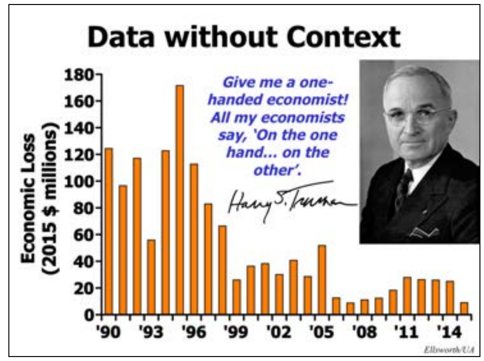
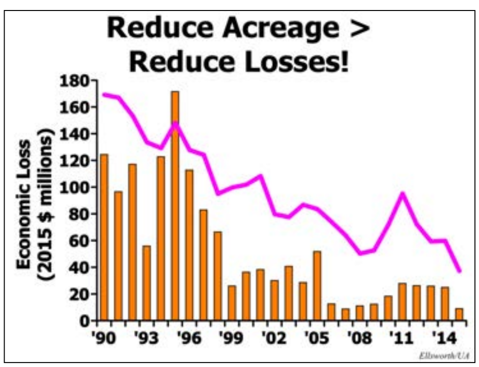
As I close my 26th season, I've had the opportunity to observe changing pest pressures and technologies as we have developed and refined IPM systems for Arizona cotton. Steve Naranjo at USDA has been my partner in science especially in the development of our understanding of the whitefly control system. Al Fournier is our IPM Assessment Specialist. [Our story goes beyond cotton to vegetable and melons and John Palumbo's efforts there; however, time does not permit us to cover these activities in today's talk.] Finally, George Frisvold is the economist on this project and while he supplied many formulas to consider, none are actually presented today and time only permits us to look at the largest economic component, direct savings by growers.

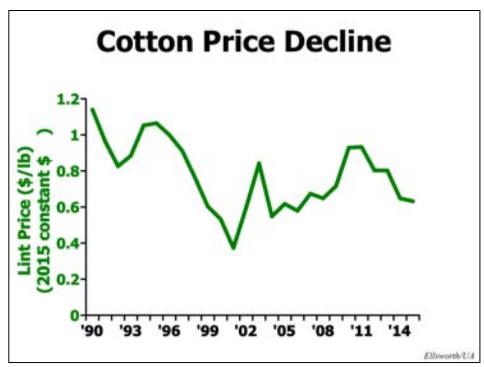


Data without context is a difficult thing to work with. This has not stopped, however, many economists and policy-makers from giving explanations, sometimes more explanations than there are data! Harry S Truman is famous for saying, "GIVE me a one-handed economist!" because of their penchant for couching their explanations on one hand and then the other, and the other, and the other.

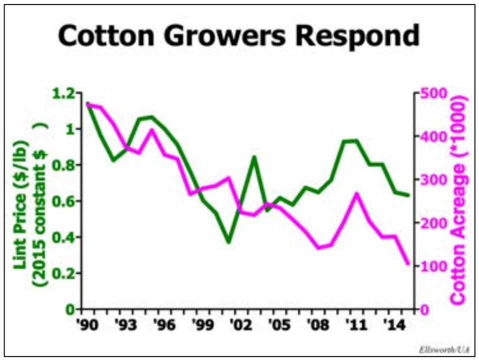


Sometimes data is quite uninteresting. For instance, a sure fire way of reducing the total economic losses to arthropod pests in cotton is to reduce the amount of cotton grown in the state. That certainly has happened over the course of this study, but it really is not where the important story is.

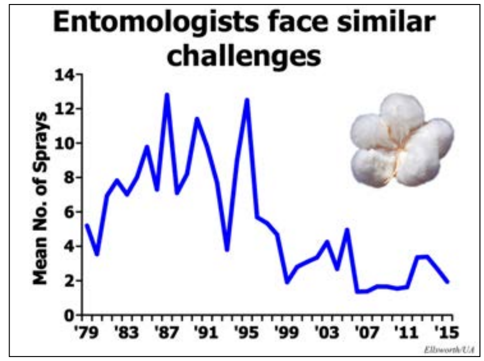
[Note, economic analyses throughout this presentation include Pima cotton but using upland (i.e., lower; often much lower) prices. Thus, results presented are very conservative.]



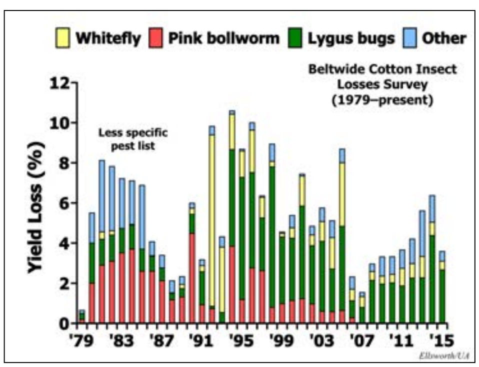
George would be quick to point out to me that cotton prices have not remained static over this piece of history. Indeed, commodity prices are quite low right now, about half of what they were at their peak in 2015 constant dollars.



