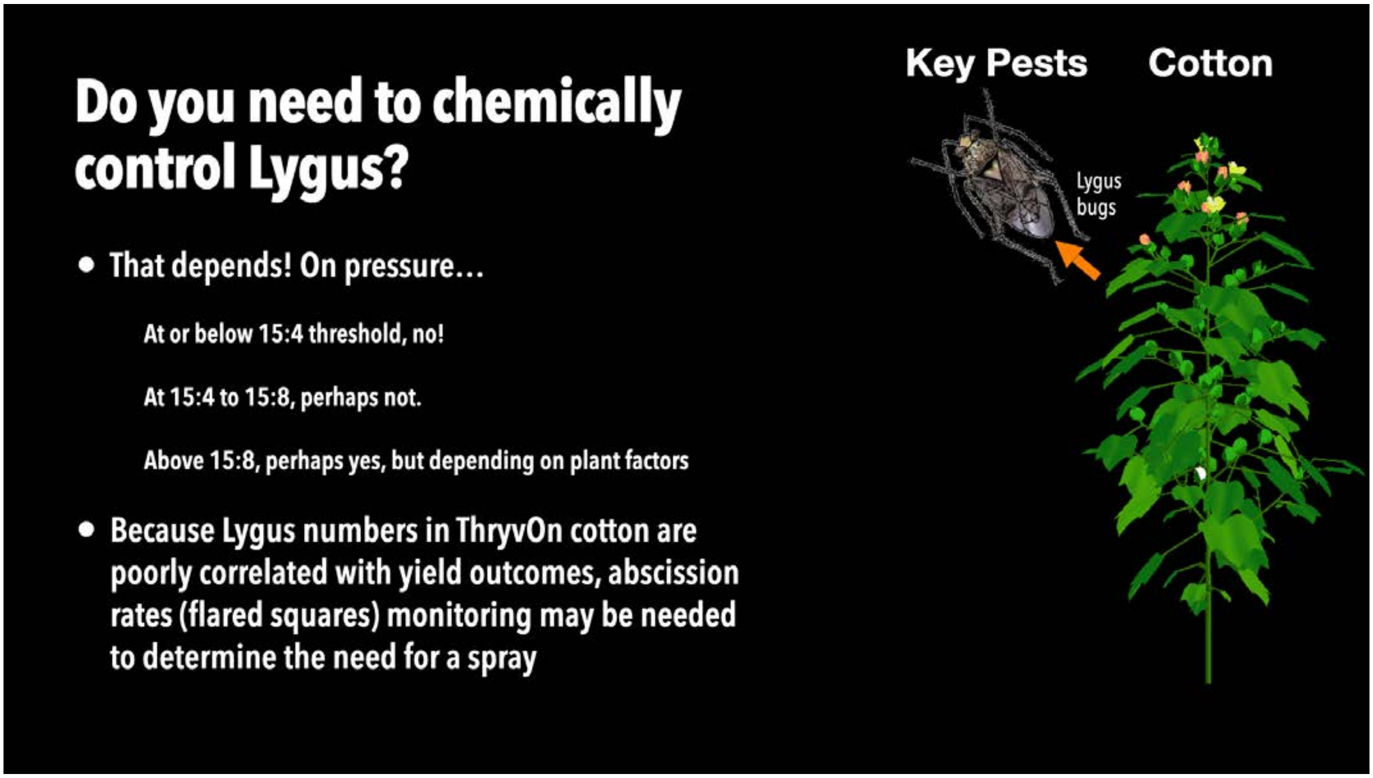
And we sprayed it on the standard threshold about a week later. That was because the protocol dictated that spray, not because it was needed. More on the topic of thresholds in a bit.



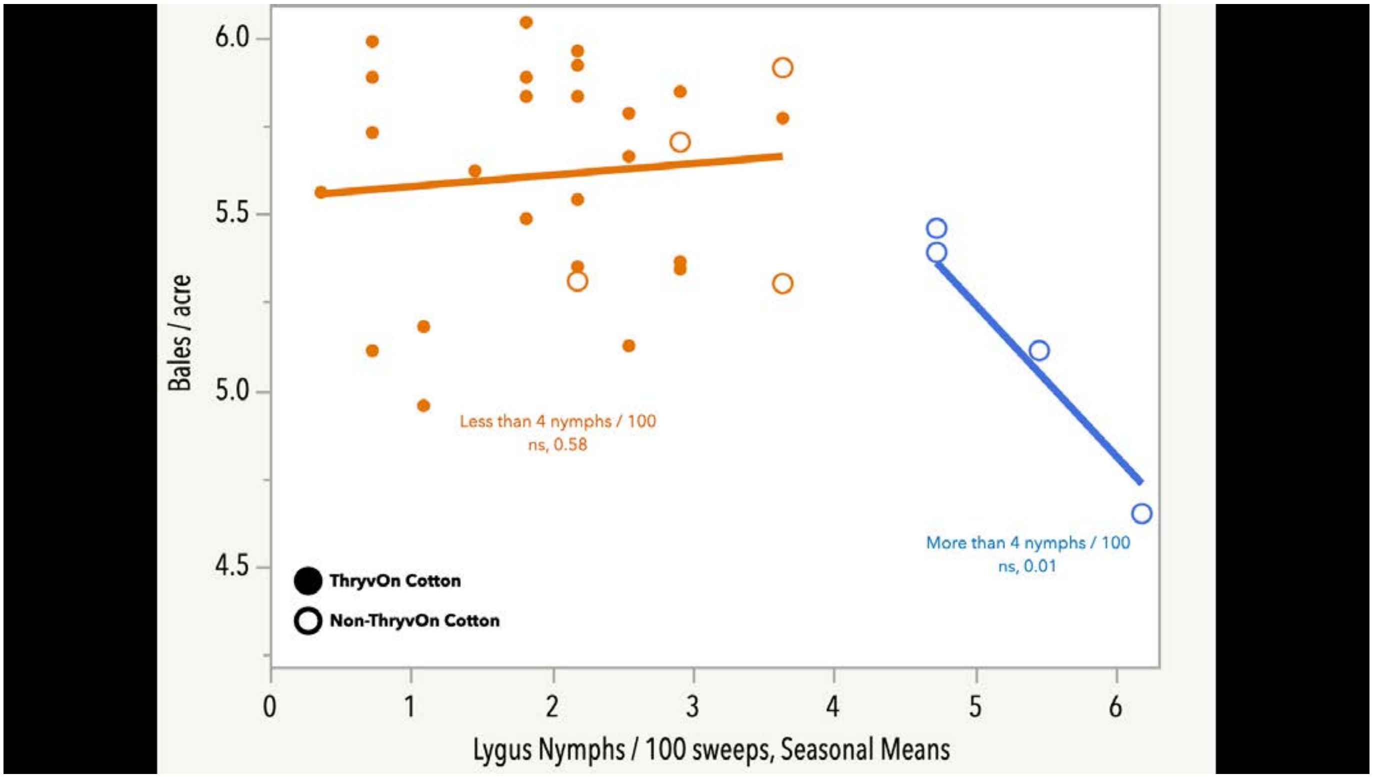
Ultimately, the youngest instars of Lygus are the most impacted by this trait. They grow slowly, which makes them vulnerable to all sorts of mortality factors including biological control or predation by predators. This reduces their numbers and their feeding on the cotton plant is greatly reduced. Net? ThryvOn reduced nymph-days by 40% in this small plot trial. In larger format trials, I think we can see even better "control" than this.



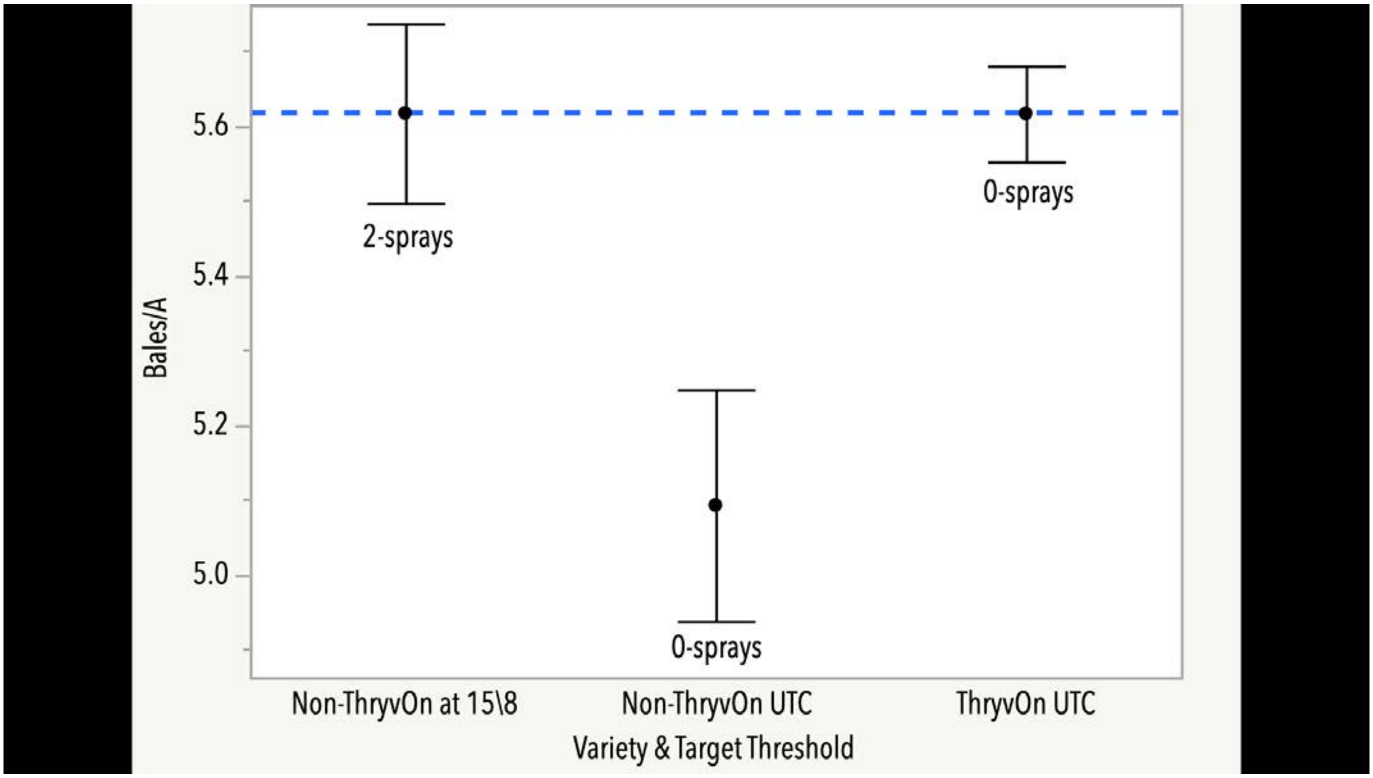
I will address the key question of whether you need to control Lygus chemically in ThryvOn cotton and if so, when. However, let me state clearly here that this specific question has not been fully addressed yet experimentally under the definitive set of Arizona conditions. We have just one year's worth of data on the question of what threshold is appropriate for ThryvOn cotton, and that was from 2022 during historically low insect pressures.



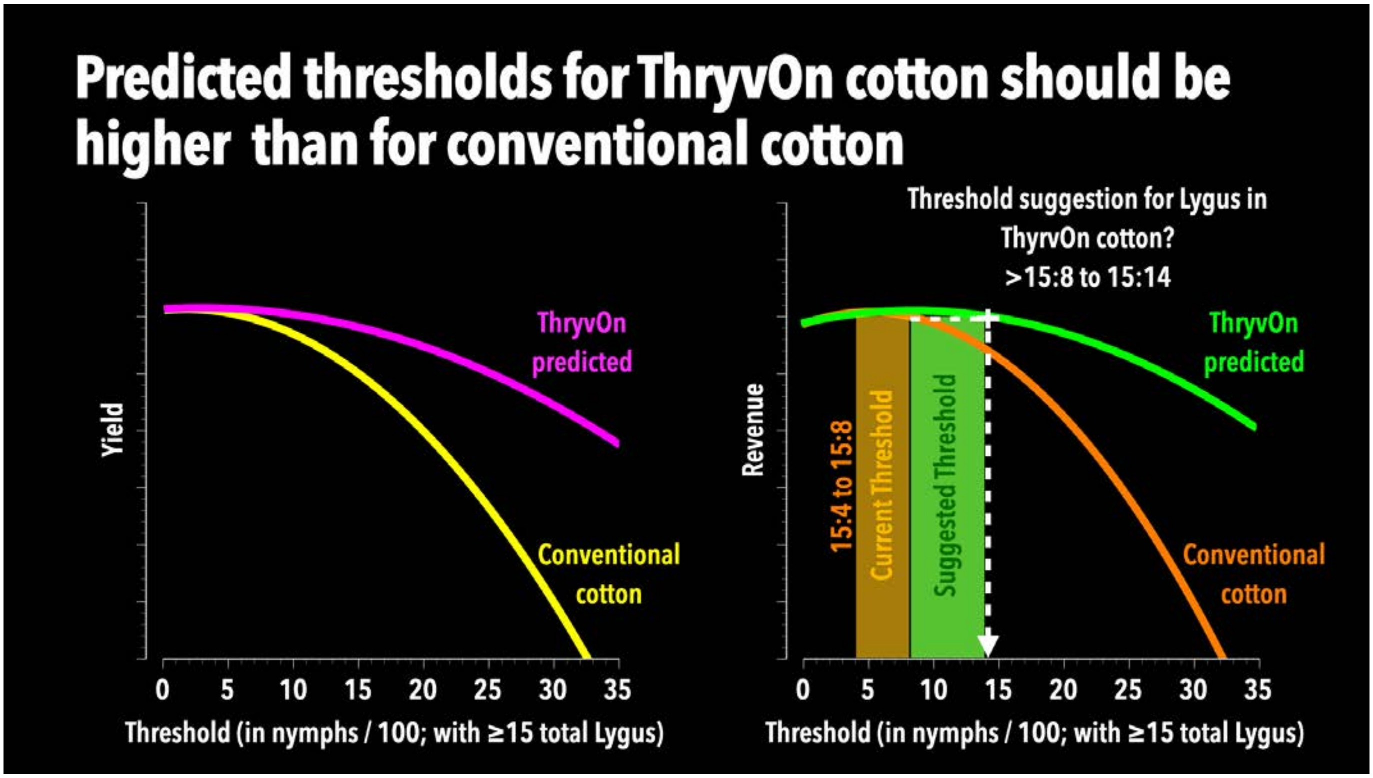
But to the question of the need for chemical control? Very likely under some conditions, ThryvOn will have to be sprayed. The question is precisely when. We presume and pretty much know you won't have to spray it as much or at the same timing as non-ThryvOn cotton. However, the topic is complex because yields are poorly correlated with Lygus numbers in ThryvOn.



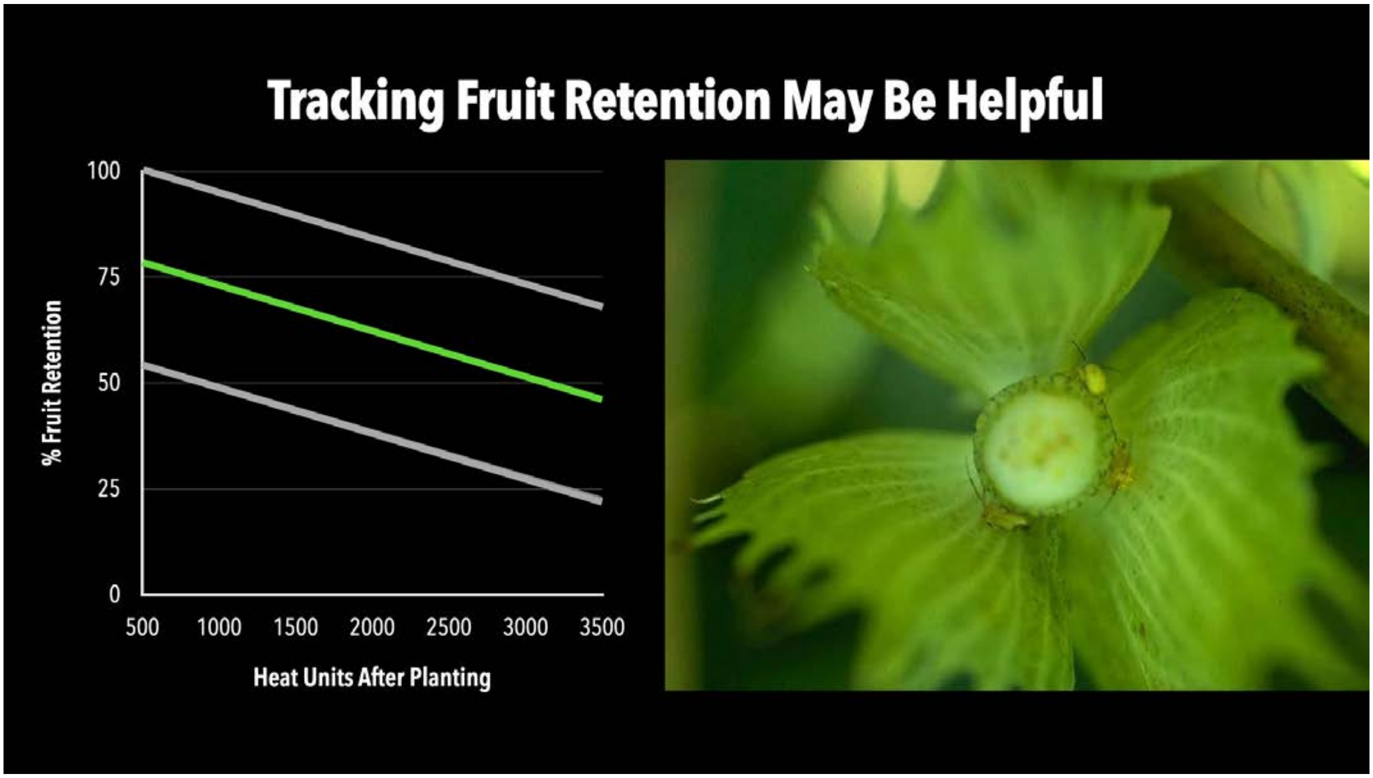
Here are some of the results from last year's trial showing seasonal mean Lygus nymph densities as they relate to yields. Whenever densities were lower than 4 nymphs per 100 sweeps, there is no correlation between those densities and yield outcomes. That makes sense, right? Because 4 nymphs per 100 sweeps is the low end of our threshold for conventional cotton. For densities over 4 nymphs per 100, we do start to see a strong relationship of nymph densities and yield in non-ThryvOn cotton – note, none of the Thryvon treatments ever reached these seasonal levels. [Each dot on the chart is from a replicate treatment in the 2022 ThryvOn Threshold trial.]



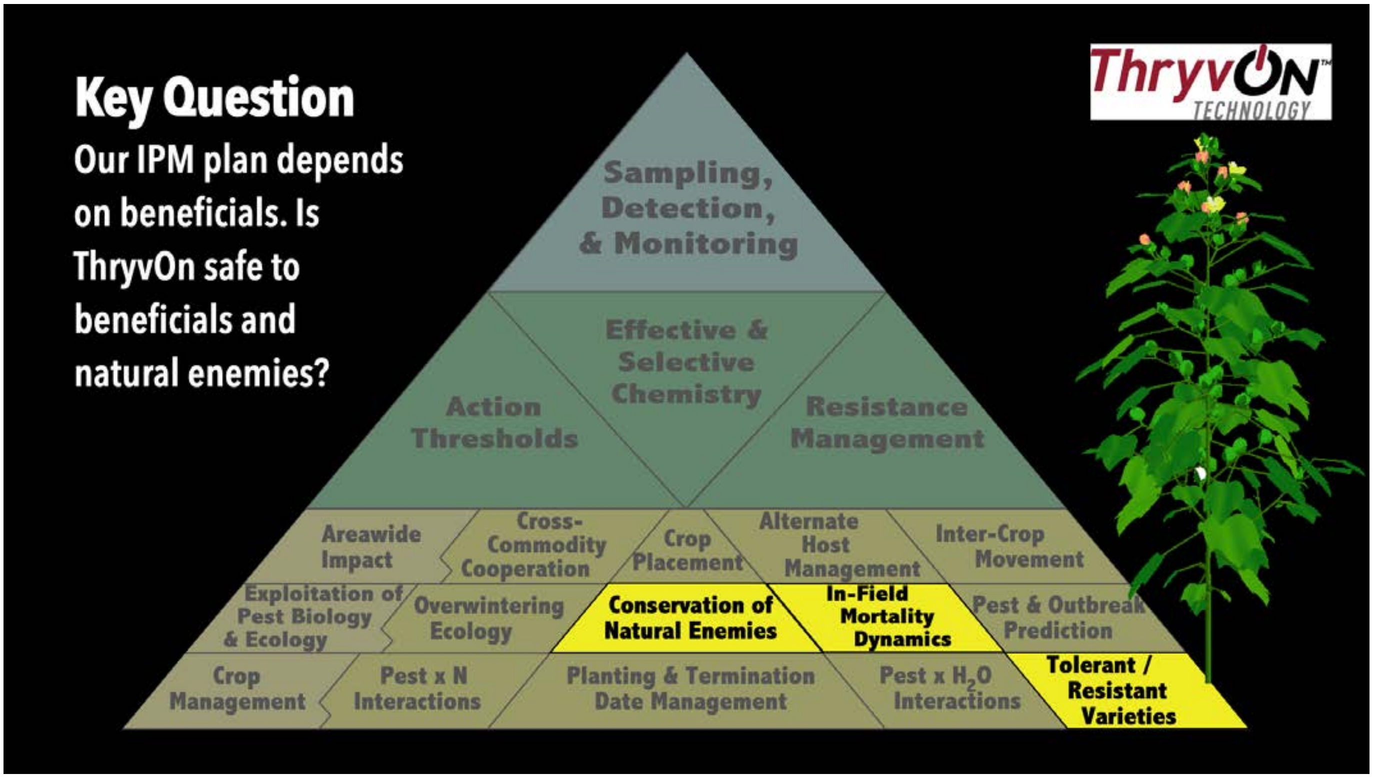
Even though bug pressure was at historic lows, Lygus did just barely reach threshold twice in the conventional cotton. After just narrowly reaching the threshold, each time we sprayed with Carbine there and made excellent yields. ThryvOn never reached even the conventional threshold and was never sprayed. The result was the same yield, despite the unsprayed Non-ThryvOn cotton losing about a half bale to Lygus. This should tell you something about the spray savings possible with ThryvOn cotton. This was the largest differential we have measured to date. Normally we see savings closer to 1 spray per season.



The standard threshold for conventional cotton is 15 total Lygus with 4 to 8 nymphs per 100 sweeps. The relationships between cotton yield or revenue and nymphs per 100 sweeps are strong for conventional cotton. This threshold work has not been done for ThryvOn cotton, but we can predict some outcomes based on the 40% reductions in nymph-days measured in ThryvOn. Likely, the threshold is somewhat to significantly higher for ThryvOn cotton, because many of the bugs present are likely sick and slowed in development, causing much less damage. Consider thresholds higher than 15:8 before spraying ThryvOn cotton, perhaps as much as 15:14, and track changes in the plant injury as well.

