

*Ecologically-based IPM in Cotton: Research,
Outreach, and Grower Adoption*

Taking Cotton IPM to a New Level: Cross-Commodity Management and Areawide Benefits

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My thanks and acknowledgment to Dr. John Palumbo, UA Vegetable Entomologist, who has been instrumental in the deployment of the program that we describe here.

A Cross-Commodity Challenge

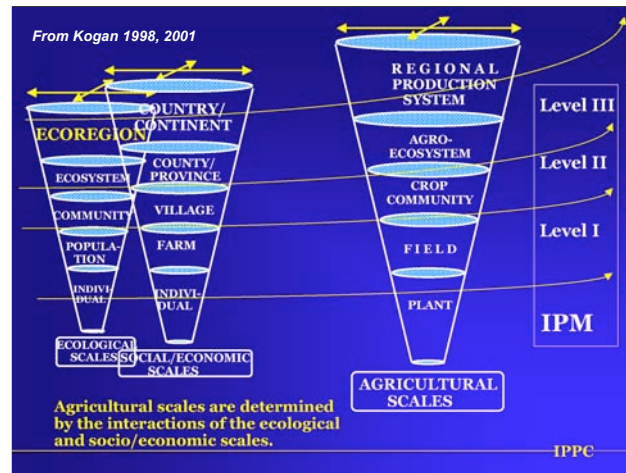
- Levels of IPM integration
- Whitefly as a keystone pest
 - Damage potential & economic impact
 - Intercrop interactions
- Areawide impact & cross-commodity IPM



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In Arizona, where cotton is just one of many crops grown, we are faced with a considerable cross-commodity challenge. In response, I believe we have been fortunate to be involved with an industry at a time in history when tools are available and motivation is high to take IPM to a higher level. Today, I will review what are the levels of integration in IPM, describe a whitefly's keystone role in our system, and detail the areawide impact and our efforts to install cross-commodity IPM in Arizona.

Photo credit: JCP



In Kogan's review of IPM (1998), he provided us a model for understanding organizational complexities across various scales: ecological, social/economic, and agricultural. In particular, integration occurs at at least 3 organizational levels. IPM has been operating for decades now and most commonly at Level I integration. Some effort is extended to Level II, and only rarely do we aspire to develop Level III IPM, where, in essence, we are architects of the agroecosystem in which IPM occurs.

Levels of Integration in IPM (from Kogan 1998, 2001)

- **Level I – “Species / population level integration”**
 - The integration of control methods for single species or species complexes
- **Level II – “Community level integration”**
 - The integration of the impacts of multiple pest categories on the crop and the methods for their control
- **Level III – “Ecosystem level integration”**
 - The integration of multiple pest impacts and the methods for their control within the context of the whole cropping system

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Kogan (1998) appropriately places the emphasis of IPM on “Integration.” At Level I, integration of control methods for a single species is common. In Level II, this integration extends to multiple pest categories and methods for control. However, under Level III integration, we should expect this all to occur within the context of an entire cropping system, or ecosystem.

Bemisia tabaci, Biotype B



- 33 µg
- > 600 hosts
- Mobile adult form
- Introduced to U.S. in late 1980's and AZ in early 1990's
- Reduces yields, contaminates with honeydew & vectors viruses

Ellsworth/UA

The primary pest in our system is *Bemisia tabaci*, the sweetpotato or silverleaf whitefly, which was introduced to the U.S. in the late 1980's and invaded AZ in the early 1990's. Near catastrophic losses were experienced throughout the agricultural sector during the early 1990's.

Biological Defoliation (UTC, 1992)

Yield Loss



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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-biotpe). Note: Danitol+Orthene in the background.] Well-controlled field plots are seen in the background.

Damage to Cotton: Direct, Yield Loss



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Large densities of whiteflies attacked and developed on cotton such that there were hundreds of adults and thousands of eggs per leaf in some areas in 1992. Even worse, however, densities far short of this are all that is needed to jeopardize lint quality...

[Video shot in Maricopa, AZ, 1992].

Excreted Sugars Host Sooty Molds

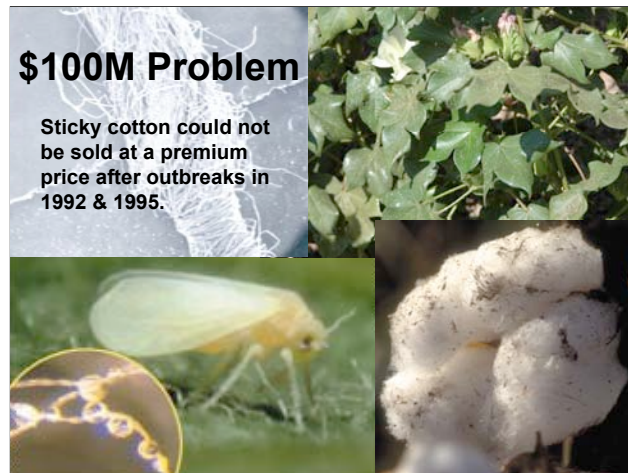
Quality Loss



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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.

