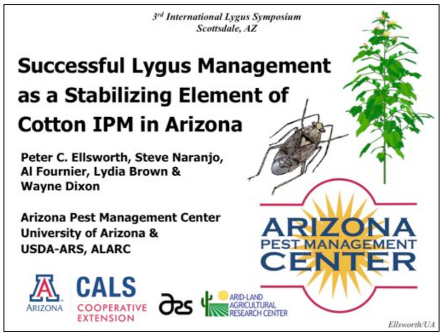
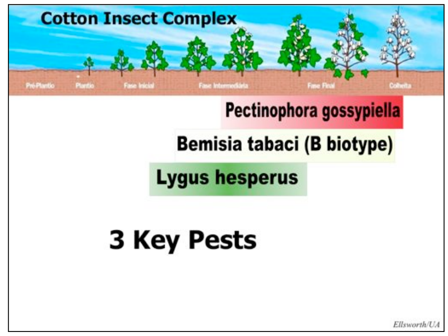
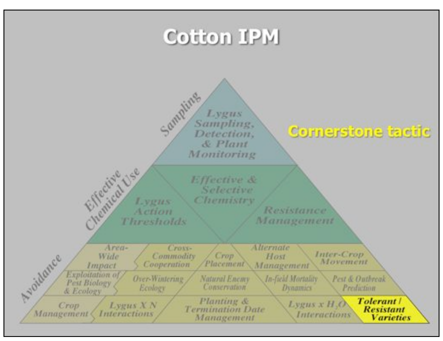


In many places and times, people highlight mirids as a destabilizing influence on IPM and arthropod pest management in general. However, the reverse can be true as well. That is, successful and innovative management of Lygus can actually help stabilize an IPM system — a reverse "treadmill" effect becomes possible. Fewer or more selective sprays for Lygus can lead to less natural enemy destruction, lower risks of resistance, and fewer sprays for other primary and secondary pests. This then leads to increases in natural controls and lessened pest pressure, which leads to fewer sprays, etc…

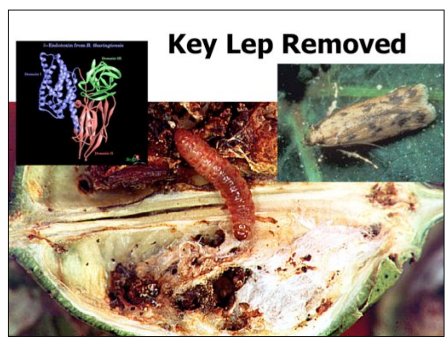
Today I will illustrate the tactical elements of Lygus management that have helped to stabilize our cotton IPM strategy in Arizona.



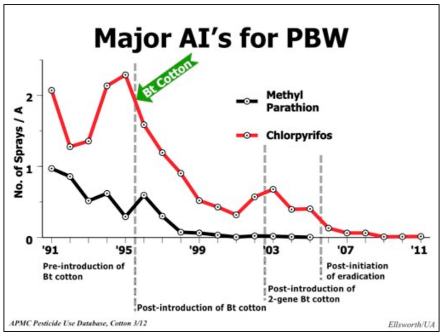
Arizona historically confronts 3 key pests, a lepidopteran (Pink Bollworm), a whitefly (Sweetpotato whitefly) and a mirid, Lygus hesperus.



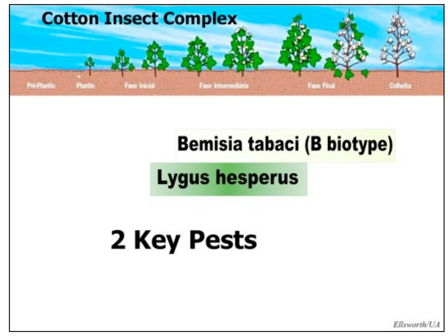
I like to begin any discussion by reviewing the overall structure of Cotton IPM as a means to understanding the potential role a new tactic may play in the system. As we all know, the cornerstone to IPM is resistant varieties. It shapes the foundation for everthing else we do in the production of cotton. Bt cotton for us in Arizona has been an all-important selective control tactic for pink bollworm, our key lepidopteran pest.



We have taken this (and other control) technology to an extreme and used it as a key to the eradication of PBW from our system. We are close to declaring AZ, if not the entire U.S. free of pink bollworm, a pest that has destabilized our system for more than 40 years.



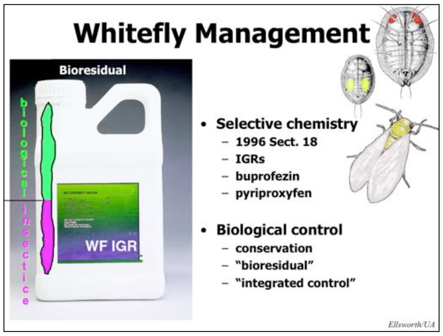
And on the way, Bt cotton has helped eliminate major broad spectrum, organophosphate and other neurotoxic chemistry.



So, we are looking now at a simplified system comprised of 2 key pests that drive our system.

This was the scene we were facing when the invasive B-biotype of B. tabaci 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.

After sharing scenes like in the previous slide, I often ask growers when they think this video was shot. Invariably, they guess dates in the early 1990's. However, this was shot in 2010 (!) as part of an experimental demonstration of the destabilizing effects that poor Lygus control decisions can have on our system.



Whitefly management was revolutionized in the mid-1990s with the introduction of very selective insect growth regulators, tools and knowledge to use them properly, and the concomitant increase in the ecosystem service of biological control and "bioresidual" of our system. This was a living example of "integrated control" sensu Stern et al. 1959.

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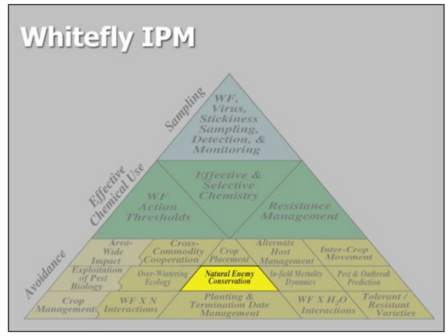

So we are talking about Lygus management. What does this have to do with whiteflies?