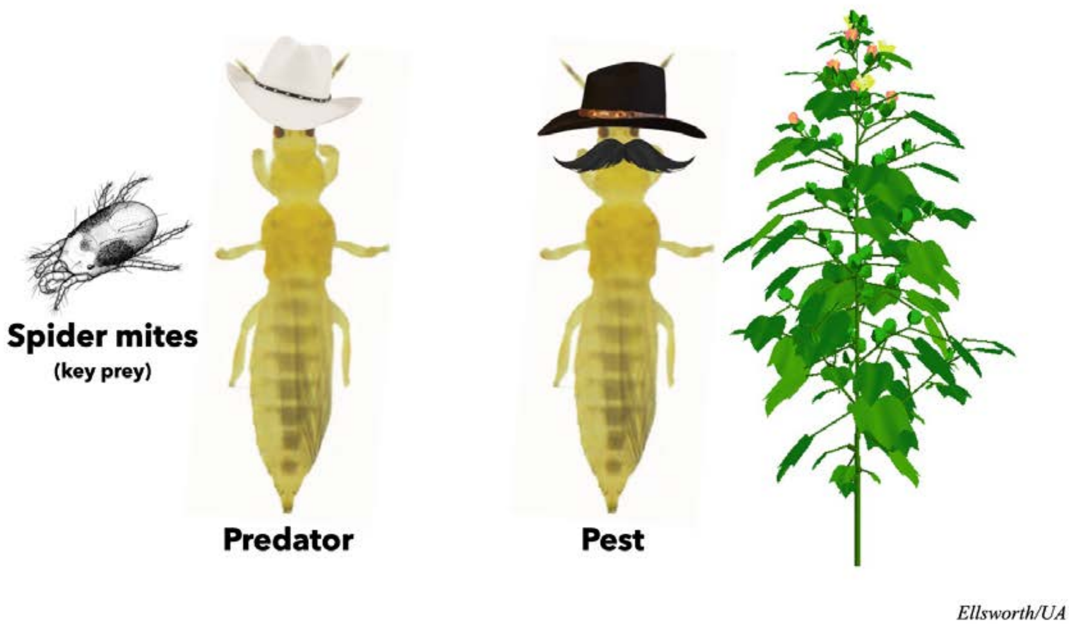


Silvertooth developed fruit retention curves for upland cotton years ago and Randy Norton updates these periodically. I think you'll want to revisit these guidelines and use them to better understand if fruit retention is being impacted at all in your ThryvOn fields. If Lygus numbers are up, flaring is apparent, and fruit retention is falling below the central baseline, then this might additional evidence for the need for a spray on ThryvOn. We hope to do survey work in commercial fields this year to see if we can develop a square sampling system for tracking the need for sprays in ThryvOn.

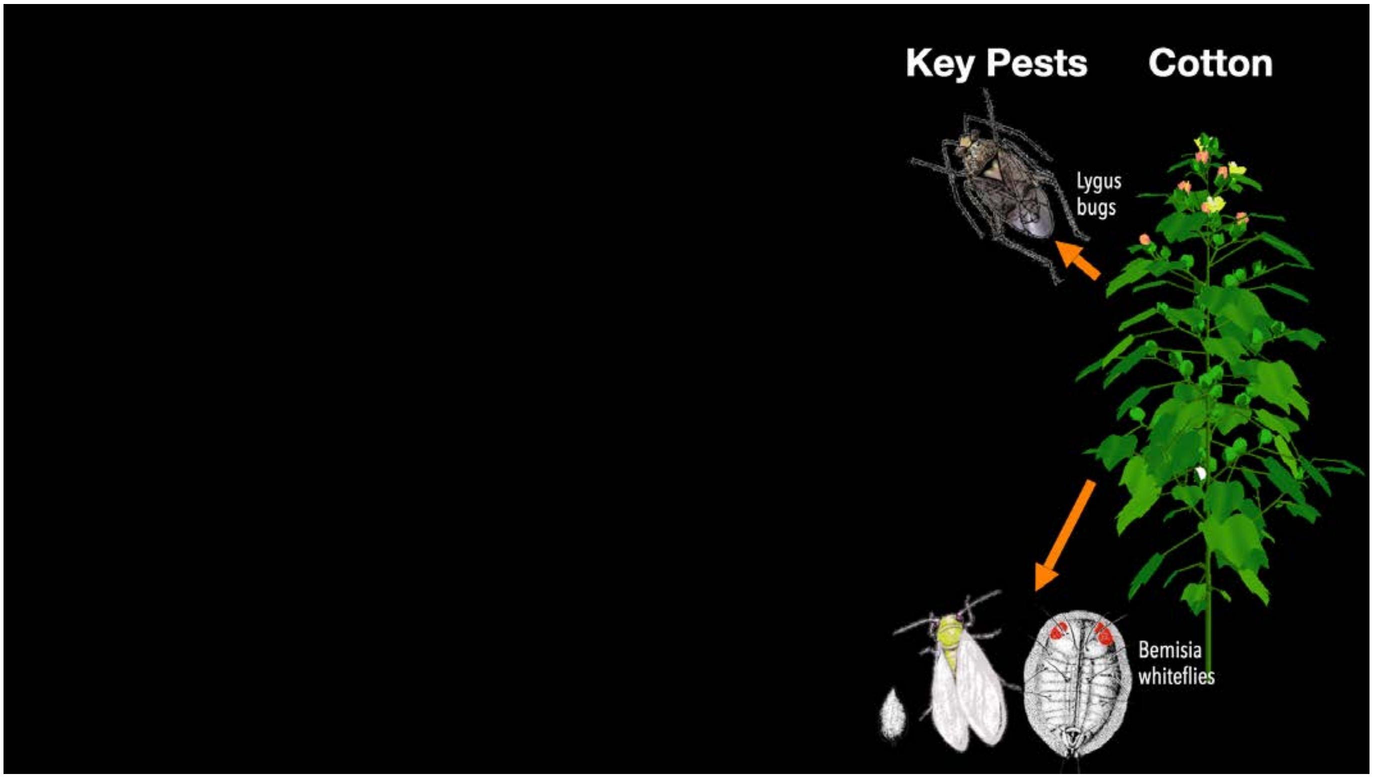


We invested time examining the spectrum of activity of this new genetically engineered trait and assessing its safety and efficacy under Arizona conditions. We are continuing research on the non-target effects of this technology to determine just how it fits into our existing IPM strategy.

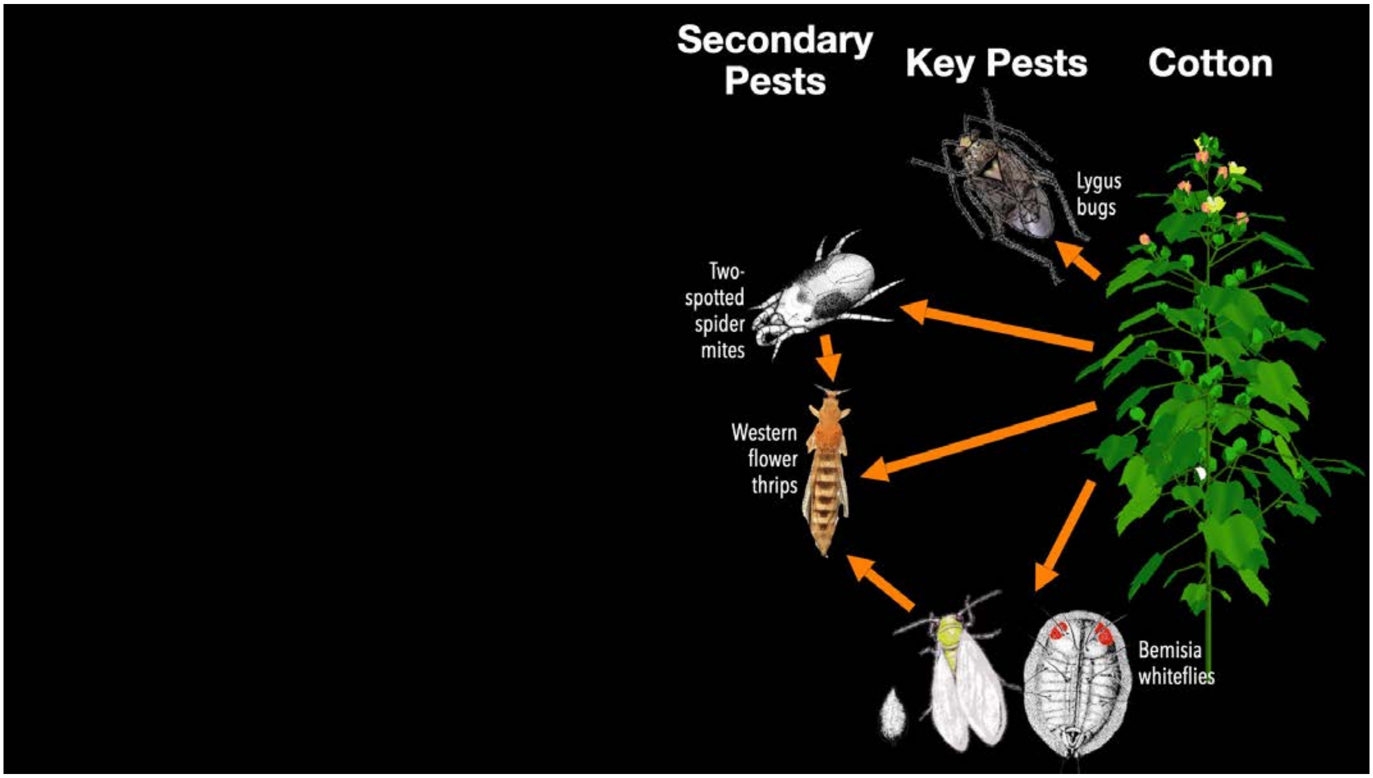
Dual Roles of Western Flower Thrips



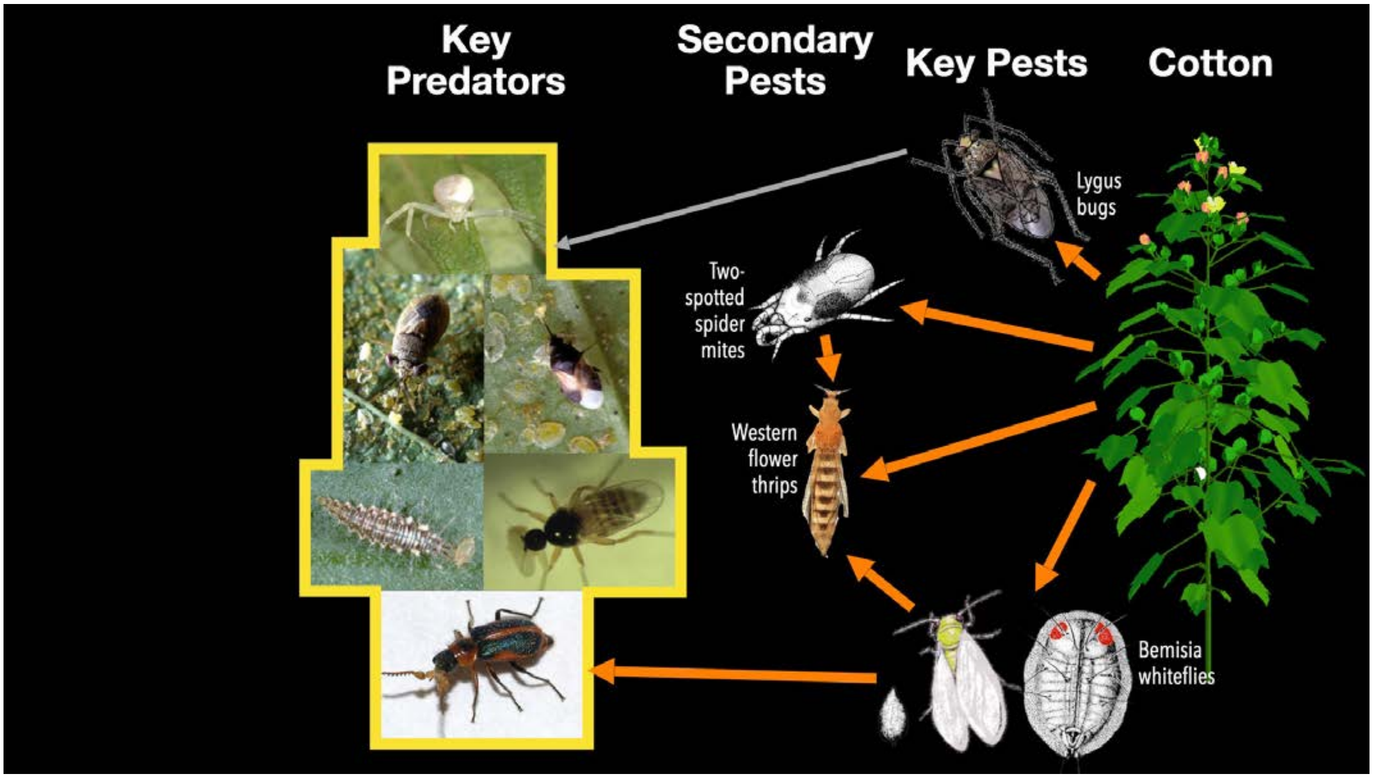
To understand impact on "beneficials", we need to review this important fact. Western Flower Thrips has a dual role as both pest, feeding on cotton, and predator, feeding on mite eggs and other insects in our system including whiteflies. It may not be something you think about. But these thrips are suppressing mites at all times, especially early season. And, they may be assisting in delaying whitefly build-ups in your fields. ThryvOn targets this "beneficial", which means you could be sacrificing some amount of biological control in your ThryvOn fields. It may mean you have to be careful in scouting it, especially if you have also used broad-spectrum insecticides.



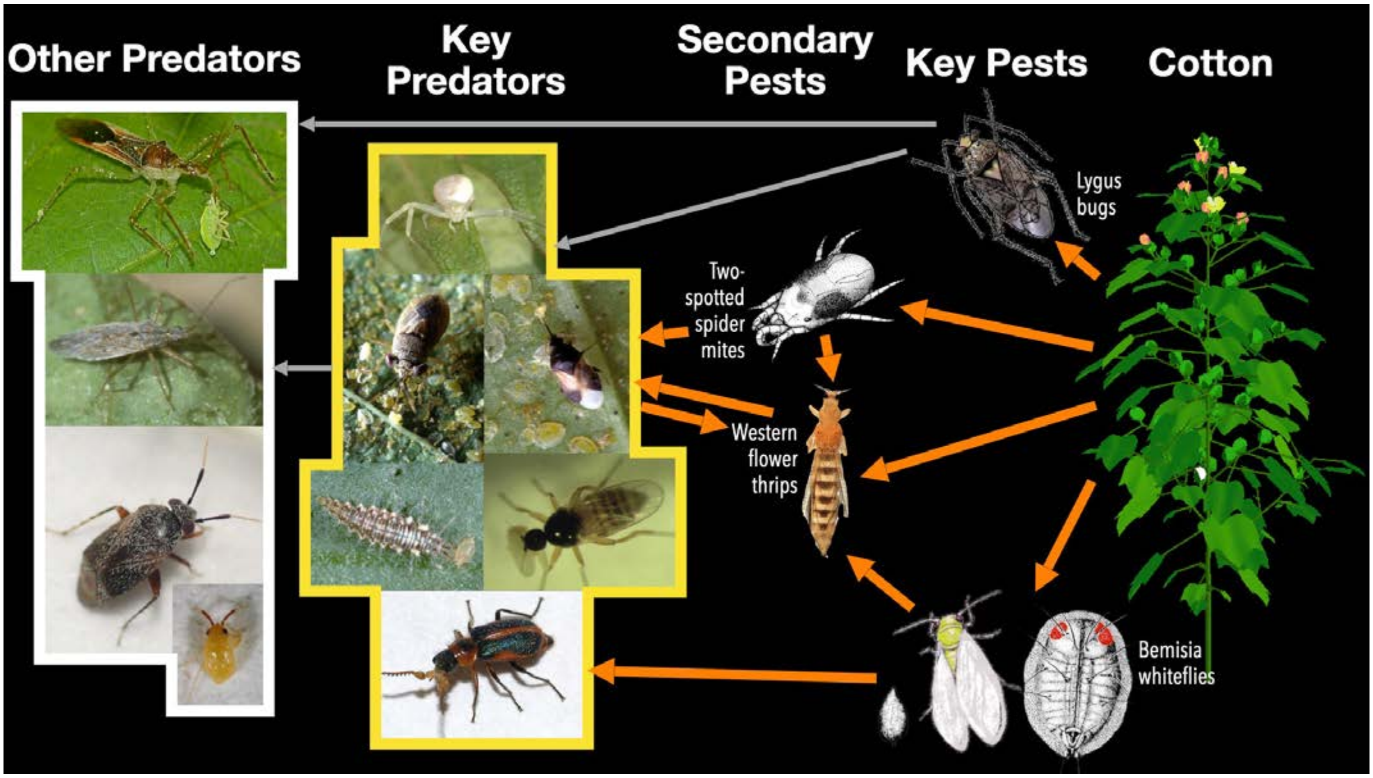
Cotton's key pests in the low deserts of AZ and CA are Lygus and whiteflies.



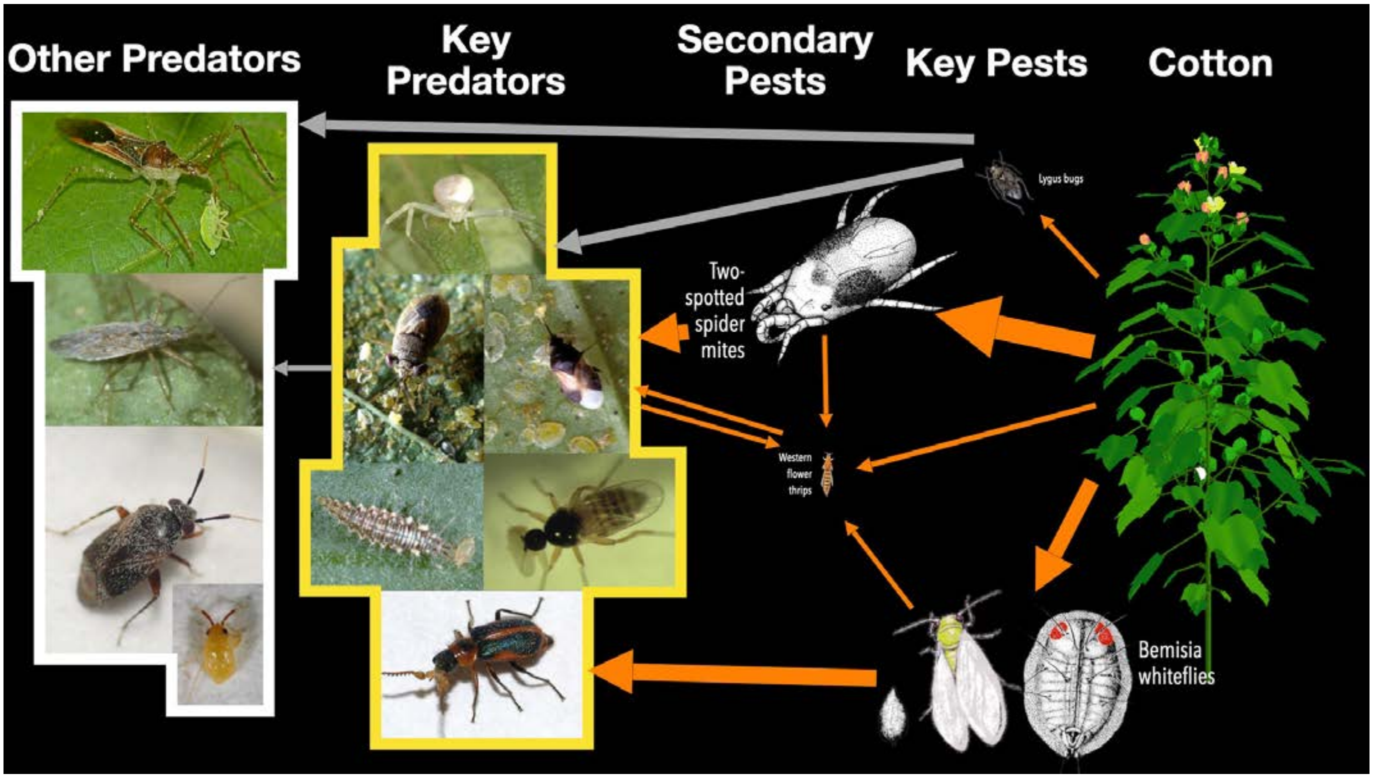
Mites and thrips would be considered secondary pests, ones that we pay less attention to because they are only occasionally at economic levels. But with Western Flower Thrips' dual roles, it also provides some suppression of mites and whiteflies. What about other predators?



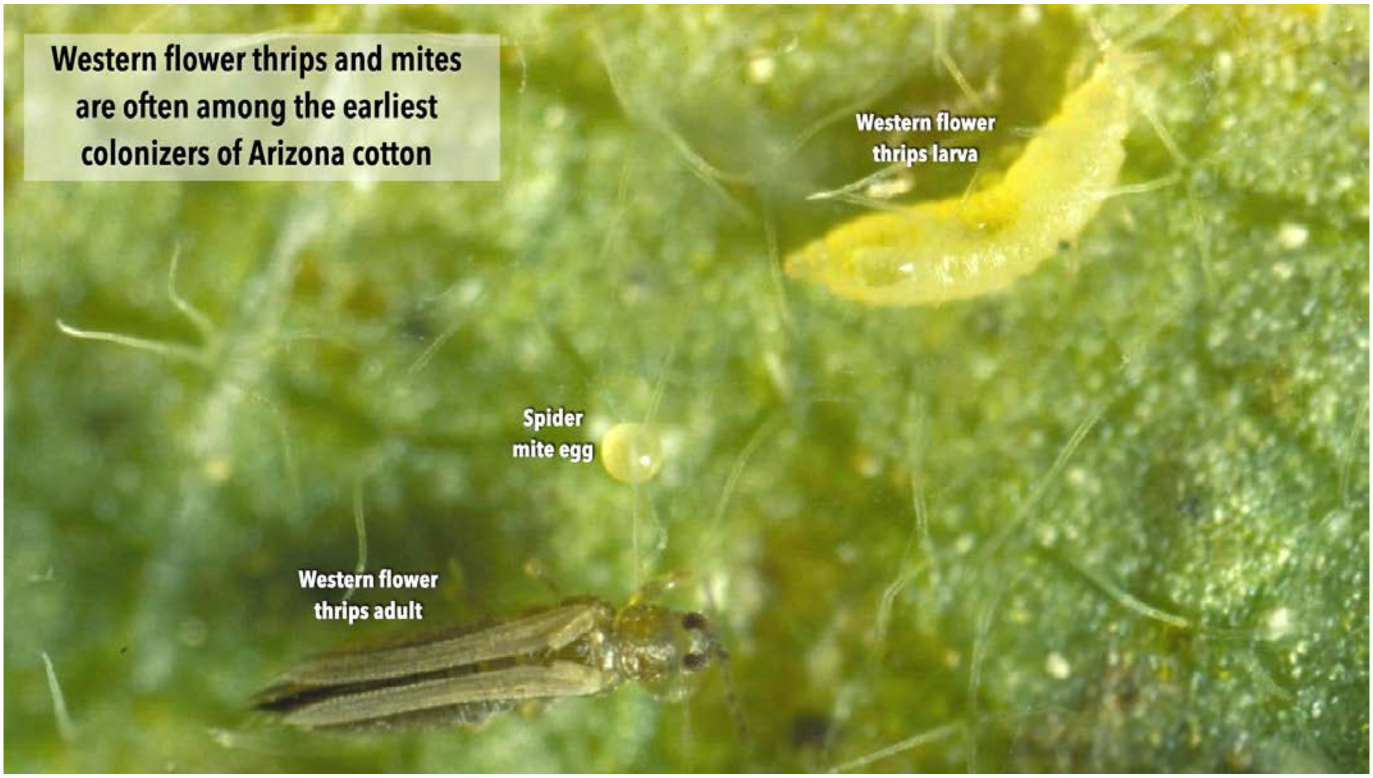
We have found ThryvOn to be very safe to the key predators in our system, the ones that we depend on for biological control of whiteflies and other pests.



