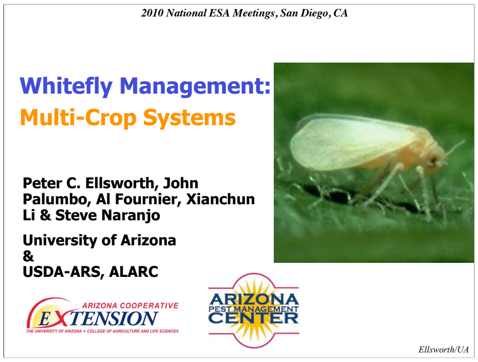
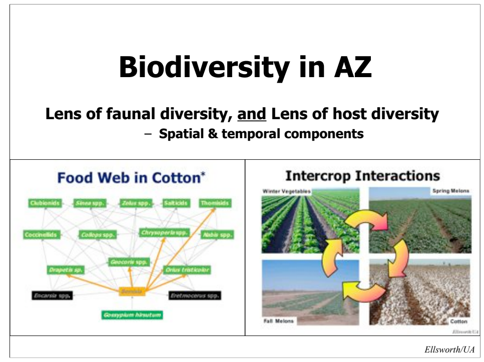
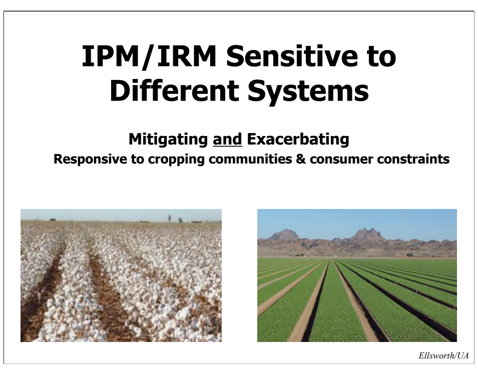


The programs I will be covering represent significant collaborations among labs that span the University of Arizona and USA-ARS. I would like to acknowledge the additional authors, Dr. Al Fournier, Dr. Xianchun Li, and Dr. Steve Naranjo, as well as my co-author, Dr. John Palumbo.

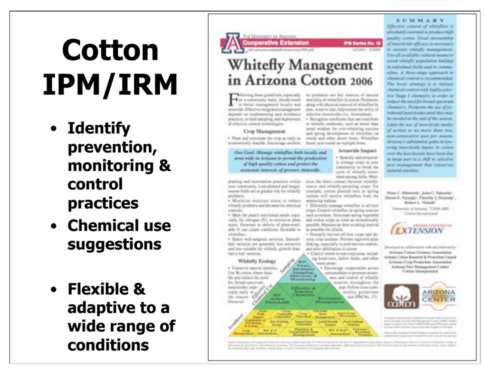
IRAC Symposium, 20 minutes, 45



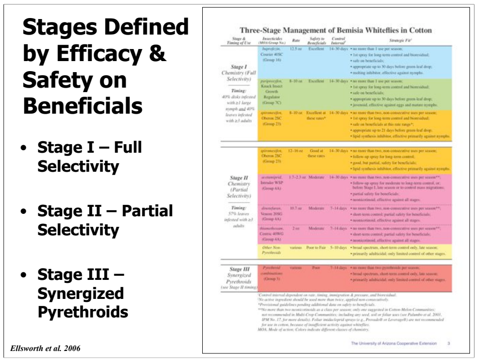
The theme of this symposium and indeed of the ESA meetings overall is "biodiversity". There are multiple ways in which to view this topic. Today I will view it through a lens focused on host diversity as has been touched upon by others during the first half of this session, as well as through a lens focused on faunal diversity. In each case, there are strong spatial and temporal components that are also operational.



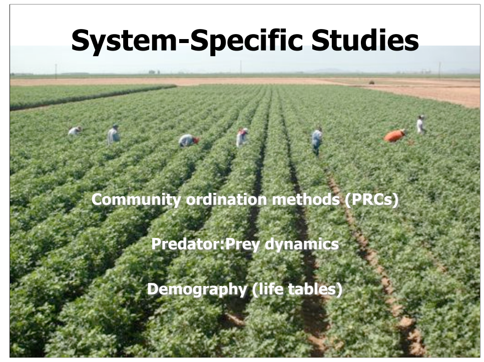
Our IPM/IRM programs in Arizona have been developed with sensitivity towards the different systems in which they are to be deployed here. In some cases the biodiversity mitigates pest issues and other times it exacerbates pest issues. It should not be assumed that all diversity is good diversity, as is often the default assumption. Whiteflies, ***Bemisia tabaci*** (biotype B), serve as an excellent case study in how biodiversity interacts with the control system.



Let's start with the Bemisia – cotton system in Arizona. We have developed guidelines which have been continually refined and taught to growers regularly in my Extension program. They focus on prevention, monitoring and control practices and include detailed chemical use suggestions, which highlight the effective and selective use of key insecticides.