Whitefly management is paramount in our system as depicted in the video scenes. Natural enemy conservation is central to our whitefly management system…

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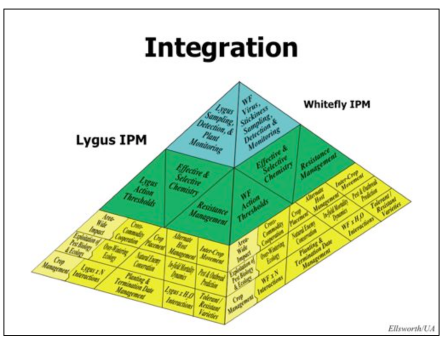

The reason is because our management practices for one pest must be fully integrated and compatible with the practices for the other key pests.

I envision an N-dimensional crystal where on the face of each dimension lies the tactical components of each pests' management strategy, and where the contents of each building block interact with the building blocks of other pests (dimensions).

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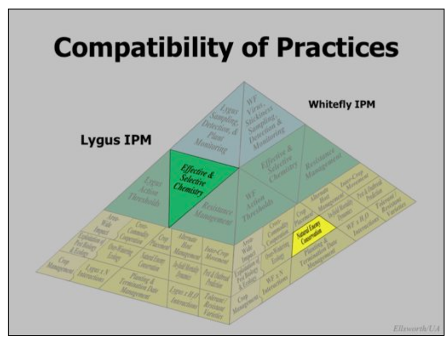
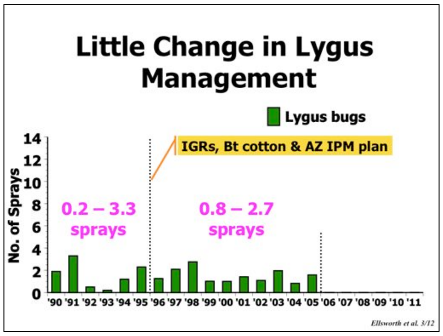


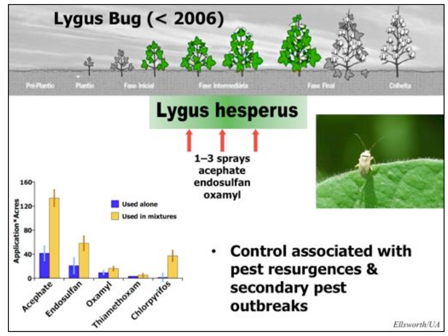
In our case, this means paying attention to the chemistry used to control Lygus such that NEs are conserved for whitefly (and secondary) pest control. Put another way, poor choices in Lygus management can compromise natural controls of our other primary pest and a whole suite of secondary pests that are normally held in check.



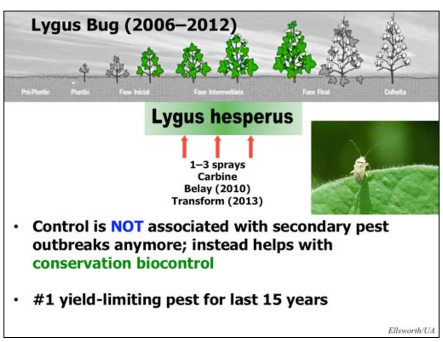
A watershed of change occurred in 1996 with the introduction of very safe and selective Insect Growth Regulators (IGRs) for whitefly control, and transgenic Bt cotton, along with an IPM plan for whitefly management and comprehensive outreach campaign that consisted of extensive grower and pest manager education.

Yet… little change in Lygus control was noticed over this period.

[Statewide average no. of sprays to control Lygus, 1990–2005]

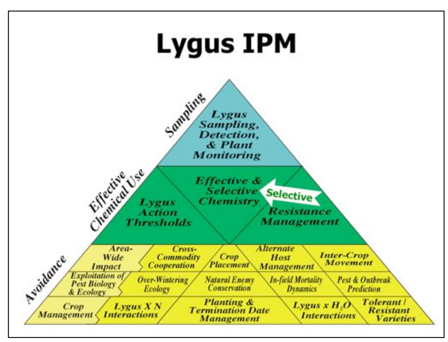


Prior to 2006, this was the typical control pattern for Lygus in cotton in Arizona: 1–3 sprays, on average, using very broad organophosphate, organochlorine, and carbamate chemistry. The result was often a control of Lygus but with consequences for pest resurgence and secondary pest outbreaks. Despite the selective gains that Bt cotton and whitefly IGRs provided us, these Lygus control practices destroyed our natural enemy populations.



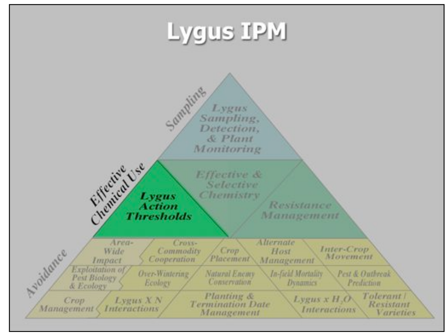
Starting in 2006, our entire cotton IPM system has once again been revolutionized, largely because of a key change in Lygus management. We still spray, on average when needed, 1–3 sprays against Lygus. But now, we used flonicamid (Carbine) that is fully selective and safe to beneficials. Belay (clothianidin) was registered in 2010 and was the first neonicotinoid to give significant efficacy against Lygus. When rates are managed properly, some safety to beneficials is also possible. In 2013, we expect another very selective and effective compound, sulfoxaflor (Transform), to be registered in Arizona cotton.

More importantly, with Carbine, control is no longer associated with 2° pest outbreaks & conservation biological control is further enabled.



