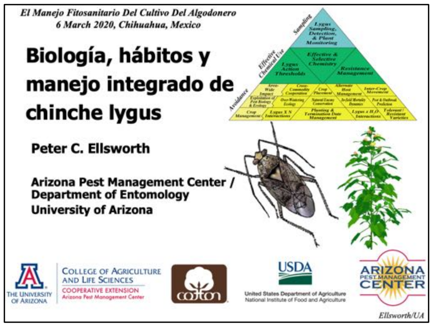
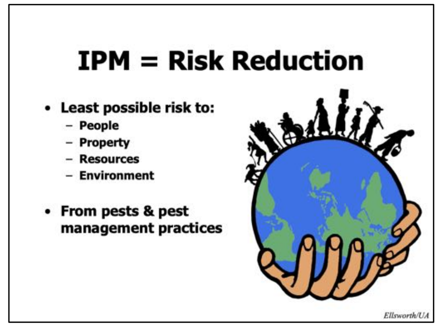
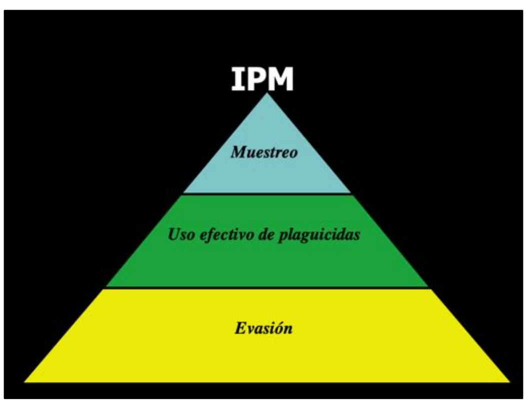


This presentation will focus on the critical elements of integrated management of Lygus bugs in cotton. IPM for Lygus is multi-faceted and contains many details that a grower and pest manager should examine and consider prior to each cotton season. We will briefly review the structure of IPM and how it is applied specifically to Lygus in cotton, but then concentrate on the major decisions and actions that a pest manager must consider once Lygus are in the cotton field. This does not minimize the importance of the many prevention and avoidance tactics that should be in place. But time today limits us to those critical actions taken to control Lygus and the knowledge needed to do so effectively and compatibly with IPM.

Invited presentation, Chihuahua, Mexico, 1.5 h total (in 2 talks); 100 attendees.

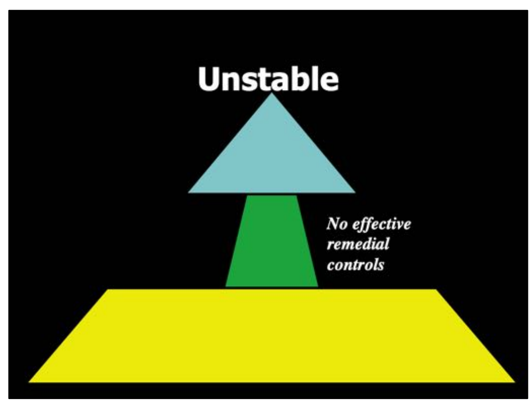


Fundamentally, IPM is a risk reduction / risk management science that limits risks to people, property, resources (economic and otherwise), and the environment, from the pests as well as the full complement of pest management practices that might be deployed against that pest.

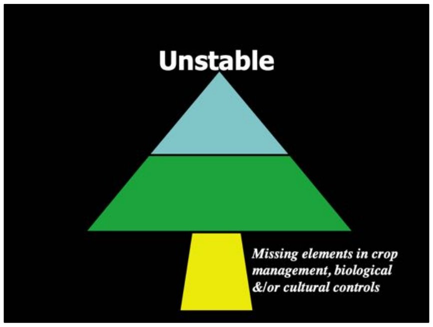


At its simplest IPM can be presented this way. The triangle or pyramid is a convenient metaphor for distilling down the major components of IPM and communicating them quickly to stakeholders.