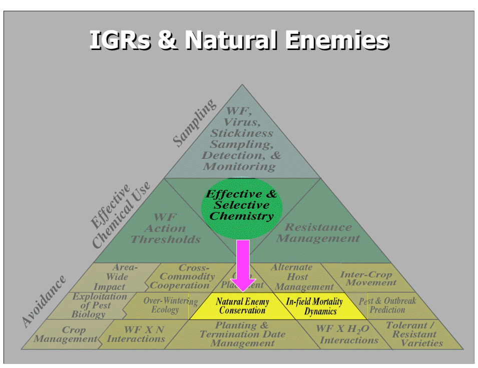


As part of our IPM program, a 3-stage chemical use plan for whitefly control identifies chemistry based on efficacy and selectivity attributes, with the ultimate goal of exploiting selectivity as much as is possible. It does not mandate a sequence but suggests more selective approaches will create more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

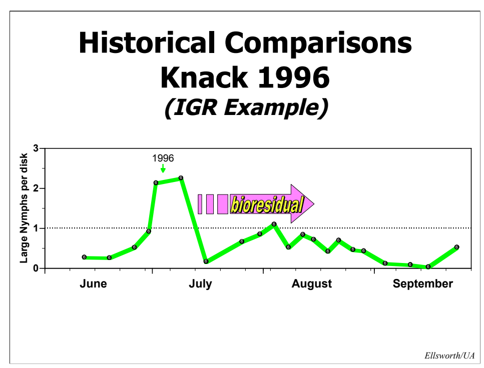


Over many years, we have conducted ecosystem-specific studies and used various approaches to identify the presence and function of natural enemies and the impact of all mortality factors.

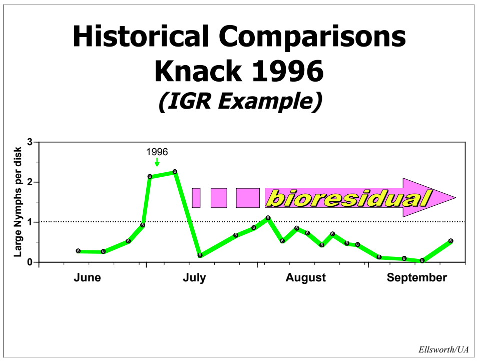
These include community ordination methods that permit the analyses of whole NE communities and construction of Principal Response Curves (PRCs); exhaustive surveys of canopy arthropods and whitefly densities to develop predator:prey ratios; and demography. From these data, we constructed life tables that tell us what mortalities are operational and which ones are most influential in population regulation.



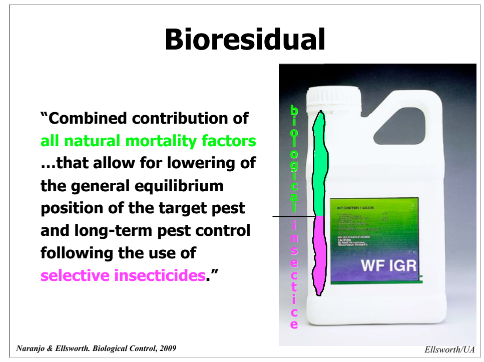
In AZ, we have shown that when selective options are available and effective, huge gains in both target and collateral control can be achieved due to much better natural enemy conservation and other natural mortalities. This ecosystem service is a foundational element of "Avoidance," and one made compatible with the these specific and selective chemical controls in our system.



We first demonstrated this "integrated control" (sensu Stern et al. 1959) with the insect growth regulators, pyriproxyfen (Knack) and buprofezin (Courier). Our IGRs are the classic example of selectivity in action. We've been running commercial scale demos for years, starting in 1996 with the whitefly IGRs. In this one example with Knack (pyriproxyfen) in 1996, we can see that we reached threshold (1 large nymph per disk or 40% infested disks), sprayed, densities continued up for a time, and then the population collapsed. We know from our studies that the chemical effects of Knack last only a few weeks at best, but…



… through the action of predators especially, and other natural sources of mortality, the whitefly population is maintained below threshold well beyond the known period of chemical residual. We term this extended suppressive interval present in a selective system, "bioresidual". We coined this term to better communicate with growers and to accommodate all the mortality processes present in a selective system, not just those related to conservation biological control.