And, growers do respond to these market signals by planting less cotton.



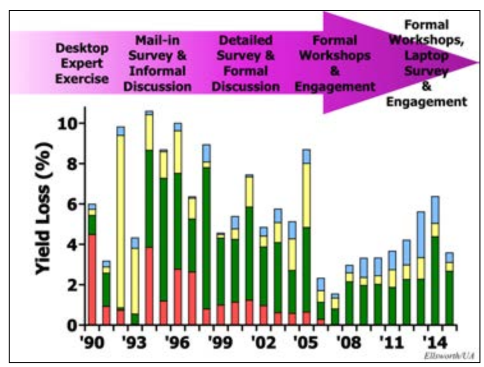
However, entomologists face similar challenges in looking at data, even data of their direct interest like average number of sprays made against arthropods statewide in Arizona cotton. Without context, it is very difficult to ascribe specific causes to these trends of spikes and valleys.



Thankfully, we have access to a long-term, contemporaneous measurement system of grower behaviors with respect to insect control practices. This U.S. beltwide cotton insect losses survey was initiated in 1979.

I'll be using these colors throughout this presentation, pink for pink bollworm, yellow for whitefly species, green for Lygus bugs, and light blue for all other arthropods.

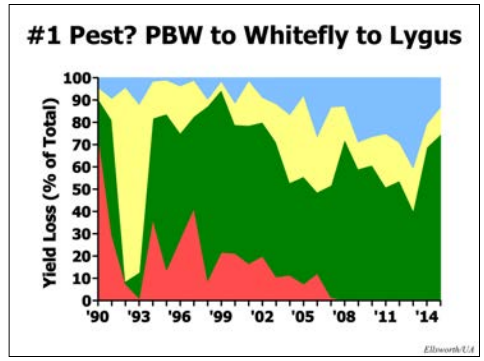
The pest list was less refined in the early years. So we'll focus on the last 26 years…



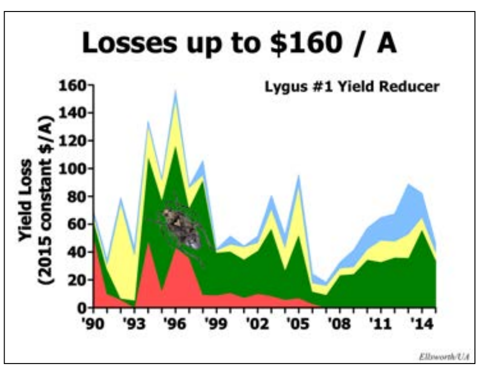
1990–2015, our survey and survey process has been refined, from one that was largely a desktop exercise of one or two experts discussing what they observed in the prior season over a cup of coffee. Soon after I took over the survey in 1992, I initiated a more detailed mail-in survey along with informal post-season discussions with growers and others. Mail-in surveys can have notoriously low response rates, so we went to more formal discussions and eventually to very formal, intensive 4-h workshop formats. These workshops served as a two-way exchange with stakeholders who could then express what difficulties they faced in accomplishing arthropod pest management. We now have a fully interactive system that makes use of laptop computers…

The laptops dramatically reduce post-hoc handling of data, something that was very common with the old paper surveys. I likened that process to sometimes "divining the chads" when interpreting responses from stakeholders. However, the laptop survey integrates live calculations to this very complex survey and assists in the understanding of the instrument so that pest control advisors, professional pest managers employed by growers, can better adjust and interpret their responses.

This scene shows Wayne Dixon our Assistant in Extension responsible for the development of the computer program and Al Fournier our IPM Assessment Specialist assisting PCA respondents during one of our sessions. What makes these data unique is that we specifically measure the "intent" of each spray made by these PCAs.

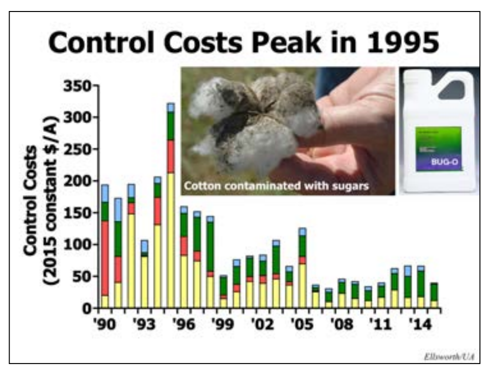


Looking at % yield loss due to arthropods, we can see that when I arrived in Arizona 25 years ago, growers had just experienced one of the worst (perhaps worst) PBW outbreak in history (1990) and there was no doubt in what was the #1 pest of Arizona cotton at that time. However, soon after, a new species of whitefly [Bemisia tabaci MEAM1] invaded our state and caused catastrophic losses in our system. However, for the most part since, Lygus bugs [Lygus hesperus], has been our number 1 pest of Arizona cotton.