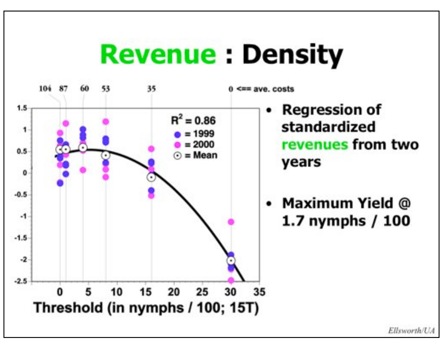
Lygus IPM is made up of our standard 3 keys, Sampling, Effective Chemical Use, and Avoidance. Central to this management approach is Effective & Selective Chemistry. Selectivity is at the heart of our entire management strategy and together with Steve Naranjo (USDA), we invest considerable resources to conduct detailed field assessments of all new cotton chemistry for their effects on non-target arthropods.

But before I address "product" selectivity, I will briefly mention how selectivity is accomplished through information in these other areas.

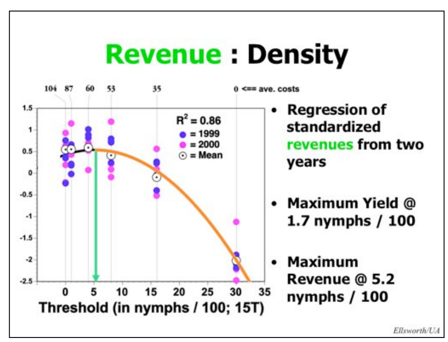


Central to remedial tactics is an effective chemical arsenal. In AZ, we have shown in whitefly management that when selective options are available and effective, huge gains in both target and collateral control can be achieved due to much better natural enemy conservation.

Part of these gains is related to development of action thresholds that help to limit and strategically schedule the use of our control chemistry.



To understand the point of diminishing return, we developed this regression that shows the relationship between standardized revenues and our tested thresholds.



Following this curve to its maximum, we see that more money is made when a threshold of 15 total Lygus with 5.2 nymphs per 100 sweeps is observed. Furthermore, this basic relationship held up under a huge variety of cotton economic conditions ($0.20-1.20 / lb). So these studies have given rise to our current recommendation which is intentionally set to be somewhat conservative to guard against excessive yield loss and to accommodate the normal time-lag between sampling, decision-making, and implementation of the action (spraying)…

This so-called '15:4' threshold represents 15 total Lygus per 100 sweeps with at least 4 nymphs per 100 sweeps. I should add here that a 15 inch sweep-net is a standard method used by our consulting community in Arizona.

These studies also discovered that the majority of damage risk was associated with nymphs, especially larger nymphs. So our threshold emphasizes this importance by dedicating a portion of the decision to a count of nymphs. Our threshold studies provided the first systematic evidence of the relationship of Lygus nymphs to cotton yield loss in Arizona.

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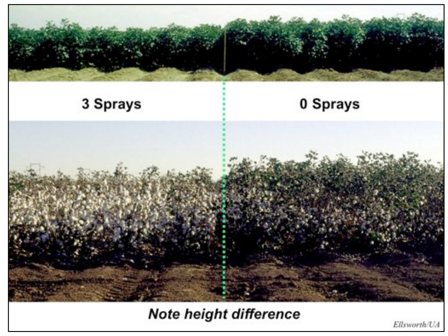

As further evidence, these effects occur over the shortest spatial scale. That is in adjacent rows, shown here in a commercial trial where cotton was sprayed 3 times on the left for Lygus and not at all on the right. The height and eventual yield differences we see are as a result of Lygus feeding and damage, as these plots were planted to Bt cotton and all other pests were selectively controlled.

Because adults are fully mobile, we submit that this is visual evidence that nymphs are the major driver of the Lygus-yield loss dynamic.

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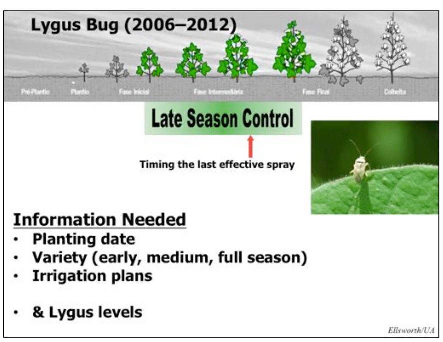

In addition to conducting threshold studies for scheduling sprays properly, we have developed a set of decision guidelines for determining the timing of the last effective Lygus spray, i.e., chemical control termination guidelines.

Without going into the details of those studies, the information needed depends on 4 factors. When Lygus are above threshold, the decision is dynamically related to 3 factors related to production risk. Early maturing varieties are at relatively low risk. Early planting dates are also at relatively low risk, as is early irrigation termination.

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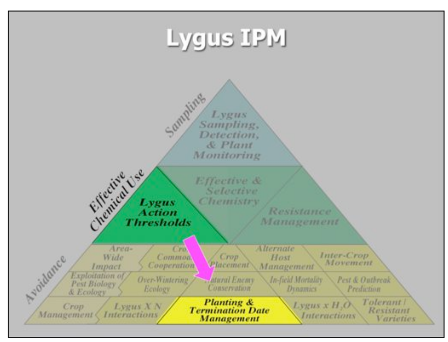
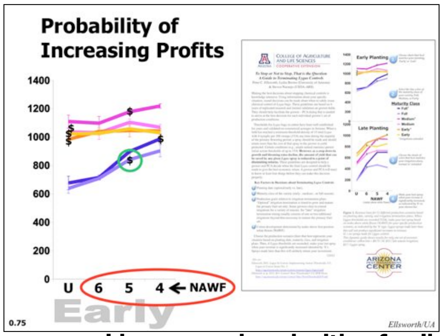
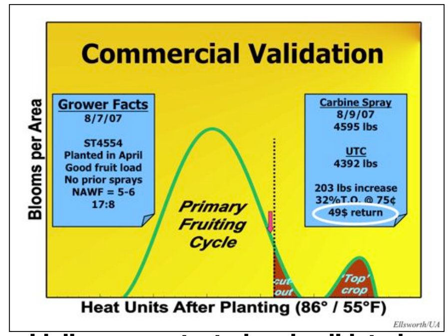


Thus, action thresholds interact directly with planting and termination plans of our growers, which are a set of prevention/avoidance tactics of crop management.