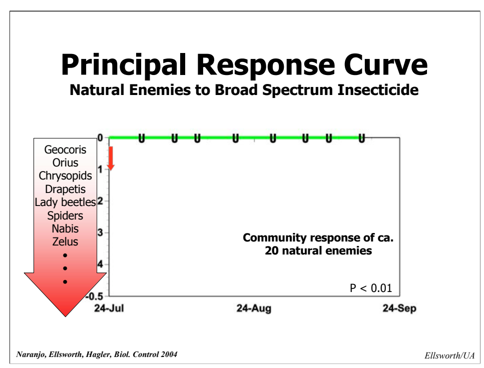


Specifically, we define bioresidual as follows:…

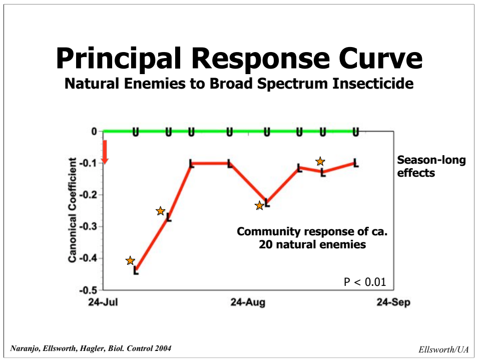
In teaching this concept to growers, I used a familiar icon as a metaphor, the IGR jug. In essence, our work showed that about half of the control interval could be directly attributable to the toxic growth-regulating effects of the IGR, while the other half was due to the biological or ecological sources of mortality that are in place already but are made more effective by the selective reduction of the previously "out of control" host, the whiteflies.

This has been a powerful metaphor for explaining why one might refrain from mixing IGRs with less selective materials. I.e., it is tantamount to dumping out half of the contents of the IGR jug.

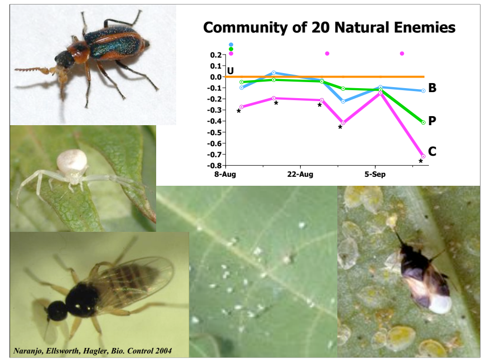
Conservation biological control is central to the regular function of the bioresidual. However, each day or week extended when a broad spectrum insecticide is not needed, increases the chance that fields will be affected by storm activity, like our monsoon-associated haboobs in Arizona. These haboobs have measurable, direct effects on whitefly adults and immatures (eggs and nymphs). That is, they cause direct mortality to whiteflies by scouring the leaf surfaces with wind, dust and rain. So weather and other abiotic factors also contribute to the bioresidual of the system.



One way to validate a selective approach is to measure and analyze whole community responses. 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. 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…

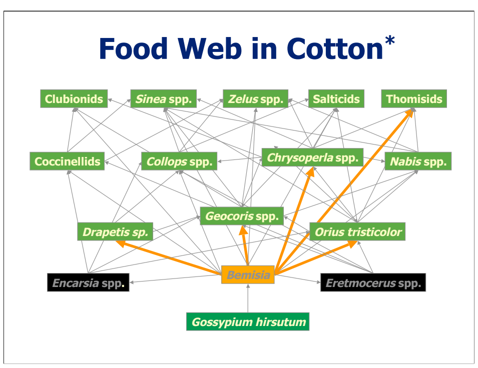


…What we see is a dramatic and immediate lowering of the density of these natural enemies in comparison to the UTC. What is more sobering is the duration and significance of this effect, all the way out to 7 weeks post-treatment. These season-long effects have grave consequences in the control of many other primary and secondary pests, as well as Bemisia and Lygus. So having potentially selective options to reduce the risks of natural enemy destruction is quite important to us.



Without dwelling on the data for each year, let me say that the PRCs show convincingly that sparing usage of IGRs (often just one spray) provided equivalent control as multiple sprays of broad spectrum insecticides, but also conserved a whole suite of natural enemies important in the control of whiteflies and other pests. Conventional chemistry, the purple line, significantly lowered densities of all predators.

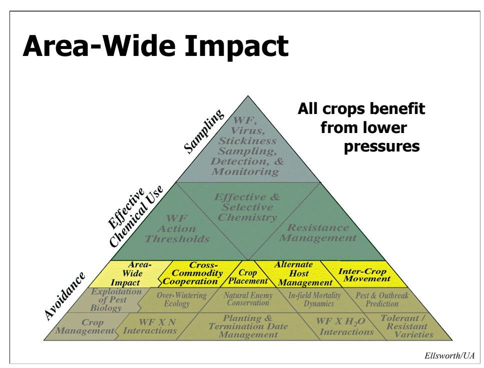
Because we are working in a very dynamic system, in some years 1 set of species may drive the PRC, while in other years another set of species drives the relationship.



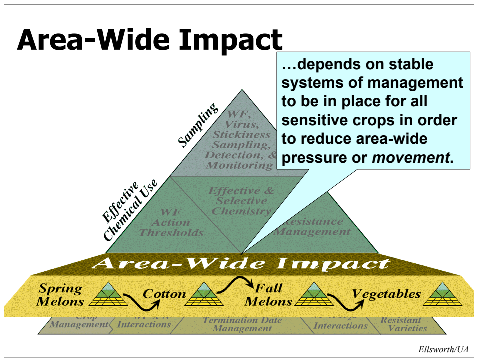
3–5 species dominate the PRCs each year.

These analyses documented the presence and abundance of a large web of natural enemies, that flexes and compensates in dynamic ways to sustain this key ecosystem service in cotton.

Additional studies confirmed the function of these key NEs in the control of Bemisia in cotton.

