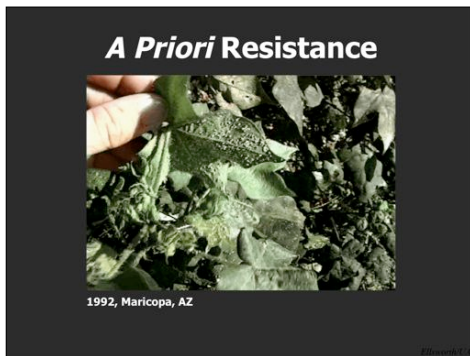


Invited presentation, Dow Agrosiences, Transform Exchange, 40 people (Dow personnel; University cotton entomologists; mid-South consultants), 20 minutes

This was the scene we were facing when the invasive B-biotype came to Arizona. The numerical pressure was overwhelming and impacting not only agricultural areas, but also Arizona's largest city, Phoenix, as seen here on the campus of a local college.

The urban friction caused was substantial, where residents had to wear masks just to jog or ride a bike in the fall of 1992.

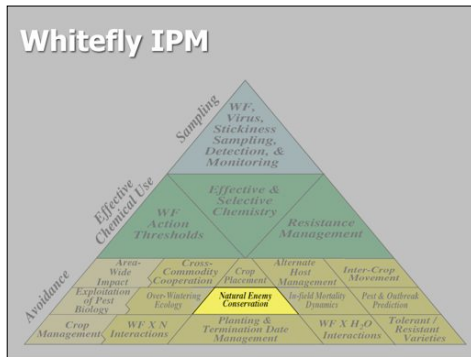
This scene has colored everything we do in cotton IPM in AZ since.



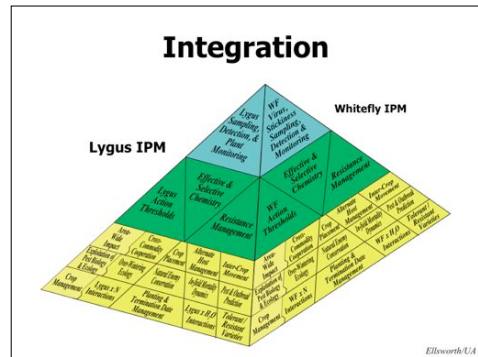
This "new" pest attacked many different crops. Here, adults cover the surface of a cotton leaf, and the immobile immatures (eggs and nymphs) encrust the leaf underside.

And, we were facing an a priori resistance in that the invading whiteflies were already insensitive to pyrethroids, as well as to organophosphates.

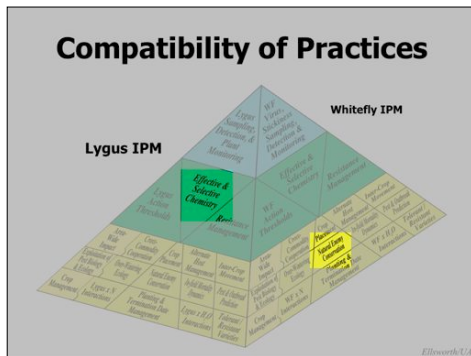
So it has been long enough now since these terrible scenes that there are growers and pest managers who are too young to recall the situation. So I now use this video to show to them and pose the question, "In what year was this video shot?" Invariably several people will guess 1992, 1995 or early 1990's. However, this was shot in September 2010 in plots where we made a set of bad decisions. This emphasizes that 1992-like conditions can be "created" in any year or in any location where inappropriate decision-making takes place, in this case in Lygus management.



So we are talking about Lygus management. What does this have to do with whiteflies? Whitefly management is paramount in our system as depicted in the video scenes. Natural enemy conservation is central to our whitefly management system...



The reason is because our management practices for one pest must be fully integrated and compatible with the practices for the other key pests.



In our case, that means paying attention to the chemistry used to control Lygus such that NEs are conserved for whitefly (and secondary) pest control.

Lygus hesperus

- Native to N. America
- No. 1 yield limiting pest for last decade
- Attacks squares, causes shed

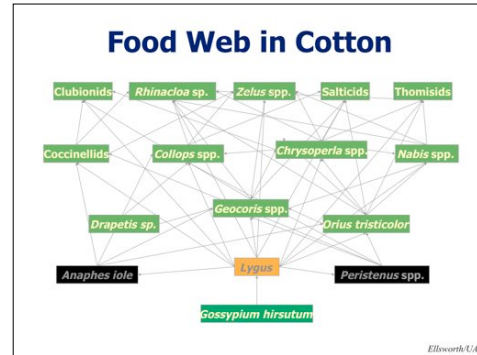
Lygus bugs have become our number one pest since about 1997, ever since more selective components of our system became available, specifically Bt cotton for PBW control and the IGRs for whitefly control. This mirid attacks squares and causes them to shed. Compatibility and integration of controls with this pest are very important.



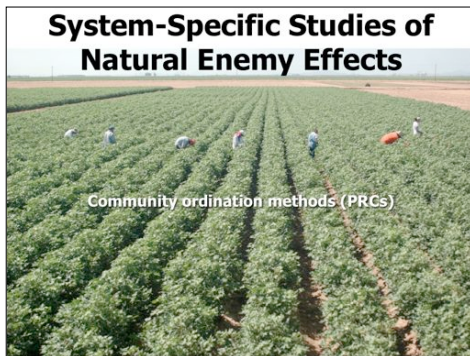
We have a large complement of potential generalist predators. Just a few pictured here.

We also have 2 parasitoids; however, *Anaphes*, an egg parasitoid, will not readily colonize cotton; and I've seen *Peristenus* (nymphal parasitoid) just once in 20 years.

However, this complex alone was not sufficient to overcome the sorts of whitefly numbers shown in the previous videos. But their impact was and is important in our very successful management system of today and the last 15 years. Plus, these same predators can be important in limiting the increase in *Lygus* populations, while suppressing/controlling all secondary pests (mites, leps, etc.).

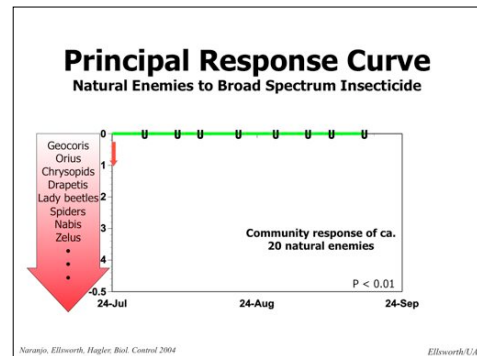


The food web in cotton is complex and dynamic. How one determines which species are driving the system has historically been a difficult problem to deal with. Experimentally, people have tried caged systems that exclude all predators or confine one or a few species with fixed numbers of prey, and even then usually only the target pest as the prey item. These are highly artificial conditions. Survey work has sometimes focused on one or a few species and failed to identify consistent patterns and relationships. These problems faced us as well; however, we applied some multivariate approaches to our data, which help us understand the complex dynamics that are operational.