A single page guide was produced with a family of revenue lines representing planting dates, variety maturity class, and irrigation plans. Termination is then related to plant development via a common cotton phenological measure, "Nodes Above first-position White Flower (NAWF)". [specifics not presented.]

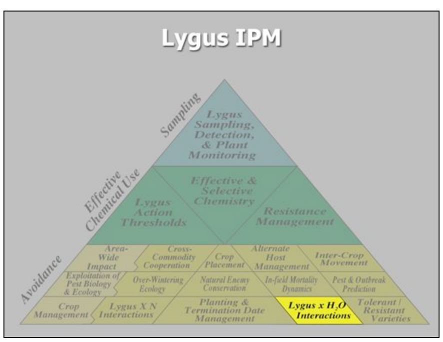
[As a full season variety (blue lines) not carried late with extra irrigation(s) (light blue line), the proper termination timing would be LT3 (green circle) or when the crop is at NAWF ~ 5. As a medium maturity variety (purple line), irrigations terminated normally (lighter shade), cotton should not benefit by these late Lygus sprays. However, as cotton prices go up 85–90¢, as they are today, the decision to terminate sprays advances to LT3].



These guidelines were tested and validated on commercial acreages. In this case, the grower had not sprayed yet at all when he was faced with determining whether this last spray was needed.

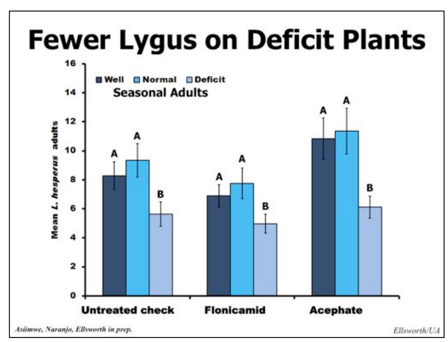
[The spray returned over 200 lbs of seedcotton. At 32% turnout to lint, that is about 65 lbs of lint. Even at 50 cents / lb, the grower made about 33$ more where he sprayed. What did the spray cost? In this case, probably about $17.

Was the spray a good choice? An investment of $17 that returns almost double that is in fact an excellent investment. But in the world of Lygus, that is only a small savings as compared to a miss-timed mid-season spray when even larger potentials for loss exist. This decision was truly on the edge of profitability, but clearly it was a better decision to spray.]

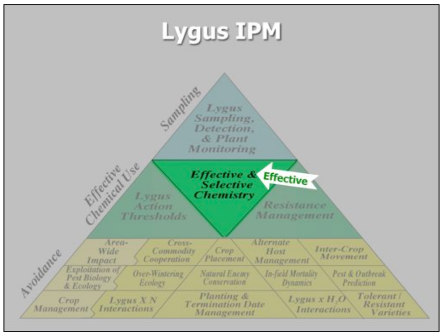


We have also examined Lygus * irrigation interactions. I have noted for years that Lygus tend to favor fields or portions of fields where water status is not in deficit. I.e., the adults will move and concentrate in areas that are well-watered or even over-watered because of soil type or position (end of an irrigation run) within a field.

As shown by our student Peter Asiimwe in an earlier session, we experimentally looked at this interaction and its impact on Lygus, whiteflies and natural enemies.



In general terms, there were fewer Lygus adults in the deficit irrigated plants, regardless of Lygus chemical controls used.



Of course, product selectivity is of little value if it is not first and foremost effective against the target pest. Producers need to be convinced that their product choices will work under their conditions.

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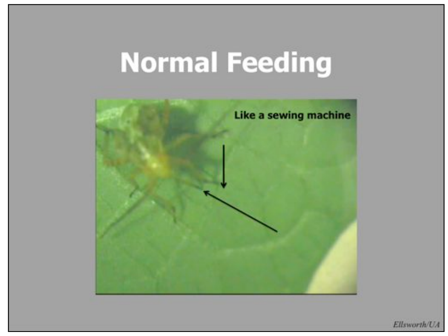

The following video depicts the normal feeding behavior of a Lygus nymph on a leaf. Their needle-like piercing/sucking mouthparts are normally rigid and operate much like a sewing machine, probing in and out searching for a suitable feeding site.

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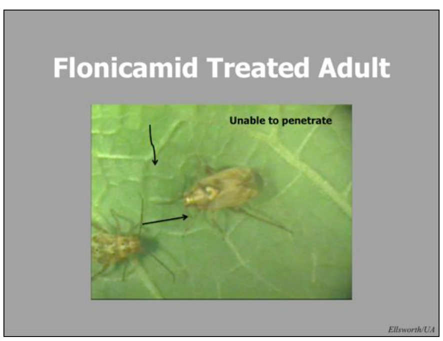

In contrast, this video shows a Carbine-treated adult attempting to orient and feed on a leaf. Notice that the mouthparts are no longer rigid and that the adult is unable to penetrate the leaf surface. This unique feeding inhibition works very quickly and eliminates any damage by Lygus. In time, these individuals either starve or desiccate under field conditions.