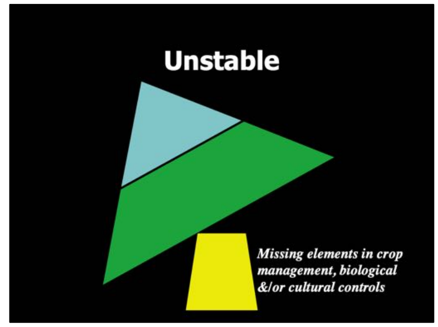
IPM for many systems can be represented by these 3 layers. They are interdependent. You must have sampling or detection systems to know when or if a pest is present as well as remedial controls, often chemical controls (even in organic systems) that can help when all other prevention or avoidance tactics fail to maintain pests below economic levels.

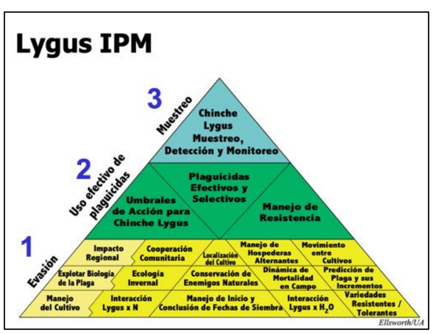


Even with the broadest and best foundation of avoidance tactics and ecological controls, there will be those scenarios where and when pests break-out and require control. If the technology arsenal is too narrow, the management becomes unstable.

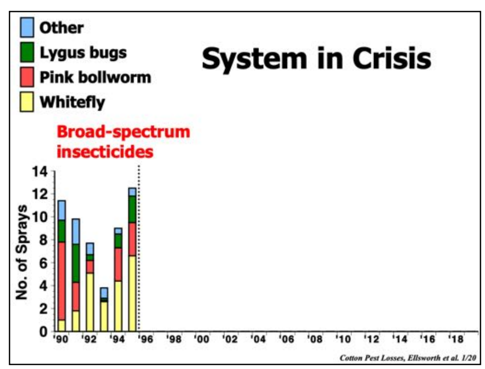


Even more seriously unstable are those systems where we have become over-dependent on the chemical tools (organic, biorational, or otherwise) and where we lack the fundamental foundation of avoidance and prevention tactics of crop management, biological and cultural controls.



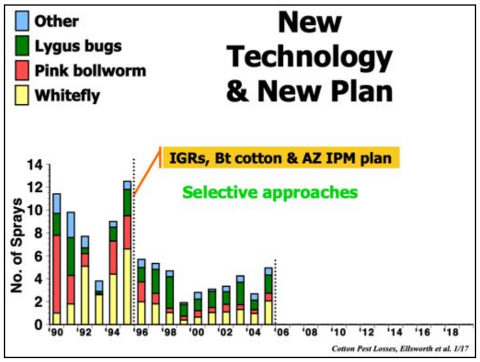


The 3 basic keys to any IPM plan are sampling, effective chemical use, and "avoidance". This is a symbolic depiction of Cotton IPM as developed and practiced in Arizona. This pyramid is not just 2-dimensional. It rotates to show many sides for other pests and pest groups, i.e., is is multidimensional.



Our Cotton Pest Losses data on number of sprays used to control our key and other pests tells a powerful story. These are direct estimates of the number of sprays made each year by growers to control all insect pests of cotton, with pink bollworm in pink, whitefly in yellow, Lygus in green, and all other arthropods in blue.

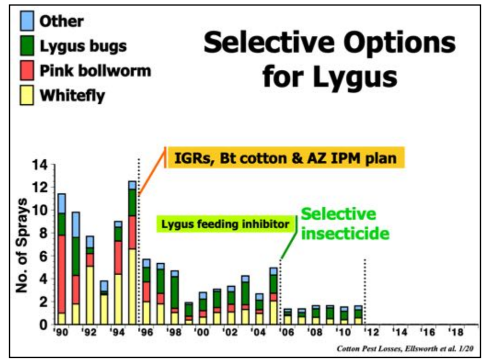
In the early 1990s, the cotton industry was reeling after a historic PBW outbreak and the introduction of a new invasive whitefly species. This was a system in crisis and entirely dependent on broad-spectrum insecticides, because that was all that was available.



New technologies and a new IPM plan began in 1996.