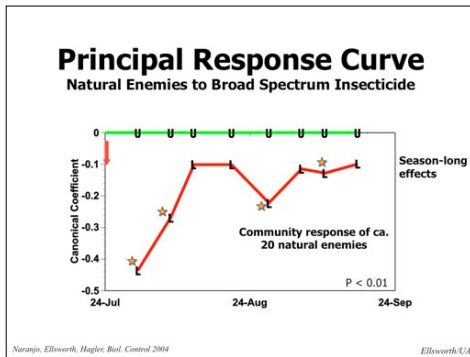
Over many years, Naranjo and I along with students, post-docs and plenty of technical help have conducted ecosystem-specific studies and used various approaches to identify the presence and function of natural enemies and the impact of all mortality factors on whiteflies and to examine non-target effects of whitefly and *Lygus* insecticides.

These include community ordination methods that permit the analyses of whole NE communities and construction of Principal Response Curves (PRCs) based on exhaustive surveys of canopy arthropods (non-target organisms, NTOs).

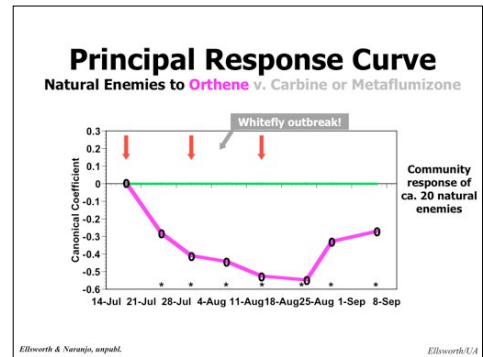


We used a multivariate, time-dependent, analytic approach that is represented graphically in Principal Response Curves. In this example we can see the green 'U' line representing the UTC as a baseline from which we compare other treatments. Departures from the baseline may be interpreted as density changes in this natural enemy community. In our case, we track densities on ca. 20 different species or species groups. The small red arrow indicates the timing of a single, very broad spectrum insecticide sprayed to control *Lygus* in a study that we did several years ago...

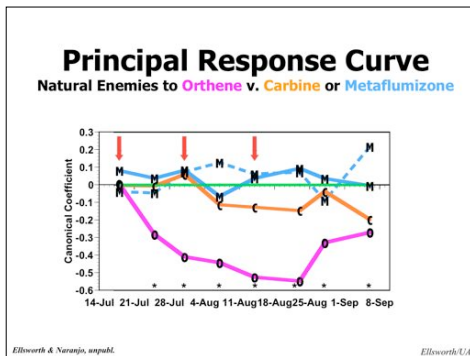
U = UTC = Untreated check



...What we see is a dramatic and immediate lowering of the density of these natural enemies in comparison to the UTC. What is more sobering is the duration and significance of this effect, all the way out to 7 weeks post-treatment. These season-long effects have grave consequences in the control of many other primary and secondary pests. Each PRC is accompanied by a table of species weights for each species represented (not shown). We have shown in past analyses that both buprofezin and pyriproxyfen (whitefly IGRs) are fully selective in our cotton system. We have extended this approach to examine candidate, novel compounds so that we can properly advise growers on how to exploit selectivity and biological controls.



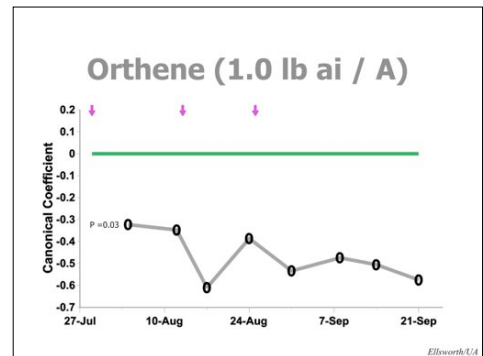
In this 2006 study, we did repeated (every other week) sprays (for a total of 3) of Lygus control chemicals. First, we can see that Orthene (acephate) predictably lowers the densities of the natural enemy community very significantly and for the duration of the season. Interestingly, 2006 was a historic low in whitefly pressure. Yet, shortly after the 2nd spray, we noted a severe and uncontrollable whitefly outbreak in these large plots (1/3 A) of Orthene. Effectively, we had damaged the natural enemy community that otherwise maintains whiteflies at very low densities. The UTC and candidate compounds had no whitefly resurgences.



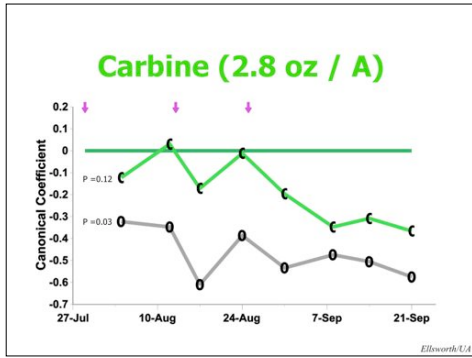
Carbine or flonicamid (orange line) showed no significant declines in the NE community. Metaflumizone at its maximum rate and for two different formulations (blue lines) also had no impact on the NE community.

And neither compound suffered from whitefly resurgence.

So Carbine became our first, "fully selective" Lygus control agent. Carbine has been registered in AZ since 2006.

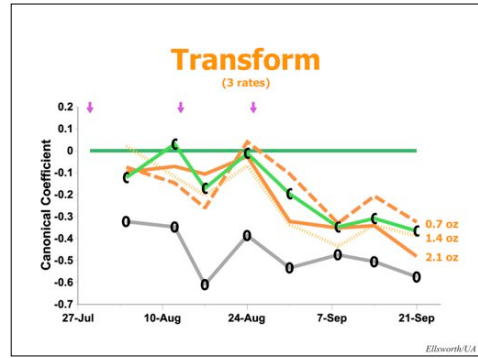


In a smaller plot (not optimal) 2009 study, we once again examined NE community responses to insecticides. Orthene sprayed 3 times; NE community severely impacted.