We also have found broad safety of ThryvOn to the other predators in our system.

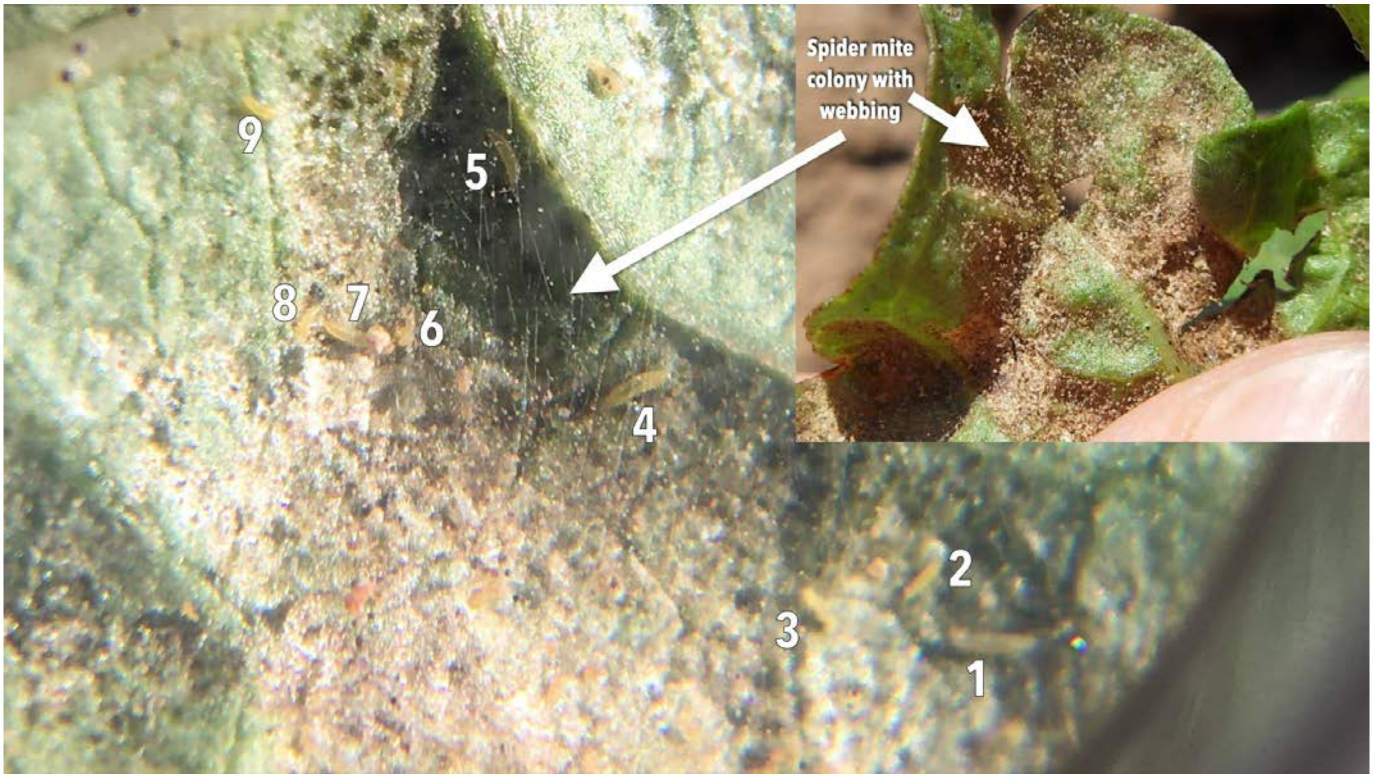


But we have to acknowledge the possibility by shrinking the role that Western Flower Thrips play in our ThryvOn system, we are opening the possibility, at least, that mites could become more problematic and whiteflies might reach economic levels sooner. Thankfully our detailed studies have NOT revealed this possibility. We think we know why. Because our system is full of beneficial, generalist predators, they are taking up the slack and stepping in to fill that biological control niche left open by the reduction of thrips. Of course, this is only true if we are careful not to deploy early season broad spectrum insecticides like dimethoate and others that used to be popular practice 30 years ago.

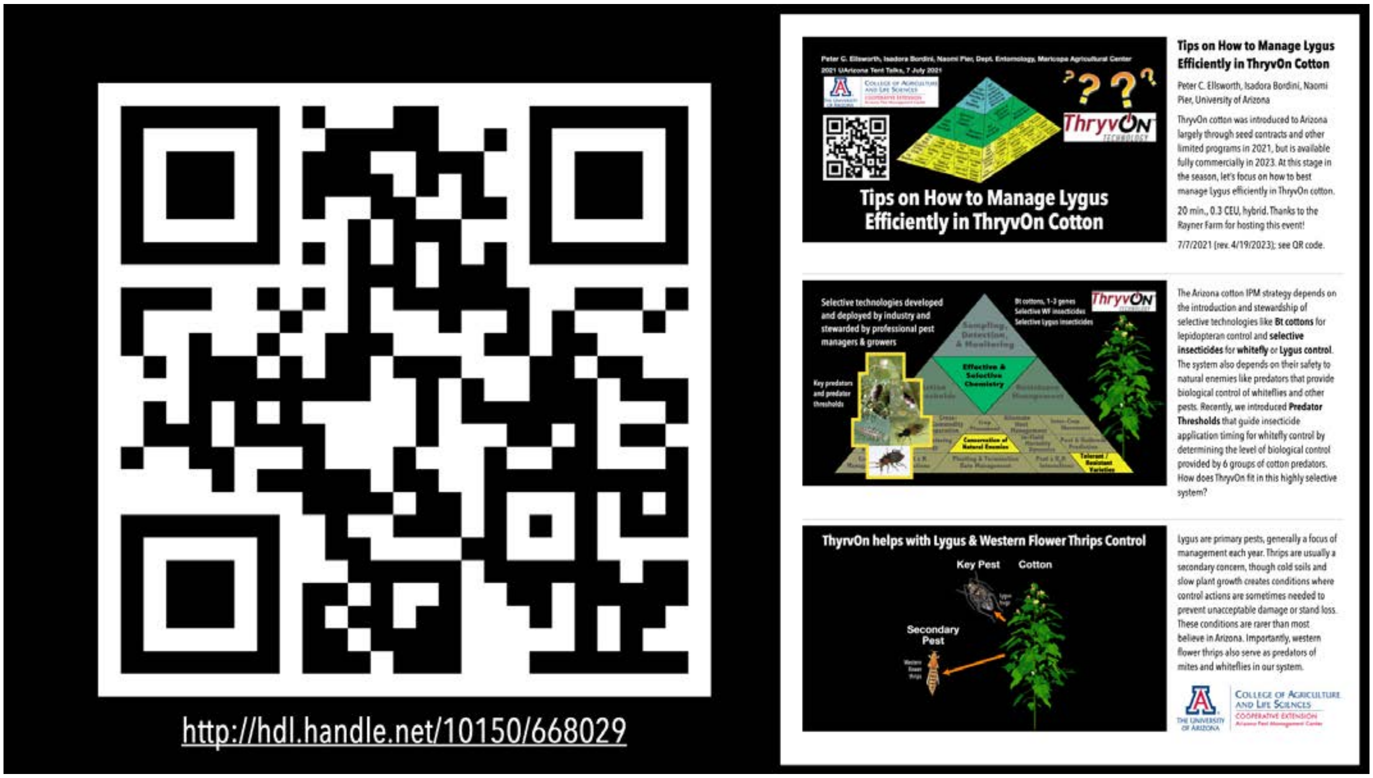


To illustrate this dynamic, notice the winged adult thrips and the thrips larva in this picture adjacent to a mite egg. Mites and thrips (and whiteflies) are the earliest colonizers of cotton. And this biological control plays out all the time such that you don’t notice either mites or whiteflies being in your seedling cotton.

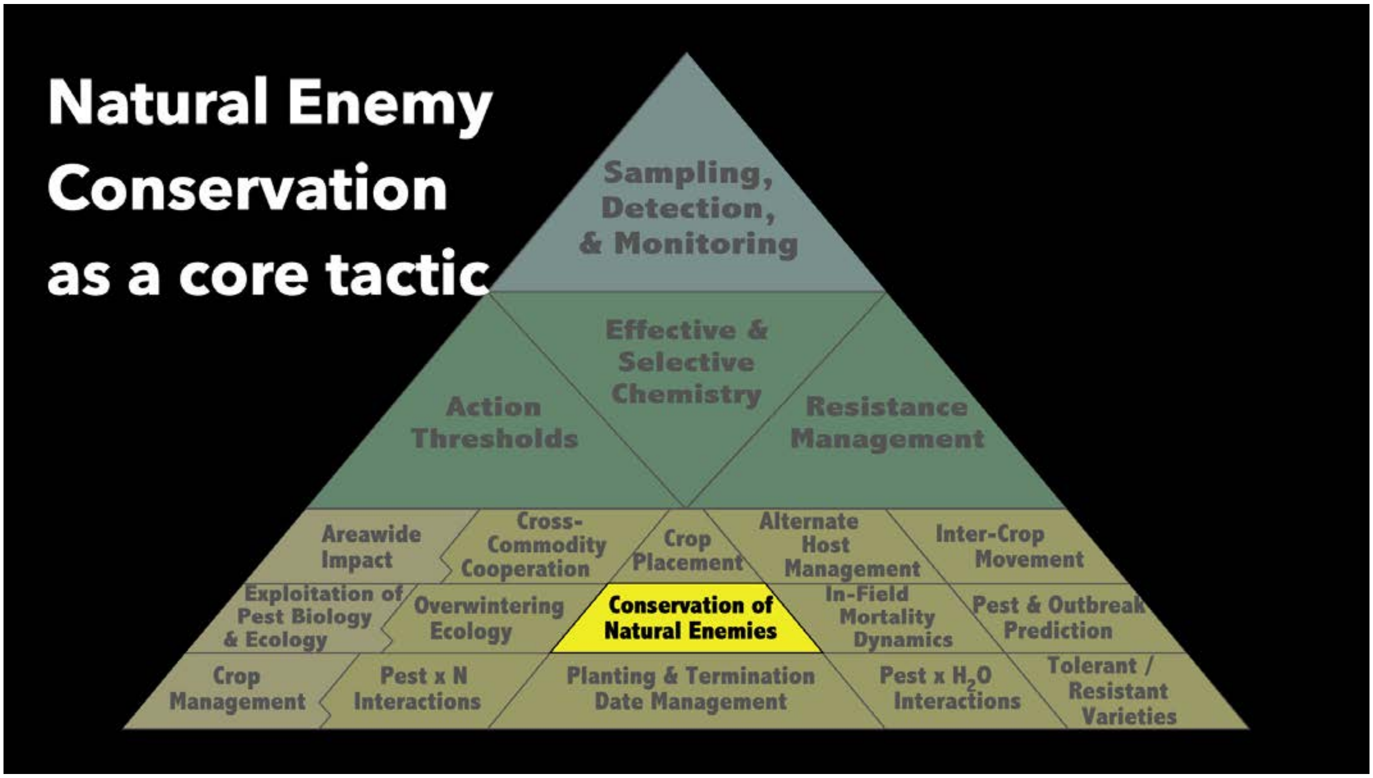
When mites do break out, they show this typical bruising on the upper side of the leaf.



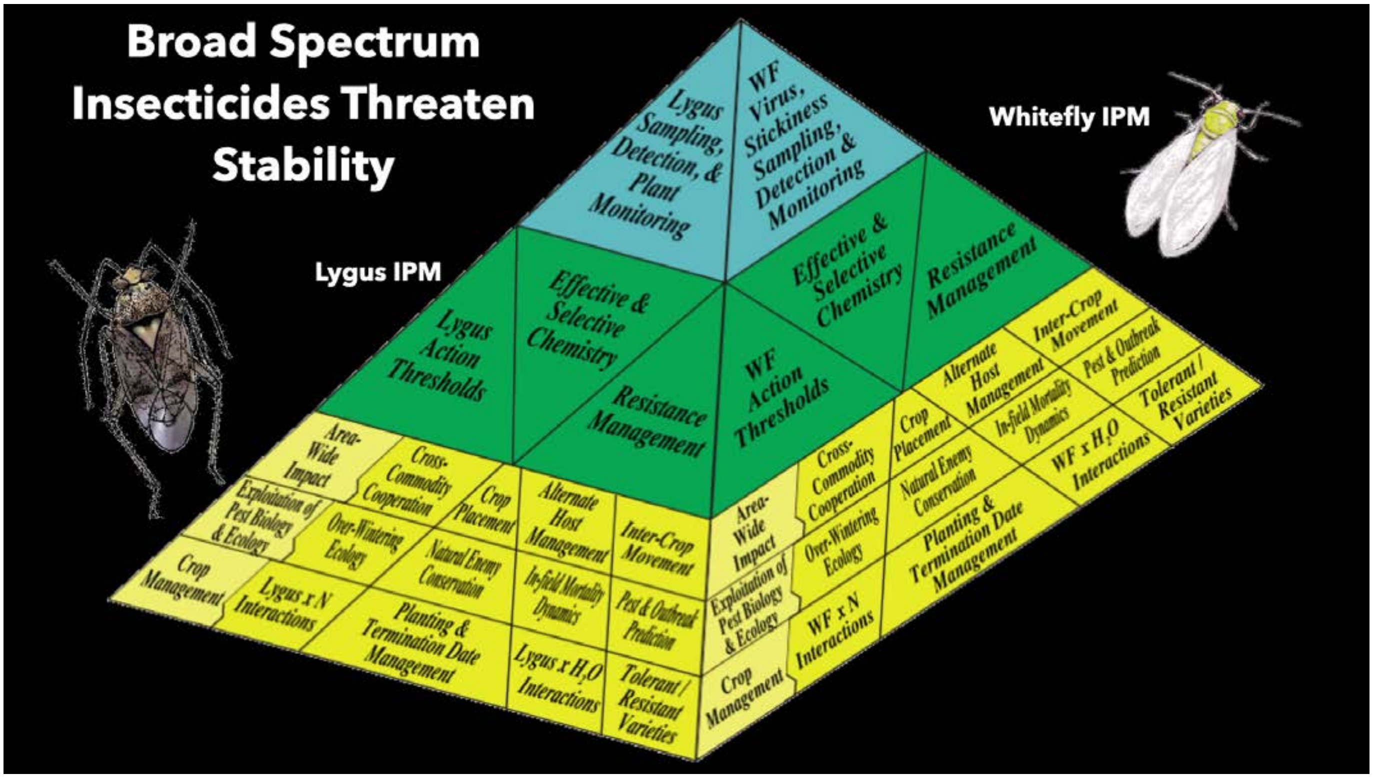
And webbing all around their colonies on the undersides of the leaf. This photo was shot through my hand lens and isn't sharply focused. But note, there are 9 thrips larvae in this mite colony – that's a lot! Importantly, however, there are no mites left on this leaf. The thrips have wiped them out. This was from a planting of conventional cotton immediately adjacent to a ThryvOn field. This tells me that mites were locally present, if not potentially abundant. But they did NOT break out in the ThryvOn cotton.



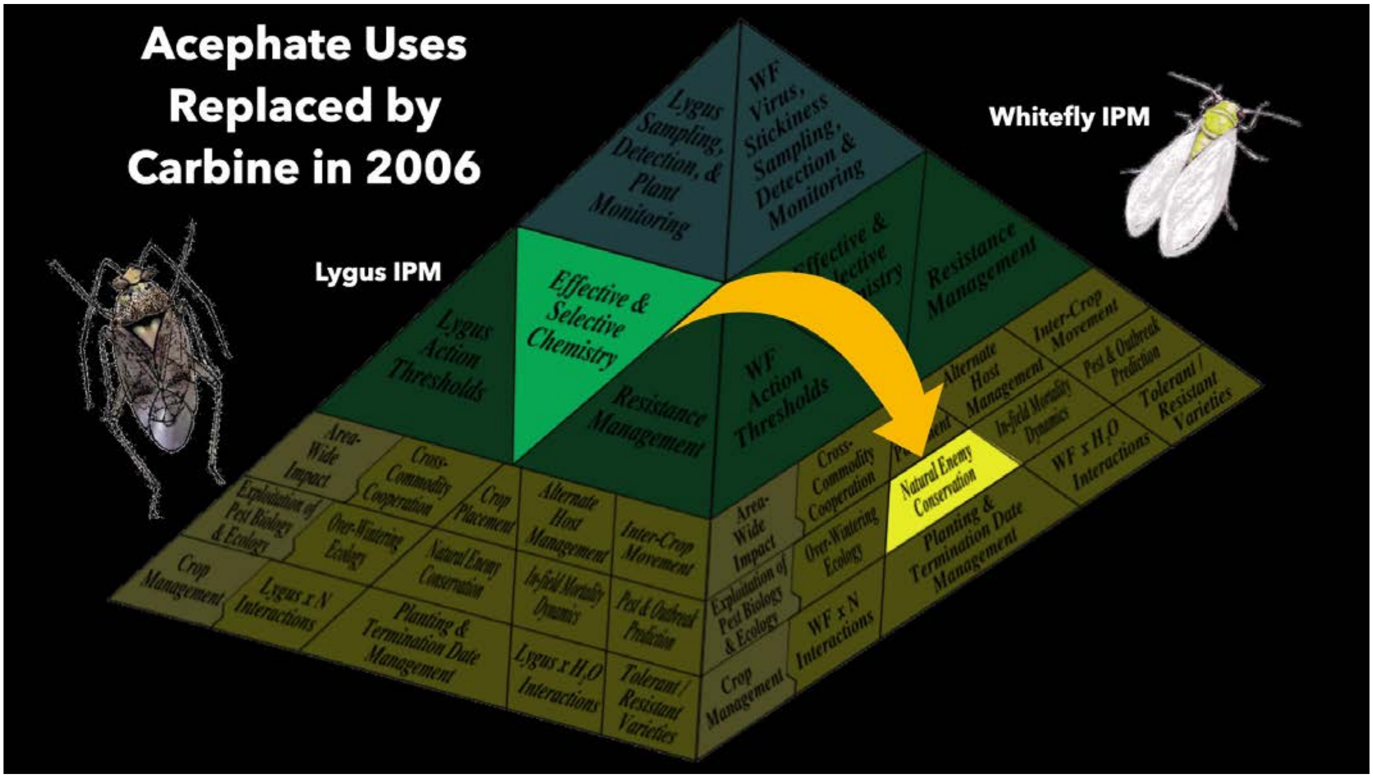
Let's pause for questions here on ThryvOn. This QR code points to some of the materials I've covered today. See, http://hdl.handle.net/10150/668029



Natural enemy conservation is the core tactic that we have been developing over the last 25 years.

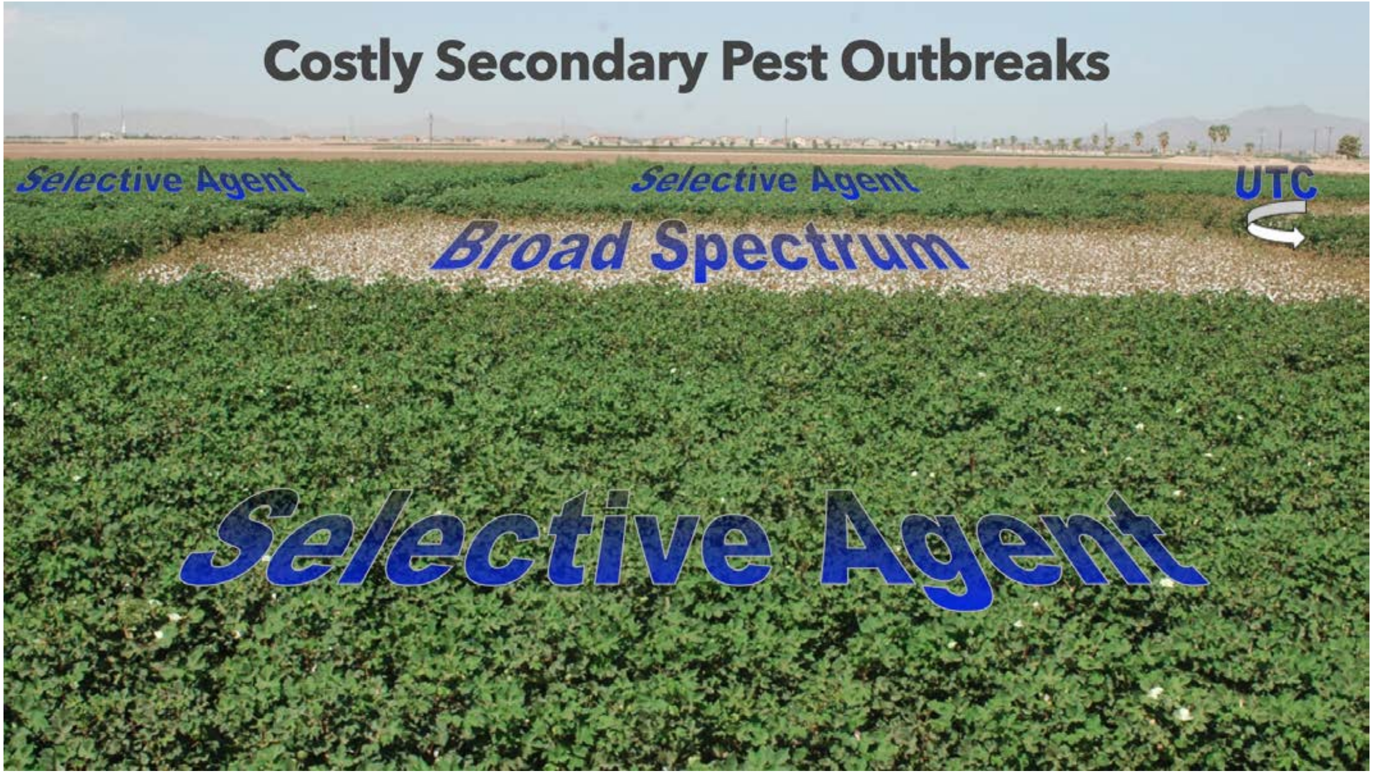


Our IPM plan is multi-faceted, too, because it addresses each of the key pests of the system. Broad spectrum insecticides threaten the stability of this system.