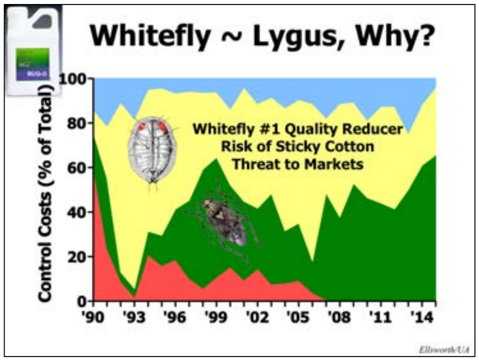


Yield loss on a per acre basis peaked in the mid-1990s at nearly $160/A and mainly due to our #1 yield reducing pest, the Lygus bug.

However, % yield loss is only one way in which economic loss occurs…

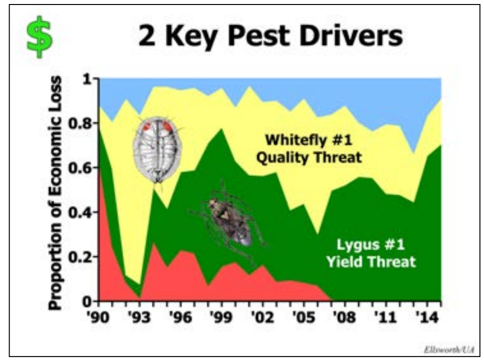


Economic loss also occurs in the costs incurred trying to control a given pest. Here we can see the spike in control costs in the early and mid-1990s to control whiteflies. This pest is not normally a major yield reducing pest. However, whiteflies excrete sugary honeydew that falls onto cotton fiber which then is a substrate for sooty mold fungi.

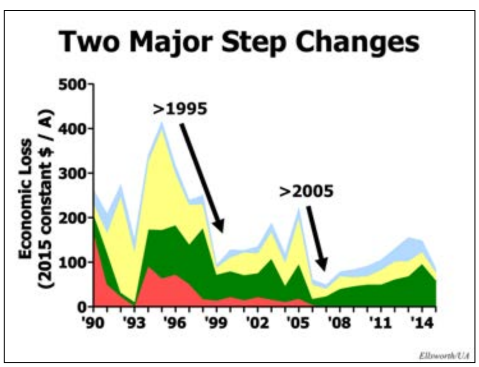


So "Number 1" is a title shared by whiteflies and Lygus. Why? Because control costs are incurred by growers for whitefly management in order to minimize risks of sticky cotton and for the long term protection of their markets, which greatly discount or not even accept cotton with any chance of excess sugars.

Whiteflies are our number 1 potential quality reducer.

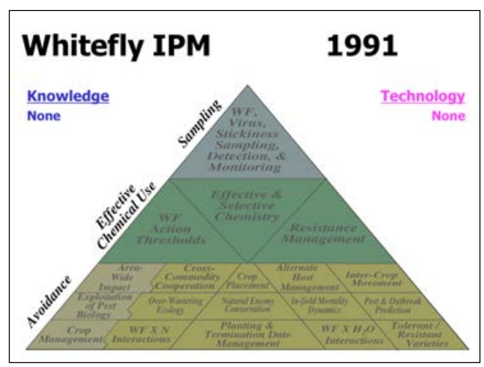


So our system has evolved to be driven by 2 key pests, one based in protection of quality, the other in protection of the yield component.



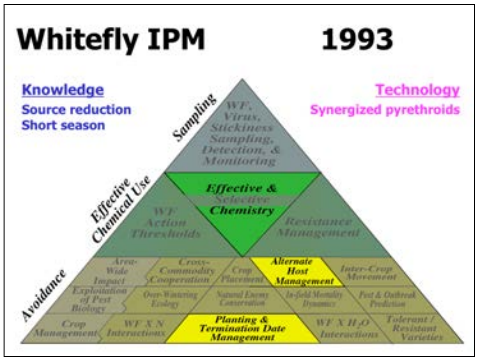
When economic loss is examined on a per acre basis, we see two major step changes in loss, one after 1995 and the other after 2005. Because of our rich dataset and contemporaneous measurement of behaviors, we have the context necessary to parse out the reasons for and infer causes of these changes.

