Advances in Understanding Insect Dispersal to Improve Pest Management in Vegetable Crops

Successful Management Adapted to a Mobile, Polyphagous Whitefly Pest in a Diverse Cropping System

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Ellsworth/UA

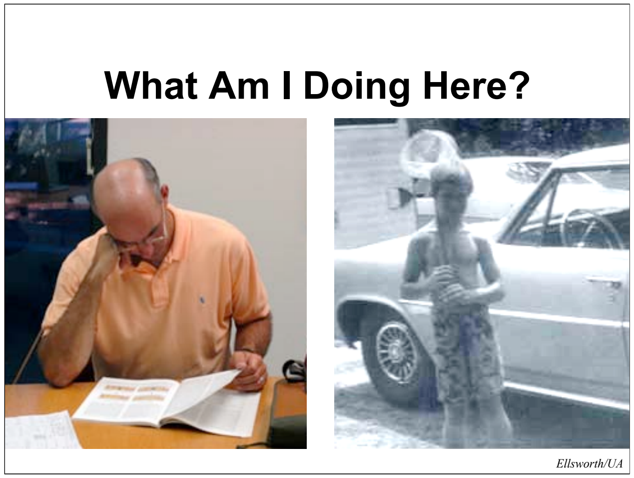
This presentation was invited by Brian Nault (Cornell University), as part of a Section F Symposium at Fort Lauderdale, FL, national ESA meeting.

What Am I Doing Here?

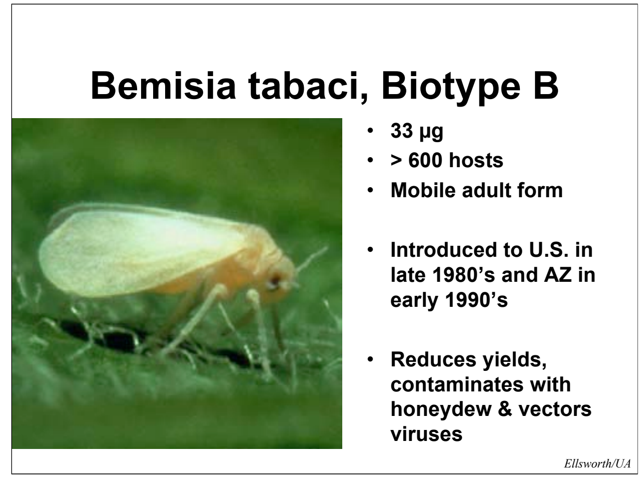
- **Vegetables?**
- **Dispersal?**

Ellsworth/UA

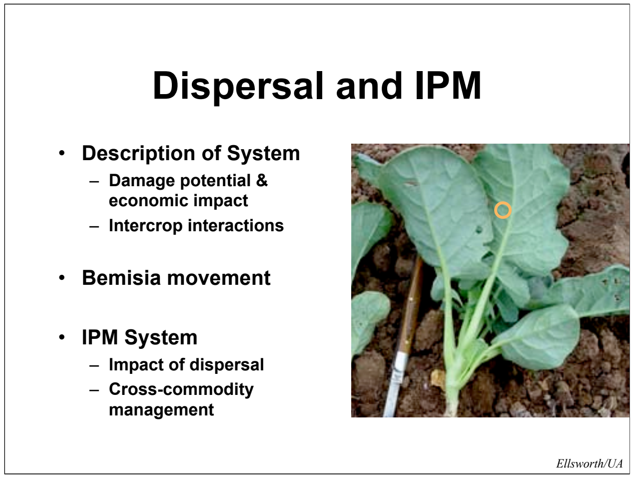
While I'm a well-trained and well-prepared entomologist, my efforts are not concentrated in the area of vegetable IPM nor in insect dispersal.



My co-author, Dr. John Palumbo, however, is eminently qualified as a vegetable entomologist, and is a major driver of the program I am going to describe today.



The 33µg heavy-weight is the reason that John and I have come together and the reason we have been forced to consider the dispersal potential of this pest in our system. Bemisia tabaci was introduced to the U.S. in the late 1980's and invaded AZ in the early 1990's, where near catastrophic losses were experienced throughout the agricultural sector.

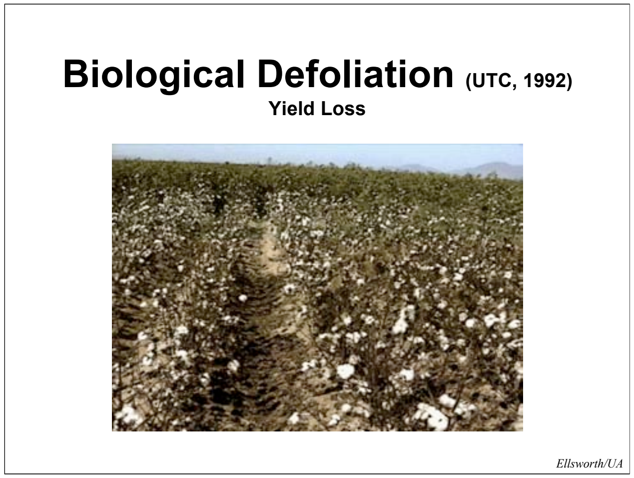


So today, I will spend considerable time describing our system, the damage potential and economic impact of this insect, and the influence of intercrop interactions. Then, I will spend some time reviewing the status of our knowledge of Bemisia movement and flight biology. I will conclude with a description of the IPM system that we have in place with emphasis on those elements that are impacted directly by insect dispersal. Finally, I will describe the system of cross-commodity management that we have progressively and proactively established in AZ to thwart this pest and the problems it presents.