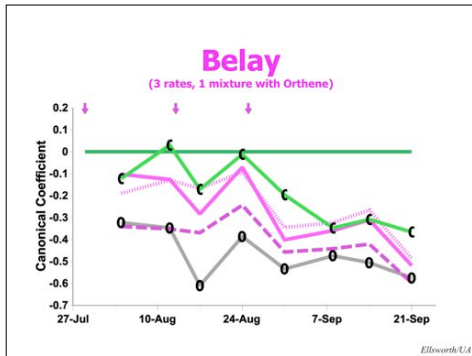
Carbine at the maximum labeled rate turned up not significantly different from the UTC, i.e., fully selective.

09F3L 2.8 oz of Carbine



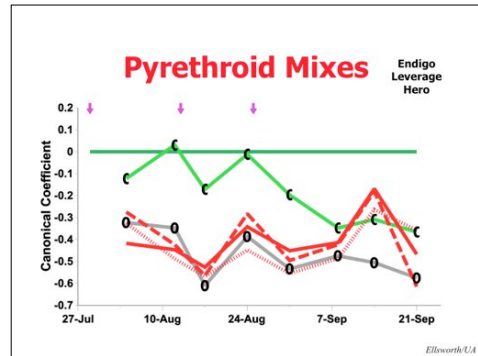
Transform with a 3-fold rate range showed surprisingly little difference in NE responses though very slightly lower than Carbine. These are small plot results, however, and we need large plot work to confirm this interesting result.

09F3L Sulfoxaflor R1, R3, R5 0.7oz, 1.4 and 2.1 oz (in that order on last date).



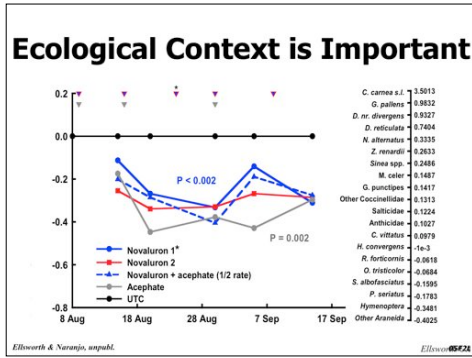
Belay is an interesting result. Of course, mixtures with even a half lb of Orthene will render any mixture non-selective. There is a slight difference in the two rates with a 6 oz rate significantly different from the UTC, and 4.5 oz only slightly better.

09F3L Belay 4.5 oz and 6 oz, and 3oz+.5lb Orthene (darker purple)



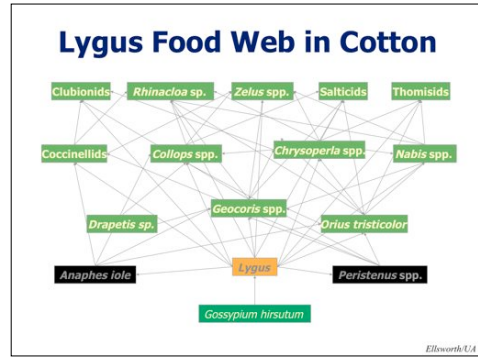
If there is any doubt, pyrethroid mixtures are very potent and damaging to NE populations, just as damaging as Orthene.

09F3L Hero, Endigo, Leverage360Hi

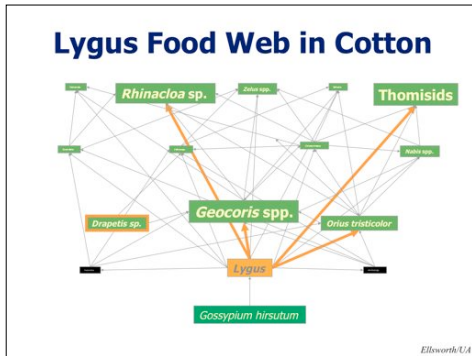


Ecological context is critical to understanding the selective potential of any approach. Novaluron, ostensibly an insect growth regulator, is actually quite a broad spectrum chitin inhibitor. In some systems, it may perform selectively. However, by these measures and in our ecological context (the AZ cotton system), it is no more selective than acephate, whether used alone or in combination two to four times. [Novaluron1* indicates that only this trt received the 3rd spray.]

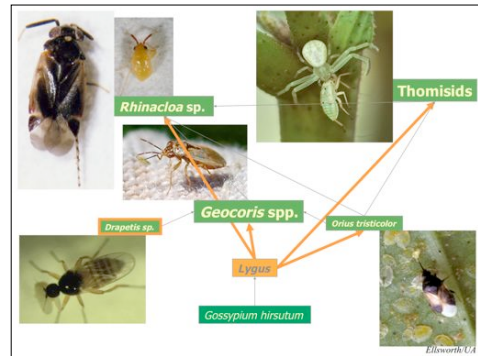
Novaluron is registered as Diamond in AZ but never recommended for whitefly or Lygus control.



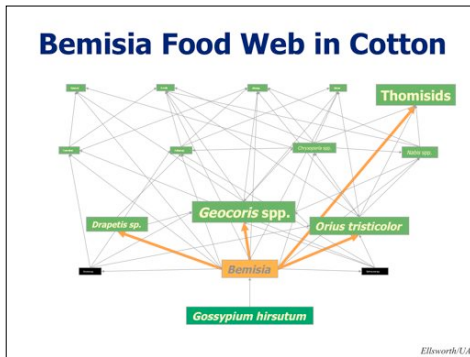
So here again is our candidate Lygus food web in AZ cotton, with parasitoids in black and all the generalist predators above. As noted, each PRC carries with it a species weights table, i.e., that represents the strength of association between that taxon and the PRC depicted. In each year in each field, it would be expected that these relationships shift among important generalist predators.



Here is that same food web as it looks like highlighting the most impacted species in the PRCs previously shown. Stronger associations are indicated by size. Parasitoids don't even occur. And several other species showed densities that were either completely random with respect to treatments or were so low that they were not influential in this dataset. Others are very much influential, including a mirid predator, big-eyed bugs, minute pirate bugs, crab spiders, and one species that likely does not feed on Lygus but does on whiteflies, Drapetis (an Empidid fly).



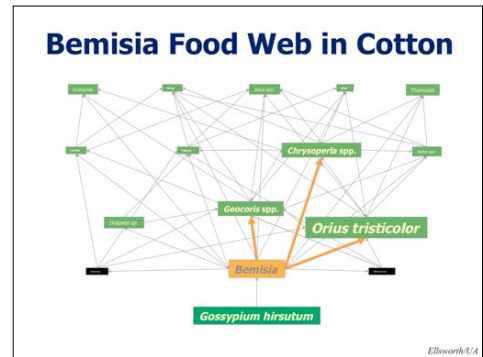
And here are the those same species that turned up in the 2009 analyses.