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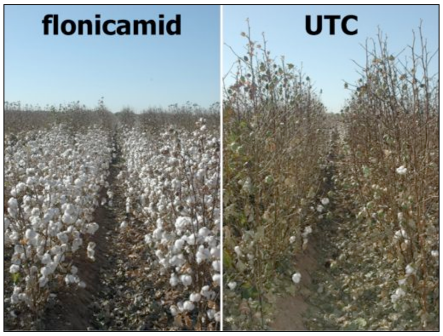
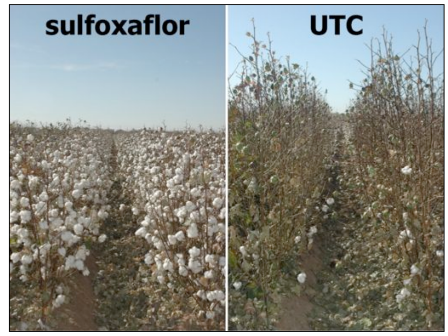
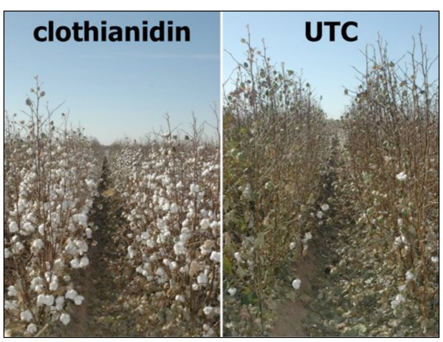
We conduct independent field tests of pre-commercial and commercial products. This is a shot of one border in my 2009 trial. Pretty easy to pick out the untreated check where Lygus bugs reduced yields over 5-fold. And right next to the foreground plot where we used three products in rotation, Carbine (feeding inhibitor) followed by Vydate followed by Orthene.



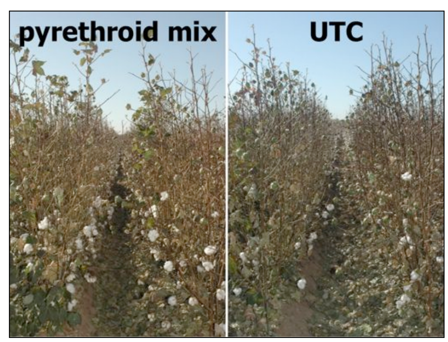
Carbine has continued to perform outstanding in control of Lygus and protection of yield.



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 often a telltale sign of Lygus injury.



Belay was registered in 2010, but the rate here shown is off-label (above the maximum currently permitted). Control was very good though somewhat less than Carbine.



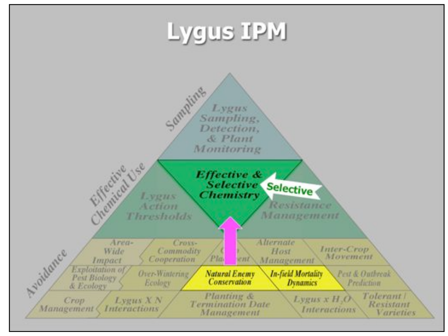
Pyrethroids (still) do not work in our system against Lygus in cotton. Every so often, people argue this point with me. So periodically, we re-examine this in trials. This time we chose to use Hero, a very active mixture of two pyrethroids (bifenthrin + cypermethrin). As you can see there was no significant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

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 <u>natural</u> 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.

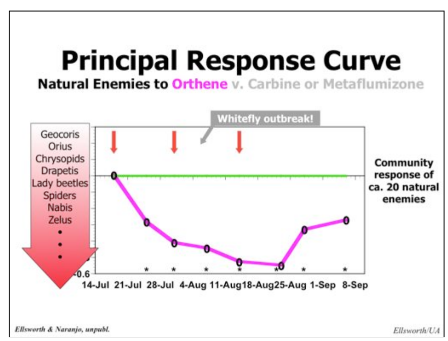


The natural enemy conservation and natural controls possible in our system for whiteflies and other pests is enabled through the use of selective chemistry for all pests, including Lygus.

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

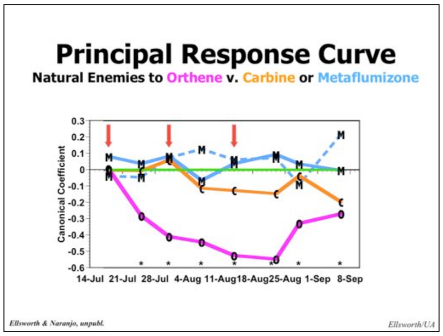
We also have 2 parasitoids; however, Anaphes, an egg parasitoid, will not readily colonize cotton; and I've seen Peristenus (nymphal parasitoid) just once in 20 years.

However, this complex alone is not always sufficient to completely overcome the sorts of whitefly numbers shown in the previous videos. But their impact is important in our very successful management system of today and the last 17 years. Plus, these same predators can be important in limiting the increase in Lygus populations, while suppressing/controlling all secondary pests (mites, leps, etc.).



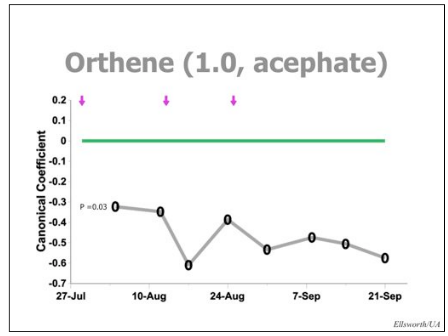
So, to examine selectivity directly, we conduct dedicated, large-scale field trials and analyze data as follows. Canonical coefficients can be thought of as density measures for the entire complex of species measured.

In our 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 (0.3 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.



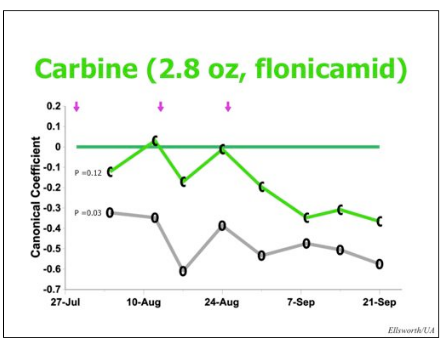
Carbine or flonicamid (orange line) showed no significant declines in the NE community. Metaflumizone at its maximum rate and for two different formulations (blue lines) also had no impact on the NE community. [Note: metaflumizone is not registered in U.S. for crop uses.]

And neither compound suffered from whitefly resurgence.