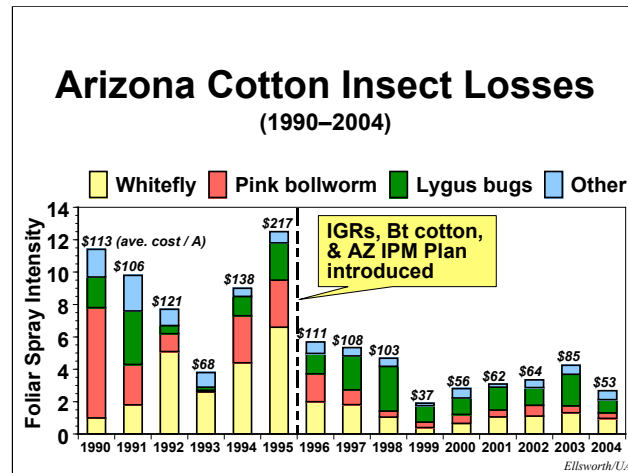
[Video shot in Maricopa, AZ, 1992].



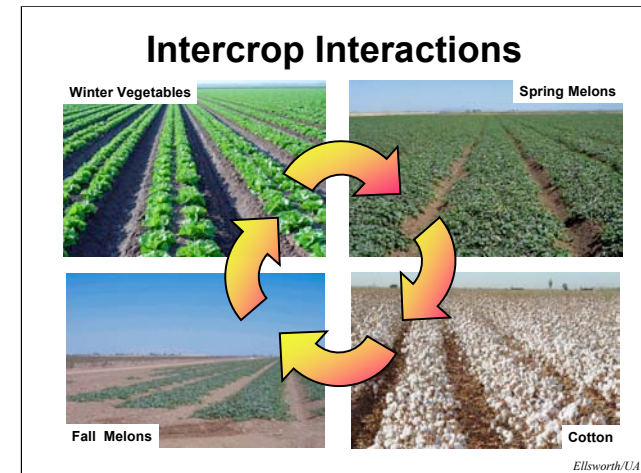
This small imperfection in the thread that is spun by millers is the result of excess sugars deposited on cotton fibers, and this occurs only if the fiber can be processed at all. Some fiber arrived at mills sticky enough to shut down the entire operation for cleaning. A 100 million dollar problem starts 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). 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 (and costs/acre) 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 most years with just 1-2 sprays season long.



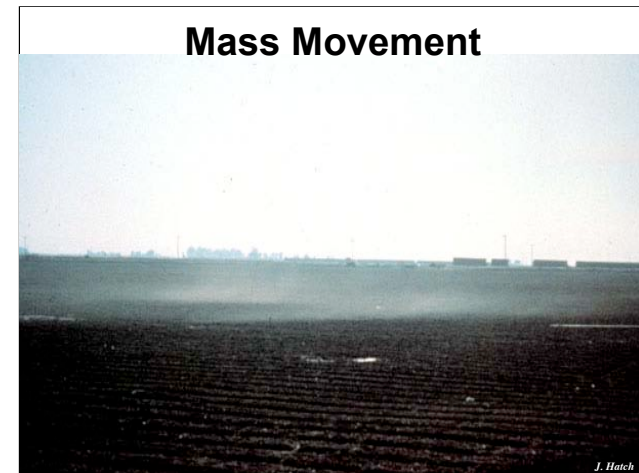
However, cotton is not the only host for this whitefly. AZ's year round growing season provides for a sequence of crop plants, winter vegetables like broccoli, lettuce, other cole crops, spring melons (esp. cantaloupes), summer cotton, and fall melons. These crop islands provide for perfect habitat for whiteflies, and our focus was on the intercrop interactions that were possible with this pest.

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 right.