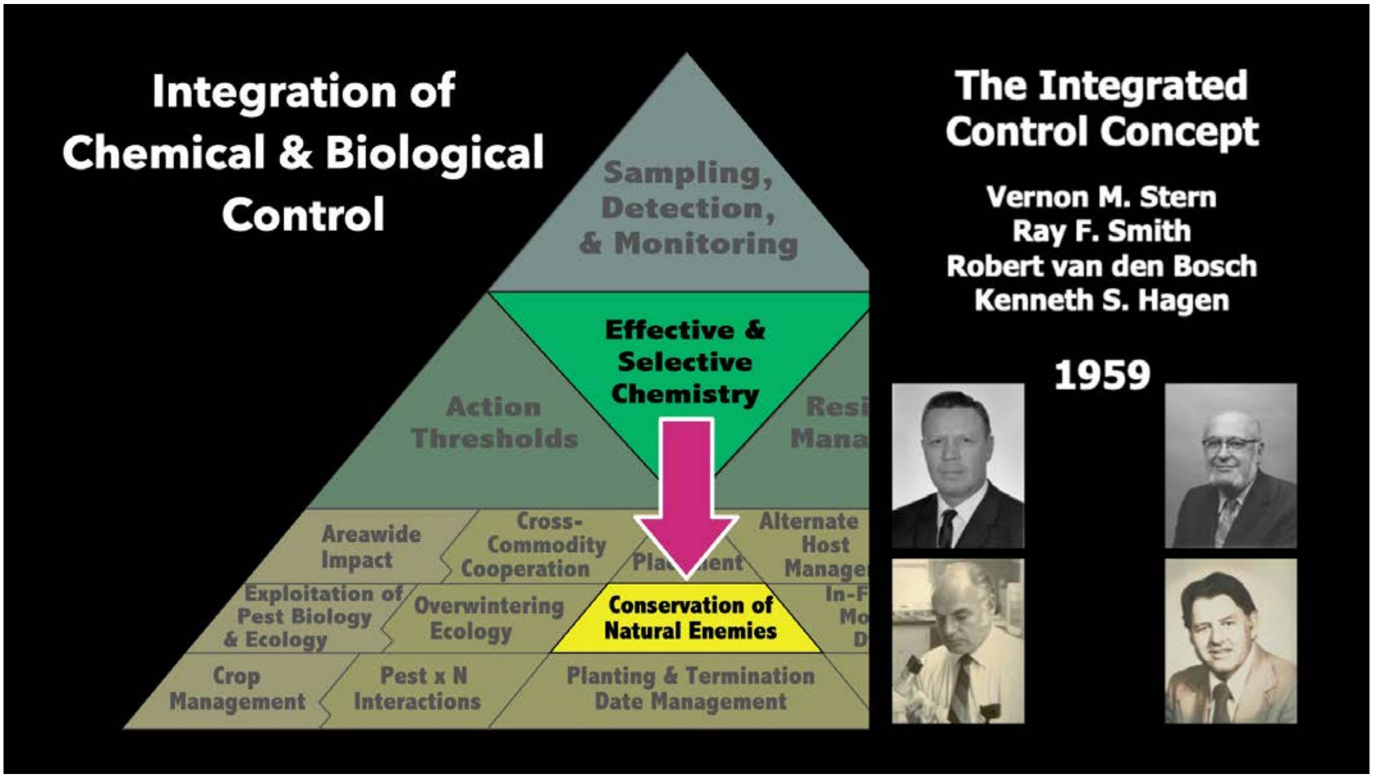


Any decision or action taken for one pest can have drastic impact on other key or secondary pests. In this case, the choices made in chemical control of Lygus bugs can negatively impact the natural enemies that we depend on for whitefly management. Thus, compatibility of practices is paramount. Prior to 2006, acephate was the number one active ingredient used in cotton because of its need in controlling Lygus. But in 2006, Carbine changed all that, as the first fully selective Lygus chemical control which didn't harm our beneficials.

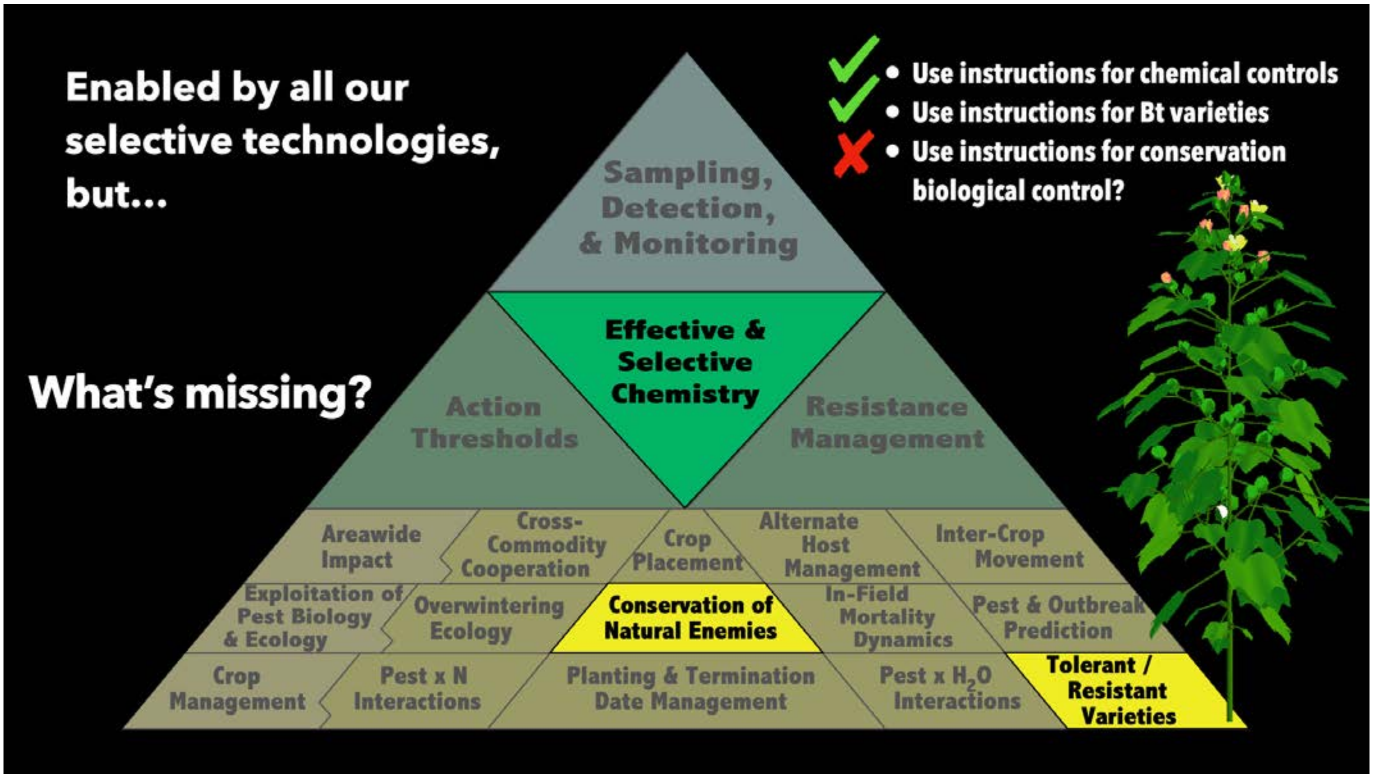
Ignoring this requirement for compatibility can lead to disastrous results due to secondary pest outbreaks and/or primary pest resurgences. The area in the center was biologically defoliated prematurely by mite and whitefly outbreaks. Right down to the row, you can see the results of inappropriate choices to use broad spectrum insecticides for the control of Lygus bugs. Elsewhere in this same field, the choice was made to use selective insecticides only, like Carbine and Transform. Mites were not an issue there. The defoliated plot lost over a bale per acre compared to the others.



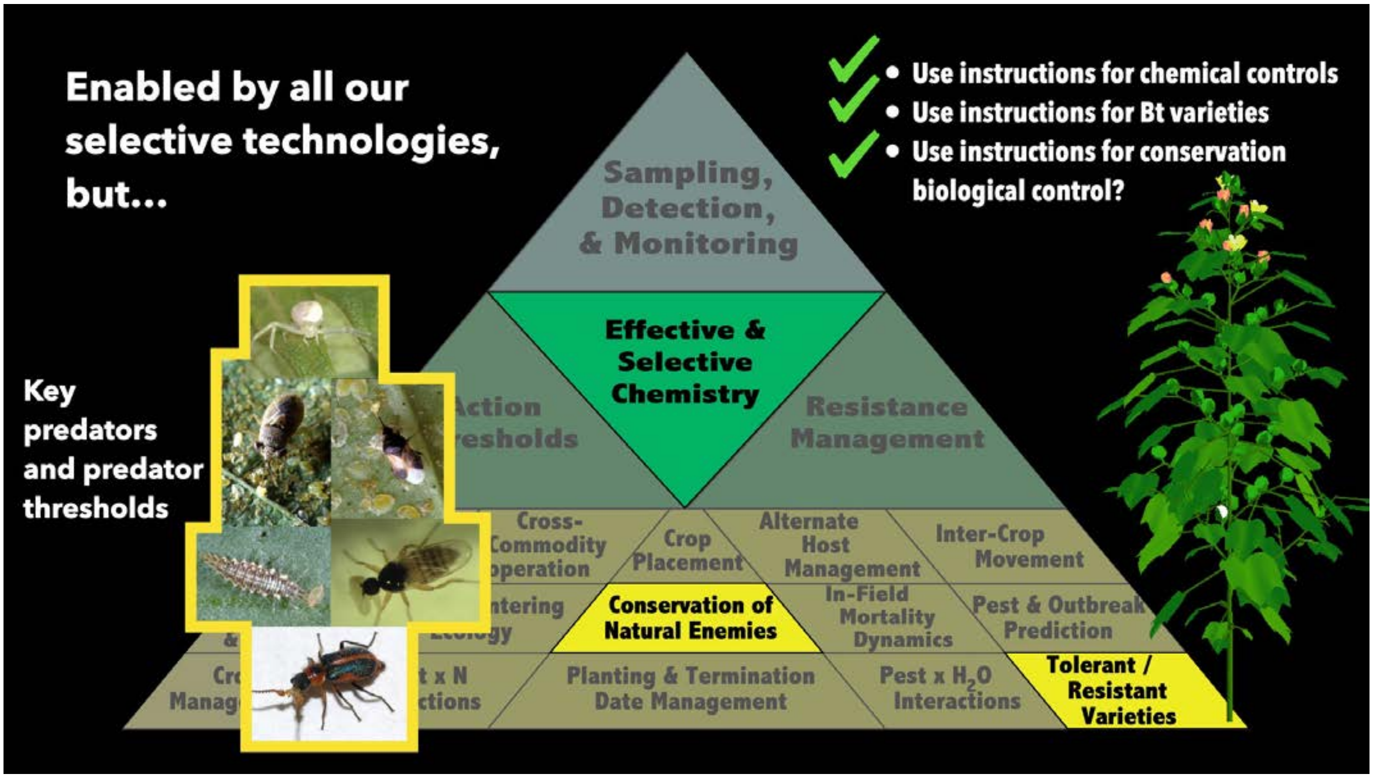
The broad-spectrum Lygus control insecticide, acephate, was used in the center; flonicamid (Carbine), the selective Lygus control agent, was used in the background plot; the other major selective Lygus control agent, sulfoxaflor (Transform), was to the left and the untreated control to the right.



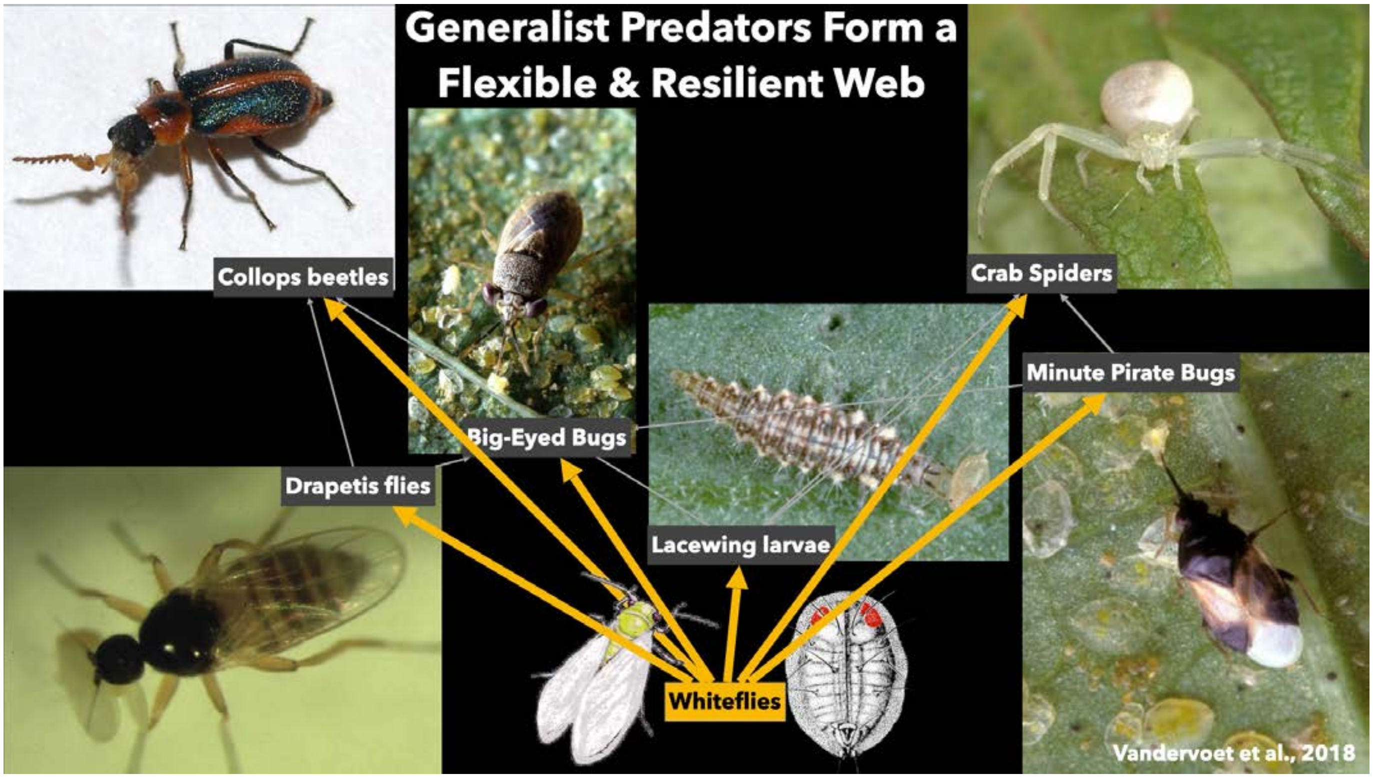
Integration of biological and chemical control in our system is paramount and central to its dramatic success. Sitting here in Riverside County, we should take pride in the entomologists that "invented" the ideas that form the basis of IPM today. Dr. Vern Stern was the lead in this effort and did much of his work in this county while a professor at UC-Riverside. Thus, this is the birthplace of IPM!



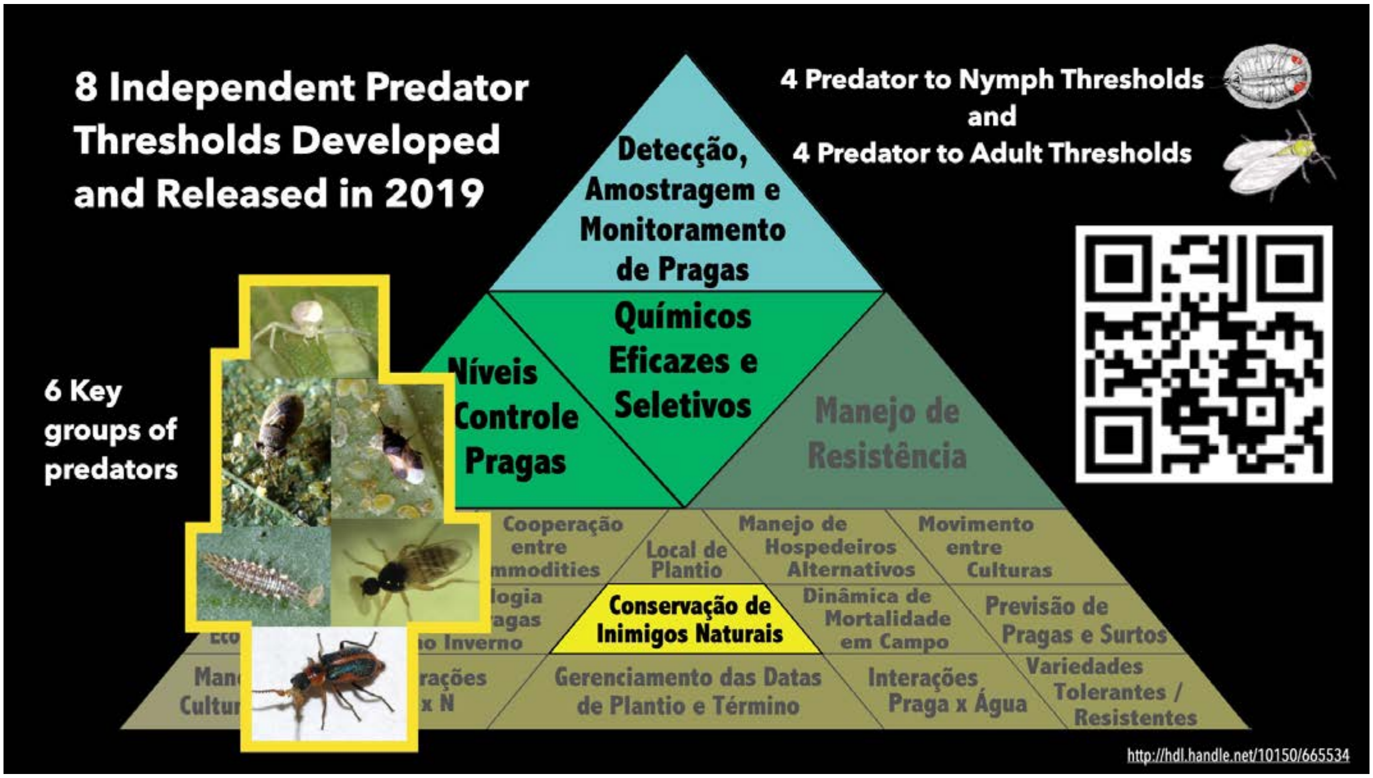
That integration is enabled by an array of selective technologies including Bt cotton. But, what's missing? We have excellent use instructions for all our chemical controls and for all our Bt varieties. We're good at developing these for hard technologies in general. However, we had no "use instructions" or specific guidance on how to conserve natural enemies. Which ones are important? How many do you need? How do they influence spray decisions? Which insecticides are safe for these natural enemies? This is all the soft technology needed to enable the system.



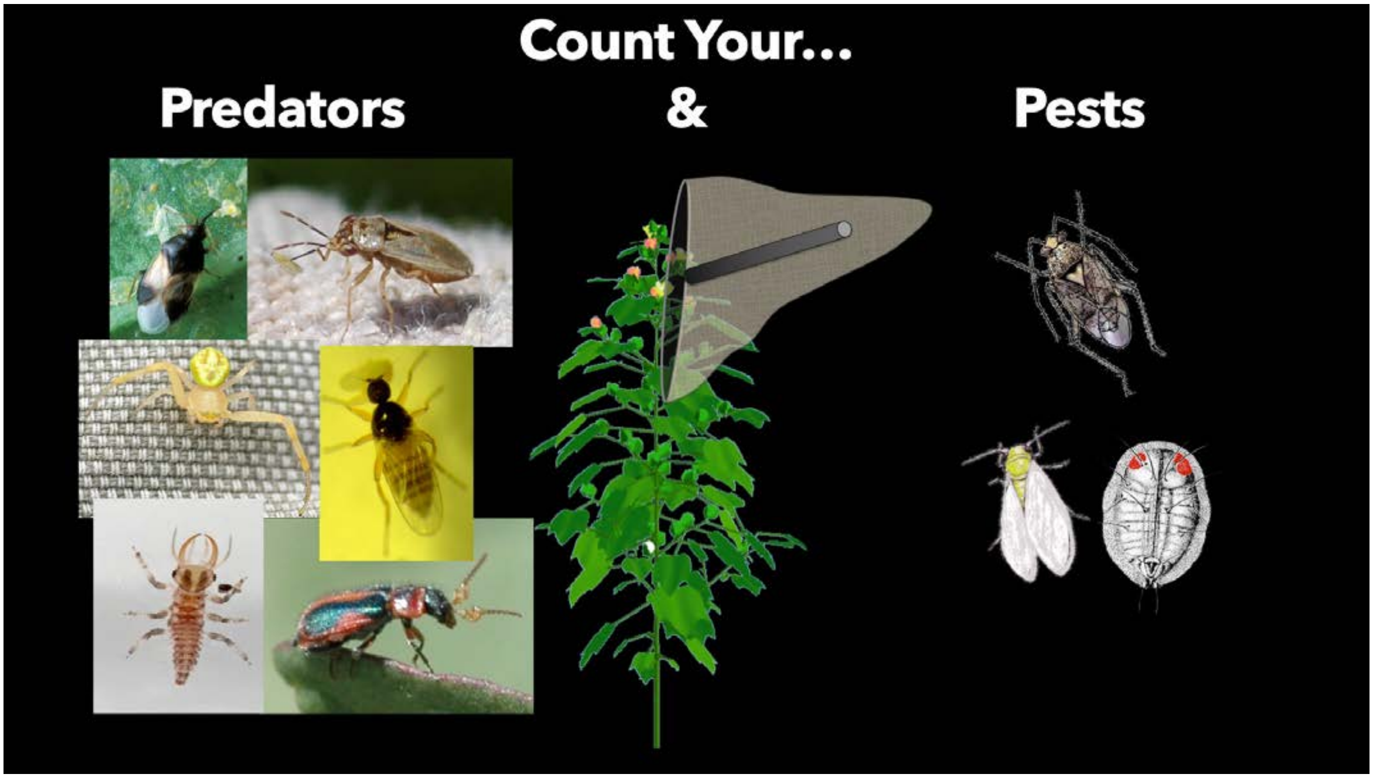
That's all changed for us. Recently, we identified the key predators to conserve and introduced Predator Thresholds that guide insecticide application timing for whitefly control by determining the level of biological control provided by 6 groups of cotton predators.



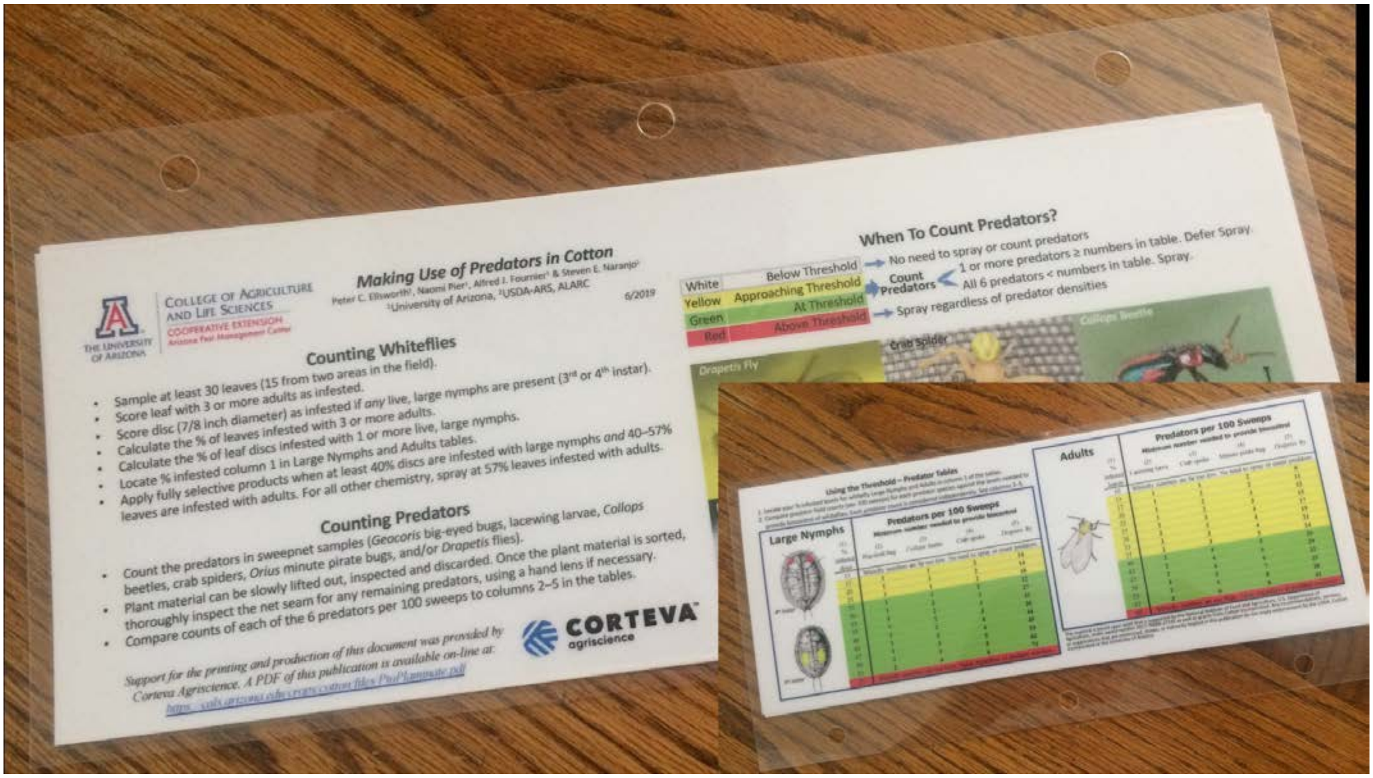
These are the six groups of arthropods we identified as influential in the biological control of whiteflies in Arizona cotton. They are crab spiders, minute pirate bugs, lacewing larvae, Drapetis flies, Collops beetles and big-eyed bugs. Most are generalist predators in Arizona cotton. This means that these predators feed not only on key pests but also on each other. These relationships make the food web resilient and flexible. In our work with Tim Vandervoet, our PhD student, we determined specific predator to prey ratios that can be used in whitefly management.