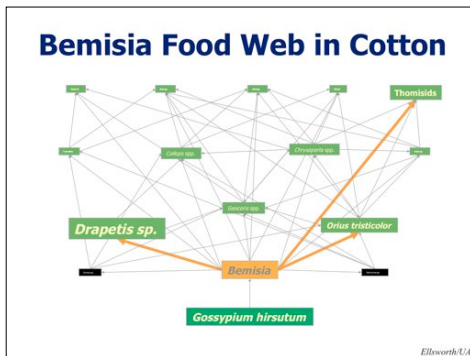
Different species dominate the relationships measured in different years or locations in AZ cotton and is a remarkable testament to the complexity of the food web (PRC for whiteflies shown here). Certain conditions may favor certain pathways in certain years and other pathways in other years. Yet the same, generally, level of natural mortality in whiteflies is expressed if the system is not disrupted with broad spectrum insecticides.

This representation attempts to show important drivers of the PRC on a scale of size, roughly equivalent to their species weights in the analysis.

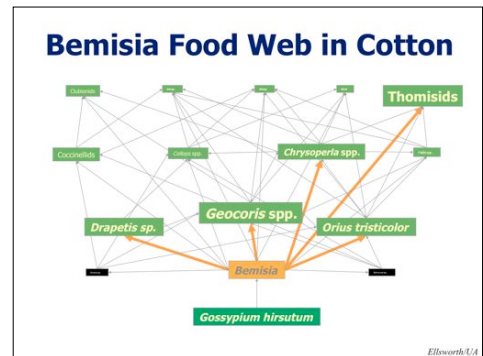
Note these are mostly generalist predators that spend time feeding on each other as well as on pest insects. Four predators dominated the PRC in this year.



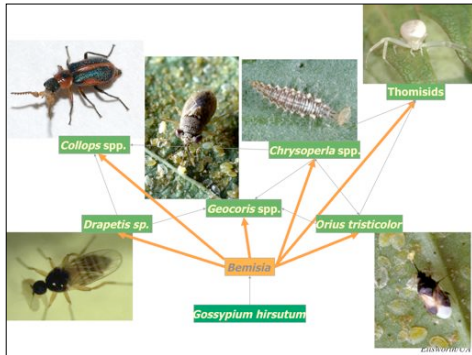
Three species in this year.



And a different set of 3 species in this year.



And 5 species dominated the PRC this year.



Over many years of intensive field study, Naranjo and I have found that most often one or more of these six predators dominated the relationship between whiteflies and their predation.

A small empidid fly that feeds on whitefly adults (not eggs or nymphs).

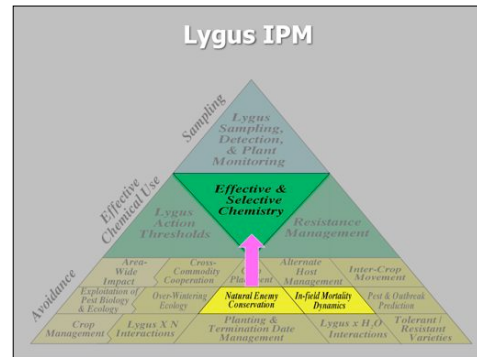
Collops beetle.

Big-eyed bugs.

Lacewings.

Crab and other spiders.

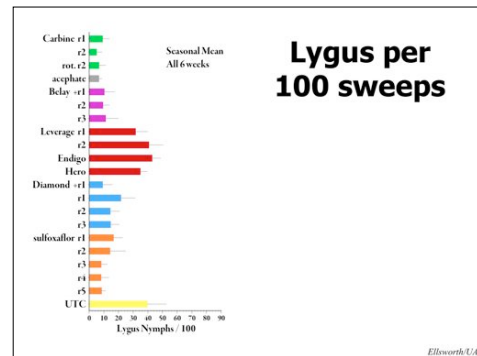
Minute Pirate bugs.



So NE conservation becomes an important objective of our overall management program including Lygus. But in the end, NEs are not sufficient to control economic levels of Lygus (or whiteflies) and effective and selective chemistry is still needed.



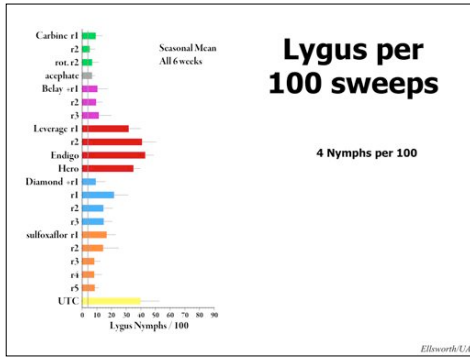
Thankfully we have good control agents for Lygus. Here's a shot of one border in my 2009 trial. Pretty easy to pick out the untreated check where Lygus bugs reduced yields over 5-fold. And right next to the foreground plot where we used three products in rotation, Carbine (feeding inhibitor) followed by Vydate followed by Orthene.



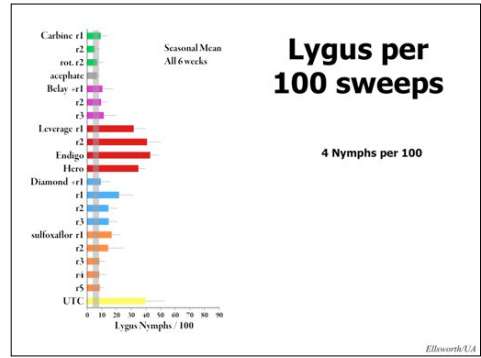
It is a challenge to show all the data at once. But once oriented to the overall data, we will examine it one section at a time.

Here we have Lygus NYMPHS per 100 sweeps from a seasonal mean of 6 weeks during the primary fruiting curve.

Different chemistries are color-coded.

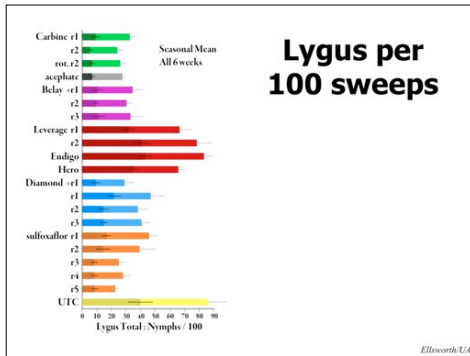


You can see that we had sustained pressure in excess of 40 nymphs / 100 sweeps. Our threshold is 15 total Lygus with just 4 nymphs per 100 sweeps (line shown). We were at 10-fold that level over a sustained period!