Photo credit: JCP

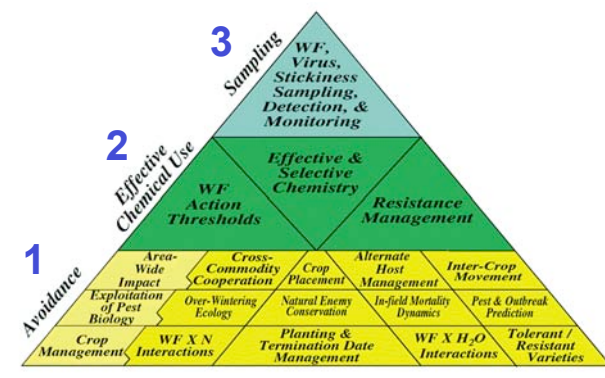


As small as this insect is, it does in fact move effectively through our agroecosystem. In this now famous slide we can see “clouds” (not dust) of whiteflies moving across a newly planted vegetable field in the Imperial Valley of California. This type of movement, aerial pressure if you will, produces a nearly impossible pest management situation.

So we have a polyphagous pest with a good ability to move through the system.

Whitefly IPM...

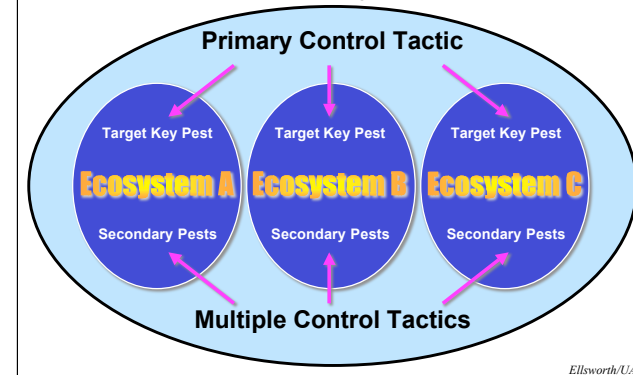
...depends on 3 basic keys



Using a pyramid metaphor, let's look at what was and continues to be our operational IPM plan in Arizona cotton. 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. A firm foundation in avoidance is critical to stabilizing the system.

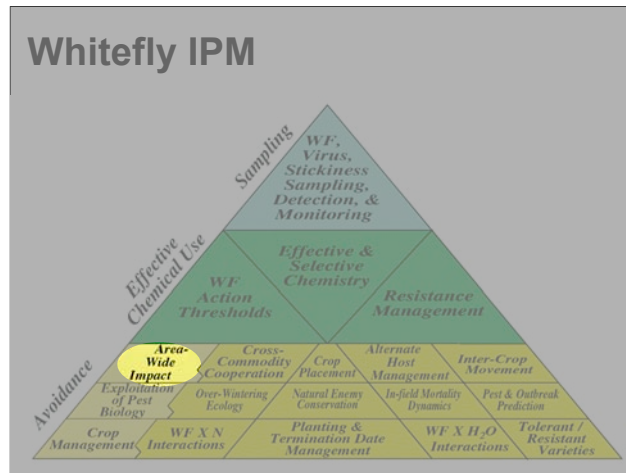
Areawide IPM

(redrawn from Kogan 2001)

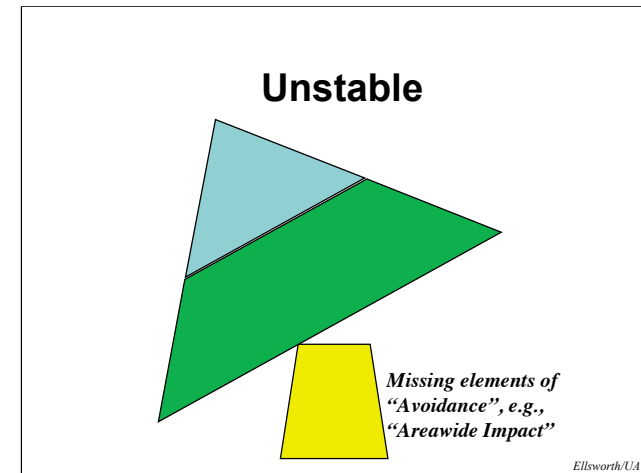


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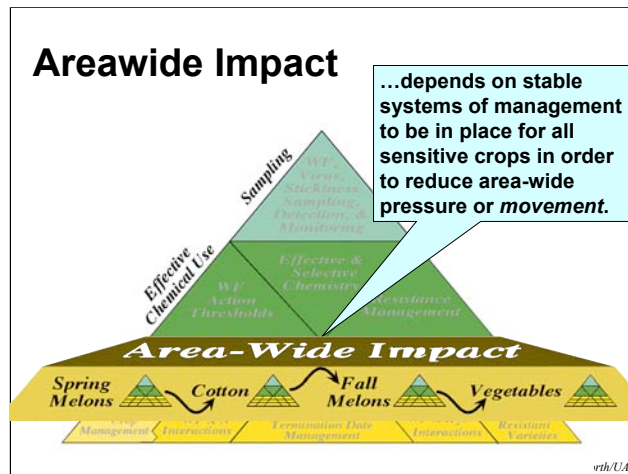
Kogan (2001) recognized that there were two different concepts that needed reconciliation. One was areawide suppression and the other our well-established IPM paradigm. A blending of these two gives us Areawide IPM or Level III IPM where the target area is a large region extending over multiple ecosystems and serves to reduce key pest densities below EILs while also addressing secondary pests with multiple control tactics.