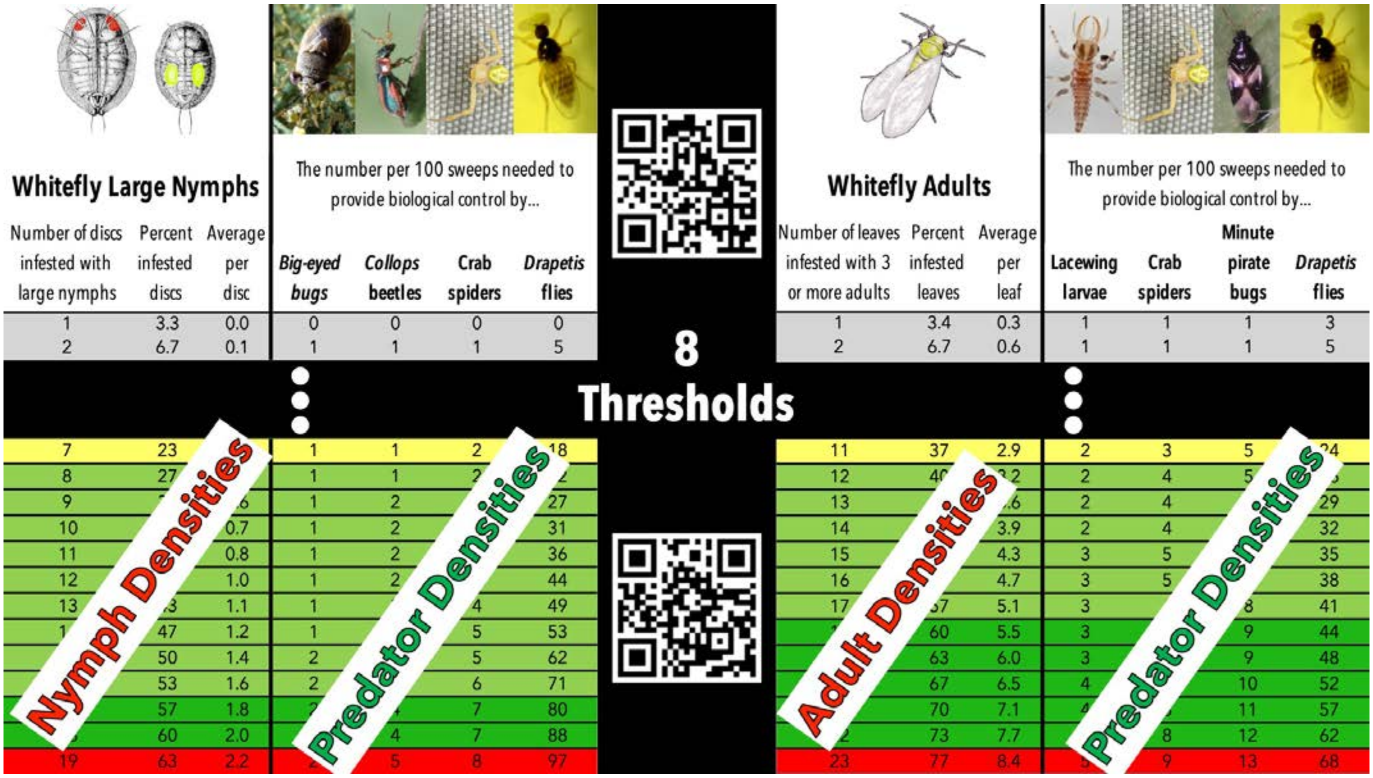
We have established 8 independent predator thresholds, which we released in 2019, 4 based on whitefly large nymphs and 4 based on whitefly adults. The QR code points to our Extension guide that explains how these ratios work for growers and pest managers. See, http://hdl.handle.net/10150/665534



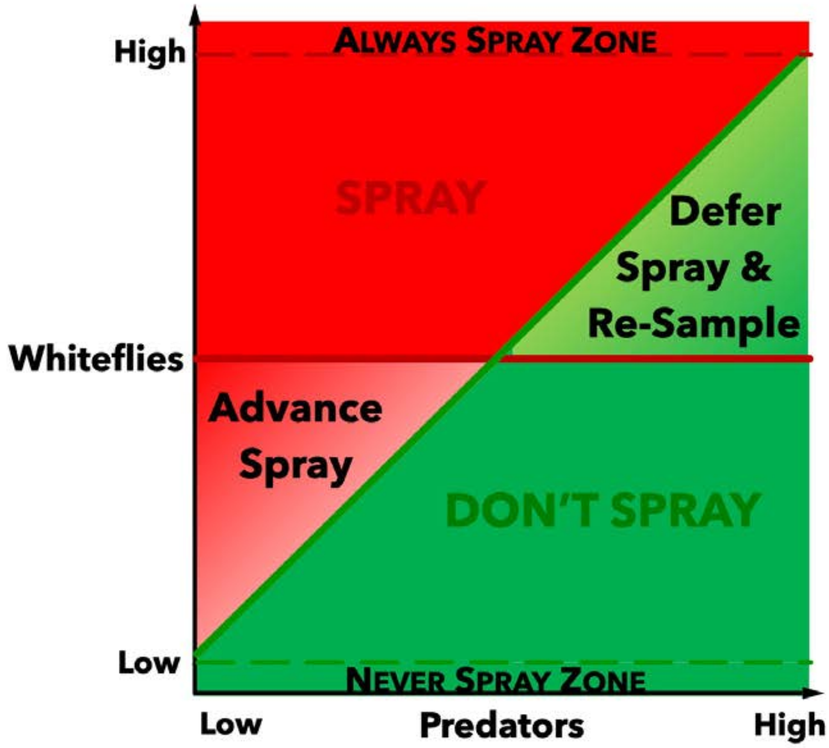
Scouting for pests is the bedrock activity of IPM. The new frontier? Scouting for predators in order to track their levels over time enables better decisions about whether biological control is working and whether or if we need to spray. We've identified 6 key predator groups that you can track in sweep counts.



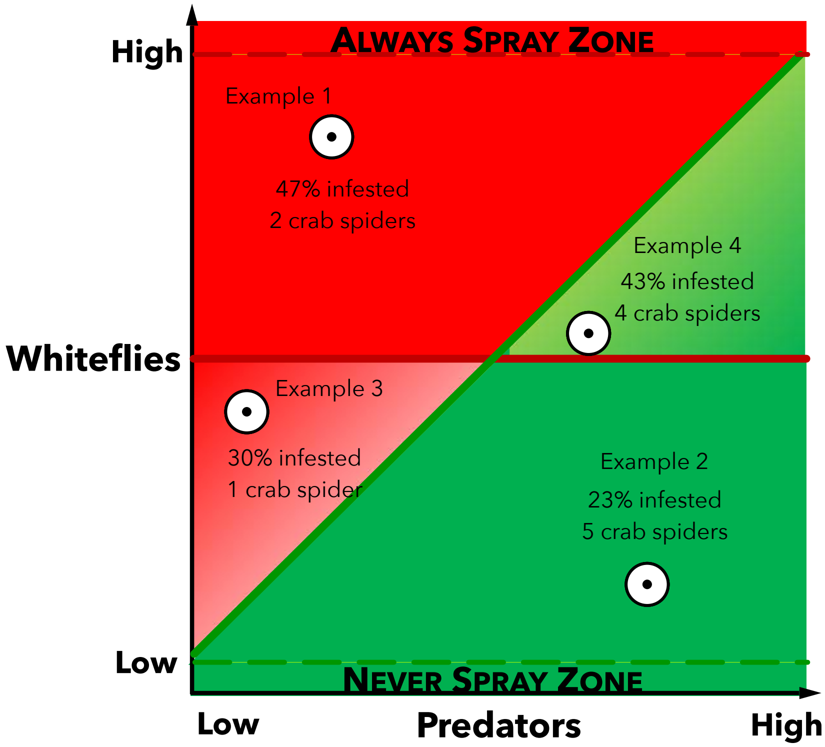
We have produced laminated pocket guides and distributed them to all pest managers in the state with industry's help. These guides provide the basic procedures to follow and the threshold tables for both the predators and whiteflies.



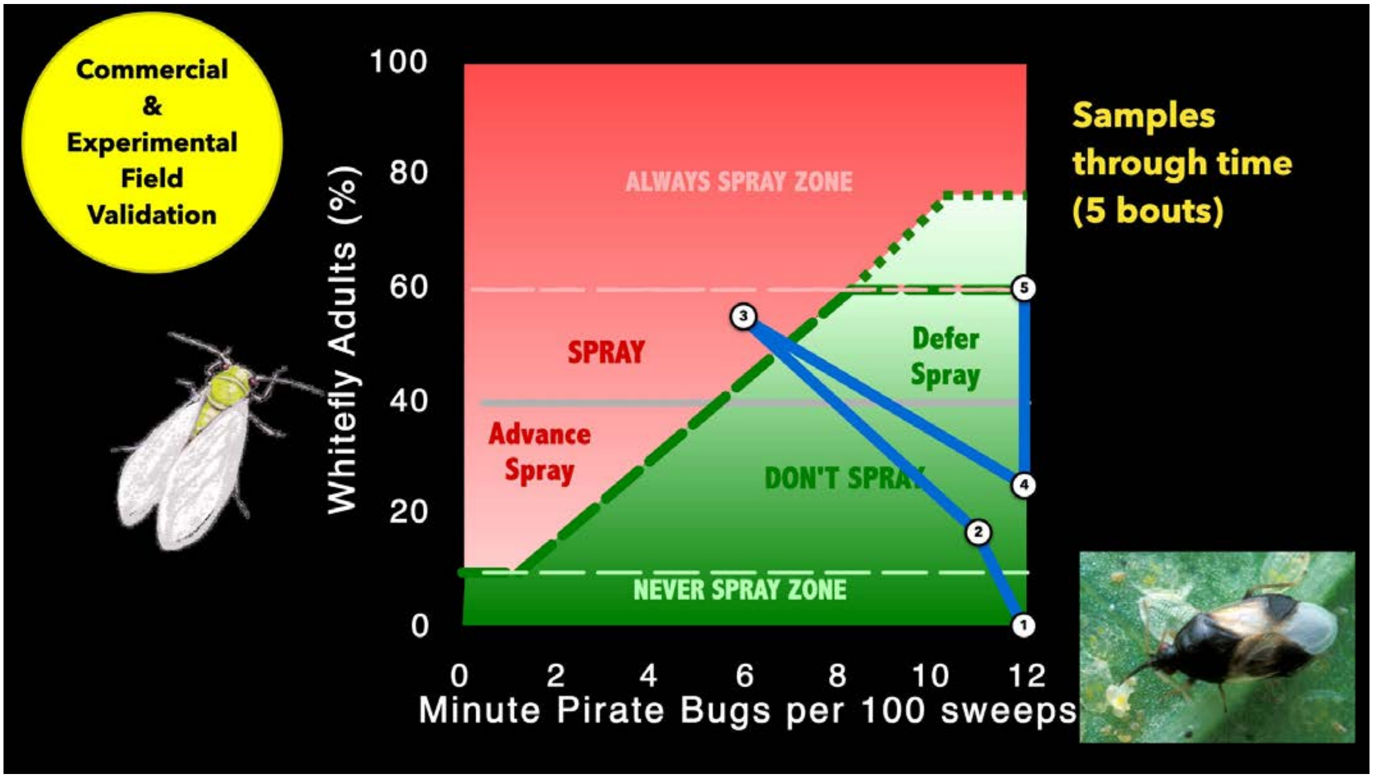
The standard pest-centric threshold is actually based on both large nymph and adult numbers. Now, we have 4 predator thresholds based on whitefly large nymph densities and 4 predator thresholds based on whitefly adult densities. We published in English and Spanish look-up tables where once a pest manager knows the prey density, they can determine the predator density that indicates whether biological control is still functioning. In the IPM Short, "Making Whitefly & Predator counts", an explanation is given on how to implement the predator thresholds system. Publication available at: http://hdl.handle.net/10150/665535 (top QR code). Additional information on how to better integrate biological and chemical controls can be found here, http://hdl.handle.net/10150/665531 (bottom QR code).



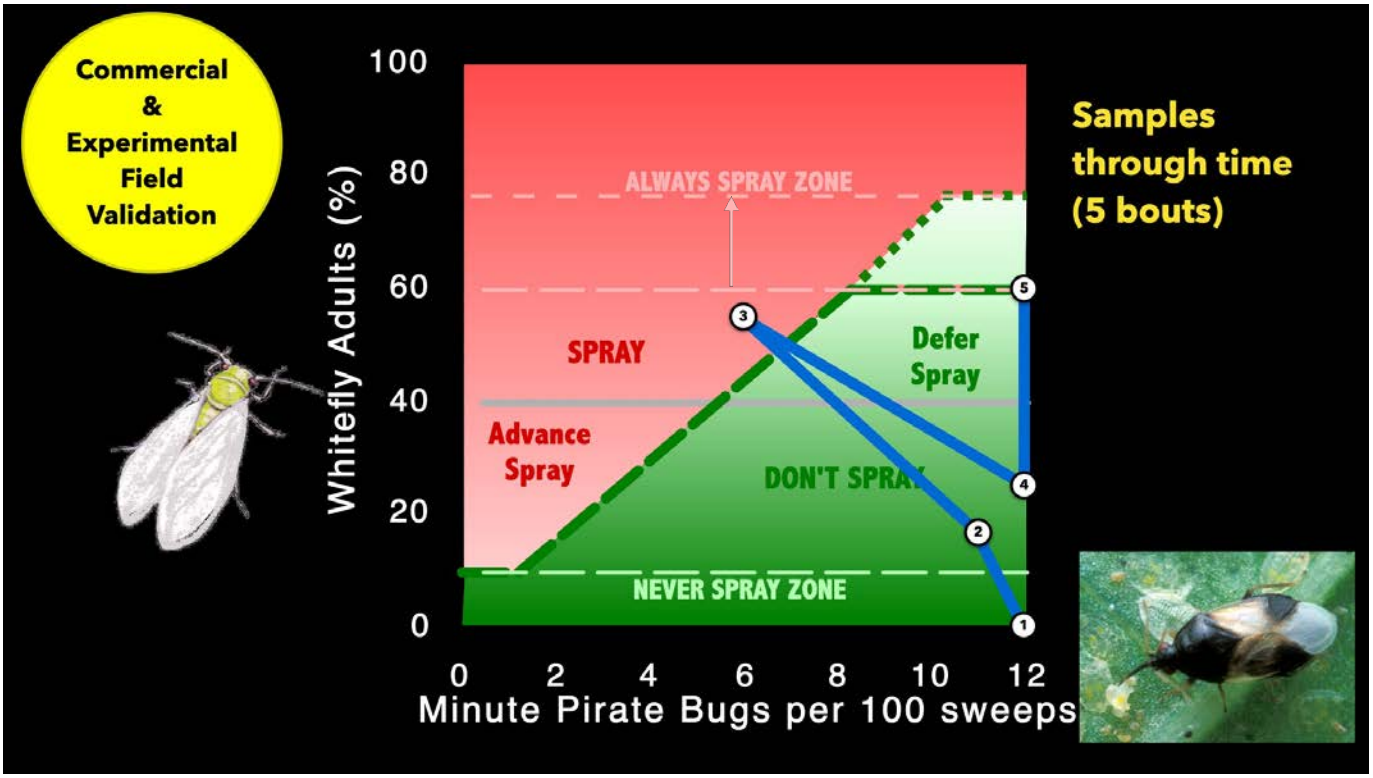
Let's examine how this new system works. Whitefly levels can be below, above, or at threshold. When whiteflies are very low, you know that you never need to spray; when whitefly levels are very high, you know that you have to spray no matter what. They're just too high. The green diagonal line represents these new predator thresholds, a ratio actually, where predator numbers needed increases as whitefly levels increase. So when whiteflies are higher than threshold, but predators are also high, you can probably safely defer your spray and re-sample in a few days. This saves you money. Conversely, when whitefly numbers are low but approaching threshold and numbers of predators are also low, biocontrol is compromised and you will want to advance your spray. This prevents whitefly damage and also saves you money by making your control efficient.



Let's work through a hypothetical example…in Example 1, whiteflies are at 47% infested leaves, which is above the standard pest-centric threshold (= 40%), and there are 2 crab spiders per 100 sweeps which is a level too low to mitigate this density of whiteflies. A spray is therefore required. In Example 2, whiteflies are at already low levels and crab spider densities are high. This is a no-spray condition. In Example 3, whiteflies are below the standard threshold, but crab spider densities are also very low. This is a situation where a spray needs to be made in advance of the standard threshold, because there simply is not enough biological control to prevent unacceptable whitefly population growth and loss. In the final example (4), whiteflies are just over the standard threshold but crab spiders are at sufficient density to signal that biological control is still functioning well enough to defer spraying in favor of sampling later on and revisiting decisions.



Here we show 5 different sampling dates (1-5 for T10), blue line. On the first date (1), whitefly adult infestation rate was 0 and the number of minute pirate bugs per 100 sweeps exceeded our scale (16/100, actually). On date 2, whitefly levels were up but pirate bug numbers were still very high. The 3rd date is interesting because we exceeded the pest-based threshold (gray line) and the new predator based threshold, and pirate bugs did decline in number. The guideline suggests to spray, but this was not the only piece of information available to us. We also had whitefly large nymph levels and the levels of the other key predators. We decided not to spray and on the date 4 we had higher pirate bug numbers (45/100, off the chart!) and lower whitefly numbers. Our 5th sample placed whitefly levels on the cusp of the "always spray zone" but still with ample pirate bug numbers (28/100). We decided to continue deferring a spray in favor of the excellent biological control taking place.



Because of this change, we have effectively widened the operational zone over which whitefly control decisions can be made using biological control information.

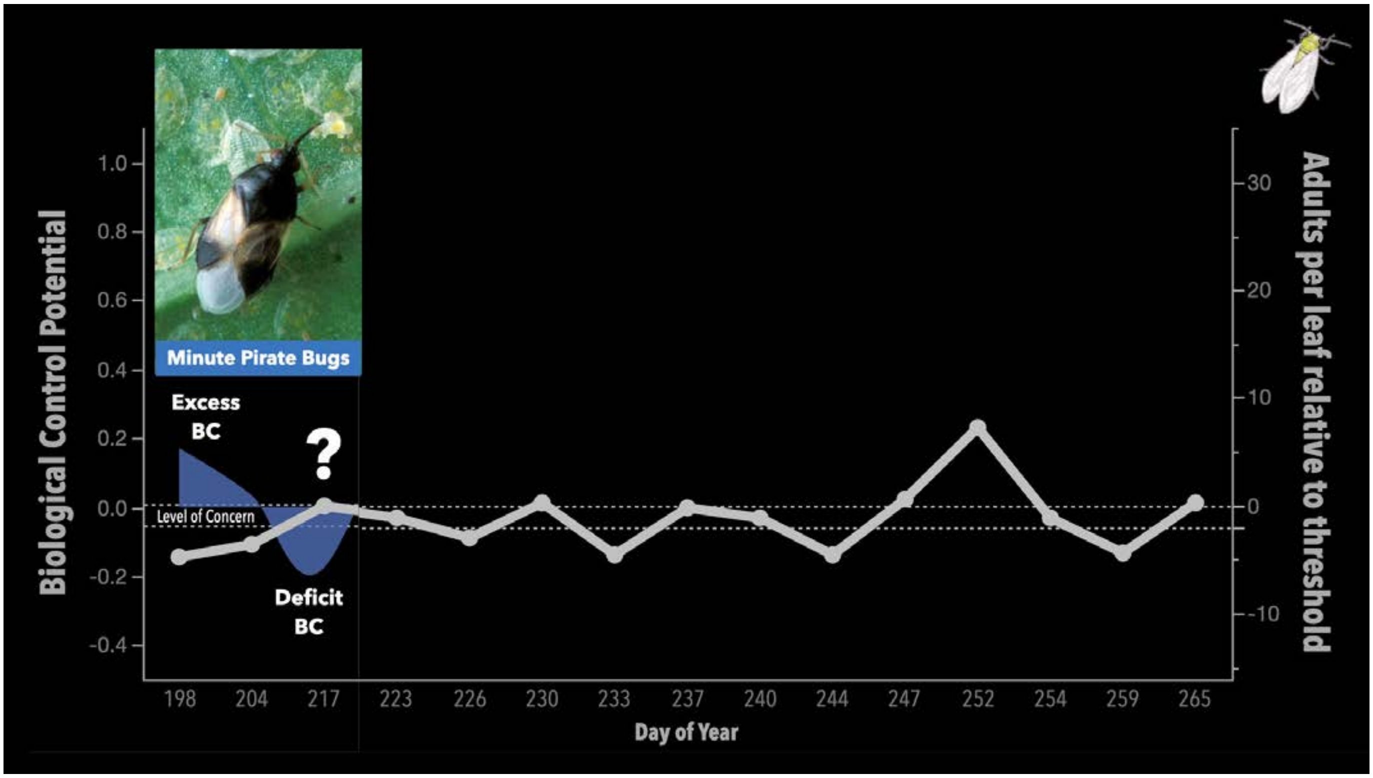
Here I'm spraying a window pane (or picture frame) with some canola oil spray just for fun!

As a demonstration of what kinds of populations of whiteflies we were experiencing, we got creative in demonstrating just how bad whiteflies got in this trial. Here I'm spreading that oil film evenly over the window pane.