To best understand the role that technologies play in these changes, we have to review the historical development of knowledge ('soft' technology) and products ('hard' technology)…



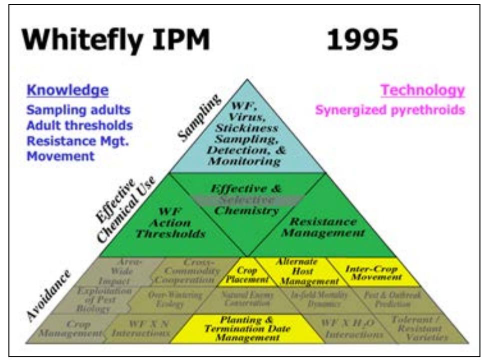
We were starting from nothing in 1991, when this new species of whitefly invaded our state.

We had almost no *a priori* knowledge ('soft', human-mediated technology) of how to cope with this invasive pest and effectively no ('hard') technology developed for its control.

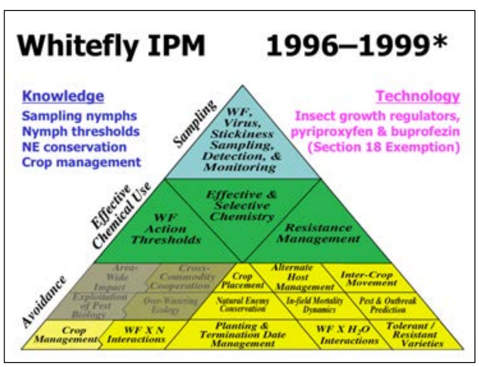


By 1993, we at least had identified some commercial chemistries that could be used to combat this problem in the form of broad spectrum pyrethroids synergized with organophosphates or other chemistries.

We had some idea of the alternate host interactions that were present in our desert agro-ecosystem and were faced with telling growers to shorten their season at all costs to avoid major damage from whiteflies. [Shortening the season had the side effect of greatly lowering yield potential.]

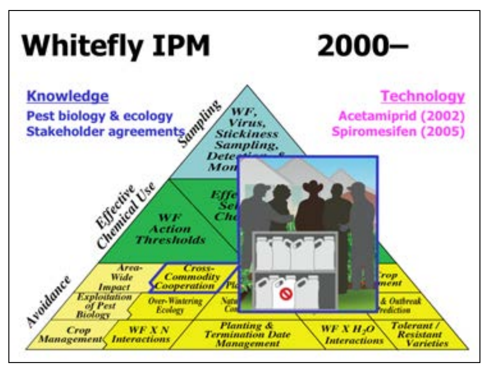


By 1995, we added adult sampling plans, action thresholds and more insight into resistances, and movement. No new technologies were added at this stage.



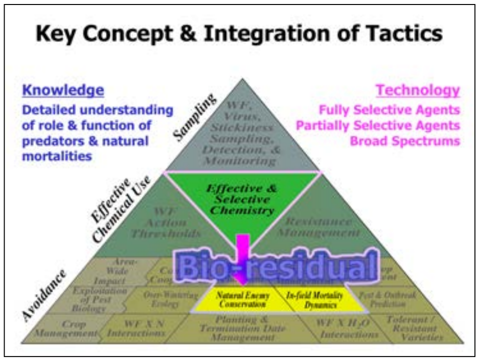
However, in 1996, we introduced some key selective chemistries, 2 IGRs for use for the first time in U.S. history, that changed everything for us.

At the same time, we added nymphal sampling plans and thresholds, and important information about the role of natural enemy conservation and broad crop management practices.

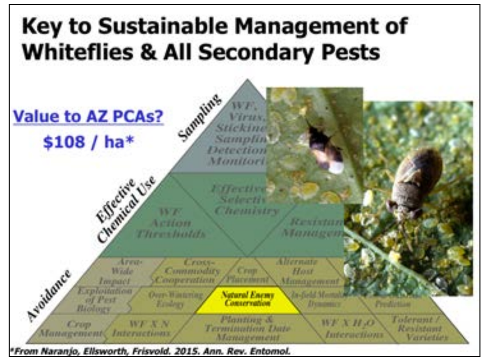


By 2000, we completed our understanding of the management system through key findings about pest biology & ecology, <u>and</u> we installed some critical cross-commodity agreements among cotton, vegetable and melon producers for sharing technologies across the ecological landscape, especially for the purposes of resistance management.

This pyramid metaphor serves as our heuristic representation of whitefly IPM in Arizona cotton. This continues to be our operational IPM plan, but has been refined still more as new technologies come on board like acetamiprid in 2002 and spiromesifen in 2005.



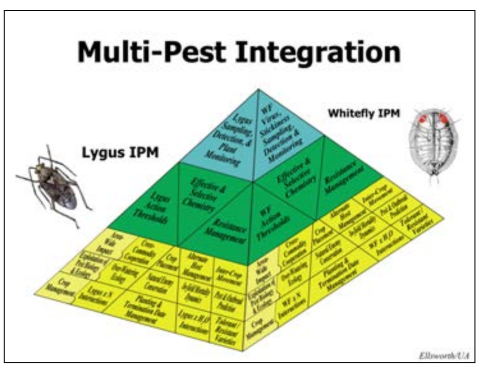
The central key concept to this effort was based in our understanding of the role and function of predators and natural mortalities in whiteflies in cotton and the integration of these mortality factors with fully selective insecticides. The two combined give us access to an extended suppressive interval known as bio-residual.