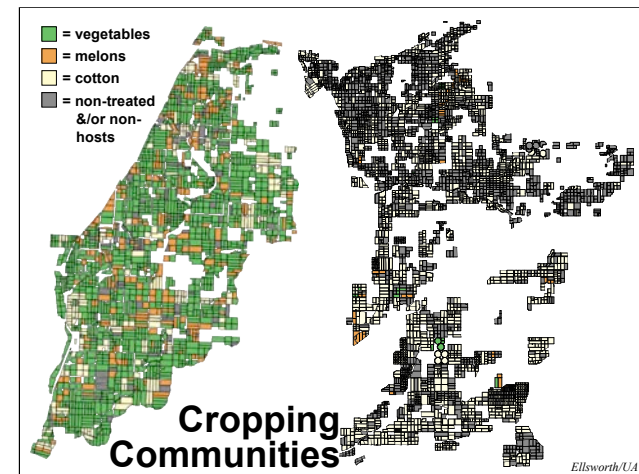
While our crop-specific model of IPM in cotton was not initially designed as an areawide IPM plan, it does explicitly address fully exploiting tactics and information that have areawide impact, all as a critical elements to building a solid foundation in avoidance.



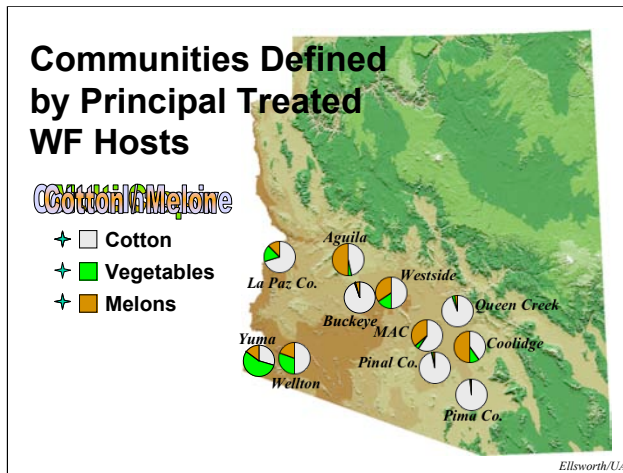
Clearly, a solid foundation in “Avoidance” is needed to stabilize our management system. Elements of area-wide impact are directly affected by management practices not only in cotton but in other host crops throughout a landscape or agroecosystem. Without these elements, uncontrolled aerial populations provide too much pressure to control or manage in any one crop.



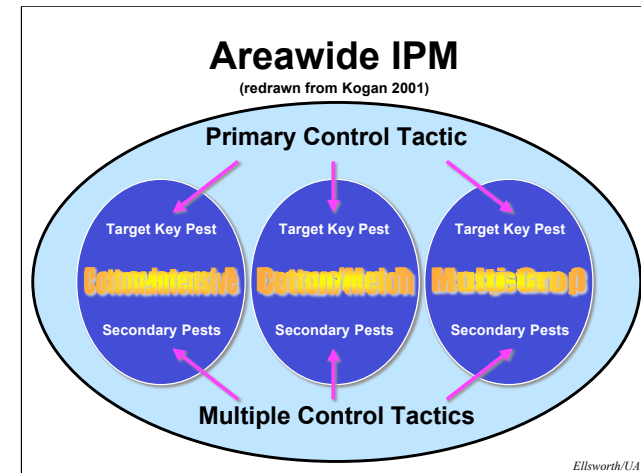
A well conceived IPM program for cotton or for any one crop is not enough to manage whiteflies sustainably in complex cropping systems. In parts of Arizona, spring melons might be followed by cotton, followed by fall melons, and later winter vegetables, though not necessarily on the same piece of ground. 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.