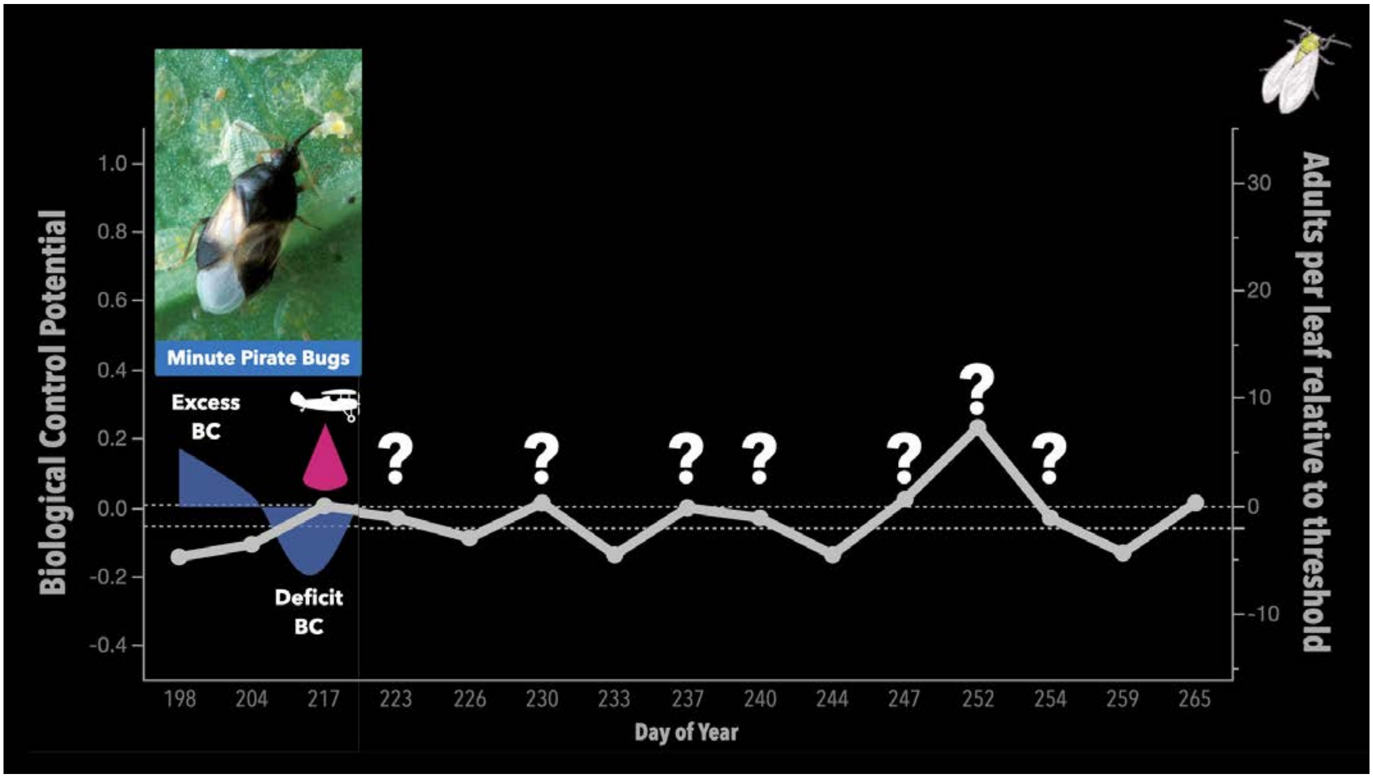
Watch as I travel the length of the experimental plot (40 ft) with that window pane out in front of me.

To give you a better idea of what that looks like, Naomi filmed while I walked backwards in the plot so that you can see whiteflies against the background of the window pane. This is in the Untreated Check (UTC-disrupted).

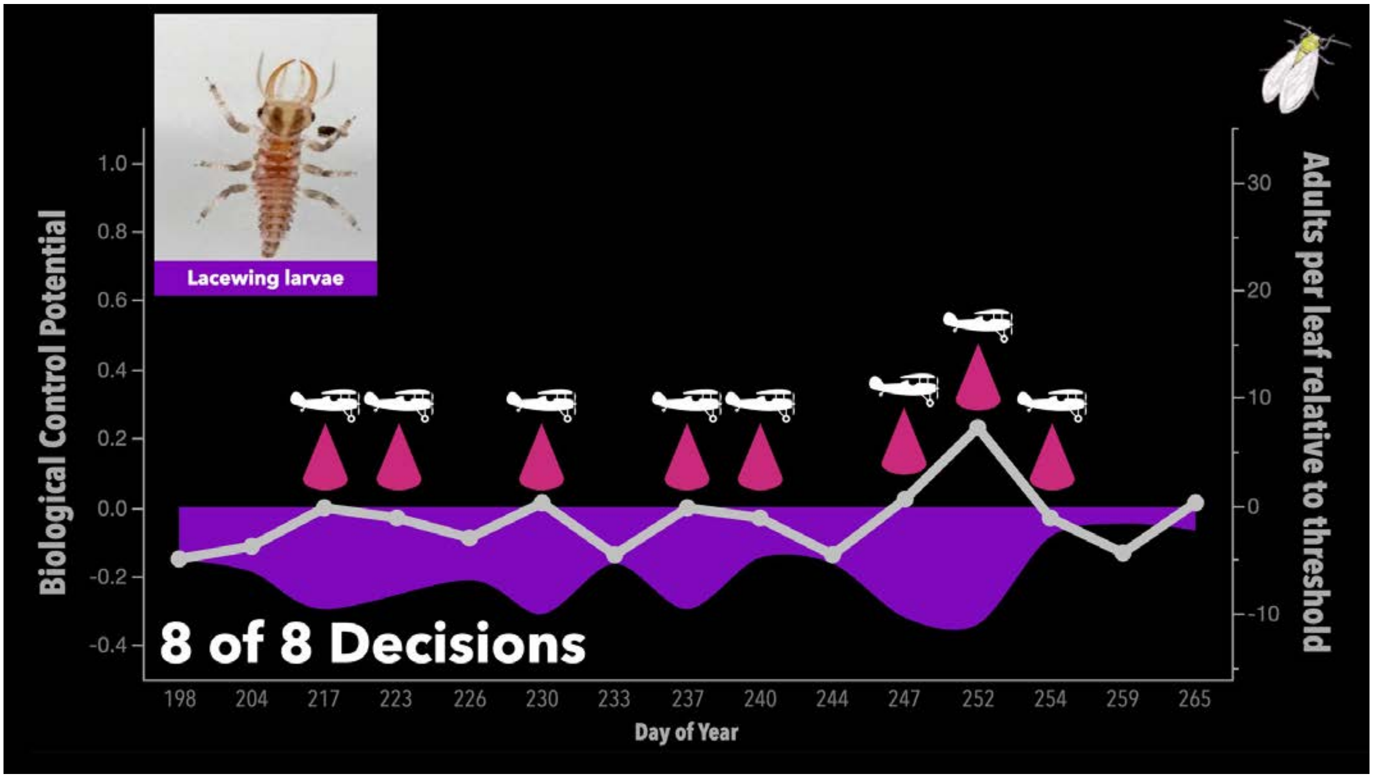
On these window panes, you can see the results in side-by-side plots, one where we eliminated predators through the use of broad spectrum insecticide earlier in the season next to one where we did not use broad spectrums. Every few years I demonstrate the disruption of biological controls that lead to these intense and costly whitefly resurgences. Neither plot at this point had received any whitefly insecticides. In essence, you are looking at two different untreated checks: Disrupted with acephate on the left and never disrupted on the right, where Carbine was used instead of acephate to control the Lygus that were present in this trial. The result was more than a month delay in the need for a whitefly insecticide where we conserved the predators.



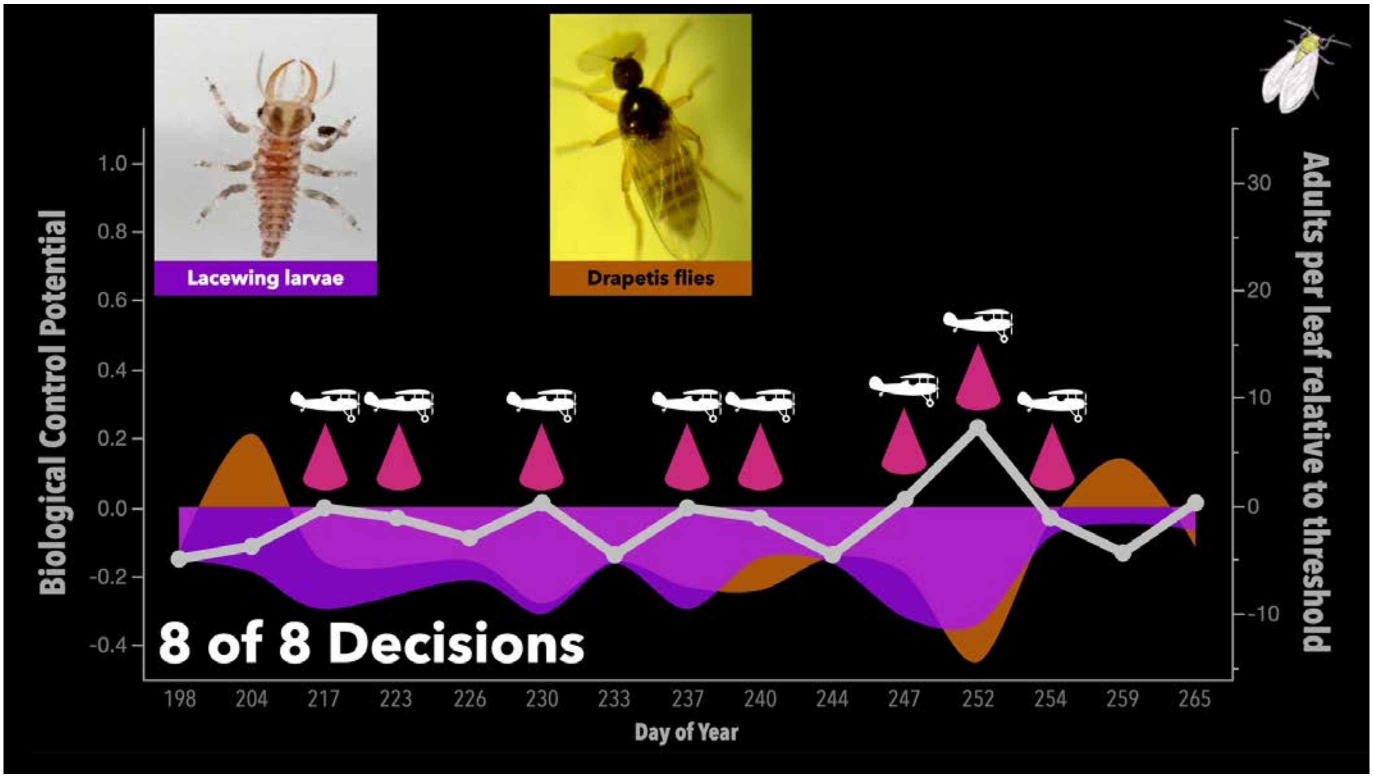
Here's how that decision played out. The right-hand axis depicts adult whitefly density relative to the pest-centric threshold or level of concern. Thus, the 0 line is the upper end of the threshold, indicated by dotted lines. The predator information appears as "biological control potential" or proportion of the total biological control available at this site. For Orius, we start the season with ample BC potential derived from their activity, "Excess BC". Two samples later, whiteflies have increased to the threshold and Orius are in insufficient numbers to counteract this density, "Deficit BC".



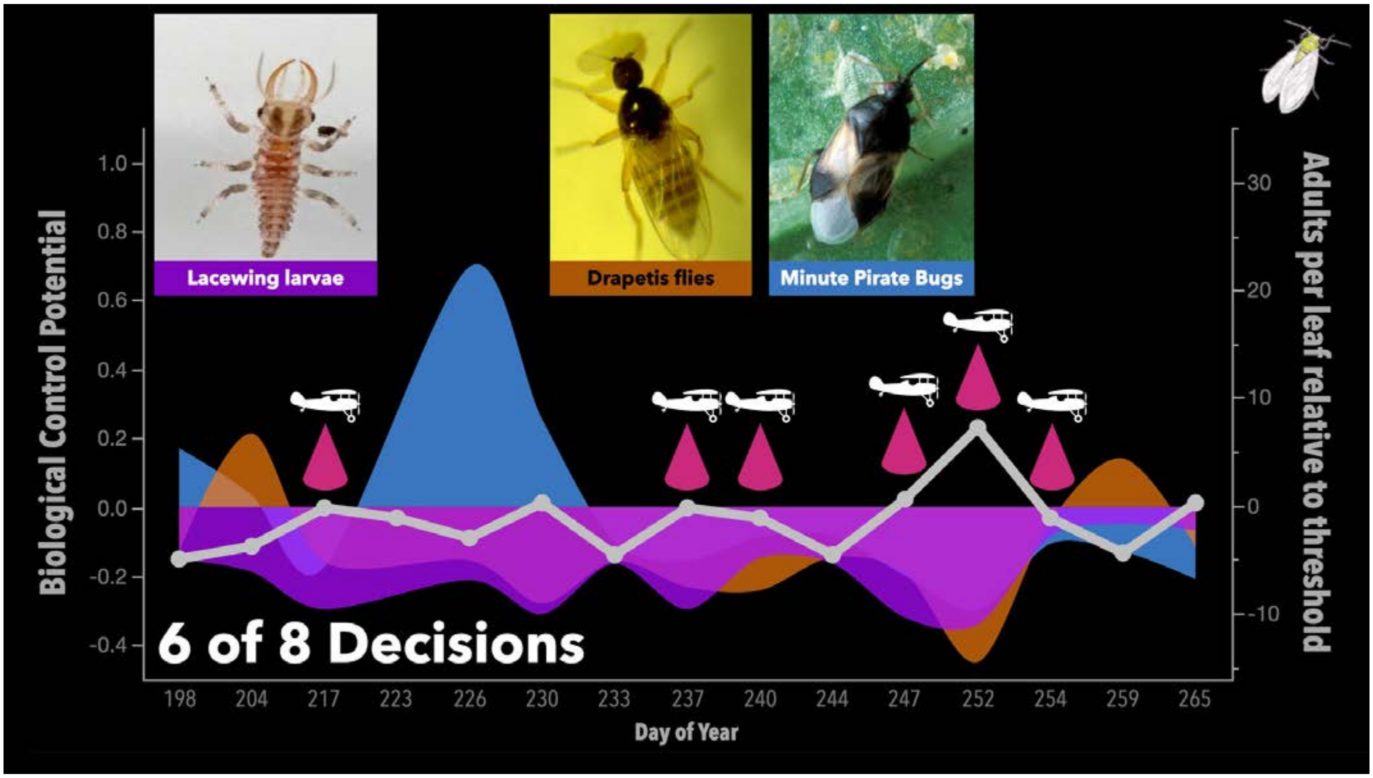
Lacking any other information, this would be a spray condition. Now let's play this out for all the four predator thresholds available for assessing whitefly adult abundance.



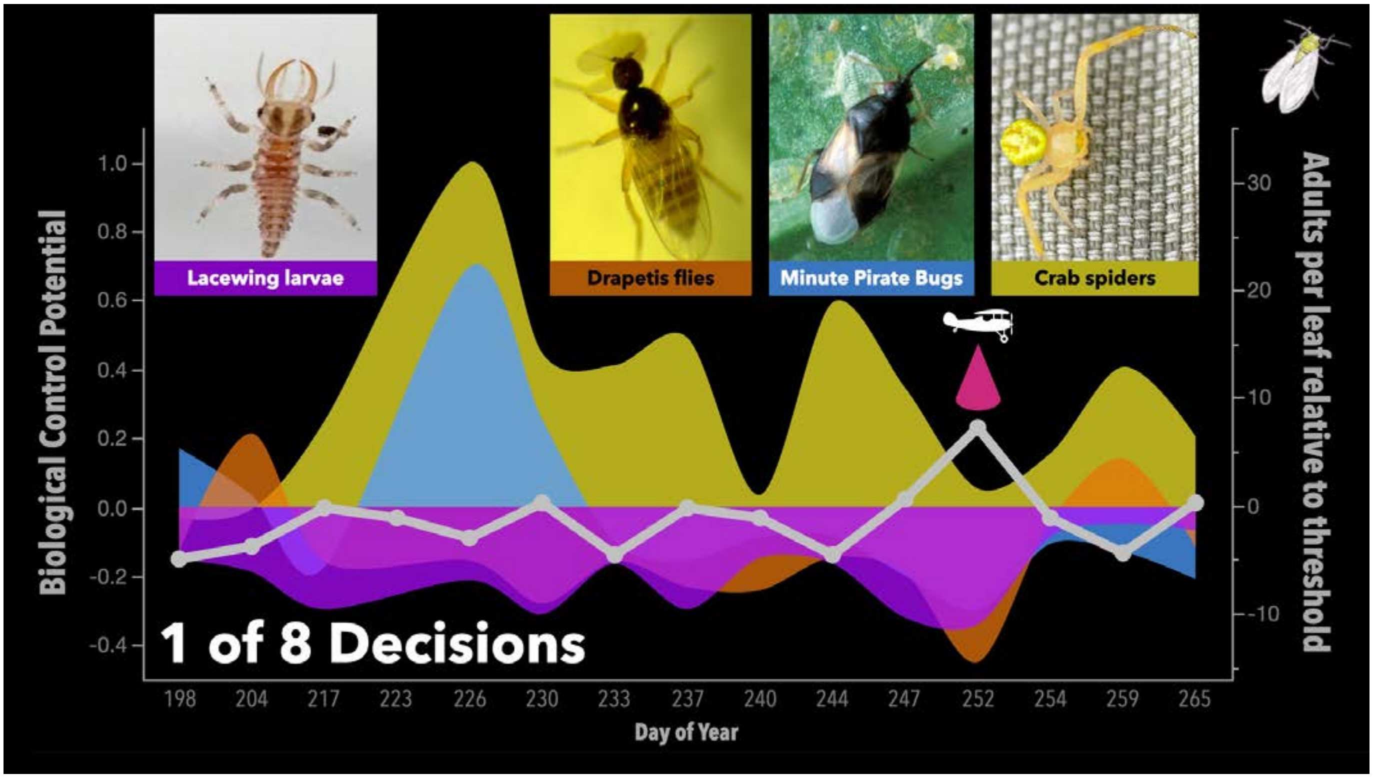
There were in fact 8 sampling bouts that resulted in densities of interest because they were at or near the pest-centric threshold. Lacewings were insufficient all season long. Thus 8 out of 8 times, the decision would be to spray.



Drapetis flies were abundant early and late, but otherwise, too, were insufficient to manage this whitefly population, 8 out of 8 times.



Orius were abundant enough to prevent the need to spray two of these times.



Crab spiders, however, were very abundant and sufficient in number to provide whitefly management on all dates except for one, the one where in fact we elected to spray.

While I was a boy, my father taught me the importance of right-sizing the tool for your situation. In this analogy, we have our tried and true measurement system of counting whiteflies. Those numbers along with our standard whitefly thresholds will help the pest manager in many cases. But now they have access to 8 new, predator thresholds. The one they choose will be the one that is right for their situation. You can't budge a 3/4 inch bolt with a 5/8ths inch socket! The fit is just not there. There is no sense in tracking Collops if they aren't there. Track what is ostensibly most abundant relative to the thresholds we have made available. Only one predator threshold needs be satisfied in order to defer a spray in favor of biological control. If none of these predators are present at sufficient densities, the pest manager will have to advance their sprays ahead of the standard whitefly threshold because they simply do not have enough biological control occurring in their fields.

Cotton Insecticide Target Efficacy, Impact on Non-Target Arthropods & Other Pesticide Risks. Insecticides have been screened for efficacy against target pests, *Lygus hesperus*, *Bemisia argentifolii* (MEAM1; silverleaf whitefly, SWF), and *Euschistus servus* (brown stink bug); as well as for their impact on non-target beneficial arthropods including >20 predators common in Arizona cotton. Those insecticides with full selectivity or safety towards these beneficial predators are in green; those that are partially selective or safe are in yellow; broad spectrum insecticides are in red. Some insecticides pose environmental and human health risks that require mitigations such as buffer zones and additional personal protective equipment (PPE). IRAC group numbers to help rotate chemistry and SWF resistance risks are also shown.

Product Name	Common Name	IRAC No.[1]	Chemical Group	Lygus Bug	Silverleaf Whitefly	Brown Stink Bug	Risk to Aquatic Life	Risk to Wildlife	Risk to Pollinators	Inhalation Risk	SWF, Risk of Resistance
Carbine	flonicamid	29	Feeding inhibitor	****							
Courier	buprofezin	16	Chitin inhibitor		**** (N)						under investigation
Exirel / Benevia	cyantraniliprole	28	Diamide		****						
Knack / Farewell	pyriproxyfen	7C	Juvenoid		**** (E,N)						mild–moderate
Oberon[2]	spiromesifen	23	Lipid synthesis inhibitor		**** (N)						under investigation
PQZ	pyrifluquinazon	9B	Pyridine azomethine		****						
Sefina Inscalis	*afidopyropen*	*9D*	*Pyropene*		***						
Sivanto prime	flupyradifurone	4D	Butenolide		****						
Transform	sulfoxaflor	4C	Sulfoxamine	****	*						
Assail / Intruder[3]	acetamiprid	4A	Neonicotinoid		****		Yes				moderate–severe
Belay	clothianidin[4]	4A	Neonicotinoid	**	**		Yes		Yes		
Centric	thiamethoxam[4]	4A	Neonicotinoid		**		Yes		Yes		
Venom	dinotefuran	4A	Neonicotinoid		***		Yes		Yes		
Acephate	acephate	1B	Organophosphate	***		*		Yes	Yes		
Bidrin	dicrotophos[5]	1B	Organophosphate	*		*	Yes	Yes	Yes	Yes	
Cormoran	novaluron + acetamiprid	15 + 4A	Chitin inhibitor	**	**	* (N)	Yes				
Diamond / Mayhem	novaluron	15	Chitin inhibitor	*	*	* (N)	Yes				
Synergized pyrethroids	various[6]	3A + 1B	Pyrethroid + organophosphate		**		Yes	Yes	Yes		moderate–severe
Vydate C-LV	oxamyl[5]	1A	Carbamate	****			Yes	Yes	Yes	Yes	

Rev. 10/7/19

Background color: **Green** = Fully selective and safe to beneficials; **Yellow** = Partially selective or safe to beneficials; **Red** = broad spectrum, not safe to beneficials; *Italics* = based on preliminary testing.
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[4] This active ingredient can significantly affect bee populations, other pollinators and birds, can persist for years in soils, and can leach into waterways and groundwater.
[5] This active ingredient is considered highly hazardous by the Word Health Organization (WHO Ib), a restricted use pesticide with signal words DANGER and POISON, requiring posting, additional PPE, and closed systems. Avoid if possible.
[6] Beta-cyfluthrin and zeta-cypermethrin are considered highly hazardous by the Word Health Organization (WHO Ib), are restricted use pesticides with signal words WARNING, and should be avoided when possible.