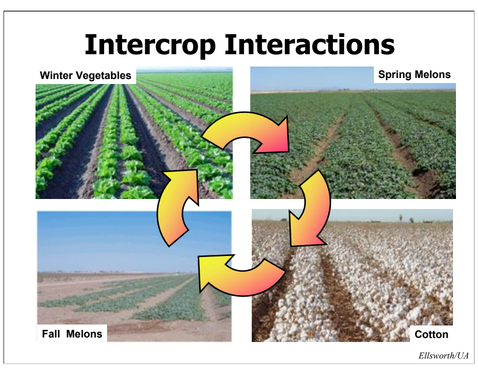


Since Bemisia is an extreme polyphage, our goal is to achieve an areawide impact on populations of ***B. tabaci*** such that all crops benefit from lower pressures on their crops.



Such a system requires stable management to be in place for all sensitive crops. And this requires that we proactively manage susceptibilities in our whitefly populations.

As we shift our focus from faunal biodiversity in the cotton system, to cropping biodiversity that includes intensively managed leafy vegetables and melons, the picture that emerges calls for consideration of producer constraints. John Palumbo and Steve Castle coined the term "the produce paradox" when examining management systems for these crops.



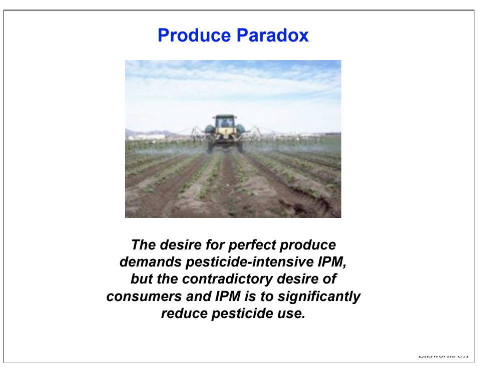
In AZ, our desert ecosystem is transformed by water into a very complex agroecosystem. AZ's year round growing season provides for a sequence of crop plants, winter vegetables like broccoli, lettuce, other cole crops, spring melons (esp. cantaloupes), summer cotton, and fall melons. These crop islands provide for perfect habitat for whiteflies, and our focus has been on the intercrop interactions that are possible with this pest and that demand a high level of integration in our IPM programs.

Photo credit: JCP

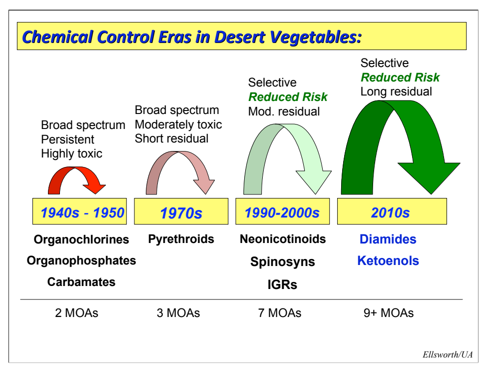
Palumbo & Castle (2009) have asked this key question. Practitioners will readily tell you that NEs are unreliable sources of damage prevention.

Furthermore, even if they were good and timely suppressors of pest populations, they themselves become sources of contamination in produce, which is considered unacceptable by the marketplace.

Ultimately "quality" is paramount in this market sector. Consumers routinely refuse any level of contamination in their leafy vegetables, leading to a virtual "zero tolerance" in the management of arthropods in AZ produce.

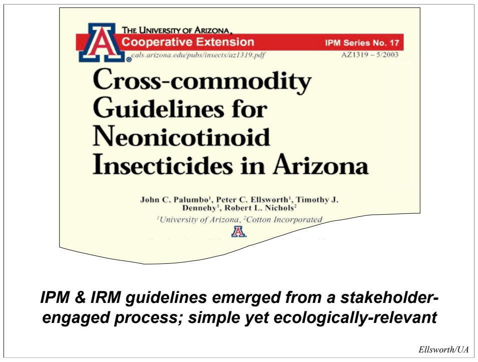


The paradox is this. We wish to have perfect produce, which demands a pesticide-intensive approach. Yet, consumers will also cite the need to significantly reduce pesticide use. The situation creates extreme difficulty for the produce grower and the pest manager.



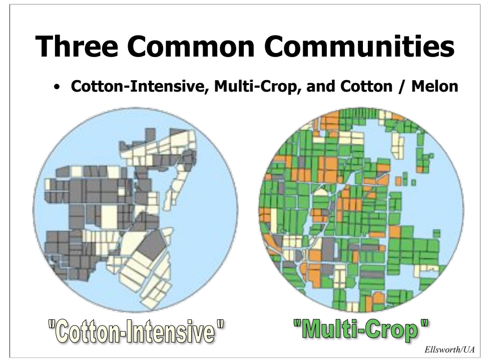
There is much to consider in this slide; however, focusing just on the bottom line with respect to Bemisia, we have seen an explosion of MOAs available to us for the control of whiteflies. And in short, the "strategy" of the produce sector is simply to out-run any potential problems with resistance.