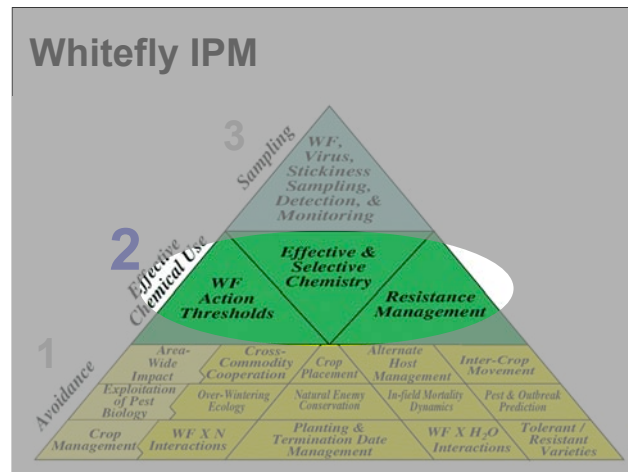
All cropping communities, agroecosystems if you will, are not the same in Arizona. In fact, where whiteflies are a key pest, the levels of host diversity and temporal complexity are quite different. Vegetable fields are shown in green; melons in orange, cotton in white, and non-treated or non-hosts in gray. On the left, Yuma Valley of Arizona, virtually every field is rotated to vegetables at some point in a 12 month period. And while cotton is grown in these communities, it is in a totally different context than we see on the right in central Arizona where cotton is grown more monoculturally with an array of untreated hosts, like alfalfa, and non-hosts like corn and small grains.



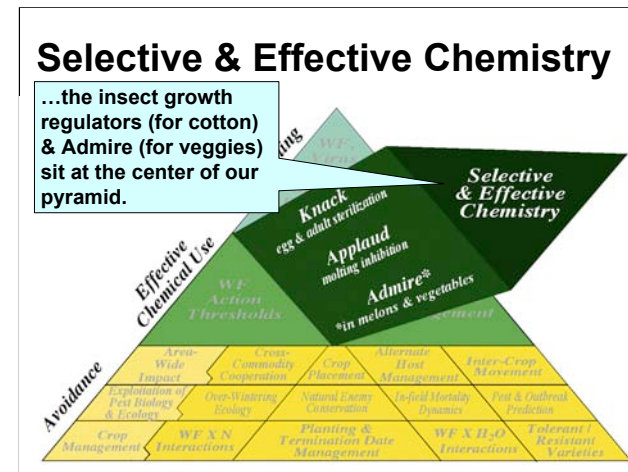
We have instances like in Yuma which are very complex and include significant acreages grown in melons, cotton and vegetables. We call this a “Multi-Crop” community. In other areas, the system is relatively simple and resembles a cotton monoculture as far as whiteflies are concerned, a “Cotton-Intensive” community. Then there are some places where a melon / cotton bi-culture exists, “Cotton/Melon” community. Hundreds of whitefly “communities” or ecosystems exist throughout the state.



Adapting Kogan’s areawide IPM concept to the Arizona - whitefly system, we can see how areawide IPM for whiteflies across multiple landscapes might look.



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. Our “primary control tactics” operate at this level.



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 for cotton 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.

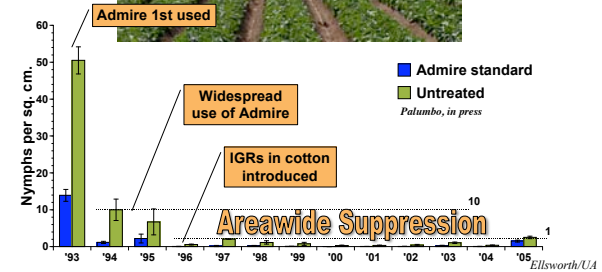
Overwhelming Pressure



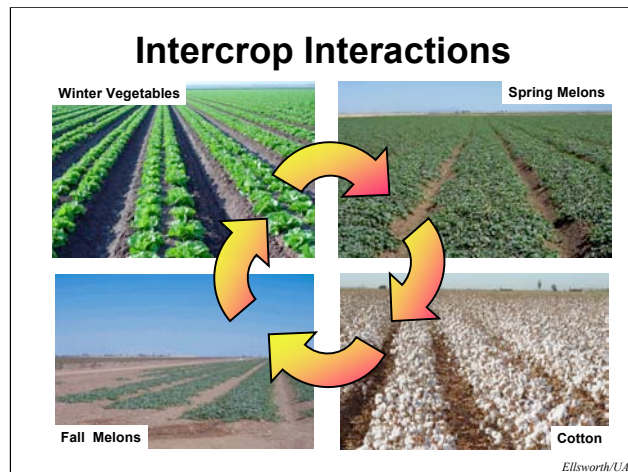
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However, no matter how good the remedial controls are, our so-called primary control tactics, they are insufficient to cope with overwhelming insect pressure like this. Thus, implementation of best IPM practices over entire communities is needed to prevent the development of outbreaks of this type. In turn, the lowered pressures pay additional dividends locally in the efficiency of all our IPM tactics. [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.]