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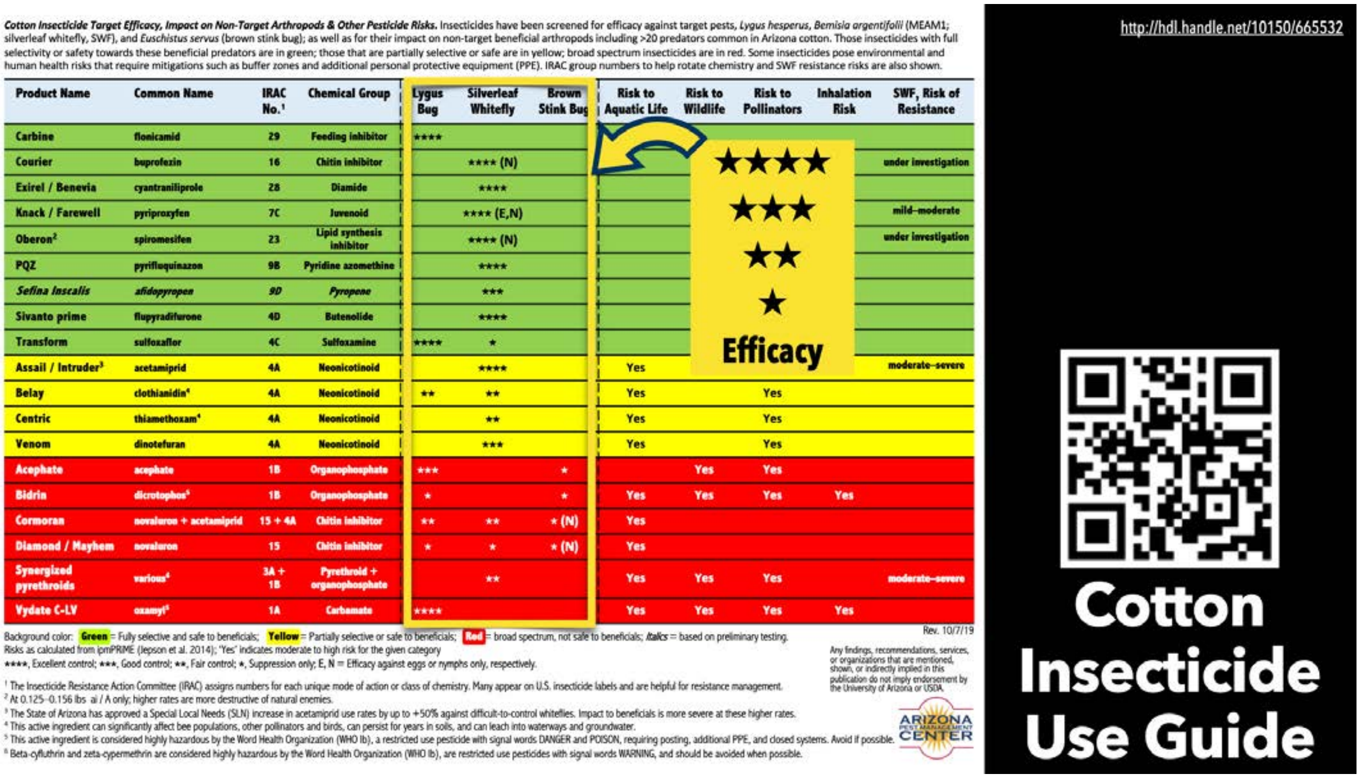
ARIZONA PEST MANAGEMENT CENTER

Our cotton insecticide use guidelines reflect our interests in selectivity and conservation biological control. The Green-Yellow-Red classification indicates fully selective, partially selective and non-selective cotton insecticides. At just 2 pages in length, our growers learn about the efficacy and selectivity of cotton insecticides alongside information about other risks including resistance. The URL links to our latest guidance on cotton insecticide risks, http://hdl.handle.net/10150/665532



Cotton Insecticide Target Efficacy, Impact on Non-Target Arthropods & Other Pesticide Risks. Insecticides have been screened for efficacy against target pests, *Lygus hesperus*, *Bemisia argentifolii* (MEAM1; silverleaf whitefly, SWF), and *Euschistus servus* (brown stink bug); as well as for their impact on non-target beneficial arthropods including >20 predators common in Arizona cotton. Those insecticides with full selectivity or safety towards these beneficial predators are in green; those that are partially selective or safe are in yellow; broad spectrum insecticides are in red. Some insecticides pose environmental and human health risks that require mitigations such as buffer zones and additional personal protective equipment (PPE). IRAC group numbers to help rotate chemistry and SWF resistance risks are also shown.

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Carbine	flonicamid	29	Feeding inhibitor	****							
Courier	buprofezin	16	Chitin inhibitor		**** (N)						under investigation
Exirel / Benevia	cyantraniliprole	28	Diamide		****						
Knack / Farewell	pyriproxyfen	7C	Juvenoid		**** (E,N)						mild–moderate
Oberon[2]	spiromesifen	23	Lipid synthesis inhibitor		**** (N)						under investigation
PQZ	pyrifluquinazon	9B	Pyridine azomethine		****						
Sefina Inscalis	*afidopyropen*	*9D*	*Pyropene*		***						
Sivanto prime	flupyradifurone	4D	Butenolide		****						
Transform	sulfoxaflor	4C	Sulfoxamine	****	*						
Assail / Intruder[3]	acetamiprid	4A	Neonicotinoid		****		Yes				moderate–severe
Belay	clothianidin[4]	4A	Neonicotinoid	**	**		Yes		Yes		
Centric	thiamethoxam[4]	4A	Neonicotinoid		**		Yes		Yes		
Venom	dinotefuran	4A	Neonicotinoid		***		Yes		Yes		
Acephate	acephate	1B	Organophosphate	***		*		Yes	Yes		
Bidrin	dicrotophos[5]	1B	Organophosphate	*		*	Yes	Yes	Yes	Yes	
Cormoran	novaluron + acetamiprid	15 + 4A	Chitin inhibitor	**	**	* (N)	Yes				
Diamond / Mayhem	novaluron	15	Chitin inhibitor	*	*	* (N)	Yes				
Synergized pyrethroids	various[6]	3A + 1B	Pyrethroid + organophosphate		**		Yes	Yes	Yes		moderate–severe
Vydate C-LV	oxamyl[5]	1A	Carbamate	****			Yes	Yes	Yes	Yes	

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Rev. 10/7/19

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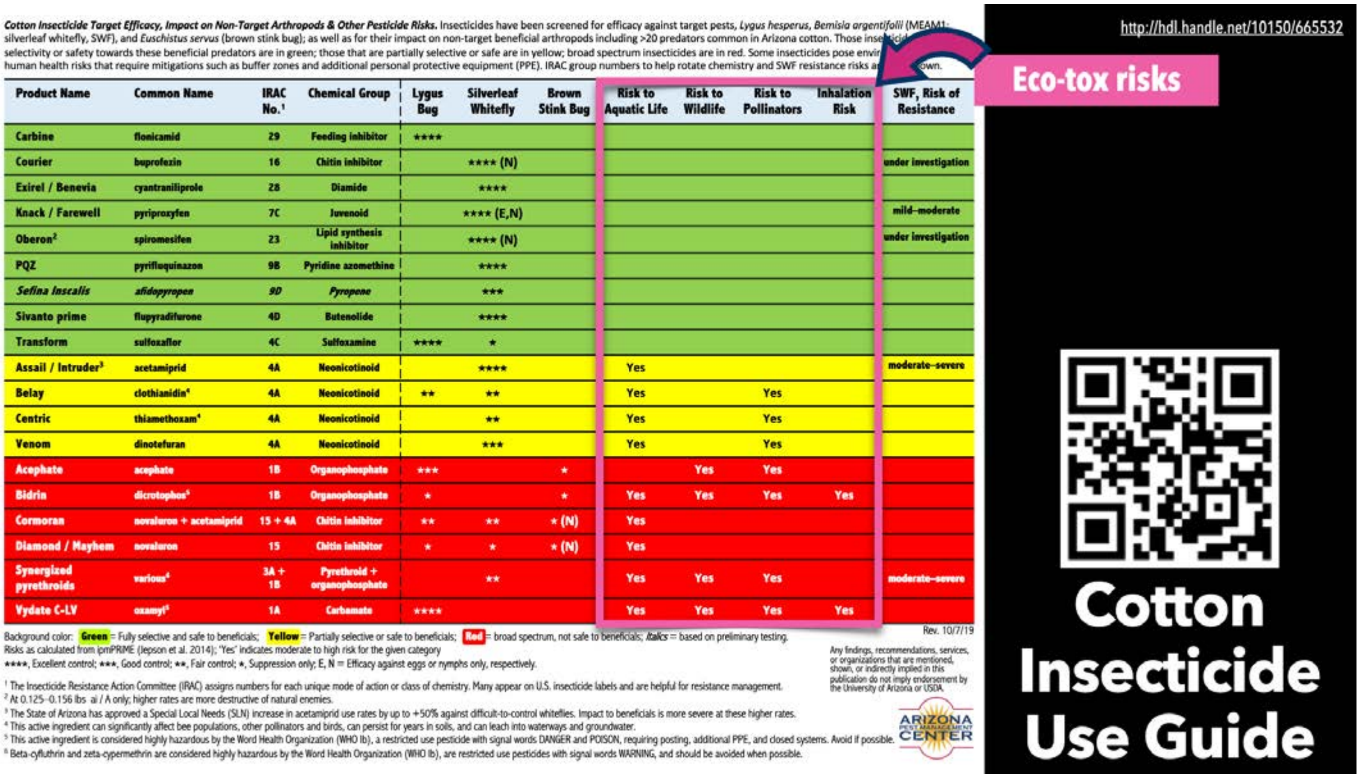
ARIZONA PEST MANAGEMENT CENTER

We include a 0 to 4-star system for rating efficacy to important pests.



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Transform	sulfoxaflor	4C	Sulfoxamine	★★★★	★						
Assail / Intruder[3]	acetamiprid	4A	Neonicotinoid		★★★★		Yes				moderate–severe
Belay	clothianidin[4]	4A	Neonicotinoid	★★	★★		Yes		Yes		
Centric	thiamethoxam[4]	4A	Neonicotinoid		★★		Yes		Yes		
Venom	dinotefuran	4A	Neonicotinoid		★★★		Yes		Yes		
Acephate	acephate	1B	Organophosphate	★★★		★		Yes	Yes		
Bidrin	dicrotophos[5]	1B	Organophosphate	★		★	Yes	Yes	Yes	Yes	
Cormoran	novaluron + acetamiprid	15 + 4A	Chitin inhibitor	★★	★★	★ (N)	Yes				
Diamond / Mayhem	novaluron	15	Chitin inhibitor	★	★	★ (N)	Yes				
Synergized pyrethroids	various[6]	3A + 1B	Pyrethroid + organophosphate		★★		Yes	Yes	Yes		moderate–severe
Vydate C-LV	oxamyl[5]	1A	Carbamate	★★★★			Yes	Yes	Yes	Yes	

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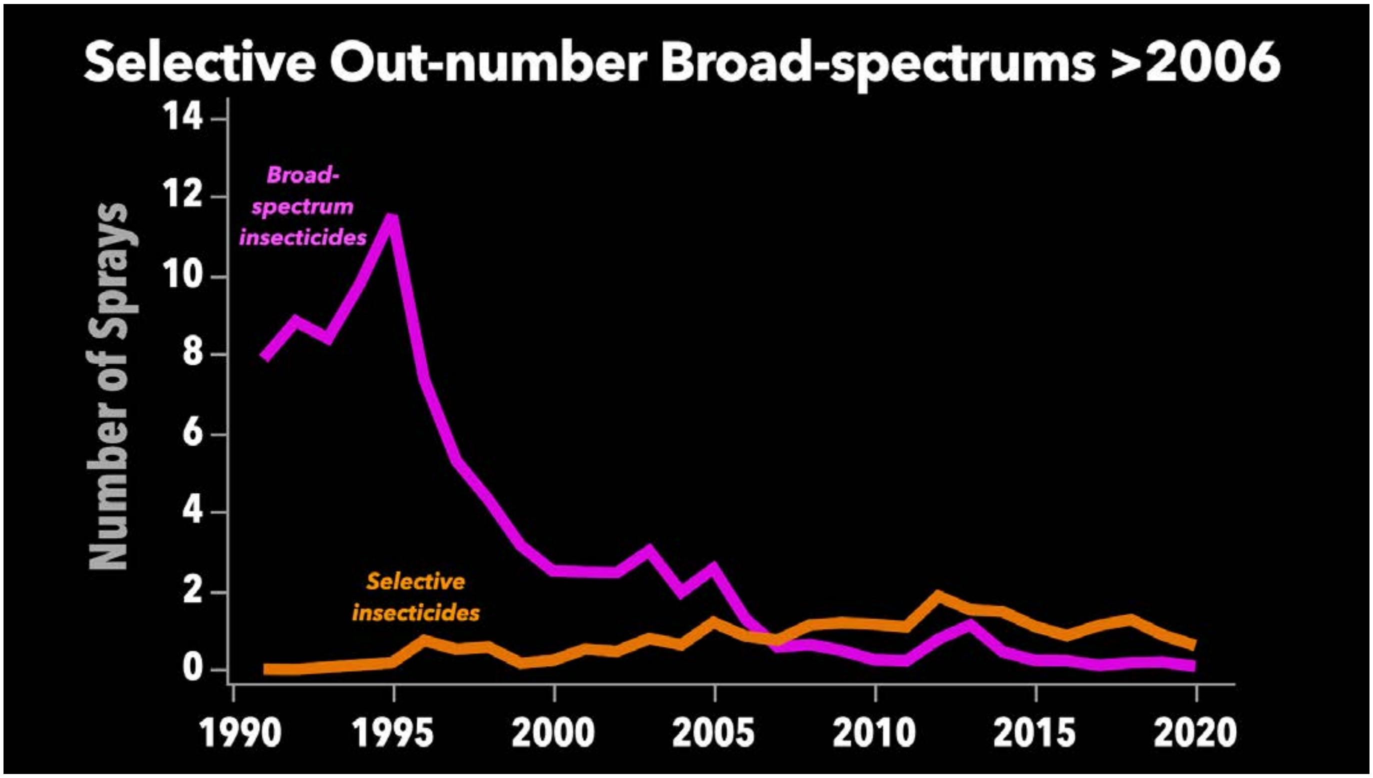
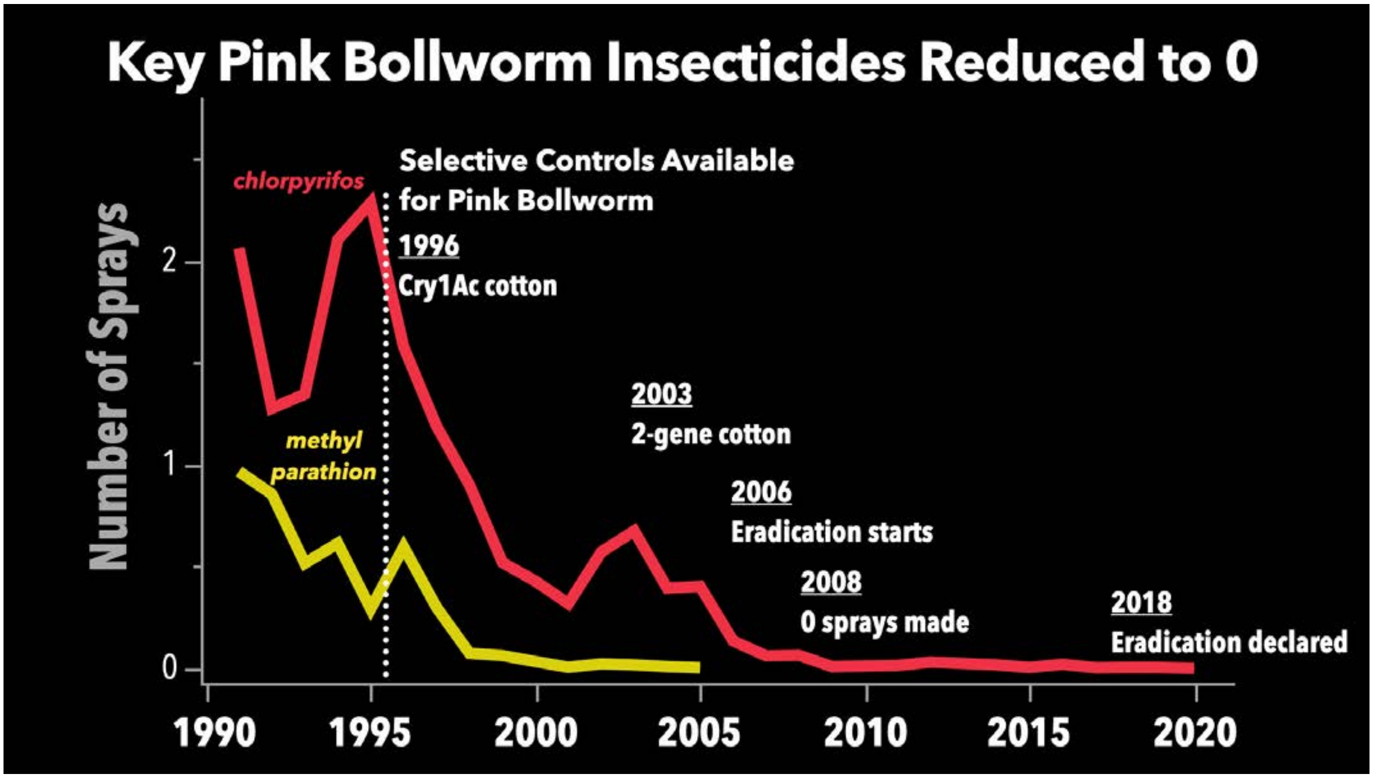
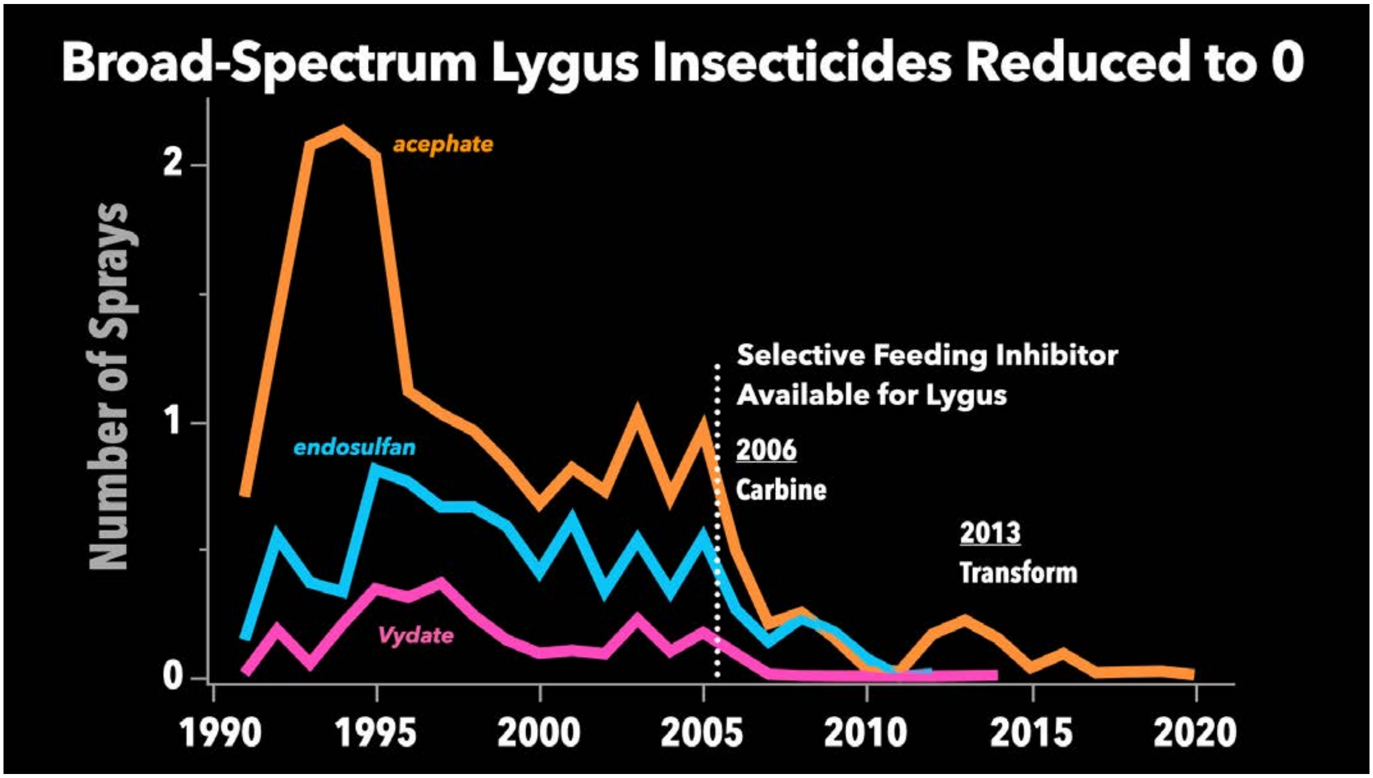
And, we detail the different types of ecotoxicological risks each insecticide's use poses so that growers can be more aware of the environmental and human health hazards associated with these choices. Note, all of our fully selective products (Green) are generally quite safe ecotoxicologically.



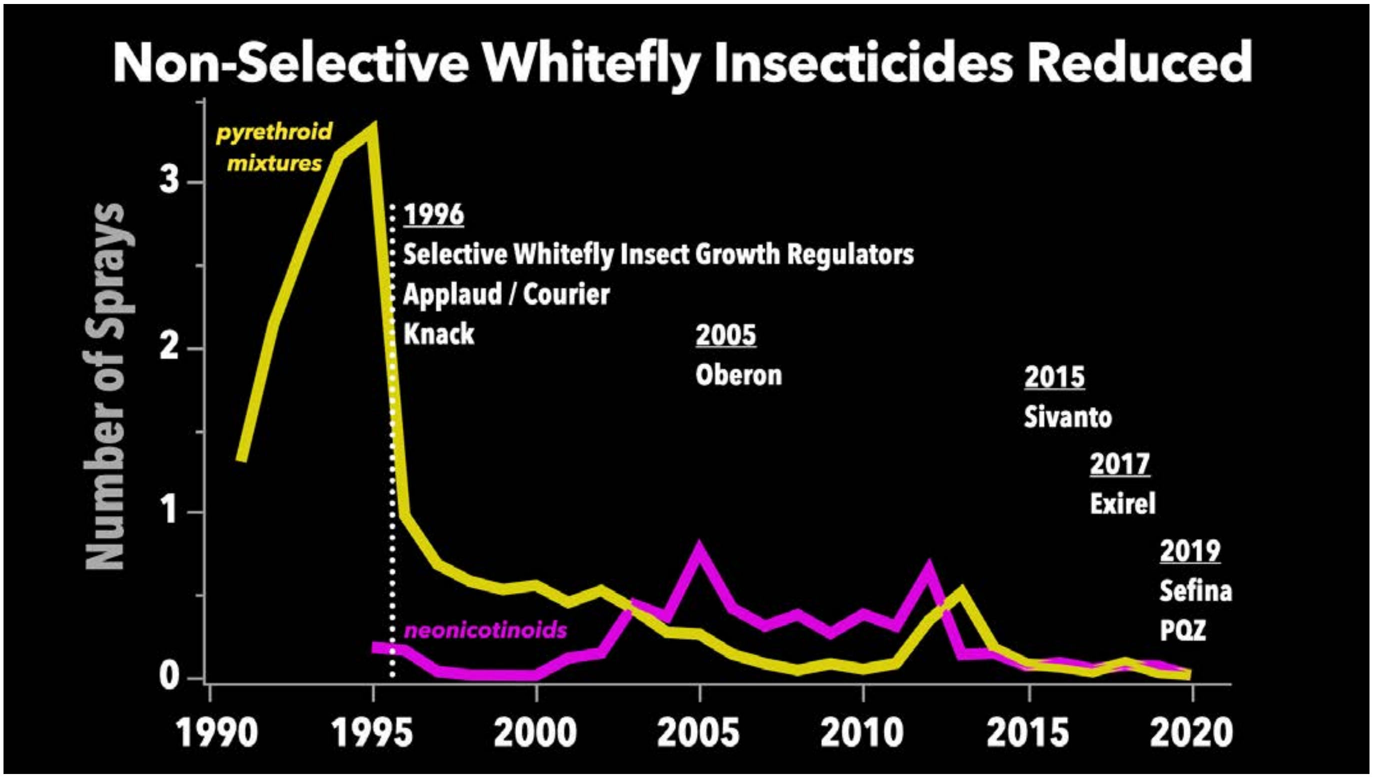
The results are a stunning transformation from where we were >30 years ago until today. Selective insecticides are now used in preference to any broad-spectrum insecticides.