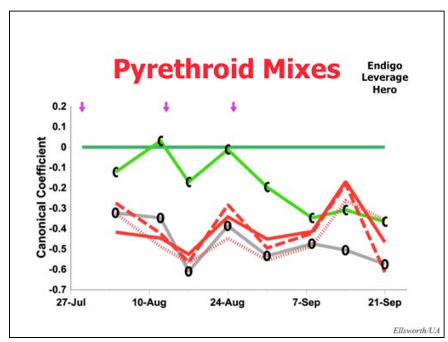
In another study (2009)…

[Gray line = Orthene (acephate) response]



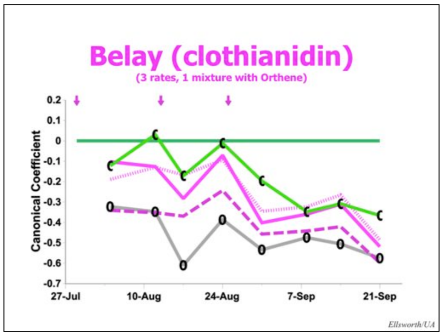
Full commercial rate of Carbine.

09F3L 2.8 oz of Carbine



Pyrethroids are damaging to our NE community.

09F3L Hero, Endigo, Leverage360Hi



Belay is partially selective and safe for beneficials, but higher rates can be more damaging.

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

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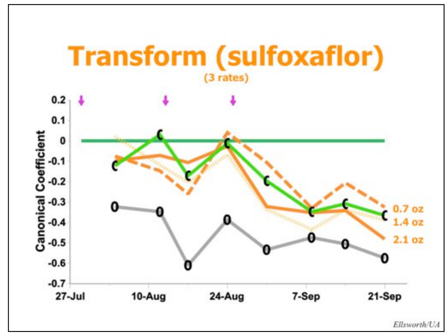

Transform with a 3-fold rate range showed surprisingly little difference in NE responses though very slightly lower than Carbine. These are small plot results. Definitive large plot results are undergoing analyses prior to registration of this compound in 2013.

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

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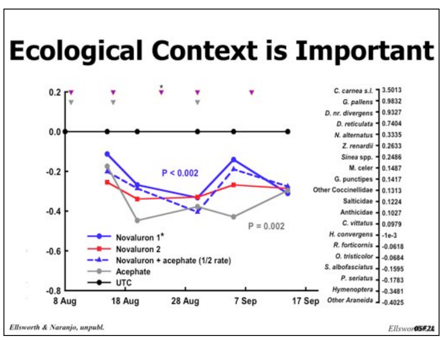

Ecological context is critical to understanding the selective potential of any approach. Novaluron, ostensibly an insect growth regulator, is actually quite a broad spectrum chitin inhibitor. In some systems, it may perform selectively. However, by these measures and in our ecological context (the AZ 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.

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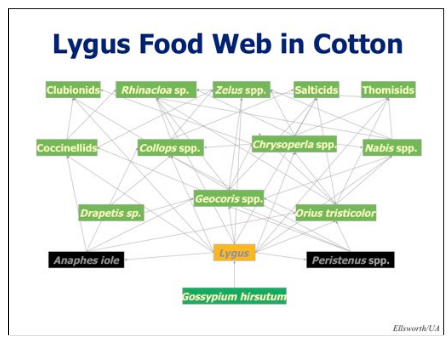
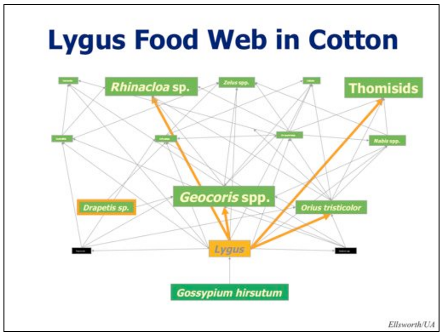
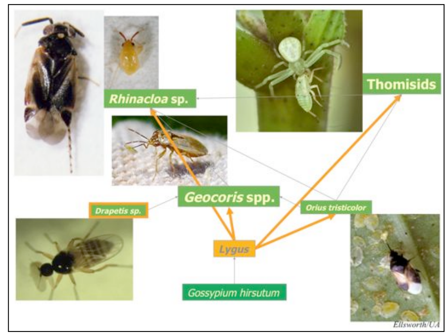


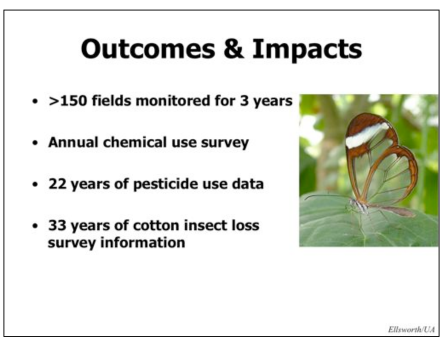
The food web in cotton is complex and dynamic. How one determines which species are driving the system has historically been a difficult problem to deal with. Experimentally, people have tried caged systems that exclude all predators or confine one or a few species with fixed numbers of prey, and even 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, the multivariate approaches to our data shown in the charts has helped us understand the complex dynamics that are operational. Each chart shown has a series of species weights that go with it. These can be represented graphically as a means to understand the NT species driving the major relationships.



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 were not even present. 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).

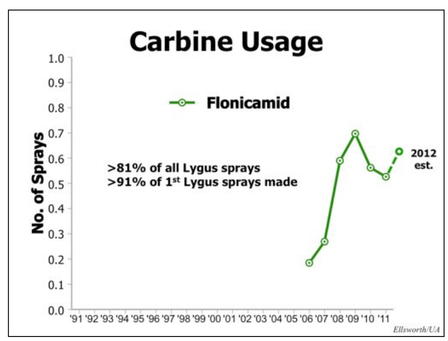


And here are the those same species that turned up in the 2009 analyses.