Areawide Pressure

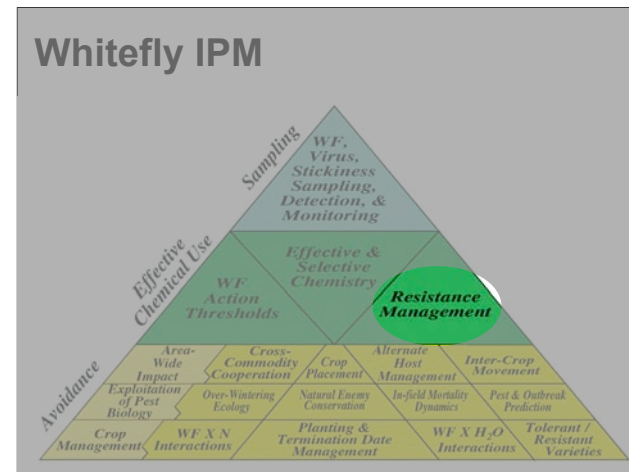


Starting in 1993, John Palumbo had the foresight to initiate an “efficacy monitoring” protocol in commercial lettuce fields, where he established untreated blocks of lettuces within these commercially-treated fields with soil-applied imidacloprid. In this chart, we see total number of nymphs per sq. 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. In 1994-1995, 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. In 1996 through today, 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. These chemistries were not the only things operating to manage whiteflies, though they were the “primary control tactics” (*sensu* Kogan, 2001).



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 insect's 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. So protection of these primary control tactics from losses to misuse, abuse and resistance becomes an important areawide concern.

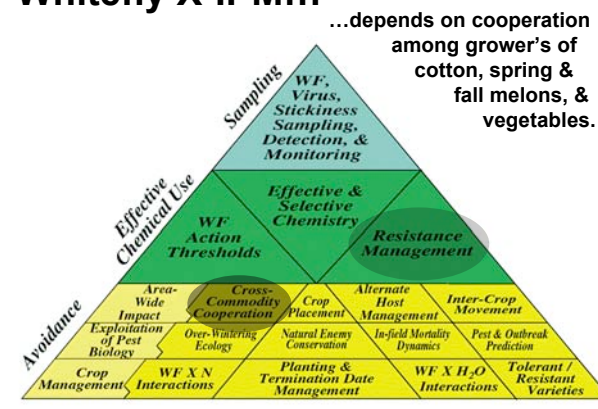
Photo credit: JCP



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 cotton exemptions of the IGRs.

Resistance management has obvious implications for individual crops...

Whitefly X-IPM...



However, resistance management in our system could not be limited to or practiced in a single crop or commodity. That is Level I integration for resistance management in a mobile, polyphagous pest seems futile, when registrations of key chemistries are broad across multiple crops. 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	?

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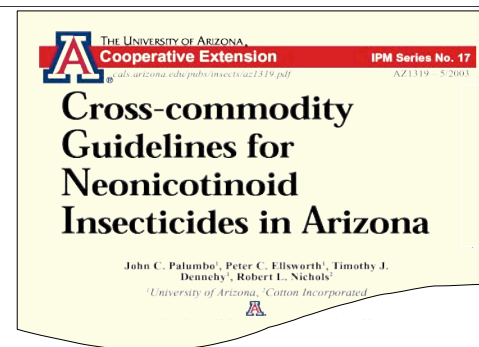
Why was / is this so important? At first blush, it might not be apparent why “cross-commodity” resistance management was needed. Afterall, we depended on the two IGRs in cotton and imidacloprid, a neonicotinoid, in melons and vegetables. In 1993, soil-applied imidacloprid or Admire was the only member of the neonicotinoids. Today, however, we now have many additional potential members of this class with many registrations across multiple crops.

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Thiamethoxam	Platinum	Soil	Melons
Clothianidin	Clutch/Poncho	various	?
Thiacloprid	Calypso	Foliar	?

Ellsworth/UA

And now, Intruder (acetamiprid used foliarly) has rapidly become one of our most popular whitefly treatments in cotton. This potential for over-usage of this class of chemistry 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.



IPM & IRM guidelines emerged from a stakeholder-engaged process; simple yet ecologically-relevant

Ellsworth/UA

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 the two poster sessions where we have a pair of posters that detail these guidelines and our efforts to measure their adoption across these communities. In this talk, I would like to focus on the spatial elements of the guidelines, which are important to the areawide integration of our IPM plan. 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.

Risks by Community



"Multi-Crop"

- Complex cropping system
- 3 major whitefly host crops
- 4 major production windows
 - Winter vegetables
 - Spring melons
 - Summer cotton
 - Fall melons

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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”.