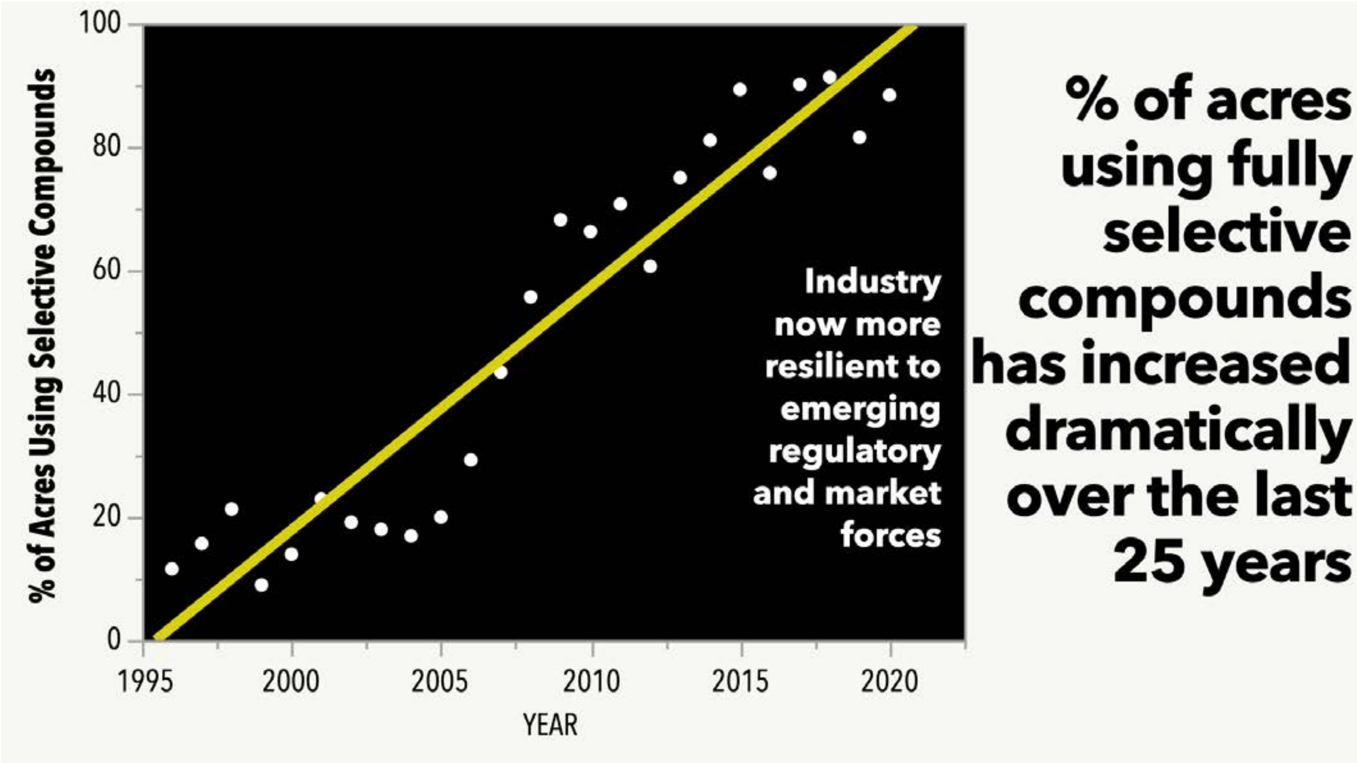
The result has been the elimination of broad-spectrum pink bollworm insecticides from our system. Note the steep decline after 1996. Today neither methyl parathion or chlorpyrifos, both broadly toxic organophosphates, are used in Arizona cotton.



Ever since 2006, our use of broad-spectrum insecticides for Lygus has been reduced to near 0. Now that we have two fully selective insecticides, flonicamid and sulfoxaflor (Carbine and Transform, respectively), there's little need for these broad spectrum options – note, endosulfan is no longer registered for use in the U.S. and oxamyl is also phased out for Better Cotton growers in the U.S.



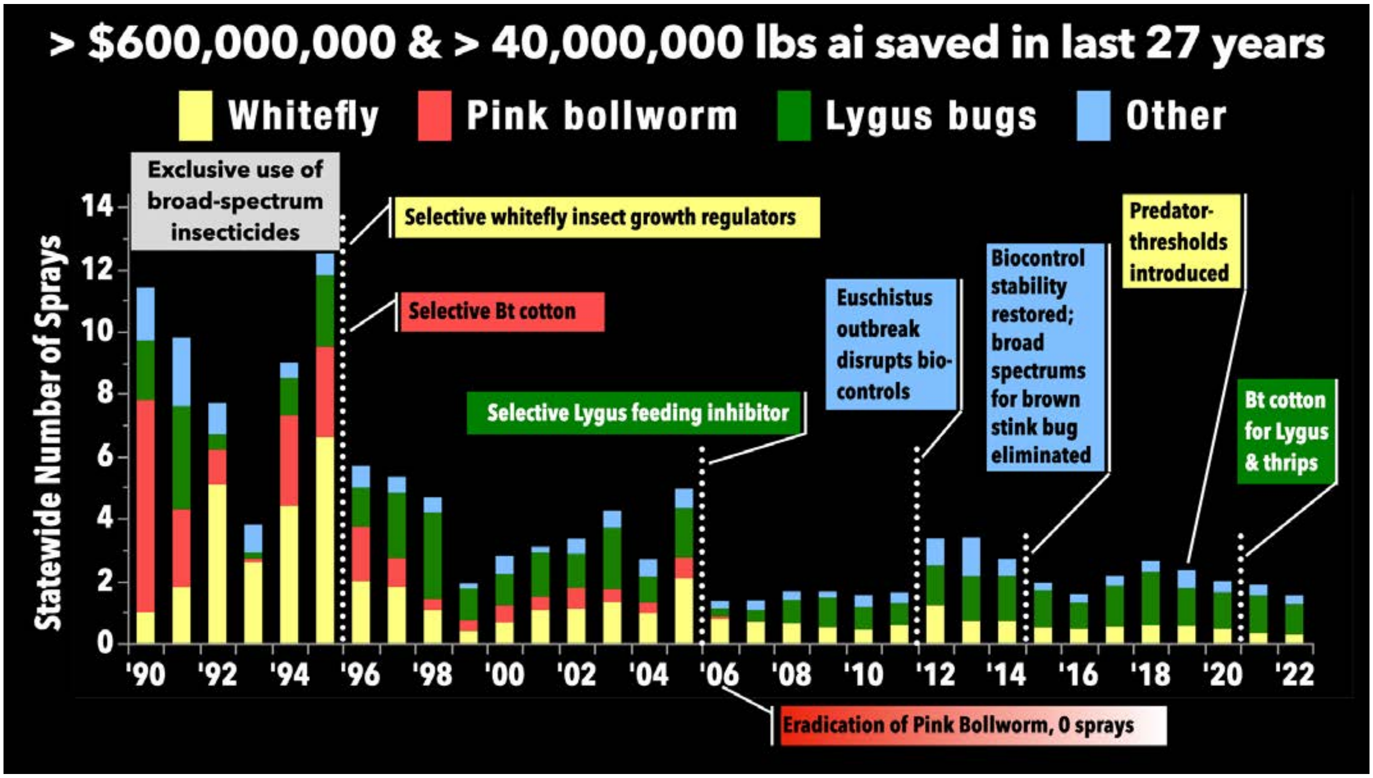
Broadly toxic pyrethroid mixtures and partially selective neonicotinoids have generally declined since selective options for whitefly chemical control have become available, starting with whitefly insect growth regulators in 1996. Our growers hardly ever use pyrethroids or neonicotinoids any longer. But this first step, moving from a broadly toxic adulticidal program to one focused on population regulation through the control of immatures (and reliance on biological controls) with the two insect growth regulators was a major shift in culture.



Ever since Bt cotton and whitefly IGRs were introduced in 1996, we have been on a steady increase in the availability and adoption of fully selective insect control technologies. This has prepared our industry and created stability that can withstand emerging regulatory and market forces. [Regression over all years, $P < 0.0001$, showing uptake of fully selective chemistries.]

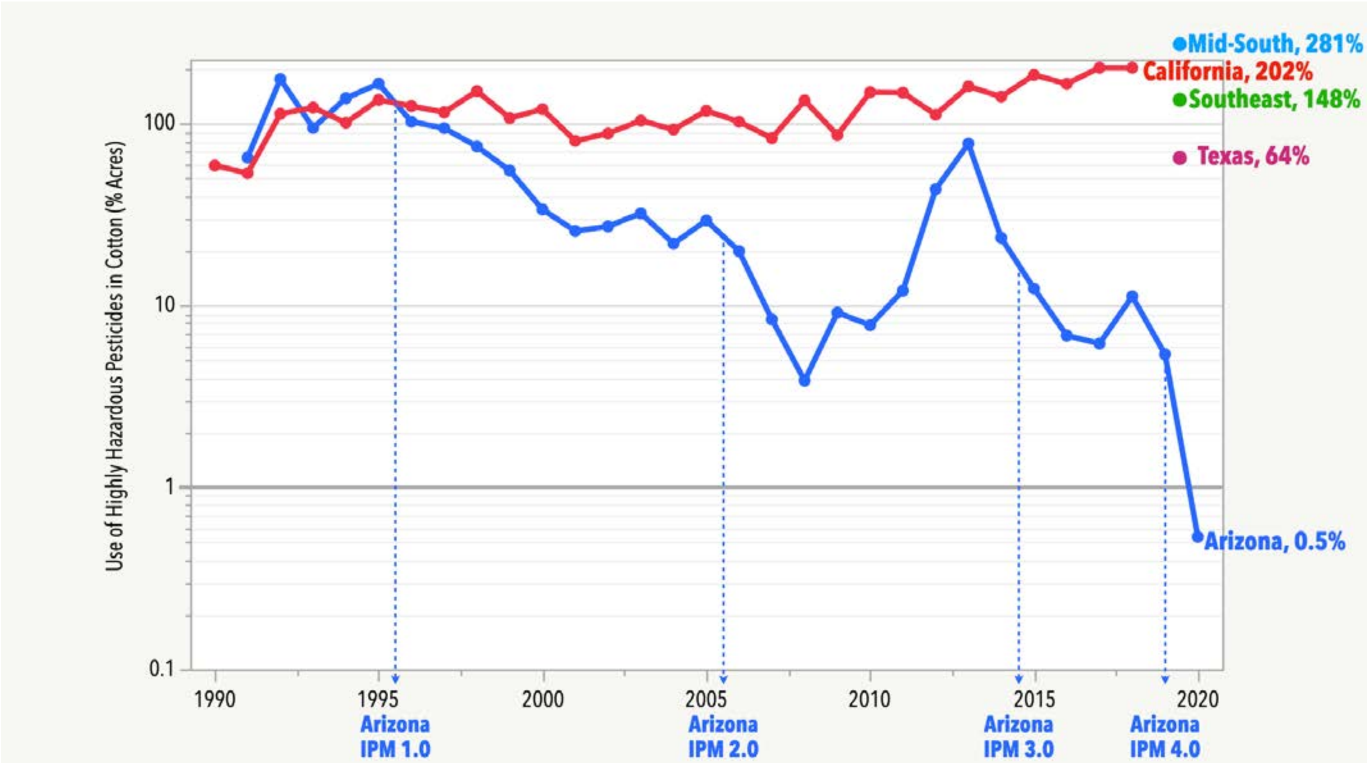
Carbine	flonicamid	29
Courier	buprofezin	16
Exirel / Benevia	cyantraniliprole	28
Knack / Farewell	pyriproxyfen	7C
Oberon[2]	spiromesifen	23
PQZ	pyrifluquinazon	9B
Sefina Inscalis	*afidopyropen*	*9D*
Sivanto prime	flupyradifurone	4D
Transform	sulfoxaflor	4C
Assail / Intruder[3]	acetamiprid	4A

There are about 20 insecticides in our guide with 10 shown here, but only 8 of them represent nearly 90% of everything that is sprayed in our cotton crop, 7 of those are fully selective. We have 6 modes of action in regular use against whiteflies and 2 modes of action among Lygus insecticides plus the additional mode of action that ThryvOn Bt cotton will be providing. Our emphasis has been on natural enemy conservation and mode of action diversification as key tactics to pest and resistance management.

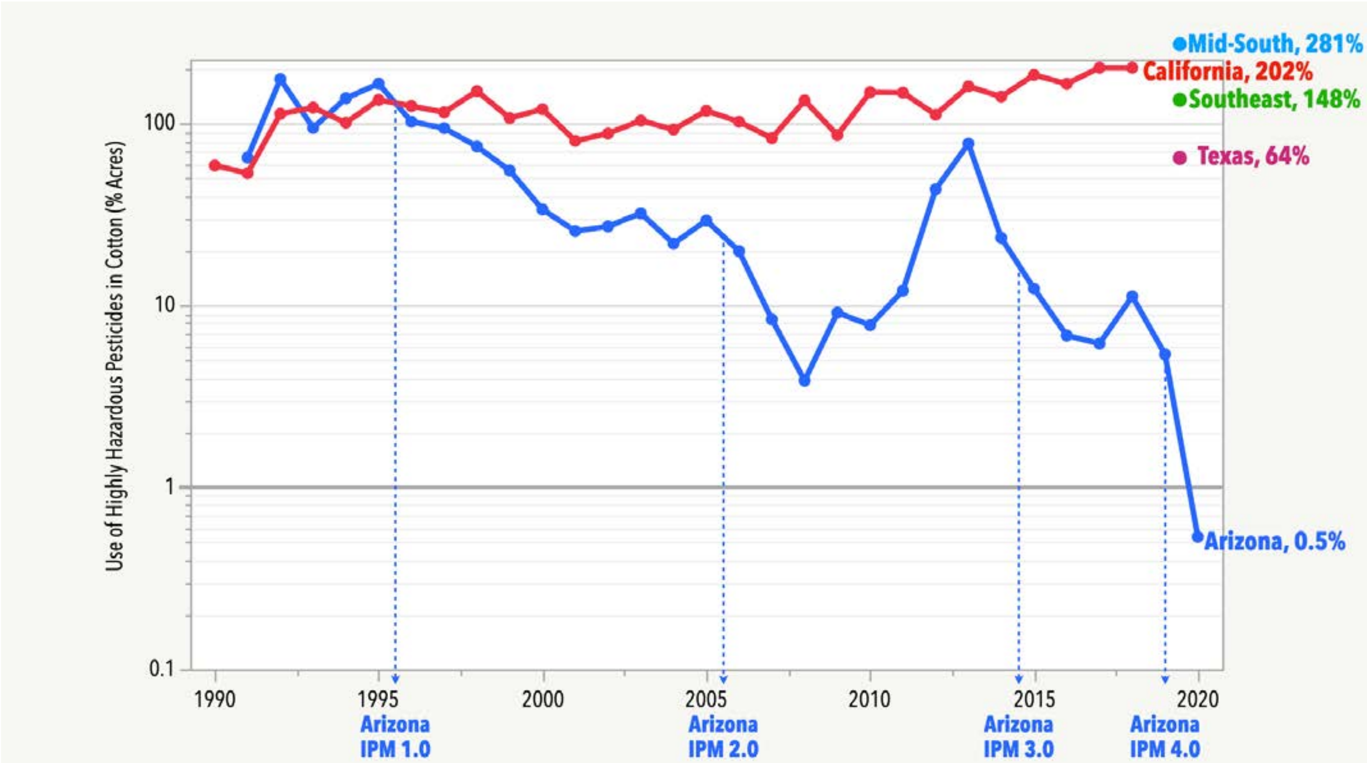


These are statewide number of insecticide sprays made to control arthropod pest of cotton obtained through an annual workshop and survey process. Thirty years ago, we were exclusively reliant on broad-spectrum insecticides. That's what we had. But starting in 1996, we began using selective technologies, including the whitefly insect growth regulators pyriproxyfen and buprofezin and Cry1Ac-based Bt cottons. Then in 2006, we introduced the first fully selective Lygus feeding inhibitor flonicamid, replacing the most popular organophosphate acephate. And, growers organized an eradication program for pink bollworm, which led to 0 grower sprays starting in 2008 and official declaration of eradication in 2018. However, we then had an outbreak of the brown stink bug Euschistus servus and growers re-introduced broad spectrum pyrethroids and dicrotophos. Soon after our research established the futility of these chemical controls, which only served to increase primary and secondary problems. Once these broad spectrums were curtailed, stability returned to the system, spray frequencies moderated, and we introduced 8 new predator thresholds to assist whitefly management. Starting in 2021, ThryvOn cotton a genetically engineered Bt cotton was introduced on a limited acreage for the control of Lygus and thrips. Cumulatively since 1996, Arizona cotton growers have saved over $600M and prevented more than 40M lbs ai of insecticide from going into the environment.

Now market forces are requiring additional changes in pest management practices. Better Cotton is the largest certifier of sustainable cotton worldwide. It started in the U.S. in 2014 and now has 317 licensed farmers on 171,000 acres. Arizona's participation is minimal. But our growers are better prepared for BCI's intended phase out of 7 highly hazardous pesticides. The changes our industry have already gone through over the last 25 years have prepared Arizona cotton growers very well (better than any others) to capitalize on premiums and market access possible through organizations like BCI.

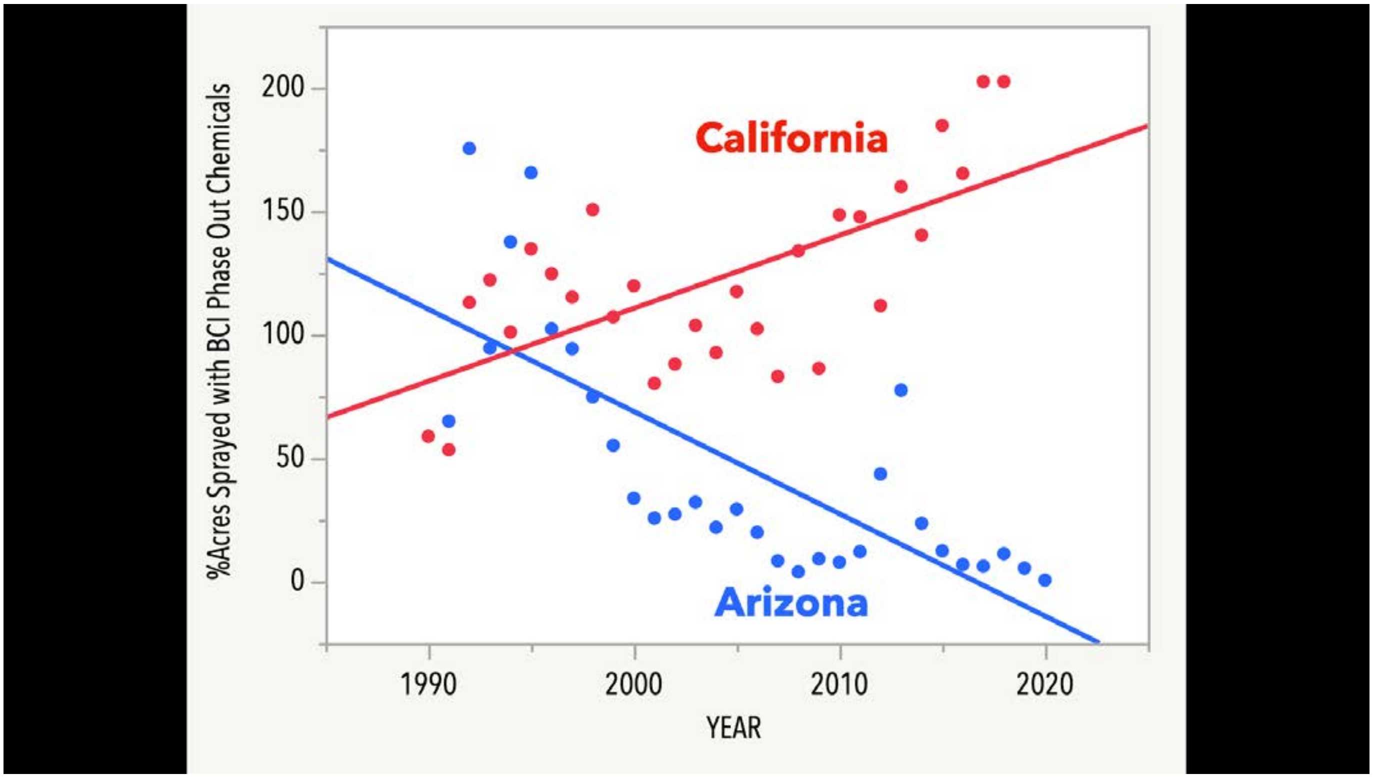


Through international conventions and agreements, countries have agreed to globally limit the use of highly hazardous pesticides. Through progressive iterations, the Arizona Cotton IPM program has been developed and deployed to minimize economic, environmental and human health risks. Due to innovations spanning 25 years, today less than 1% of Arizona's cotton acres make use of any of seven highly hazardous pesticides targeted for elimination by sustainability standards. In contrast, California uses these same pesticides on over 200% of its acres, and the rest of the cotton belt remains highly dependent on one or more of these insecticides. My program has helped prepare Arizona cotton growers to better withstand environmental and regulatory disruptions, while providing opportunities to market their cotton as a premier sustainable product in the global marketplace. My program has focused on the development of technologies and the operational and knowledge resources needed to successfully and and safely control insect pests. More details…



Details

The first Arizona IPM plan (1.0) was deployed in 1996 with new technologies (insect growth regulators and Bt cotton) and knowledge resources (whitefly sampling plans and action thresholds) to control invasive whiteflies and pink bollworms. Ten years later, we program helped to identify an environmentally benign insect feeding inhibitor and action thresholds needed to successfully control cotton's number one yield-limiting pest, Lygus bug (2.0). After destabilizing outbreaks of brown stink bugs (2012–2014), we identified the economic losses associated with broadly toxic insecticides used by growers against this pest, which led to elimination of these highly hazardous pesticides in our system and a return to conservation biological control and system stability (3.0). Most recently (2019), we identified for the first time six key predators in Arizona cotton fields that can be used to accomplish biological control of whiteflies and other pests, further reducing dependence on insecticides. These predator thresholds help growers understand when and where natural enemies are abundant enough to forgo insecticide sprays and are a rare example of operationalizing conservation biological control (4.0).



The annual trends in usage of these 7 insecticides is striking. Blythe and other low desert locations in California are more like Arizona than they are like the rest of California cotton in the central Valley. Which direction should we be going in? The answer is clear. We've progressively improved cotton IPM in Arizona. But California ostensibly is managing insects in a manner that is only increasing their dependence on highly hazardous pesticides. The reasons why are complex and will have to be discussed in a future session.

AZ: Sum(PctAcres) = 8357.2539 - 4.1441961*YEAR

RSquare Adj 0.543664

Root Mean Square Error 32.95132

CA: Sum(PctAcres) = -5801.084 + 2.9558477*YEA

RSquare Adj 0.423753

Root Mean Square Error 28.66162

Where do we go from here? 1) We need to continue to build resiliency in the system. 2) We should continue our transition away from broad-spectrum insecticides and shift to much more sparing usage of selective technologies. 3) We should maintain a very strong integration of chemical and biological controls, as originally conceived as the basis to IPM. 4) Our ultimate success, however, has been in the development of all the attendant "soft" technologies to accompany the hard technology and biological control in our system. This conscious effort to put use instructions in the hands of growers and pest managers has helped us to move an entire industry forward. But it depends on pest managers surveying, measuring and using natural enemies in their decision-making. 5) Finally, we need to identify and exploit market opportunities for our growers. We are growing some of the best – most productive, highest quality, most sustainable – cotton in the world and our producers should be rewarded for that!

The research and Extension funding for this effort is extensive, but primarily supplied by the Arizona Cotton Growers Association and Cotton Incorporated, along with capacity support from the USDA Extension Implementation Program, and Signature Program support of the Western IPM Center. Thanks to Better Cotton (BCI) for supporting our work to analyze pesticide use belt wide and better support our growers desire to grow better cotton. I also want to acknowledge our close collaboration with the Arizona Department of Agriculture who regulates the pesticide user community and supplies all pesticide use records to the Arizona Pest Management Center. I also wish to thank our hard-working IPM staff and students who support all that we do. Lastly, I want to acknowledge my three-decade collaboration with Dr. Steve Naranjo from the USDA-ARS facility adjacent to the University of Arizona's Maricopa Agricultural Center, where I work.