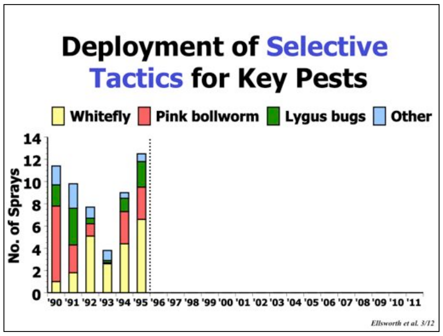
In Cooperative Extension, we are continually challenged to systematically and scientifically measure outcomes and impacts. Are we having an impact on IPM practice in Arizona cotton? We believe that the Extension IPM program has been critical in the establishment of our foundation in IPM discovery, development and implementation science, and in IPM Assessment.

These are the datasets that we have used for the following outcomes and impacts that I wish to share today. We have the chemical use practices and other measurements on 150 commercial fields; we conduct an annual chemical use survey of pest managers; we collect & improve pesticide use data that is reported to the state; and, we have a long-standing cotton insect losses database developed through surveys.



We can track Carbine uptake rates. After introduction in 2006, Carbine sprays have increased, displacing more disruptive alternatives. In our commercial field monitoring, we found that 81% of all Lygus-targeted sprays were Carbine. We recommend that it be used first, and in fact 91% of all 1st Lygus sprays were Carbine.

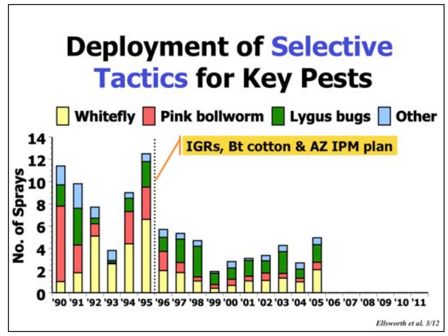
This is extraordinary uptake of a technology! It exceeds the rate of adoption of Bt cottons in Arizona cotton, which was a 100% effective means of controlling PBW. So we believe that we played a major role in transitioning growers to this new Lygus feeding inhibitor so quickly.



Our cotton insect losses surveys provide us rich information on state-wide pest management practices, in this case no. of sprays targeting each major pest.

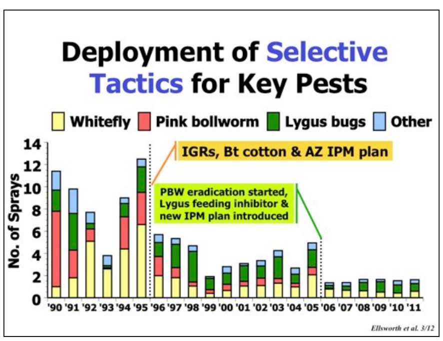
It is a striking history, where we can see the no. of foliar insecticides used to control each of 3 key pests over time, whitefly, pink bollworm and Lygus bugs.

This period, the early 1990s, was not sustainable with over 10 sprays of broadly toxic insecticides quite common.



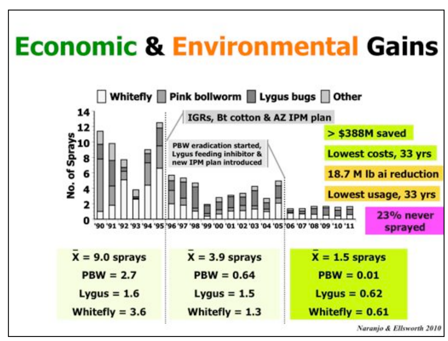
A watershed of change occurred in 1996 with the introduction of very safe and selective Insect Growth Regulators (IGRs) for whitefly control, and transgenic Bt cotton, along with an IPM plan especially for whitefly management and comprehensive outreach campaign that consisted of extensive grower and pest manager education.

No. of sprays, on average, were easily cut in half.



More recently, growers in collaboration with state agencies began PBW eradication in 2006. At the same time, we introduced flonicamid (Carbine) in 2006 as our first fully selective control agent, a feeding inhibitor for Lygus, as well as a new IPM plan that detailed the knowledge needed to properly use these technologies.

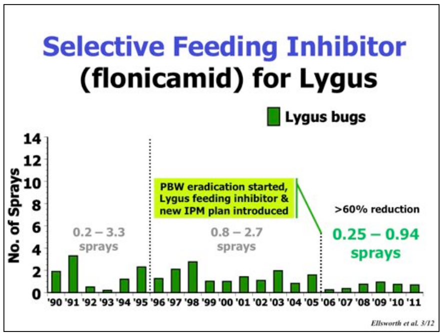
Adapted from Naranjo & Ellsworth 2009.



If we draw out information from these critical periods, we can see rather dramatic declines in overall insecticide use, as well as huge declines in PBW, Lygus and whitefly sprays made by growers.

At one time, we averaged 9 sprays. Our 1996 programs cut that by more than half to ca. 4 sprays, and our 2006 programs have cut this by more than half again to just 1.5 sprays. In the process we are in the lowest foliar insecticide control costs in history, we're spraying less than at any time in history, and have saved growers cumulatively over $388M in 2011 constant dollars and prevented nearly 19M lbs of insecticide ai from reaching the environment.

On average today, ca. 23% of our acreage is never sprayed for arthropods, something we never thought would be possible on a single acre 20 years ago.



As we isolate on just Lygus control practices, we can see that since 2006 we finally have reduced the no. of sprays required to control this pest. On average over all cotton acres, we average around 3/4ths of 1 spray to control Lygus now.

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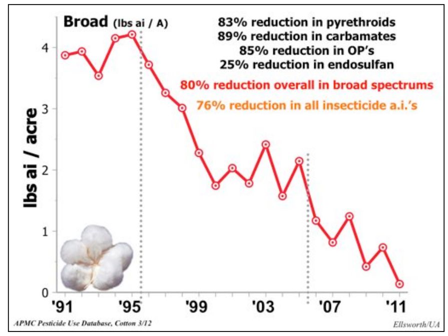

As impressive as these gains are, what has been key has been the shift away from broad spectrum insecticidal inputs. We have seen huge reductions in pyrethroid, carbamate, OP, and endosulfan usage, with an overall reduction in lbs ai / A of 80% in broad spectrum inputs.