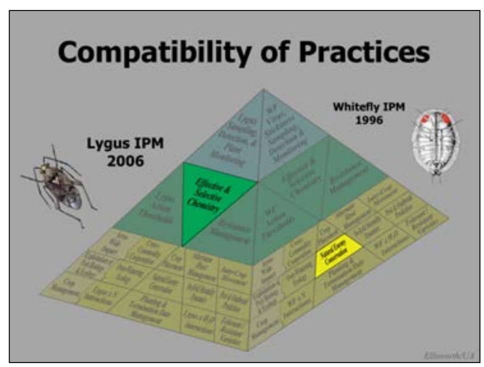
This harnessing of natural enemies is valuable to whitefly key pest control as it is in the continued suppression of all secondary pests.

It is now widely recognized and valued by our stakeholders. In a survey conducted 2 years ago for our ARE article, we asked Arizona pest managers (PCAs) how much do they value biological controls in cotton. While the range was large, the average response was $108/ha or about $44/A.

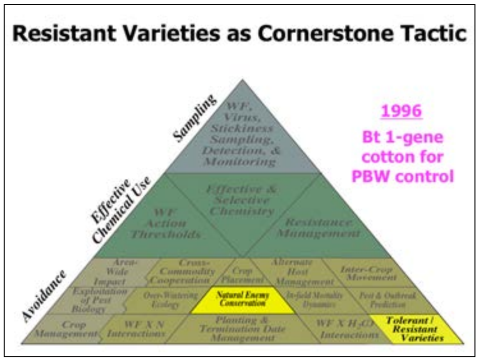
This recognition by practitioners is the economic incentive to implement the plan developed. But it also exposed a remaining weakness in our system after 1996 and even after 2000.



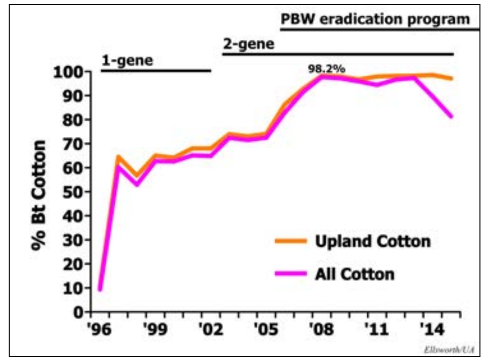
This is because management practices for one pest must be fully integrated and compatible with the practices for other key pests.



Chemical controls for Lygus prior to 2006 were all very broad spectrum and potentially damaging to the natural enemies we were seeking to conserve for whitefly management. But in 2006 after years of development, we introduced flonicamid (i.e., Carbine), a fully selective feeding inhibitor to control Lygus such that natural enemies were conserved for whitefly (and secondary) pest control. [In 2012, a second, very effective & selective Lygus control agent was introduced, sulfoxaflor or Transform, that solidified our selective approach.]



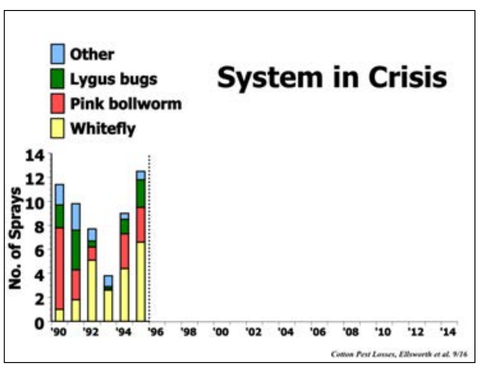
As we all know, the cornerstone to IPM is resistant varieties. It shapes the foundation for all else that we do in the production of cotton. Bt cotton first deployed in 1996 for us in Arizona has been an all-important selective control tactic for pink bollworm, our key lepidopteran pest. However, as that cornerstone, it also serves us in whitefly (and other pest) management by enabling even greater opportunity for conservation of natural enemies and biological control.



1-gene Bt cottons were deployed in the U.S. now more than 20 years ago, followed by 2-gene Bt cottons in 2003 (and Roundup Ready Flex cottons in 2006). And, starting in 2006, growers in AZ and later throughout western U.S. cotton and northern Mexico, began a cooperative program for eradicating PBW from our system.

There have been no grower sprays against PBW since 2007 (or program sprays since 2008). The last moth recovered was in 2012.