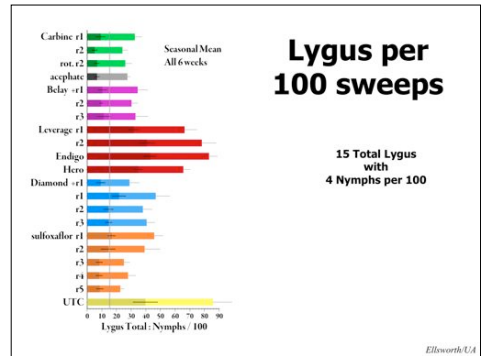


In my experience, the 4 nymphs per 100 is a good, but conservative threshold. If after spraying, under this kind of pressure, a product manages to hold nymph levels below 8 nymphs per 100 (gray bar), it is performing maximally.

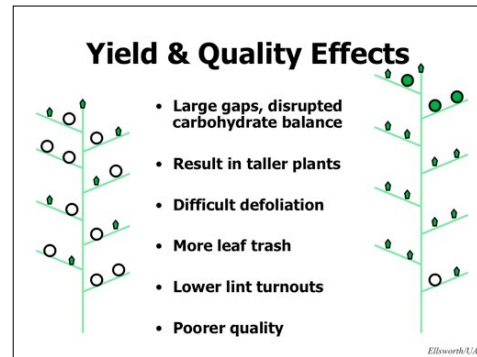
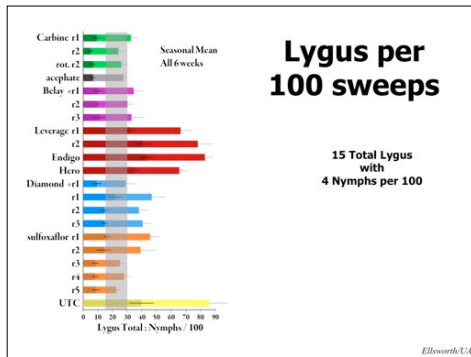
You can see that some products managed this level of control; some didn't.



Now I am overlaying the remaining Lygus numbers to give a total count (total Lygus / 100) with nymphs shaded.



The threshold is 15 total Lygus per 100 sweeps (line shown). We sustained 5-6 times this level for 6 weeks.



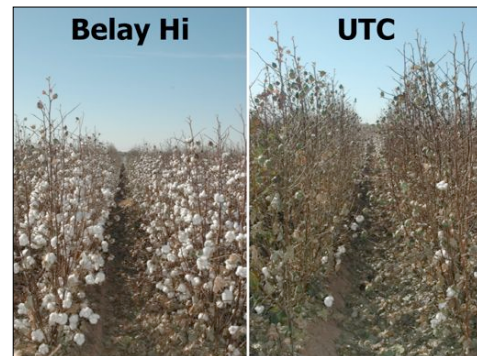
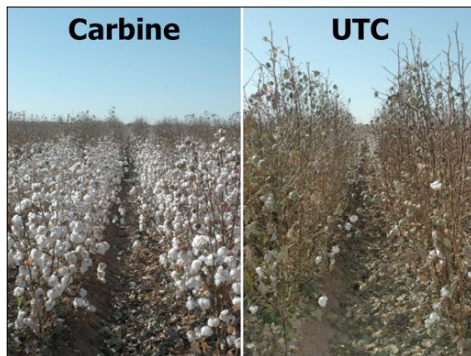
Again, operationally, if a product held levels below 30 per 100 sweeps (gray band), it was performing very, very well.

By all criteria, Carbine performed great as usual. Orthene also did well. Of the new compounds, Belay was right there and sulfoxaflor (examined at 5 rates) did very well from rate 3 and up (≥ 1.4 oz).

Pyrethroids and neonicotinoids (except for Belay) performed poorly.

Lygus damage also affects the pattern of fruiting to such extent that large gaps can sometimes be created. These gaps represent disruptions to the allocation of carbohydrates. Where normally, carbohydrates are shunted to the boll sinks, now they are redirected to the growing tip of the plant, making for a taller plant, one that is more difficult to defoliate (also because of disrupted / excess N-balance). This leads to more leaf trash in the harvest, which in turn, lowers lint turnouts and produces lint of poorer quality.

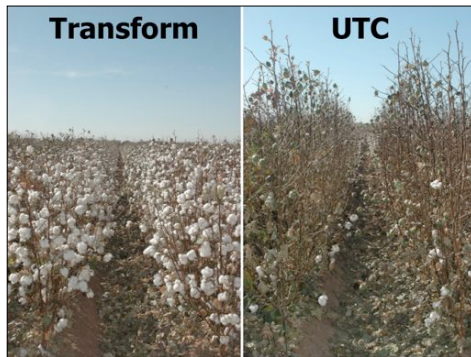
Each of these effects has been measured in our studies and represents some of the hidden costs of Lygus damage. Yield impacts can be great, but we should not forget these other losses as well.



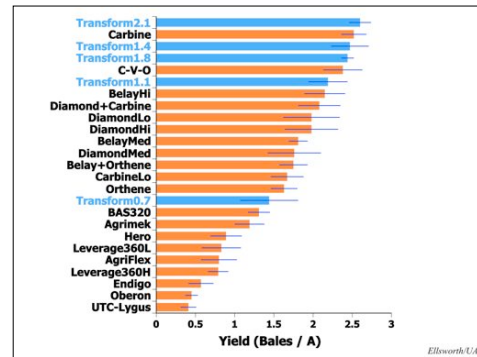
Carbine has continued to perform outstanding in control of Lygus and protection of yield. Note the height differences.

It is our Lygus control standard and is adopted in over 80% of all Lygus applications made in Arizona cotton today and in over 90% of the first applications made for Lygus (as recommended).

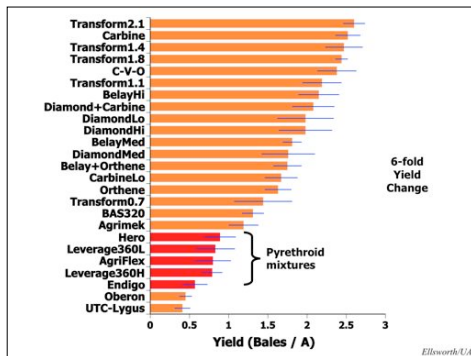
Belay was registered in 2010. Control was very good though somewhat less than Carbine. This seems to be an enduring trend. Carbine is generally more effective than Belay.