Risks by Community



"Cotton-Intensive"

- Simple cropping system
- 1 major whitefly host crop
- 1 production window
 - Summer cotton

(other crops grown but not major hosts for whiteflies:
alfalfa, wheat, barley, sudan grass, corn)

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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”.

Three Common Communities

- Cotton-Intensive, Multi-Crop, and Cotton / Melon



"Cotton-Intensive"

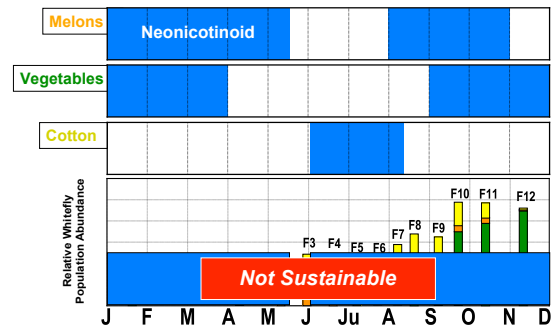


"Multi-Crop"

Ellsworth/U/A

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.

Resistance Risks Associated with Shared Neonicotinoid Uses in a Multi-Crop Community (eg., Yuma – potential usage)

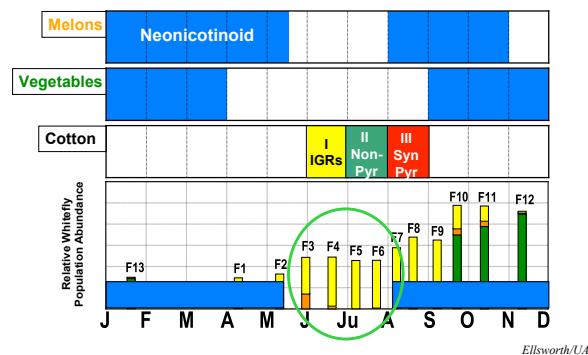


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To illustrate the extreme risks of resistance in our most complex cropping system, we can view the generational production and relative abundance of whiteflies through time at the bottom and our 3 cropping systems outlined above. Neonicotinoid usage, or really the periods during which residues are present, is shown for Yuma valley vegetable and melon crops. If neonicotinoids were to expand to the cotton crops in these complex communities, these products would be depended on in the mid-summer window as well. Transposing these potential use patterns over whitefly generations, and the potential problem becomes apparent. This potential overall use pattern for neonicotinoids in this ecosystem is not sustainable.

From Palumbo et al. 2003

Preserve a *Neonicotinoid-free Period* in MCC

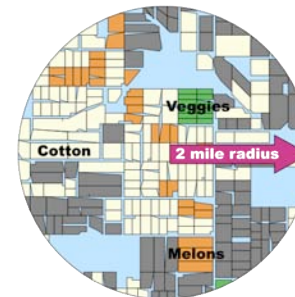


Our guidelines, which suggest the use of IGRs (Stage I) and non-pyrethroids (Stage II) other than the neonicotinoids in cotton, preserve a neonicotinoid-free period similar to what had been occurring in a de facto system for the previous 10 years (1993-2003).

From Palumbo et al. 2003

Spatial Considerations

- Whiteflies residential in-season
- Opportunity for 3 – 4 “transfers” per year
- 2.2 km range for < 5% of population, annual range of 6.6 – 8.8 km
- Whitefly “communities” = all those sensitive host crops grown within a 2-mile radius annually



While the differential risks are obvious, some sort of spatial scale had to be defined. Without discussing the details today, 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.

Sharing Neonicotinoids

Neonicotinoid Limitations: Maximum usage by crop per season*

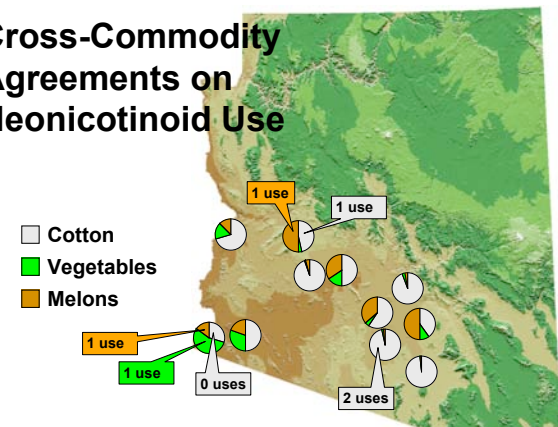
Community	Cotton	Melons	Vegetables
Multi-Crop	0	1	1
Cotton / Melon	1	1	—
Cotton-Intensive	2	—	—

*Seed, Soil, or Foliar

Ellsworth/U/A

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.