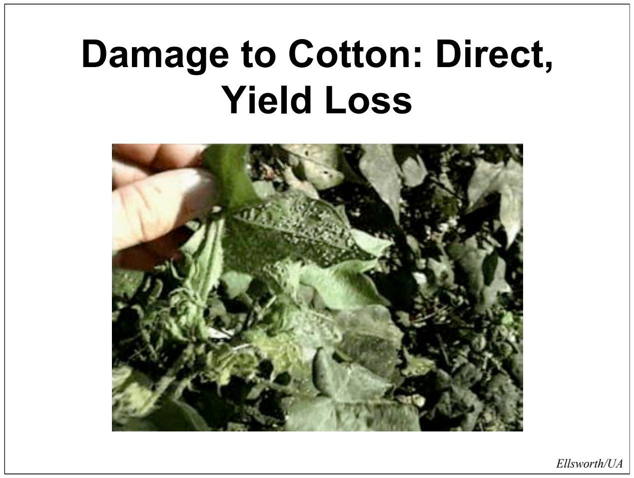
Photo credit: JCP

Vegetables, particularly those grown in the fall, are severely impacted by uncontrolled populations of B. tabaci. Reduced yields are common as seen in these lettuce plants, treated on the right, untreated on the left. Reduced quality in the form of sooty mold, as seen in the cantaloupes on the right, or in the form of reduced sugar content is also a major concern. However, lost markets can cause the greatest economic losses, for example when whitefly damage slows development of the plant such that a specific harvest window is missed because of delays in maturity; see cauliflower, middle and left.

Photo credit: JCP

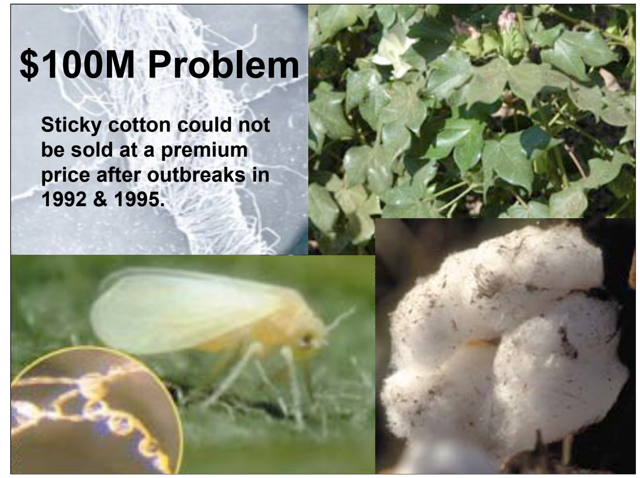


Damage to cotton comes in different forms, too. At its most severe, uncontrolled populations can biologically defoliate cotton plants, where these sucking insects have removed so much phloem sap that the plants prematurely senesce. [This video from 1992 shows my UTC plots being defoliated due to severe stress by whiteflies (B-biotype). Note: Danitol+Orthene in the background.]



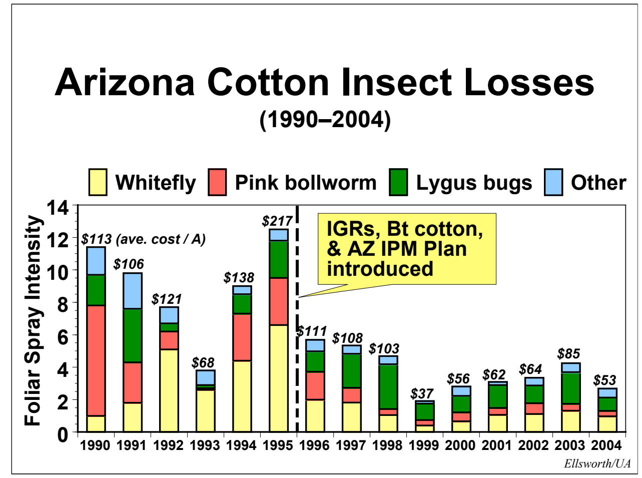
These direct yield losses occurred at rather high insect densities and while common in 1992 and then again in 1995, are rather rare scenes these days. However and unfortunately, densities far short of this are all that is needed to jeopardize lint quality…

Much more modest densities of whiteflies are all that is needed to deposit enough honeydew sugars to create risks of "sticky cotton". This type of damage is sufficient to have an area of production black-balled in the marketplace, making the sale of any cotton, clean or sticky, very difficult.

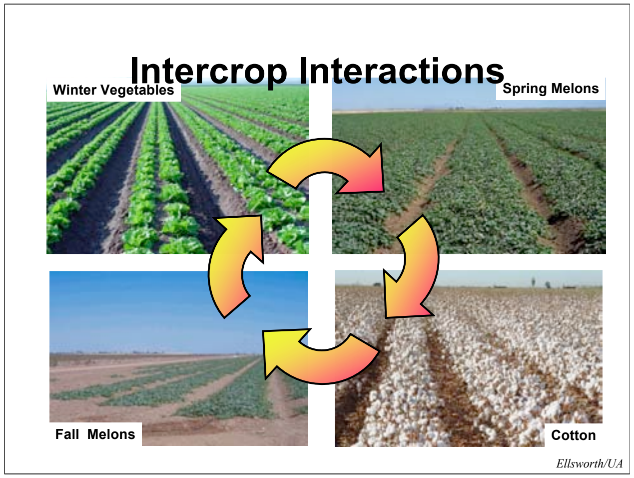


A 100 million dollar problem starts with honeydew dropping on leaves, and cotton fibers, and finishes (if it can be processed at all) with knotted fabrics or yarns (pictured in the background). All are of very low quality and generally undesirable. And most times, the lint cannot even be processed and worse yet causes costly shutdowns of modern mills for cleaning. At the grower level, local outbreaks that deliver sticky cotton to the marketplace are penalized indefinitely as being a "sticky" cotton area. Since the stickiness itself is not routinely or reliably measured, marketers play it safe by avoiding buying fiber from whole areas where previous episodes of sticky cotton have occurred. This has a chilling effect on cotton prices locally. [Photo credits: International Textile Center (Lubbock, TX), upper left, Lynn Jech (inset), USDA (wf), pce (remaining)].

Growers were subject to a double whammy. Losses due directly to this insect as well as in the increased costs associated with increased spraying. Desperate attempts to control this pest resulted in many, many sprays. When this animal arrived at our borders in the early 1990s, we did not know how or when to control it. The result was a great deal of indiscriminate spraying with very broad spectrum chemistries that were destructive to other advances in IPM and were, now we realize, counterproductive. For the grower, huge spray bills were all the motivation they needed to want to learn about the new whitefly management plan.