Here is sulfoxaflor used at a very high rate and showing very good Lygus control. Note the huge difference in plant heights. When Lygus are not controlled, fruiting positions (and fruit) are lost. Then all the energy the plant produces goes into unproductive vertical growth. Tall cotton is a telltale sign of Lygus injury many times.



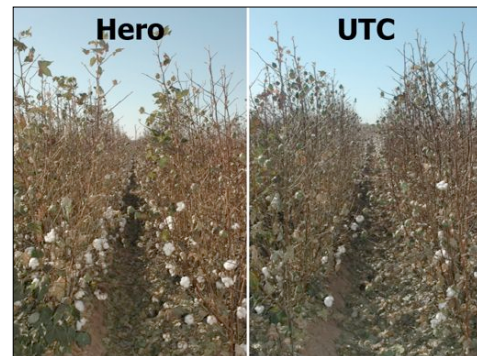
The 1.4 oz rate seems to perform as well as even higher rates but much better than lower rates. Control of Lygus and yields were excellent with Transform. The lower rates were less reliable. [2009 study].



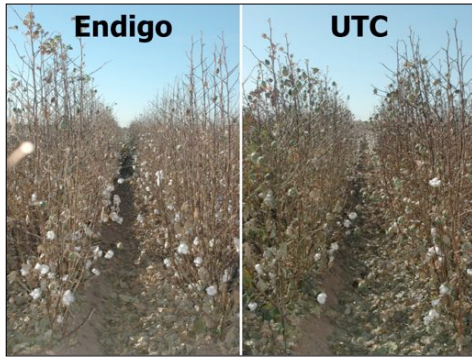
It is just as important to demonstrate to farmers which products do not perform well. Here we show yield from the lowest UTC at less than 0.5 bales/A to our best products at ca. 2.5 bales/A.

These are all pyrethroid containing treatments. None performed well, despite being sprayed 5 times (2 more than any other material).

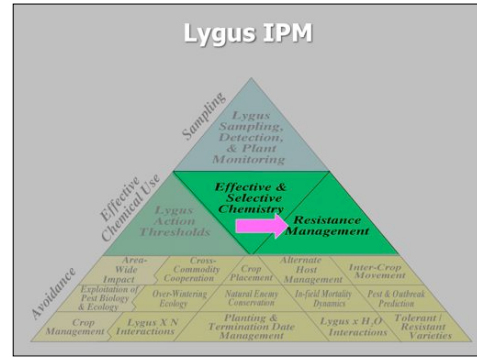
Note, too, that Orthene is off 1 bale. This is not due to poor Lygus control; Lygus control was good. This is due to the defoliation that occurred due to mites which broke out after destroying their natural enemies (most likely Western Flower Thrips).



Pyrethroids still don't work in our system against Lygus in cotton. Every so often, people argue this point with me. So periodically, we re-examine this in trials. This time we chose to use Hero, a new very active mixture of two pyrethroids (bifenthrin + cypermethrin). As you can see there was no significant control of Lygus. Note the height of the crop. (Sprayed 5 times instead of just 3 of the standard).



Addition of neonicotinoids to these pyrethroids does nothing to enhance control.



Resistance management is important in our system, because of what happened to us with whiteflies.

But rather launching into resistance survey data or complex models of resistance evolution, at this point we go back to the fundamentals. Our system is dependent on selective, strategic approaches that work to kill the target efficiently, but leave most other beneficial arthropods intact.

Stages Defined by Efficacy & Safety on Beneficials

- Stage I – Full Selectivity
- Stage II – Partial Selectivity
- Stage III – Synergized Pyrethroids

Stage	Chemistry	Application	Notes
Stage I	ACEPHATE	1.5 oz/A	Non-selective; broad-spectrum; destroys beneficials.
Stage II	ORTHENE	4.5 oz/A	Partial selectivity; some beneficials preserved.
Stage III	Transform 1.5 oz/A	1.5 oz/A	Synergized pyrethroids; high selectivity.

In our system, resistance management cannot be addressed without considering the actual efficacy of the products involved; and efficacy in our system cannot be completely considered without looking at selectivity once again. It's circular, but it all comes back to selectivity of the approach.

As part of our IPM program, a 3-stage chemical use plan for whitefly control identifies chemistry based on efficacy and selectivity attributes, with the ultimate goal of exploiting selectivity as much as is possible. It does not mandate a sequence but teaches growers that more selective approaches will create more effective ecosystem services that provide regulation of all pest species.

Not surprisingly, we wish to construct parallel recommendations for Lygus.

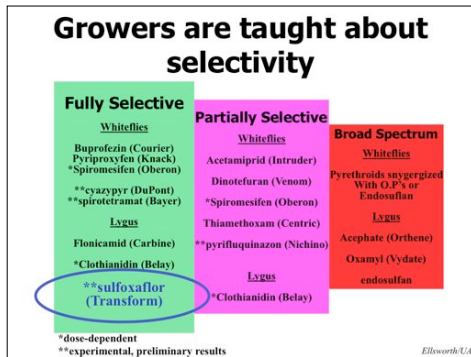


So what happened here? Inappropriate selection and use of a broad-spectrum Lygus insecticide (acephate, Orthene) destroyed the NE complex. Only this time, whiteflies did not resurge nearly as much as did two-spotted spider mites. The resulting stress on the plants defoliated the entire plot right down to the row. In contrast 3 sprays of any of the other products including Transform at 1.5 oz / A (or no sprays at all, UTC) resulted in conserved NEs that were critical in maintaining natural control of spider mites.

These sorts of results on a large plot basis give us the confidence to categorize products as to selectivity in our system.

11F32NTO, 2011 large plot study, 3 sprays at roughly 2 week intervals; effects visible prior to 3rd spray.

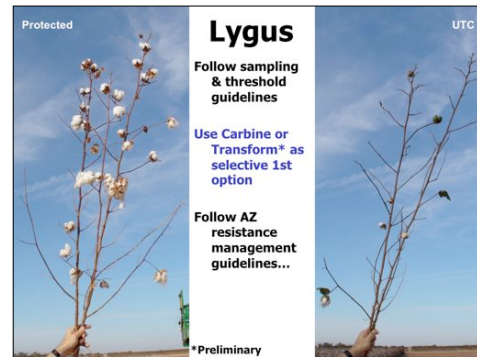
This is a non-target study.