Cross-Commodity Agreements on Neonicotinoid Use



Palumbo et al. 2003

Ellsworth/U/A

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. Further, the ecological context is relevant to the key pest target. Compliance is voluntary, but we have a project to measure this explicitly in Arizona.

Areawide IPM (from Kogan 2001)

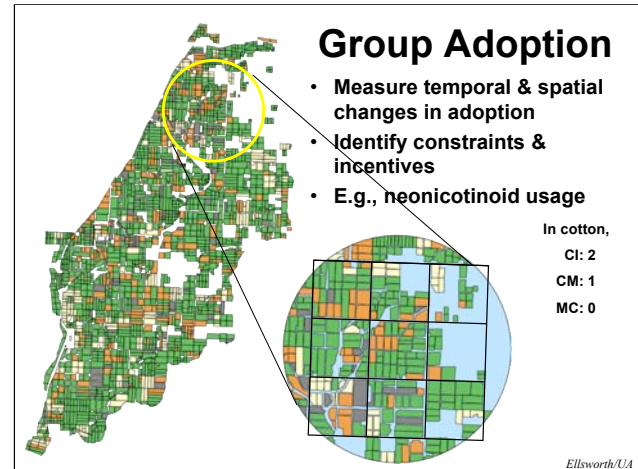
- Targeted against a key pest whose control enhances IPM options for secondary pests.
 - NE conservation enhanced; fewer secondary problems
- Aimed at suppressing populations of key pests and keeping all other pests below EILs.
 - Whiteflies, losses in multiple crops minimized
- Implemented over meso- or macro scales, but regionally focused.
 - Areawide suppression realized over very large scale
- Regionally coordinated with grower participation.
 - Stakeholder-engaged guidelines; all voluntary
- Provides special incentives to entice growers to participate.
 - Improved control, lower regional costs, risk reduction

Ellsworth/U/A

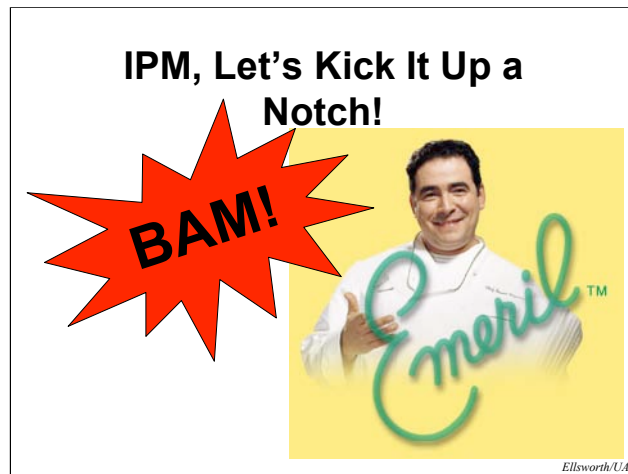
Kogan (2001) detailed several elements of “Areawide IPM” (~ Level III integration). In our system, we target a keystone pest of multiple crops. Through efficient & selective control of this key pest, we have reduced the impact of secondary pests. Economic injury is now rare & other pest outbreaks are less frequent. The scale extends over multiple ecosystems in the deserts of AZ. There is no regional coordination, per se, though considerable organization of stakeholders in workgroups, e.g., CROP and APMC, exists. The incentives are implied but mainly involve both a carrot & stick: improved utility & efficacy of key control chemicals & fewer problems with secondary pests; the threat of huge economic loss due to lost markets and/or performance-degrading resistances in our whitefly populations. Ultimately, cotton, vegetable and melon growers take pride in their efforts to develop higher level IPM that extends across multiple cropping communities. The stabilization of pest conditions as a result has provided immeasurable savings for all growers in this state.

Group Adoption

- Measure temporal & spatial changes in adoption
- Identify constraints & incentives
- E.g., neonicotinoid usage



We hope to measure what incentives and constraints there are in complying with our cross-commodity guidelines through a new and innovative project to measure pesticide use both spatially and temporally across various cropping communities. 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 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 I don't know if what we have installed in Arizona as cross-commodity IPM qualifies as Kogan's Areawide IPM or Level III integration. However, we have been challenged by a mobile, polyphagous, keystone pest to elevate our practices and our strategic management. As Emeril says, "Let's kick it up a notch!" The benefits and the stakes are great. Time will tell if adoption is high enough to forestall resistance problems and to produce the areawide impact we need to have in order to sustain whitefly management across the agroecosystems of the low deserts of Arizona.



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