This chart details the statewide foliar spray intensity for all cotton pests, by cotton pest. The yellow stack represents the foliar intensity (~ sprays) to control whiteflies. 1992 was the first widespread outbreak year. We did not know how to control this pest. By 1995, over-reliance on a limited set of chemistries (mainly pyrethroids synergized with OP's) led to increased levels of resistance and reduced efficacies. However, 1996 was a watershed year for pest management. We introduced Bt cotton, which effectively provides for PBW immunity, and whitefly-specific insect growth regulators under Section 18s. We also introduced our new IPM plan in a comprehensive, organized educational outreach campaign. The results have been impressive with 1999 being the lowest foliar insecticide intensity in nearly 30 years. Whitefly control is now accomplished in 1-2 sprays season long.



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 was on these intercrop interactions that were possible with this pest.

Photo credit: JCP

Whiteflies do in fact fly, as is evident in this now famous slide showing "clouds" of whiteflies moving across a newly planted vegetable field in the Imperial Valley of California. This type of movement, aerial pressure if you will, produces a nearly impossible pest management situation.

One Man’s White-Fly…

Ellsworth/UA

However, vegetable growers are a perverse lot. Like no other, they reap huge gains when their fellow growers are suffering the ravages of this pest. “One Man’s White-Fly… is another’s ‘Gold-Fly’”, as was seen after 1991 when one Yuma grower was seen to have changed his license plate to reflect the high prices he rec’d for his production that year. So, despite our best efforts to develop and deploy efficient IPM programs, there is still this sort of relationship between production and profit in the highly competitive vegetable industry.

Whitefly Movement & Dispersal

Ellsworth/UA

So let’s consider movement & dispersal in this 33µg heavy-weight. There was a time when experts conjectured that they were nothing more than aerial plankton, aloft for very short periods of time, subject to the wind only, and never far from the ground.

What Do We Know?

From Byrne, Blackmer et al.

- Longer flights during morning hours in females, though flight is possible all day
- Females have greater rates of climb

- < 1 d old or > 7 d. old, flight muscles not adequately developed for flight
- Longer duration flights at 3 – 5 d of age
- Gravid females do fly, though > 4 eggs inhibits long-duration flights

Ellsworth/UA

What do we know about this subject? In AZ, Dr. David Byrne had been studying insect migration, especially in whiteflies, through the late 1980's and early 1990's. With a lab full of students and post-docs, most notably Dr. Jackie Blackmer (now of USDA-ARS in Phoenix), they developed the basis of our understanding movement in this pest species. Flights occur all day; females for even longer durations in the morning and with higher rates of climb. Flight musculature is immature or senescing in young and older individuals, respectively. Longer duration flights occur at adult age's of 3-5 d. Interestingly, females can and do fly while gravid without inhibition unless they contain more than 4 mature eggs.

Short-Range Migration

From Byrne, Blackmer et al.

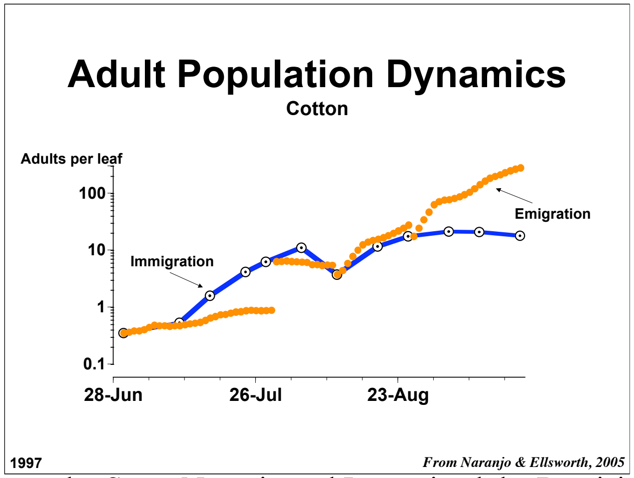
- < 5% have sustained flights > 2 hrs
- Ca. 6% exhibit behaviors consistent with migration
- After which, sustained flight (> 15 min.) required to respond to visual cues

- Heavily dependent on wind direction
- Mark / recapture of individuals up to 2.7 km
- Bimodal distribution with majority near source ("trivial" flyers) & some at ca. 2.2 km ("migrators")

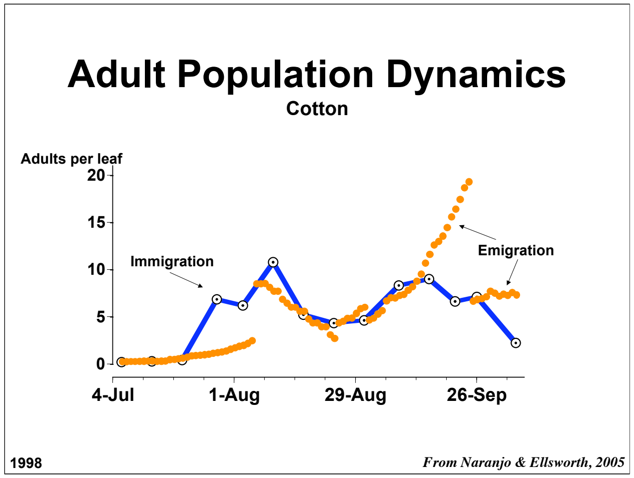
Ellsworth/UA

Byrne and others began to describe a phenomenon they labeled short-range migration, where less than 5% of the population carries out sustained flights in excess of 2 hrs, and around 6% exhibit behaviors consistent with migration (disinhibition; non-responsive to vegetative cues). This behavior was not abated until sustained flights of at least 15 minutes were taken.