So we teach growers not only the efficacy of key insecticides but their selectivity in our system. We place all chemistry into one of three boxes and encourage growers to use fully or partially selective insecticides, if needed and whenever possible.

The key message here is that the important attribute of Transform is not that it kills the target pest effectively, it is that it does so selectively by not killing the natural enemies critical to our system of conservation. Once this fact is realized, it becomes clear why using Transform as "just another control agent" or mixing it with broad-spectrum Lygus insecticides is a foolhardy approach that denies the central value of this product.

NOTE: Data for Transform are based on a single study, small plot study (2009). Belay in "fully selective" and partially selective box is tentative and preliminary, until further studies are analyzed.



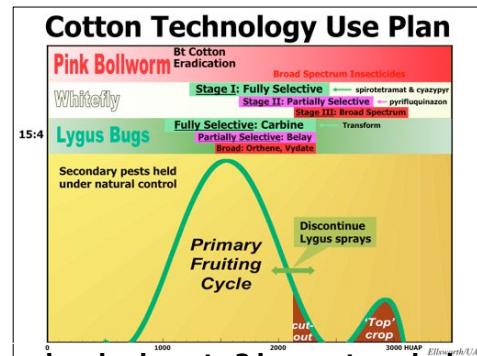
Our guidelines for Lygus control are based in sampling both adults and nymphs in 100 sweeps per field, in observing research-tested and commercially validated thresholds, and in responding with Carbine or very likely Transform as the first selective option for control of Lygus that extends the period over which beneficials contribute to overall pest management.

We have a deep experience with lost efficacy and resistance to insecticides, thanks to the whitefly. So following our AZ guidelines for resistance management is another key factor in our management program for all pests.

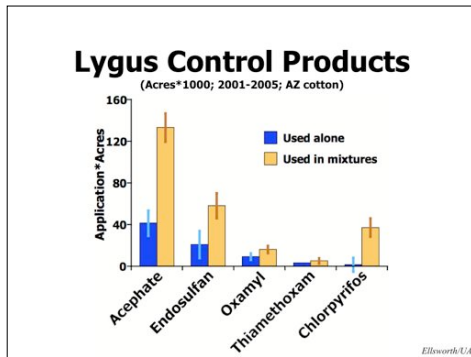
Representative plants (2) from the Carbine (2.8 oz) plot on the left v. the same from the UTC from our 2005 trial. Photo credit: John Braun.



So we recently had a field tour in Maricopa, AZ. We were rolling past some interesting plots, including those that showed complete defoliation by mites. And I think Hub was thinking hard about his new challenges coming up in Australia, where they are very aggressive about resistance management. And, he was thinking, too, about what's best for our system in Arizona. In the end, we never have perfect data or perfect inference when it comes to resistance management. However, there is a prudent course that we follow in AZ that is now manageable because of the diversity of effective and selective approaches that we have. No class or single active ingredient should be used more than twice per season. This is critically important for new and valuable chemistry, like Transform, especially when it is being labeled so broadly across many crops. Hub agrees.



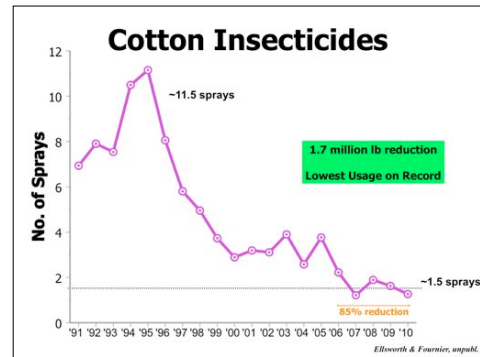
Our system breaks down to 3 key pests and a large array of secondary pests that never become significant, IF disruptions of natural controls do not occur. For PBW, Bt cotton is the ultimate biorational, and now with eradication, broad spectrum insecticides for its control are fading completely from our system. For whitefly, we have organized our insecticides into 3-stages based on selectivity, deferring all broad-spectrum inputs until the end of the season, if needed at all. For Lygus, we have one selective insecticide, fonicamid, and perhaps one partially selective compound, Belay, that was registered in 2010. Cotton IPM in AZ has become an exceptionally well-developed and selective system where conservation biological control is firmly established as a key element. We hope to add new insecticides and new classes of chemistry to our management system, and Transform may prove to be a critically important, fully selective option for lygus control and whitefly suppression.



The story would end there, if the only result was swapping broad spectrum chemistry with selective chemistry but still spraying the same number of times. However, our history teaches important lessons.

Our history in controlling Lygus is this. Growers were using some very broad spectrum insecticides both alone and in mixtures to control Lygus. These data are from AZ cotton. Whether mixed with other chemicals or used alone, acephate, endosulfan, and oxamyl have been our mainstay products for Lygus control. Acephate was our number one active ingredient 8 out of 9 years for cotton, 1998–2005

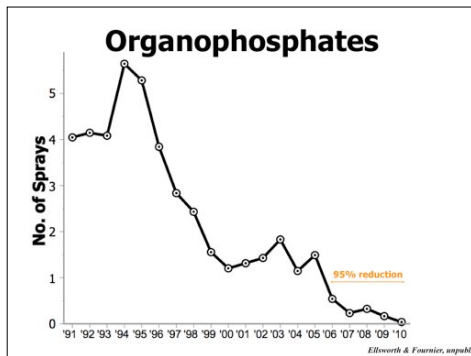
(Ellsworth reports to EPA, see Tables 1: http://ag.arizona.edu/apmc/docs/Endosulfan_Response_9-29-06.pdf & http://ag.arizona.edu/apmc/docs/Endosulfan_Response_12-4-02.pdf)



However things have changed.

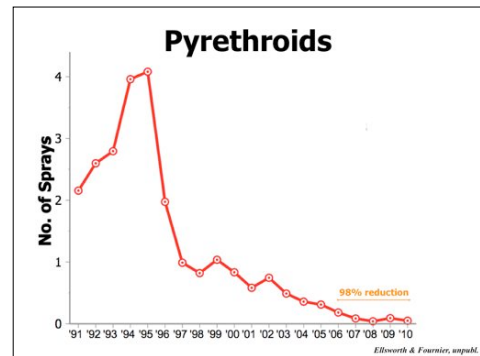
From a 30-yr high in 1995 of nearly 11 sprays used on average statewide for arthropod control to just 1.5 sprays in recent years. And virtually all pyrethroids, most organophosphates, all carbamates, and nearly all endosulfan uses have been eliminated in cotton in favor of reduced risk chemistries, mainly neonicotinoids, flonicamid (feeding inhibitor), ketoenols (lipid inhibitors, i.e., spiromesifen or Oberon), and IGRs, all of course, used over the top of Bt cottons.