And these innovations in development of control chemistries have thankfully been accompanied by positive trends in selectivity and risk reduction.



So with this in mind, we determined that neonicotinoids, initially represented only by imidacloprid, were keystone to our system.

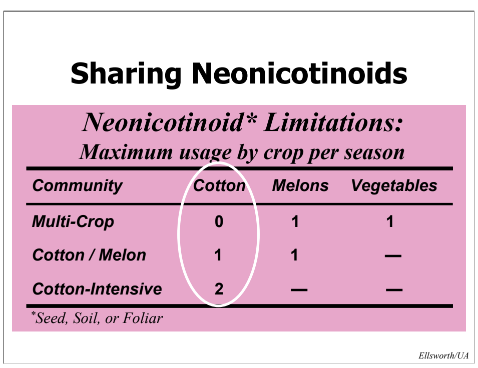
The specifics of the stakeholder process are beyond the scope of what I can cover in this presentation. However, I can say that this was not a desktop exercise limited to 1 or 2 people. Instead, these guidelines, which were published and disseminated in 2003, were the result of a year-long, stakeholder-engaged process spear-headed and led by Dr. John Palumbo. And while we did not and never do have perfect data or information, by engaging clientele directly in the development of these guidelines, we were able to forge a very simple set of rules for neonicotinoid usage. Yet through understanding of our system spatially, we also have ecologically-relevant guidelines as a result.



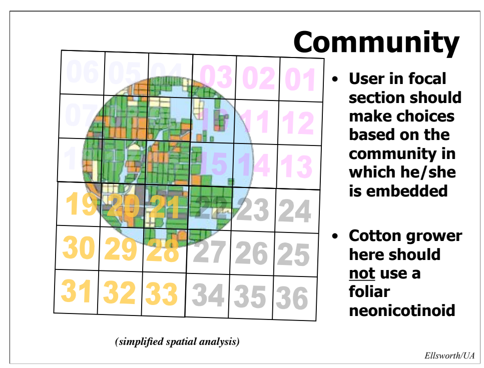
Neonicotinoids are critical to our whitefly control system. Yet real and perceived risks for resistance among growers of different crops within different communities in Arizona are not the same.

So rather than develop a single rule to be followed statewide, we attempted to develop guidelines that could be applied differentially according to cropping community and proportional to the inherent risks of whitefly problems and resistance.

Three cropping "communities" were identified and targeted for this approach: Cotton-Intensive, Multi-Crop, and Cotton/Melon (not pictured). White = cotton; orange = melons; green = vegetables (mostly lettuce); and gray = non-treated and/or non-whitefly hosts (mostly small grains, corn, sorghum, and alfalfa).



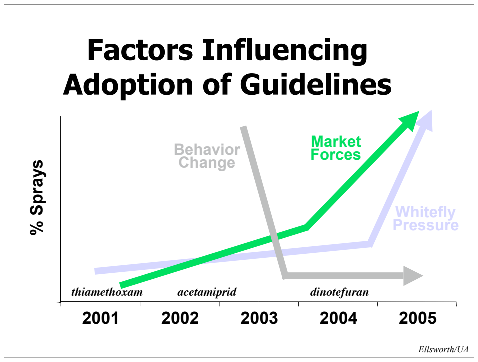
Under John Palumbo's leadership, we developed a stakeholder-driven set of guidelines that, in its simplest form, in essence, restricts neonicotinoids as a class to just two uses per cropping community. In a Cotton-Intensive community, growers of cotton there can use up to 2 non-consecutive neonicotinoids per season, while in Cotton/Melon communities, those two uses are shared between the cotton and melon grower. Perhaps most controversial, in the Multi-Crop community, the cotton growers there forego any usage of this chemical class, reserving the two uses to melon and vegetable growers there who are so dependent on this class for their whitefly control.



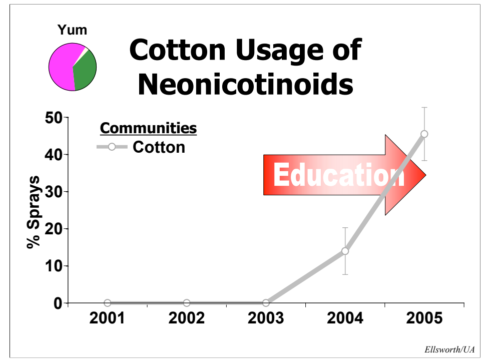
In this project, we examined communities and the section level pesticide records for those areas. In specific, we examined neonicotinoid use by cotton growers in each of the 3 community types defined by the guidelines. Can a grower perceive "resistance risk" properly in his/her area and follow the applicable guideline?

I.e., A user in a focal section should be making whitefly control product choices based on the community in which he or she is embedded.

Note this is a simplified spatial analysis of Section-level percentage averages in cotton only. So, for example, we will estimate the % of sprays made in a section that contain a neonicotinoid or other insecticides.