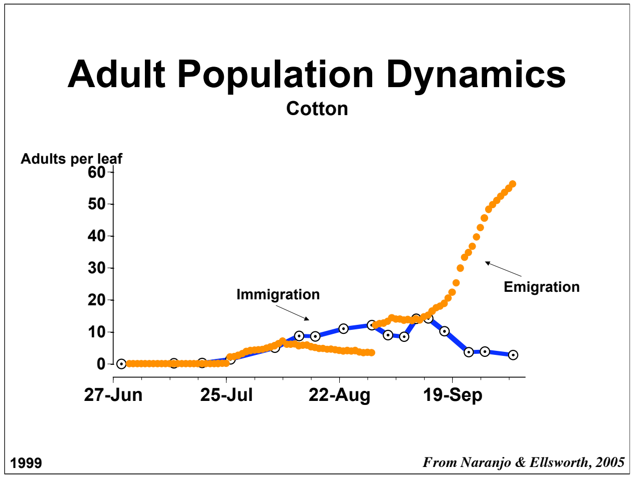
All of this work was the result of laboratory and vertical flight chamber studies. However, in a series of mark and recapture studies, Byrne et al. also found that their flight was heavily dependent on wind direction. Captures were made up to 2.7 km away from a source. Flight distributions showed two modes, one very near the source field and another some distance away, ca. 2.2 km.



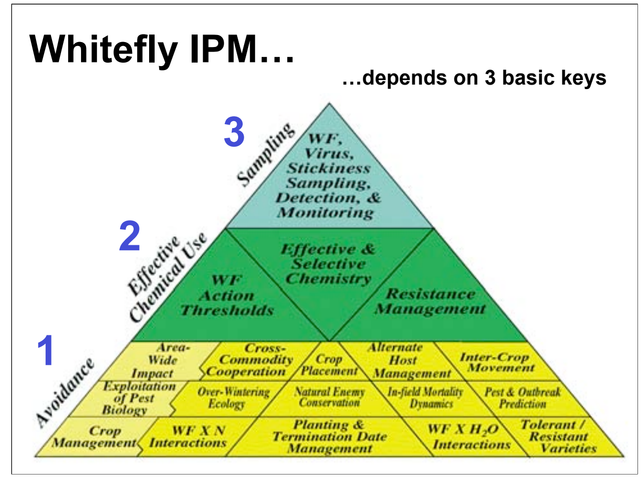
More recently, Steve Naranjo and I examined the Bemisia tabaci using life tables in cotton. We identified, described and quantified all sub-imaginal mortality factors. In these studies, we monitored population dynamics in unmanaged cotton. Here we see the number of adults per leaf in blue. When we run a whitefly simulation model using the identified mortality rates and bio-fixes for each generation studied, we initially see exceptionally good agreement in the predicted adult levels. However, eventually we see that the actual densities of adults track higher than what was predicted. We hypothesize this as the impact of immigration into the system. Still later, in-season, we note very good agreement between the simulations and the actual densities, suggesting that the populations are residential in cotton. However, late in the season during a time when cotton is approaching physiological senescence (I.e., cut-out), we find that the simulated densities are in excess of what is actually in the cotton field. We hypothesize this as being emigration from the system.



This relationship held up over years and over a wide variety of conditions and adult densities.

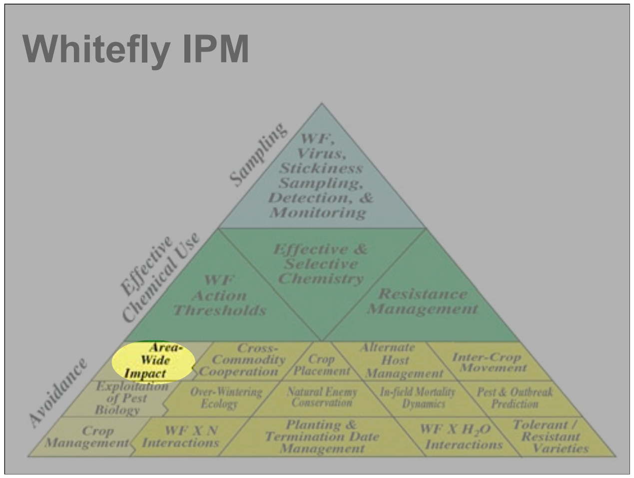


From Naranjo & Ellsworth, Entomologia Experimentalis et Applicata, 2005.

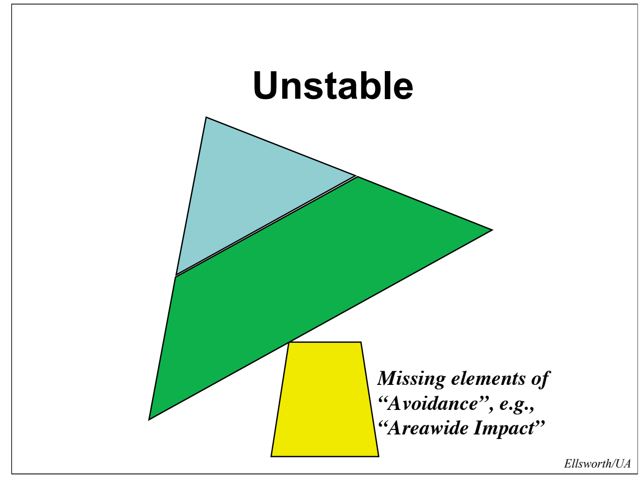


Using a pyramid metaphor, let's look at what was and continues to be our operational IPM plan. At its simplest, it is just 3 keys to management, Sampling, Effective Chemical Use, and Avoidance. One can break this down further and examine each building block of the pyramid and see an intricate set of interrelated tactics and other advances that have helped to stabilize our management system.