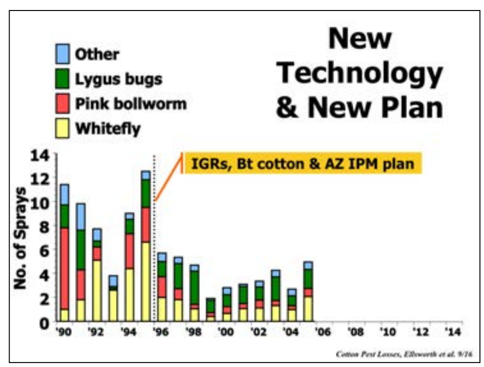
Bt uptake peaked in 2008 at more than 98% of all cotton planted (upland and Pima cotton species). Bt is not a trait available in Pima cotton and PBW pressure is one of the reasons why Pima cotton faded from the AZ landscape 20 years ago and today is returning as a result of functional eradication of PBW.



Let's review this history in terms of statewide average number of sprays in the context of the advances already noted.

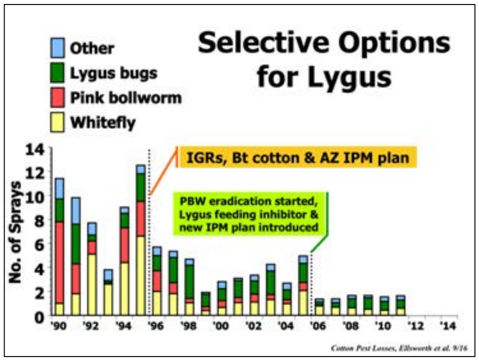
The early 1990s was reeling after a historic PBW outbreak and the introduction of a new invasive whitefly species. This was a system in crisis.

Adapted from Naranjo & Ellsworth 2009, & Ellsworth, unpubl.



In 1996, we gained IGRs for whitefly management, Bt cotton for lepidopteran control, and developed a new Arizona IPM Plan. These advances in "selective" technologies and approaches to insect pest management were based on our need to better manage and conserve the natural controls in our system, such as predators of whiteflies.

Adapted from Naranjo & Ellsworth 2009, & Ellsworth, unpubl.



In 2006, we saw deployment of a selective Lygus feeding inhibitor [flonicamid (Carbine)] and the cotton industry banded together to develop a major pink bollworm eradication campaign.

Under this new IPM plan, growers and pest managers throughout the state saw a continued lowering in the need for foliar insecticides for all insect pests, halving it once again relative to the previous period.

These advances in "selective" technologies and approaches to insect pest management were based on our need to better manage and conserve the natural controls in our system, such as predators of whiteflies.

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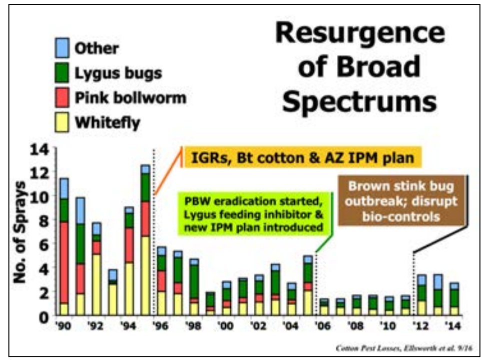
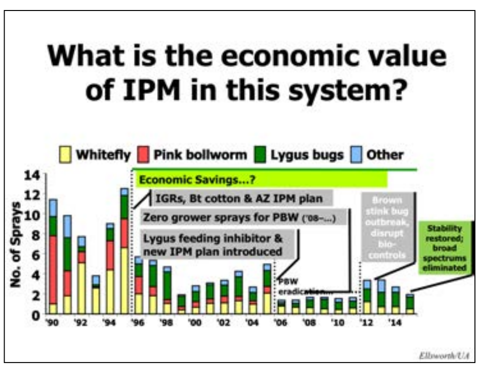


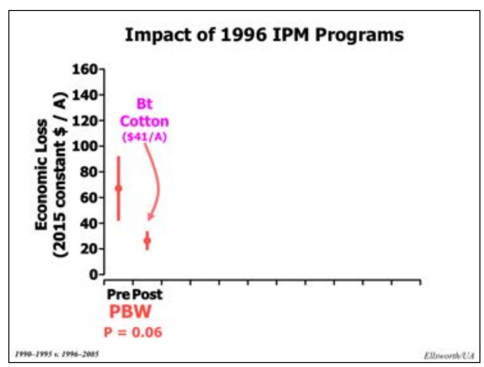
In 2012, we see an increase in the use of broad spectrum insecticides in response to elevated populations of the brown stink bug (Euschistus servus). In many areas, the use of broad spectrum insecticides disrupted biological control and led to resurgences of whiteflies and outbreaks of mites.



And in 2015, after integrated, empirical and economic research, and a campaign to show growers that current, broad spectrum chemical controls were not only ineffective but uneconomical against BSB*, we have restored stability to the system and seen a concomitant reduction in the total number of sprays deployed to manage arthropod pests.