Source, Arizona Pest Management Center Pesticide Database queried 12/2010.



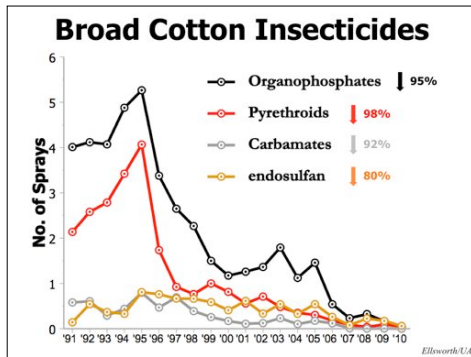
Organophosphates are another important group of insecticides used to control PBW, especially chlorpyrifos and methyl-parathion, as synergists of pyrethroids in the control whiteflies, and as Lygus control agents (acephate). This group has also declined to almost nothing. Carbine introduction has been very important to this continued trend in recent years as a selective Lygus feeding inhibitor (since 2006).

Source, Arizona Pest Management Center Pesticide Database queried 12/2010.



Pyrethroids, too, were used and became very important in whitefly control; however, their usage has declined almost to zero in cotton here.

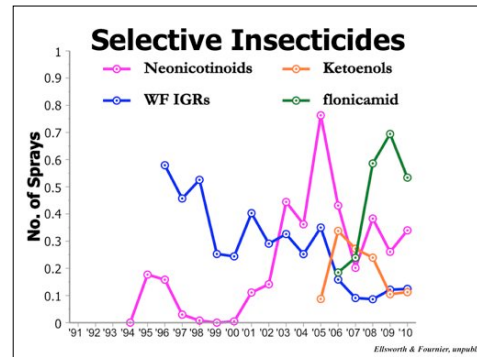
Source, Arizona Pest Management Center Pesticide Database queried 12/2010.



In collaboration with the state Department of Agriculture, we maintain a 20-yr database of pesticide use records within the state for all crops. Broad spectrum cotton insecticides have gone down dramatically nearing zero in most cases.

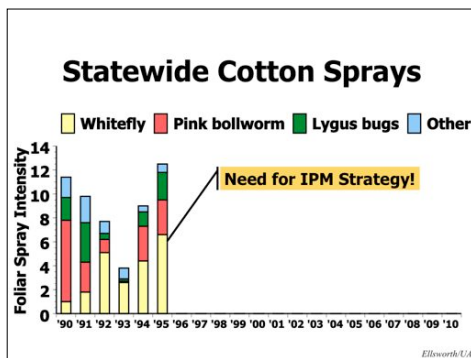
Comparing the last 5 years to our all-time peak year of 1995, organophosphates have declined 95%, pyrethroids by 98%, carbamates by 92% and endosulfan by 80%.

Source, Arizona Pest Management Center Pesticide Database queried 12/2010.



Selective, reduced risk chemistries, mainly neonicotinoids, flonicamid (feeding inhibitor), ketoenols (lipid inhibitors, i.e., spiromesifen or Oberon), and IGRs, have all replaced the broad-spectrum chemistries of the past and done so more efficiently. The scale on this chart is less than 1 spray per season.

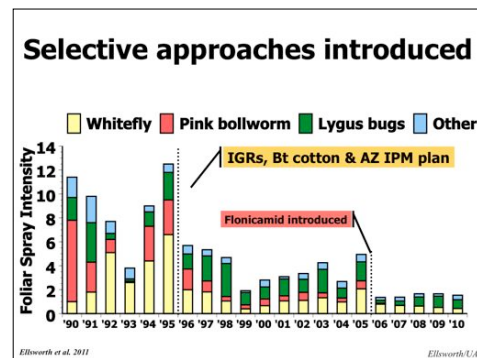
Source, Arizona Pest Management Center Pesticide Database queried 12/2010.



The need was great; the situation dire. Cotton growers were spraying 5-15 times to control an array of pests. Whitefly, Pink Bollworm, and Lygus bugs are our 3 key pests of cotton in AZ.

There was a critical need for an IPM strategy, especially after the whitefly outbreak of 1995 precipitated in part by a resistance episode.

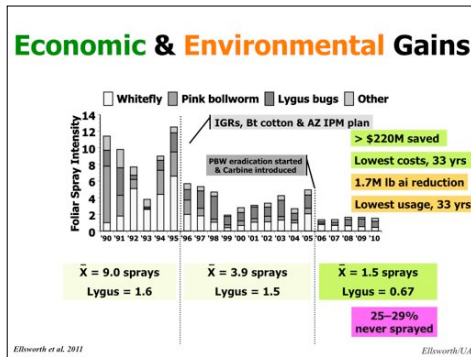
Statewide average cotton foliar insecticide spray intensity by year and insect pest (Ellsworth et al., 2011).



The results have been striking. A watershed of change occurred in 1996 with the introduction of very safe and selective Insect Growth Regulators for whitefly control, and transgenic Bt cotton, along with an IPM plan for whitefly management.

Flonicamid, a feeding inhibitor and very first fully selective compound for Lygus control was also first introduced in 2006.

The reduction in insecticide inputs is obvious.



Looking at these critical periods in our history, we can see rather dramatic declines in overall insecticide use, as well as huge declines in whitefly and now Lygus sprays made by growers. Compared to 1995, we estimate that cotton growers have saved cumulatively over \$220 million during this period. The cost of their foliar insecticide control budget over the last 5 years is the lowest it has ever been on record (33 yrs). During this same period, we have witnessed an annual insecticide reduction of ca. 1.7M lbs active ingredient used in cotton and the lowest overall usage in 33 years.

We spray Lygus just ca. 0.67 times per season now. And growers now report between 1/4 and 1/3 of their fields as going unsprayed with insecticides at all! This was inconceivable 15 and 20 years ago.



Thank you for your attention and to Dow Agrosiences for making this scientific exchange possible. Thanks, too, to the many growers, pest control advisors and others who collaborate to make this such a successful program. I also thank my institution and institution of my collaborator (Naranjo), Univ. Arizona & USDA-ARS, ALARC, and numerous funding agencies that have supported our research and outreach over the years.

The Arizona Pest Management Center (APMC) as part of its function maintains a website, the Arizona Crop Information Site (ACIS), which houses all crop production and protection information for our low desert crops, (<http://cals.arizona.edu/crops>), including a copy of this presentation.

Photo credit: J. Silvertooth