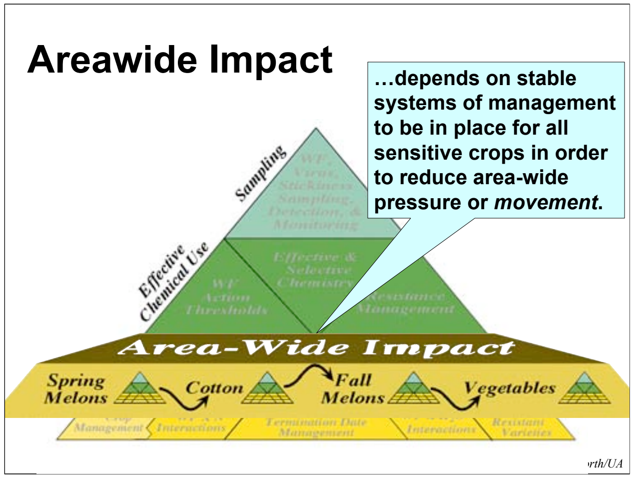
Dispersal impacts a number of these elements. Even things like our sampling plans, our action thresholds, and the efficacy of our chemistry was impacted, however…



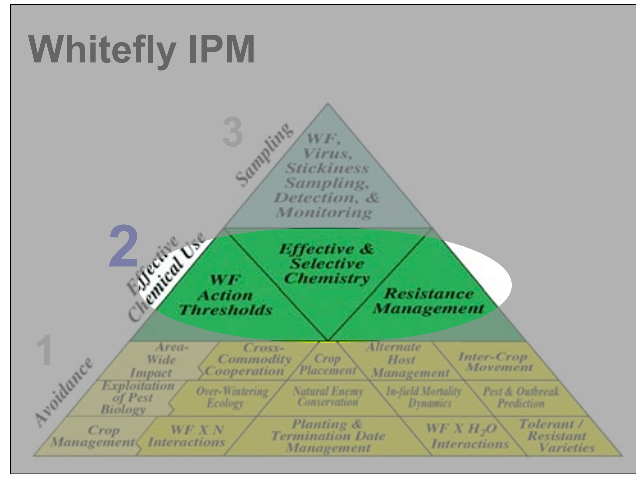
For the purposes of this talk and of this symposium, I will focus my comments on those elements that constitute “area-wide impact” within our system.



Clearly, we believe that a solid foundation in “Avoidance” is needed to stabilize our management system. Elements of area-wide impact are directly affected by this insect’s movement potential.

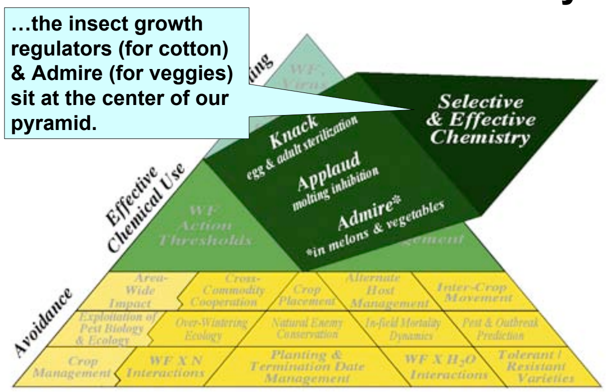


A well conceived IPM program for vegetables or for any one crop is not enough to manage whiteflies sustainably in complex cropping systems. In parts of Arizona, spring melons might be followed by cotton, followed by fall melons, and later winter vegetables, though not necessarily on the same piece of ground. So having functional systems of management, including ones adapted to the dispersal potential of this pest, is key to achieving the area-wide impact that is needed and serves all crops within our agroecosystem.



Of course, part of having a functional and stable management system is having the appropriate remedial controls and the technology and education to support them in place.

Selective & Effective Chemistry

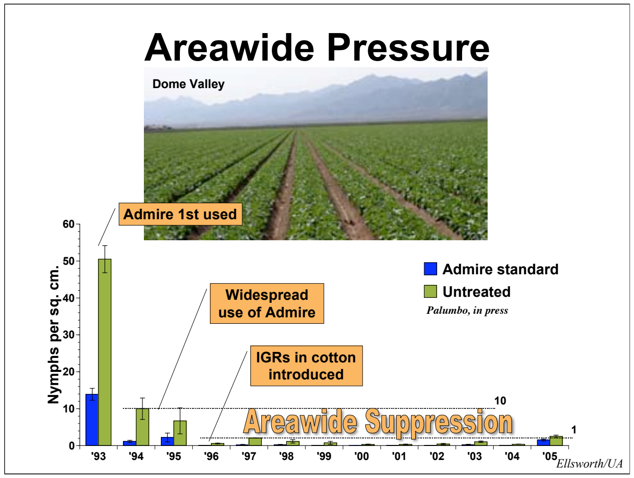


Central to these remedial controls is "selective and effective chemistry." The IGRs, pyriproxyfen and buprofezin, were absolutely key to our system when they were introduced under section 18s in 1996. However, imidacloprid, when used in the soil, is also a highly effective whitefly control agent that can also be fairly selective for natural enemies in our melon and vegetable crops. All three compounds excel at the control of immature stages of this insect, whereas prior to this we were using broad-spectrum adulticides in a sometimes vain attempt at stopping population development.

Overwhelming Pressure

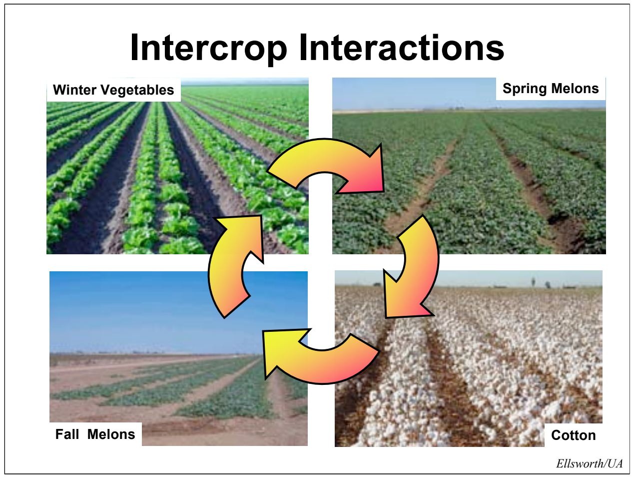
Ellsworth/UA

However, no matter how good the remedial controls are, they are insufficient to cope with overwhelming insect pressure like this. Thus, implementation of best IPM practices over entire communities is needed to prevent the development of outbreaks of this type. [This video was shot in 1992 on the campus of a community college located within the city limits of Phoenix. Truly this was everyone's problem.]