So what is the value of all this IPM innovation and the development and deployment of both soft and hard technologies in Arizona cotton?

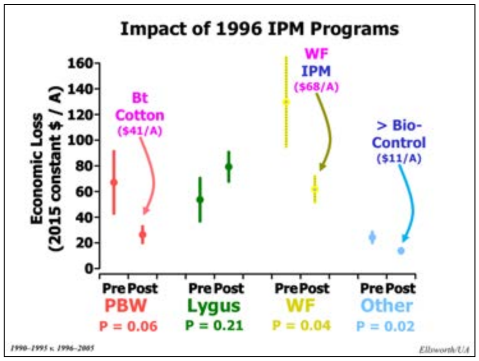
***L. Brown, Toews, Frisvold, Naranjo & Ellsworth, unpubl.**



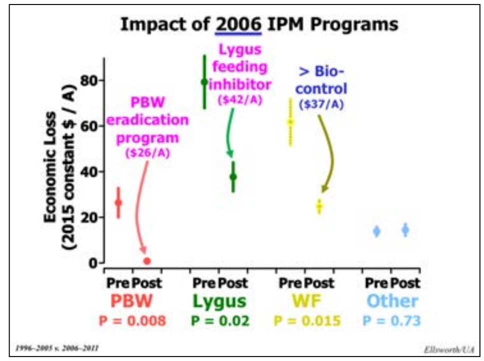
Comparing periods of time through history, we can examine each pest of cotton and ask the question of whether our IPM programs were coincident with the gains made in pest management.

This chart shows "Economic Loss" in 2015 constant dollars per acre by pest for a 6-yr period both before and after the introduction of our 1996 IPM program. There is a significant reduction in economic loss after the introduction of our IPM programs. For PBW, $41 per acre was saved in our system (but exclusive of gene technology).

[No gains were made in Lygus management during this period.]



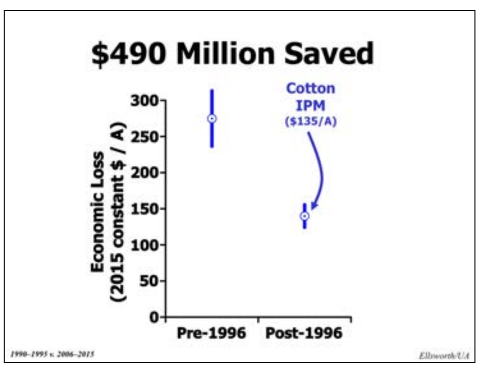
During this same period, we also see a $68/A gain to our growers in whitefly management. Again, some might point to the coincident deployment of the whitefly insect growth regulators, buprofezin and pyriproxyfen, and suggest "they" alone were responsible. However, the conservation of natural enemies made possible by the reduced / eliminated spraying for whiteflies & PBW along with the IPM plan taught to growers at the time was also contributing to these major advances in whitefly control. There were also significant economic gains in management of all other insect (and related arthropod) pests, with no associated "hard" technology deployed. Why? We suggest that this was due to the overall IPM plan, as designed, which was enabling natural forces including conservation biological control to better hold secondary pests in check.



Fast-forwarding 10 years to 2006 after progressive improvements to the system, we see additional gains made by our growers. $26/A more was gained in PBW management and some might suggest this was due to historic adoption of Bt cotton and the PBW eradication program*. $42/A more was gained in Lygus management; some would suggest that this was because of deployment of a Lygus feeding inhibitor.

But what about whitefly management? No specific products were introduced at this time. Why then was there a gain of more than $34/A? <u>What</u> was the intervention made here? We suggest it is the additional biological control made possible through reduced spraying practices enabled by adoption of selective control technologies.

***Exclusive of Bt technology and eradication program costs.**



The gains through history since major adoption of both 'soft' and 'hard' technologies are very large for this industry sector. We estimate that since 1996, Arizona cotton growers have saved over $490,000,000 through the 2015 cotton season, or ca. $135 / acre.

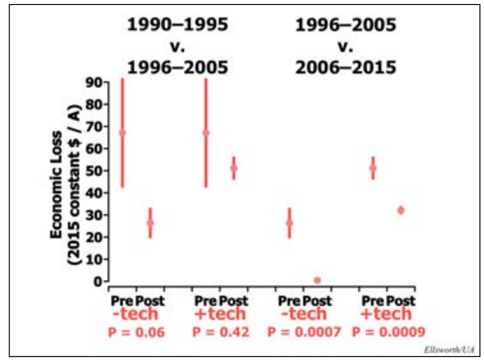
[This estimate does not attempt to incorporate the additional benefits of preserving an economy and culture that may not have been possible if not for the advances made at the time.]