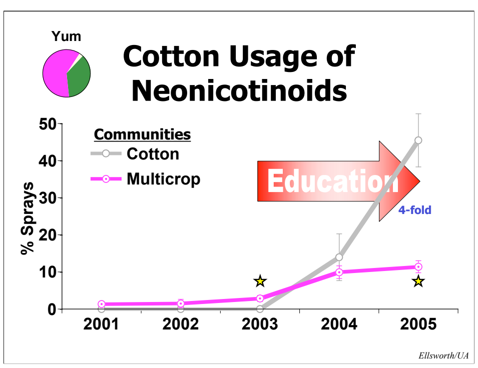


Documenting changes in behavior through time requires a clear understanding of competing forces & inherent change in the system. Market forces (new registrations) push users towards greater usage. In 2001, thiamethoxam was available, but by late 2002, acetamiprid became available as well. Still later (2004), dinotefuran was available to cotton growers. All the while, imidacloprid was available as a foliar spray either alone or in mixture with a pyrethroid. Whitefly pressures also change over time. In our case, pressures were low but increasing 2001-04 until 2005 when whitefly pressures were at a decade high. This pushes usage upward. Our impact on behavior should show some kind of decline in usage as a consequence of deployment of our educational programs for cotton growers in Multi-Crop communities, for example.



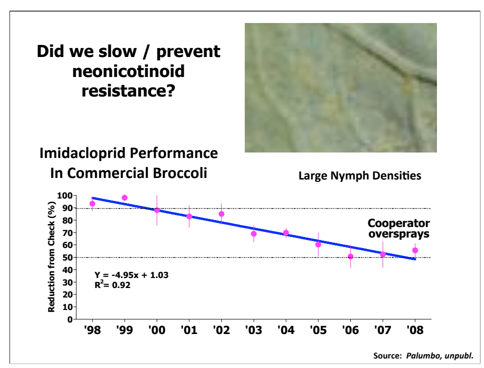
% Sprays that contained a neonicotinoid for cotton fields in Cotton-Intensive communities of Yuma Co. These growers should be limited to no more than two non-consecutive neonicotinoid sprays (gray line). Cotton neonicotinoid usage started at 0% in 2001-2003 and increased as acetamiprid use increased, topping out at ca. 45%.

Our guidelines were published in 2003 and our educational efforts were intense to begin with and then re-intensified in 2005 (red arrow).



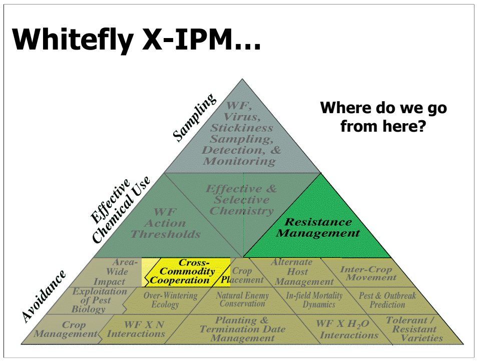
Cotton growers in Multi-Crop communities of Yuma Co. had very small usage of this class of chemistry in 2001-2002, and significantly higher usage in 2003. By 2005, the trend was reversed, presumably as a result of our education, showing a 4-fold reduction in neonicotinoid usage in comparison to cotton users in Cotton-Intensive communities.

Of course, the guidelines would have suggested no neonicotinoid usage in Multi-Crop communities. So ca. 10% of the applications made were at odds with the guidelines.



In short, perhaps not (!) at lease with respect to imidacloprid.

John Palumbo has been doing systematic examinations of imidacloprid efficacy (soil uses) in broccoli for the past 10 seasons. Charting efficacy relative to a control shows rather marked reductions in efficacy in these studies. While users don't widely report problems with this use pattern and soil uses, especially in fall crops, are still almost universally practiced, this is a warning sign that we must re-consider our management program and decide whether further steps are needed to stabilize the control system. A dialog is currently underway with clientele through our Cross-Commodity Research and Outreach Program working group.



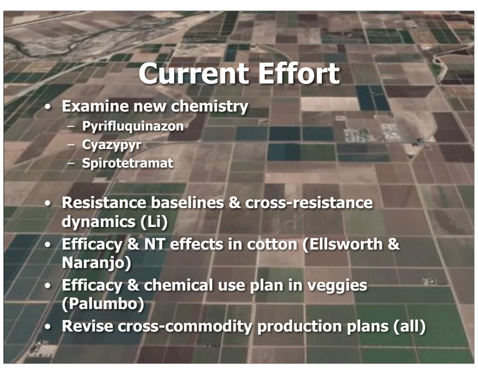
Singular attempts to deploy recommendations in one crop especially for a mobile, polyphagous pest seems futile, when registrations of key chemistries are broad across multiple crops. Thus, our cross-commodity effort concentrates on elements where we can integrate our practices across multiple crops. Resistance management is a shared responsibility that extends across commodity borders. Cross-commodity cooperation can be key to the sustainability of a resistance management plan, and in Arizona, as just shown, we have achieved some remarkable agreements among growers of several key whitefly crop hosts.

But where do we go from here?