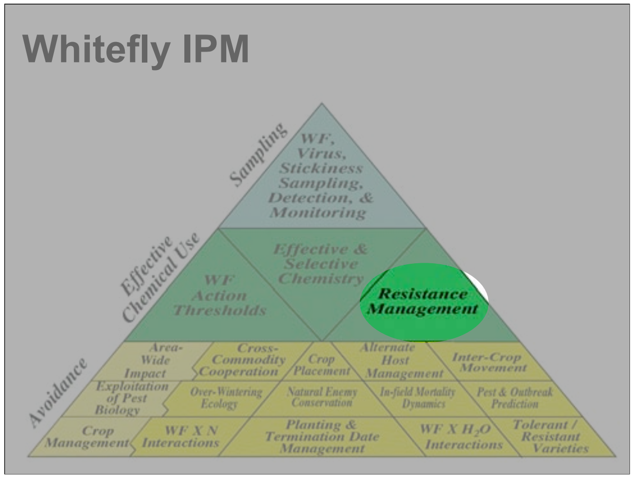
Starting in 1993, John Palumbo has the foresight to initiate an "efficacy monitoring" protocol in commercial lettuce fields, where he established untreated blocks of lettuces within these commercially-treated fields with soil-applied imidacloprid. In this chart, we see total number of nymphs per sq. cm. (seasonal average), starting in 1993 when Admire was 1st used under a Section 18. Pressure was extreme as seen in the UTC green bar, but Admire did an excellent job at reducing these numbers. Moving to 1994 and 1995, we see a period where widespread use of Admire was prevalent throughout the fall vegetable landscape and numbers were reduced in the UTC by nearly an order of magnitude. Moving to 1996 through the present day, we enter a period where the IGRs were first registered and used in AZ cotton and used on a wide-scale. The result is another magnitude lowering in the overall whitefly density, and what we think of as area-wide suppression of whitefly populations.

Photo credit: JCP



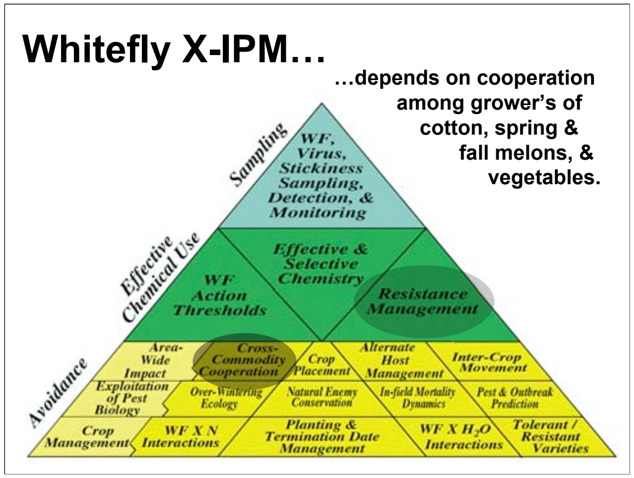
So, by now, it should be evident that not only is there a close interaction among these crops, but that there is an interdependence that is driven largely by this insects ability to move and be transferred from one crop and production window to the next. Further, coordinated use of chemistry over multiple crops helps the system reduce area-wide movement and pressure.

Photo credit: JCP



The central role that our chemistry plays in our systems naturally leads us to concerns about resistance management. Our growers had scares when this whitefly arrived with an a priori resistance to pyrethroids in the early 1990's and then began to overcome our synergized pyrethroids by 1995. So resistance management was an explicit component of our IPM plan and for our Section 18 exemptions of the IGRs.

Resistance management has obvious implications for individual crops…



However, resistance management in our system could not be limited to or practiced in a single crop or commodity. This shared responsibility extended across commodity borders. Cross-commodity cooperation can be key to the sustainability of a resistance management plan, and in Arizona, we have achieved some remarkable agreements and so far excellent cooperation among growers of several key whitefly crop hosts.

Neonicotinoids: A Major Class

A.I.	Product	Application	Crops Uses
Acetamiprid	Assail	Foliar	Lettuce, Cole
Acetamiprid	Intruder	Foliar	Cotton
Dinotefuran	Venom	Foliar, Soil	All
Imidacloprid	Admire, etc.	Soil	Melons, Lettuce, Cole
Imidacloprid	Gaucho, etc.	Seed	Cotton
Imidacloprid	Provado, etc.	Foliar	Lettuce, Cole (Cotton)
Thiamethoxam	Centric	Foliar	Cotton
Thiamethoxam	Cruiser	Seed	Cotton
Thiamethoxam	Platinum	Soil	Melons
Clothianidin	Clutch/Poncho	various	?
Thiacloprid	Calypso	Foliar	?

Ellsworth/UA

Why was / is this so important? Well in 1993, soil-applied imidacloprid or Admire was the only member of the neonicotinoids, a major new class of chemistry with many important future uses. Today, however, we now have many additional potential members of this class with many registrations across multiple crops.

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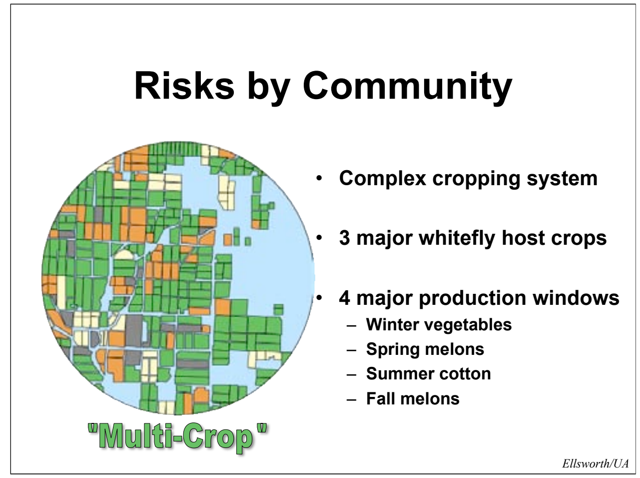
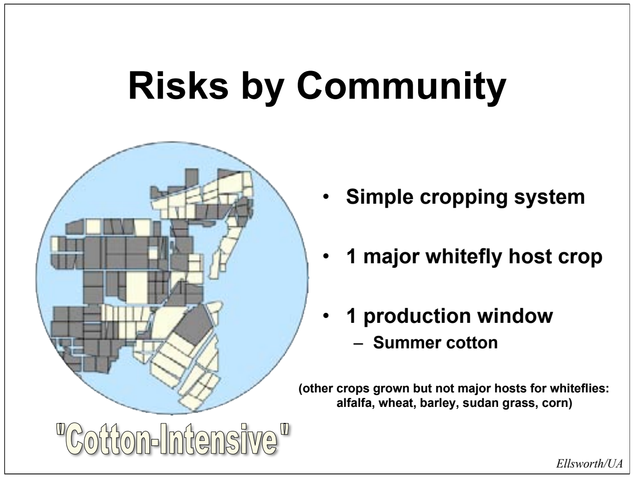
Ellsworth/UA