What we have learned from this effort is that contemporaneous measurement of behaviors and the condition of the industry enables our ability to quantify, understand and explain progress made and gaps remaining in our growers' IPM plans.

It also provides us the opportunity to develop scientifically defensibly insights into the impact of component technologies, both soft and hard, and the overall IPM systems developed through history.

But really, the greatest benefit is being able to tell a powerful, compelling story that energizes our stakeholders and quickly conveys to broad audiences, even ones unfamiliar with farming, science or economics, why they should care about the science and technology applied to agriculture. In the process, we hope it helps dispel myths about technologies and how they are used to benefit society.

We thank the supporters and collaborators of our research and outreach programs, who are many and span many years!



Postscript:

The costs of spray technologies were discounted in each economic analysis to reflect what growers saved in sprays. The costs of the GM technology, in this case 'Bt', were not shown in this presentation as the estimates of these costs are somewhat tenuous and intractably linked and bundled later on in history with herbicide resistance technologies provided in seeds. Nevertheless, this chart shows our estimates of savings to growers both without (left) and with Bt technology costs (based on user surveys) included (right) for the two periods under study (left half and right half). This shows that initially the costs of Bt technology (paid to technology providers) was similar to the costs of spraying against PBW prior to the introduction of Bt cotton.

REFERENCES

Ellsworth, P.C. & J.L. Martinez-Carrillo. 2001. IPM for Bemisia tabaci in North America: A Case Study. Crop Protection 20: 853–869. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.485.6712&rep=rep1&type=pdf

Ellsworth, P.C., J.C. Palumbo, S.E. Naranjo, T.J. Dennehy, R.L. Nichols. Whitefly Management in Arizona Cotton 2006. IPM Series No. 18. University of Arizona Cooperative Extension Bulletin, AZ1404, 5/2006. URL: *http://cals.arizona.edu/pubs/insects/az1404.pdf*

Ellsworth, P.C., J.W. Diehl & S.E. Husman. 1996. "Development of integrated pest management infrastructure: A community-based action program for whitefly management." In D. Gerling, ed., Bemisia 1995: Taxonomy, biology, damage, control and management. 448 pp. An invited, refereed book chapter reporting original work to the Bi-National Agricultural Research and Development (BARD) International Bemisia Conference, Shoresh, Israel. pp. 681–693.

Naranjo, S.E. & P.C. Ellsworth. 2009. Fifty years of the integrated control concept: moving the model and implementation forward in Arizona. Pest Management Science, 65: 1267–1286. http://onlinelibrary.wiley.com/doi/10.1002/ps.1861/full http://afrsweb.usda.gov/SP2UserFiles/person/4056/NaranjoEllsworthPMS2009.pdf

Naranjo, S.E. and P. C. Ellsworth. 2010. Fourteen years of Bt cotton advances IPM in Arizona. Southwest. Entomol. 35: 437-444. http://www.usmarc.usda.gov/SP2UserFiles/person/4056/NaranjoEllsworth%20SWE2010.pdf

Naranjo, S.E., P.C. Ellsworth, George Frisvold. 2015. "Economic Value of Biological Control in IPM of Managed Plant Systems." Annual Review of Entomology 60: 1–25. 10.1146/annurev-ento-010814-021005 http://www.annualreviews.org/doi/pdf/10.1146/annurev-ento-010814-021005 http://www.annualreviews.org/eprint/uskgNdQRRXNHC3xTRFd3/full/10.1146/annurev-ento-010814-021005

Palumbo, J.C., P.C. Ellsworth, T.J. Dennehy, & R.L. Nichols. 2003. Cross-Commodity Guidelines for Neonicotinoid Insecticides in Arizona. IPM Series 17. Publ. No. AZ1319, 4 pp. http://hdl.handle.net/10150/146722

Tabashnik, B. E., M. S. Sisterson, P. C. Ellsworth, T. J. Dennehy, L. Antilla, L. Liesner, M. Whitlow, R. T Staten, J. A. Fabrick, G. C. Unnithan, A. J. Yelich, C. Ellers-Kirk, V. S. Harpold, X. Li and Y. Carrière. 2010. Suppressing resistance to Bt cotton with sterile insect releases. Nature Biotechnology, 28(12), 1304-1307. DOI: 10.1038/nbt.1704

Tabashnik, B.E., S. Morin, G.C. Unnithan, A.J. Yelich, C. Ellers-Kirk, V.S. Harpold, M.S. Sisterson, P.C. Ellsworth, T.J. Dennehy, L. Antilla, L. Liesner, M. Whitlow, R.T. Staten, J.A. Fabrick, X. Li, and Y. Carrière. 2012. Sustained Susceptibility of Pink Bollworm to Bt Cotton in the United States, GM Crops., 3(3). 1-7. doi: 10.4161/gmcr.20329 Full article: http://dx.doi.org/10.4161/gmcr.20329