The first thing that we do in AZ is listen to our stakeholders. This is a critical step in guidelines development, because without it, our recommendations may go forward ignored.

They tell us two things:

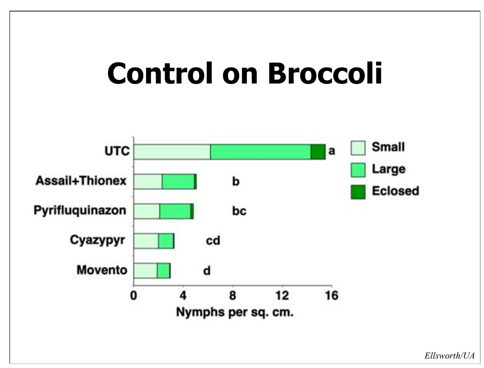
1) **Continue to strengthen management in cotton through integrated control practices, I.e., by leveraging natural controls; and,**
2) **Place more emphasis on development of overall production plans for produce that incorporates these new chemistries and helps growers diversify MOAs in use (as opposed to just developing IRM guidelines, *per se*).**



Our current effort is fueled by a USDA-Pest Management Alternatives Program grant. Our goal is to examine 3 key new chemistries and develop the knowledge base necessary to optimally deploy them in our multi-crop systems.

…

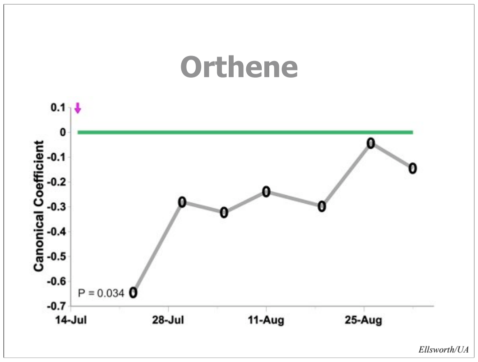
Our final objective will be to develop cross-commodity production plans that clearly outline the potential fit(s) for these chemistries in integration with other chemistries (esp. in produce) and with NEs (esp. in cotton).



Some quick results so far…

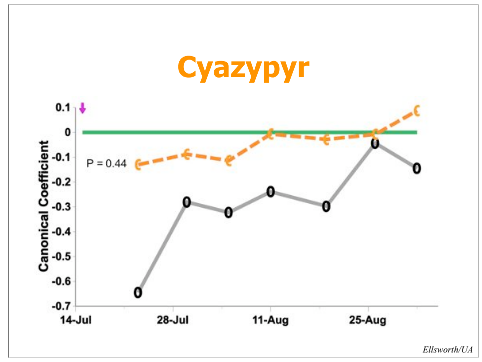
Dr. John Palumbo has shown that these three new chemistries are highly effective in the control of whiteflies in winter vegetables. Movento, in particular, is very effective in part because of its full systemicity when used foliarly.

Note the standard foliar neonicotinoid (acetamiprid = Assail, plus endosulfan).

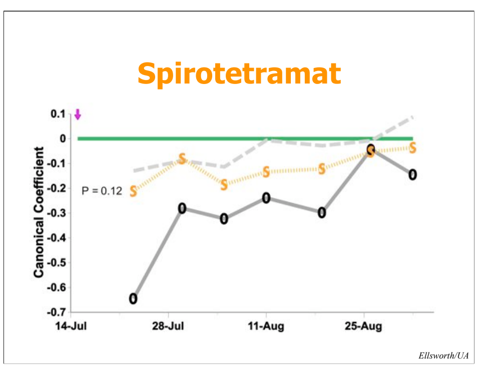


Looking again at our PRCs for usage of these chemistries in cotton:

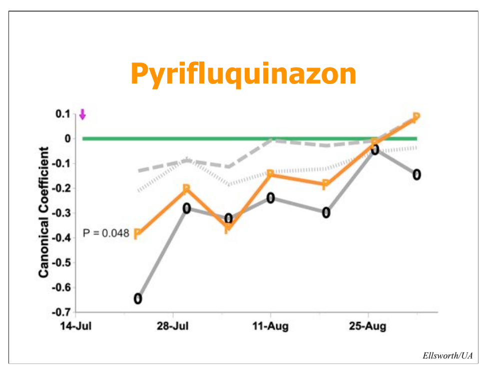
Orthene when used just once is highly destructive to the NE community present in our cotton system.



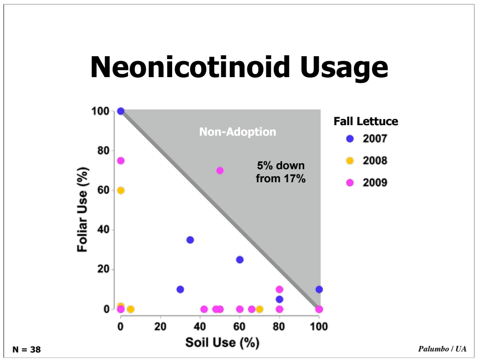
Cyazypyr, under development by DuPont, is not significantly different from the untreated check, suggesting excellent safety for our NE community.