And now, Intruder (acetamiprid used foliarly) has rapidly become our most popular whitefly treatment in cotton. This potential for over-usage within our system gives us great concerns about future erosion of efficacy due to resistance. Rather than waiting to see what happens, we worked through our cross-commodity stakeholder process to develop proactive guidelines for the rational use of this class of chemistry and for management of whiteflies overall.

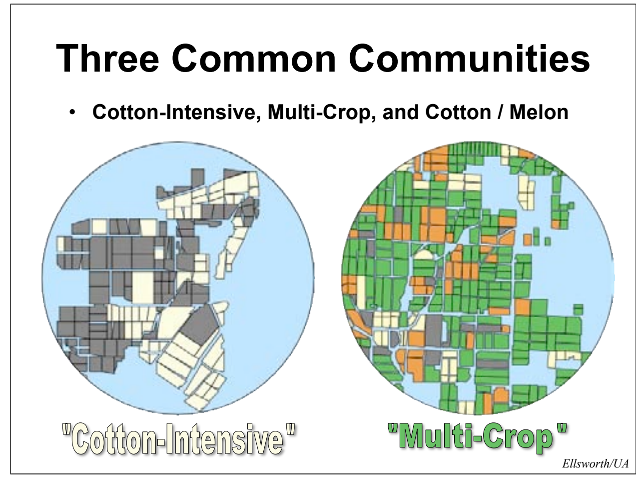
The specifics of the stakeholder process and even the guidelines themselves are beyond the scope of what I can cover in this presentation. However, I would suggest that you attend John Palumbo's talk tomorrow where he will go into greater detail on this topic in the IRAC symposium. In this talk, I would like to focus on the spatial elements of the guidelines, which are influenced directly by the movement of this pest.



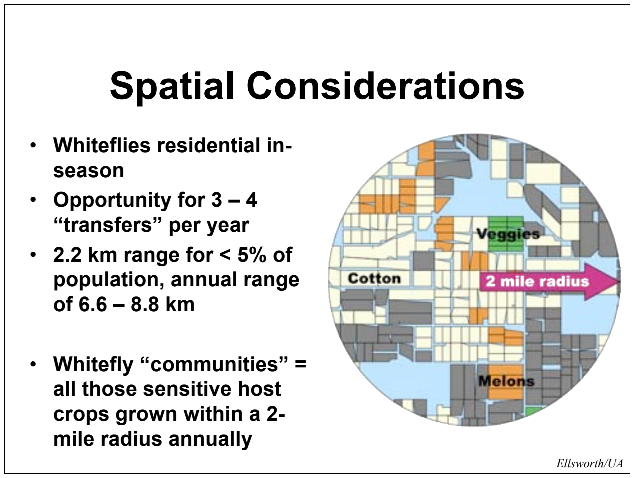
Resistance risk, indeed risks of all sorts (insect pressure, economic loss, markets, etc.), are not all the same across AZ agricultural production. Some areas have extremely complex cropping systems, where 3 major whitefly host crops are grown, and 4 different production windows exist [winter vegetables (in green), spring melons (orange), summer cotton (white) and fall melons (orange)]. We refer to these areas as "multi-crop".



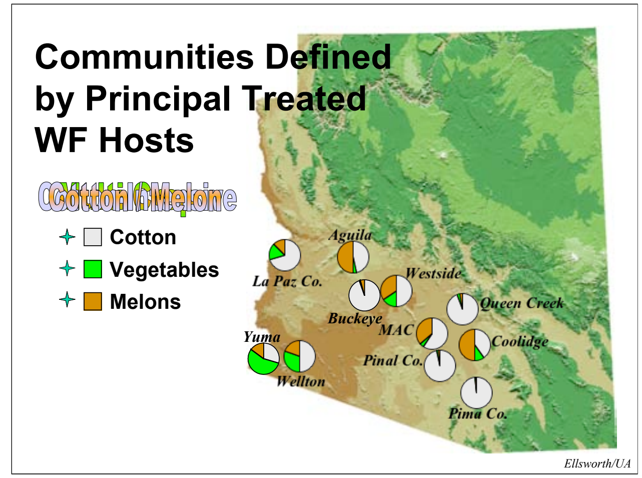
While still other communities have relatively simple cropping systems, only 1 major whitefly host crop and 1 production window, summer cotton (white). We refer to these communities as "Cotton-Intensive".



The risks of losing neonicotinoid chemistry are different between these two types of communities and with a 3rd one, not shown, where cotton and melons are grown in a summer bi-culture.



While the differential risks are obvious, some sort of spatial scale had to be defined. In our case we settled on 2 miles based on the following facts: Whiteflies once in-season for each of these host crops are 'residential'; opportunities for transfers through the system occur about 3 or 4 times each year at a maximum; from David Byrne's work (et al.) we know that a small fraction of the population is capable of "migrating" 2.2 km, representing an annual range of movement of about 6.6-8.8 km (or ca. 5 miles). Thus, for this and for operational reasons, we defined our whitefly "communities" (areas of potentially interbreeding and moving whiteflies) as all those sensitive host crops grown within a 2-mile radius annually. This happens to be an area that we believed that crop consultants (PCAs) could readily identify and anticipate production and insecticide use in a local area.