1990-1995 v. 2006-2011

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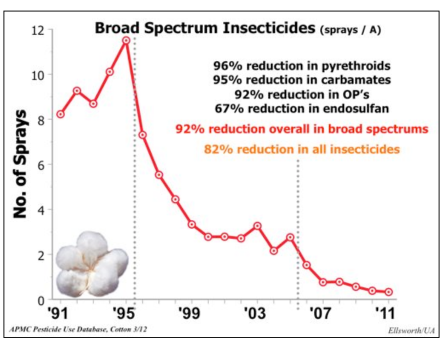

These data are independent from our survey data of pest managers, and they concur with what I have shown you in the bar charts. We have reduced all insecticide usage by more than 80% and broad spectrum usage by more than 90%.

1990-1995 v. 2006-2011

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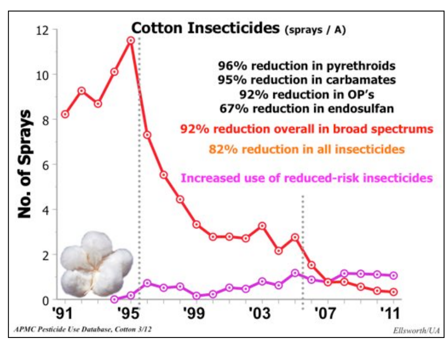
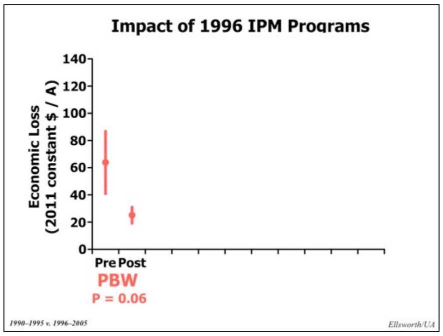


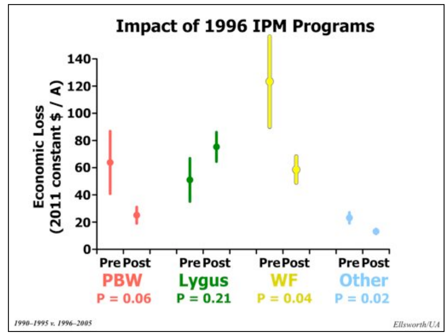
These gains were accomplished by the comprehensive IPM programs enacted in 1996 and progressively improved since with major changes to our Lygus control system in 2006. Furthermore, this was enabled by the strategic introduction of selective technologies into our system, and now we see the usage of reduced-risk insecticides out numbering broad spectrum insecticides. Most importantly, this has created opportunity for an ever increasing role for conservation biological control. In addition, it is difficult to quantify the stability in pest management that growers now enjoy. But we no longer see wide swings in pest activity and damage to the crop.

1990-1995 v. 2006-2011



Even with such great gains, we are challenged to depict results in a manner that can objectively measure progress. These are not replicated systems. However, we can examine periods of time by pest of cotton and ask the question of whether our IPM programs were coincident with the gains made in pest management.

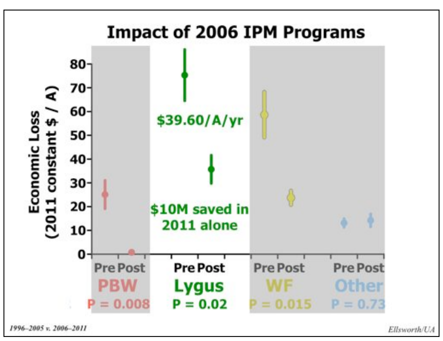
This chart shows "Economic Loss" in 2011 constant dollars per acre by pest both before and after the introduction of our 1996 IPM program. There is a significant reduction in economic loss, in this case for PBW, after the introduction of our IPM programs.



We can look at the balance of pests in our system and see that we made major reductions in whitefly related economic losses as well. By lowering the no. of sprays needed for PBW and whiteflies, we reduced losses to secondary pests as well, because we were stepping off the Pesticide Treadmill. In some sense, we were reversing the treadmill. Lower spray frequencies, especially of broad spectrum insecticides, permits us to further lower spray frequency because secondary pests are held in check.

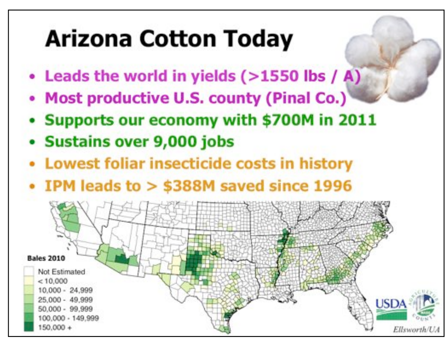
The one major challenge before us remained, curbing losses to Lygus hesperus.

***Exclusive of Bt technology costs.**



Our changes made in 2006 enabled further gains overall, but very major savings in Lygus control specifically. Over $10M saved in economic losses associated with Lygus in 2011 alone.

[Continued gains were made in PBW savings (due to eradication and nearly 100% adoption of Bt), and whitefly savings (due to even greater activity of beneficials enabled by selective Lygus control), but no further gains in "other" pests (because they have become so rare, effectively prevented by natural controls).]



Cotton is the major agricultural summer resource for insects. Some may not realize that AZ produces the highest yields in the world with a statewide average of just over 1550 lbs of lint per acre. Also, in terms of total production of cotton by county, Pinal County, AZ, has the largest cotton production in the U.S..

At the same time, we are endeavoring to produce and protect a crop over a very long period of time (Feb-Dec) under conditions of an abundance of heat units.

Thank you for your attention.

Thanks, too, to the many growers, pest control advisors and others who have collaborated with us and allowed us into their fields and provided pesticide records for this project. Not included on the slide, but should have been, were Cotton Incorporated and Arizona Cotton Growers Association, who also help fund much of the work presented.

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