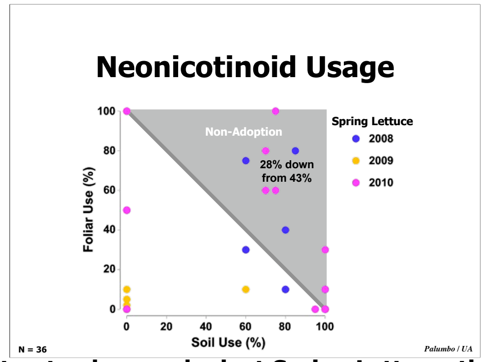
Spirotetramat or Movento also appears to be quite safe to our NE community.



Pyrifluquinazon, while very effective against *Bemisia* whiteflies, appears to be more damaging to the NE community, though not nearly as much as acephate (Orthene). These negative impacts appear to be driven largely in the first 3 weeks post-application.



Five years have past since our last set of x-commodity guidelines were assessed. Has compliance with recommended practice changed at all? One way to test this is to examine usage of foliar neonicotinoids over the top of soil neonicotinoid uses, a practice considered risky with respect to resistance and our guidelines (and even some labels). In this chart, we look at user responses in fall lettuce. Those points falling in the gray zone represent acreage that was most certainly treated twice with neonicotinoids. The non-adoption rate is just 5%! Furthermore, this is down from 17% measured 5 years earlier!

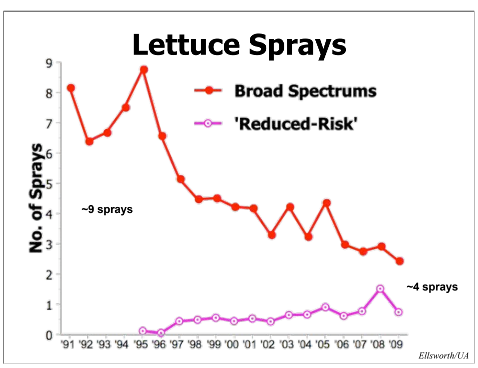


In contrast, when we look at Spring Lettuce, the non-adoption rates are much higher (28%), though still remarkably lower than what was measured 5 years earlier (43%).

So why more usage in the spring? Ostensibly because most pest managers are not thinking about whitefly control; they are treating with neonicotinoids for aphid control and don't perceive this as a risk to whitefly resistance.

Why are non-adoption rates down in both cases? Because, in part, they are doing what they had hoped to do; outrun resistance issues with new and more MOAs. Flonicamid helped in aphid control and now Movento (spirotetramat) has displaced much neonicotinoid usage in the spring.

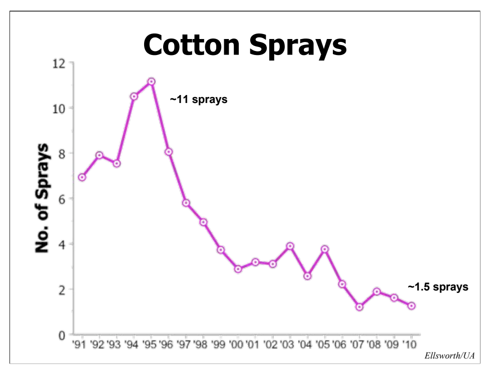
Perhaps, too, they listen to our recommendations!?



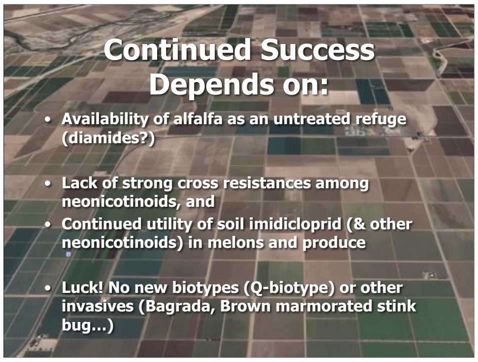
Through the Arizona Pest Management Center and in collaboration with the Arizona Dept. of Agriculture, we analyze collected pesticide records that are reported to the ADA.

Over the last 20 years, spraying in lettuce has gone down significantly from about 9 sprays to only about 4 sprays against all arthropod pests.

The character of those sprays has also changed drastically. Reduced-risk chemistries are now a larger and larger share of the insecticides used by lettuce growers.



The story in cotton has been even more dramatic. 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), and IGRs (growth & development inhibitors).



Our continued success depends on a number of factors, many of which I have not addressed directly in this talk:

Alfalfa is a huge whitefly untreated refuge. [However, diamides (Coragen) now has a label for use in alfalfa.]

So far, we have not detected strong cross resistances among our key neonicotinoids, esp. imidacloprid and acetamiprid.

And, paradoxically, imidacloprid remains effective (and cheap) enough in produce that it is almost always used in the fall.

Luckily, we've not experienced any catastrophic changes in our system such as due to the arrival of new invasive pests.

Thank you for your attention.

Thanks, too, to the many growers, pest control advisors and others who have already 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