We have instances like in Yuma which are very complex and include significant acreages grown in melons, cotton and vegetables. In other areas, the system is relatively simple and resembles a cotton monoculture as far as whiteflies are concerned. Then there are some places where a melon / cotton bi-culture exists. Through these definitions, one could anticipate hundreds of whitefly communities throughout the state, and depending on land use changes and leasing agreements, an area might shift from one community type to another in a relatively short period of time (1 year). The power of this approach, not limiting our guidelines to geographic or political boundaries, provides for great flexibility and applicability to nearly any situation throughout the state. The guidelines are sensitive to these differences…

Sharing Neonicotinoids

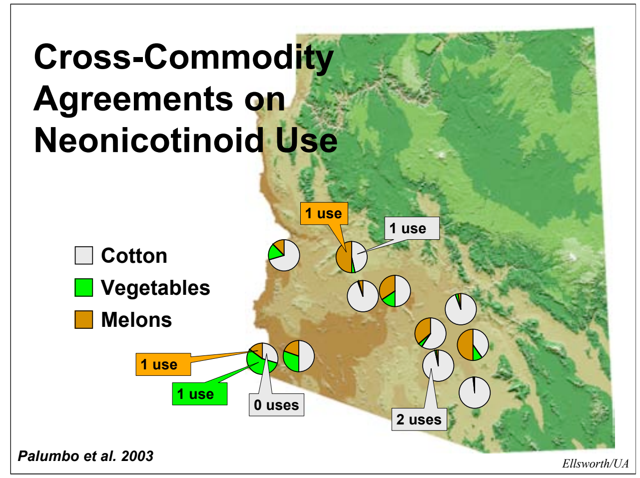
Neonicotinoid* Limitations:
Maximum usage by crop per season

Community	Cotton	Melons	Vegetables
Multi-Crop	0	1	1
Cotton / Melon	1	1	—
Cotton-Intensive	2	—	—

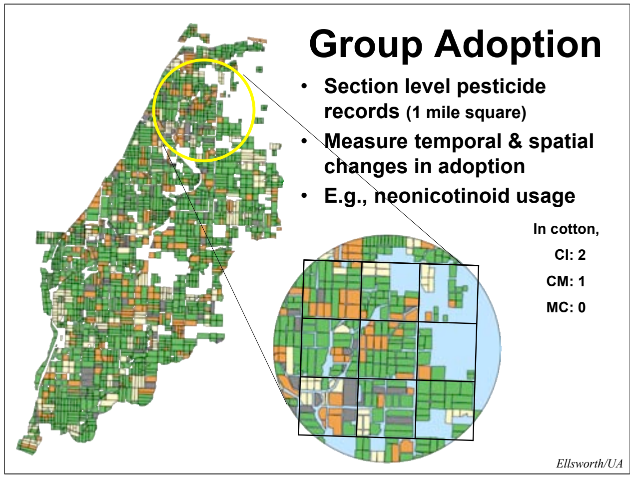
*Seed, Soil, or Foliar

Ellsworth/UA

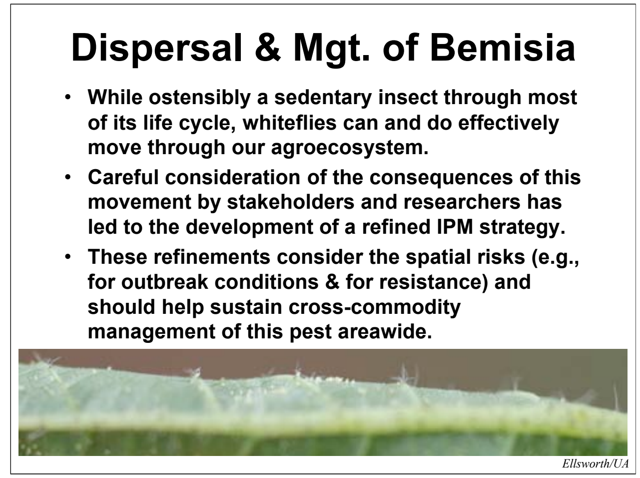
Under John Palumbo's leadership, we developed a stakeholder-driven set of guidelines that in essence restricts neonicotinoids as a class to just two uses per cropping community. Several years of effort can be distilled down to this single table. In a cotton-intensive community, growers of cotton there 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.



I want to emphasize that these guidelines did not come from a vacuum. They were developed in consultation with the industries they serve, cotton growers, vegetable and melon growers, professional crop consultants, and the affected agrochemical companies. Compliance is voluntary, but we have a project to measure this explicitly in Arizona.



Because the unit of interest is a community, individual behaviors are not as important as the adoption by whole groups within each community. We are initiating a new project that you can see described in greater detail in 2 posters available tomorrow in the poster session. In this project, we will examine communities and the section level pesticide records for those areas. A section is 1 mile square and a 9-section grid roughly approximates our 2-mile radius communities. With these data, we will measure changes in adoption both temporally and spatially. In specific, we will examine neonicotinoid use by cotton growers in each of the 3 community types to see if no more than 2 uses are being made in cotton-intensive areas, no more than 1 use in cotton/melon bi-cultures and no uses in multi-crop communities.



So to conclude our examination of dispersal and its role in impacting management of Bemisia, we can note the following. This is a sedentary insect that is leaf bound as an egg and throughout the nymphal stage. Even so, whiteflies can and do effectively move through our system. We were forced to consider the consequences of this movement in our system and this has helped us to refine what was already a successful IPM strategy (I.e., to accommodate a changing landscape of new neonicotinoid chemistry). Spatial risks are explicitly part of our analysis, and implementation according to community types should help sustain cross-commodity management of this pest area-wide.

Dispersal & Mgt. of Bemisia

Ellsworth/UA

Anything we do to improve our management plan will help avoid scenes like this from 1992 and help prevent outbreak conditions where area-wide pressure is too high for any IPM plan.

Dispersal & Mgt. of Bemisia

Ellsworth/UA

In summary, we had no choice. These scenes have forced us to consider dispersal by this insect; forced us to coordinate management across multiple crops; and that management has undoubtedly led to increased area-wide impact, which creates positive feedback on reduced dispersal through the system.

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, including a PDF version of this presentation for those interested in reviewing its content.

Photo credit: J. Silvertooth