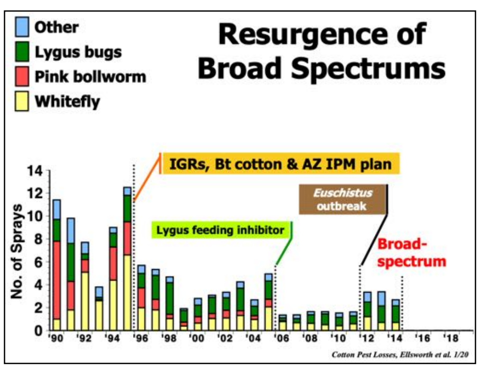
We installed two powerfully selective approaches starting that year: 1) insect growth regulators (IGRs) for whitefly management, and 2) Bt cotton for lepidopteran control. As part of a new Arizona IPM plan, these advances in "selective" technologies and approaches to insect pest management positioned us to better manage and conserve the natural controls in our system, such as predators of whiteflies and secondary pests.

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



In 2006 a selective Lygus insecticides was introduced (flonicamid) enabling a further reduction in broad-spectrum sprays. This all but eliminated organophosphate and endosulfan uses from our cotton IPM system.

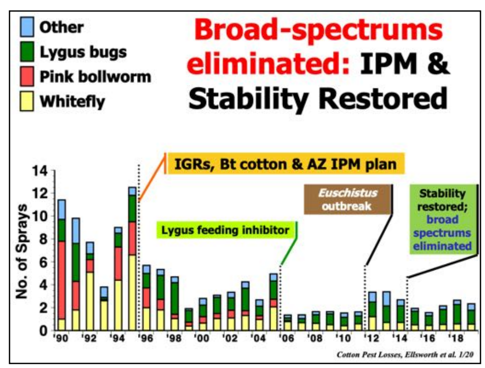
Adapted from Naranjo & Ellsworth 2009, & Ellsworth, unpubl.



Set-backs occur, too! An outbreak of a native pest that hadn't been seen in damaging numbers since 1963. The brown stink bug brought with it efforts to control it with broad spectrum chemistry.

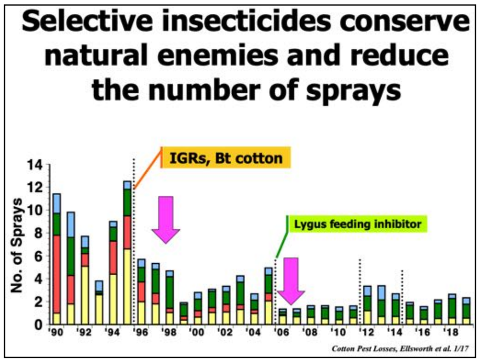
In 2012, we see an increase in the use of broad spectrum insecticides in response to elevated populations of BSB. In many areas, the use of broad spectrum insecticides disrupted biological control and led to resurgences of whiteflies and outbreaks of mites.

This was a reminder of the true cost of using broad spectrum chemistries for cotton insect control.



Our research showed that chemical control of the brown stink bug was not economical. It also showed that these broad spectrum chemistries were creating conditions for primary pest resurgences (Lygus and whiteflies) and secondary pest outbreaks (mites and others). The costs of pest resurgence (whiteflies) and secondary pest outbreaks (e.g., mites) resulted in net losses when brown stink bug chemical control was attempted.

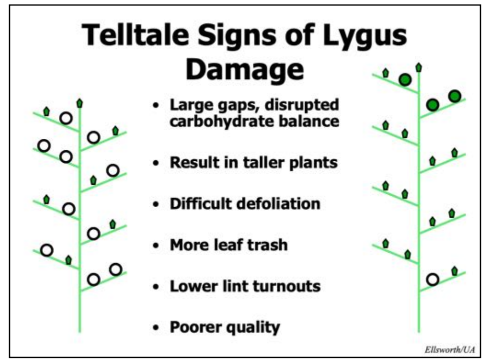
With the return to little to no use of broad spectrum insecticides, stability has returned to our system. We now spray about twice per season, on average, to control all insect pests in cotton.



What is clear from this history is that selective approaches including selective insecticides conserve natural enemies and reduce the number of sprays required to control our insect pest complex.

This tells us something very important. Some of these selective insecticides were considered “very expensive” when they were introduced. However, they ended up being the most economical approach, because they so effectively eliminated the need to spray more times. This was not just because they were effective against the target pest; it was because they were conserving the natural controls in the system that assisted us in obtaining extended periods of control.

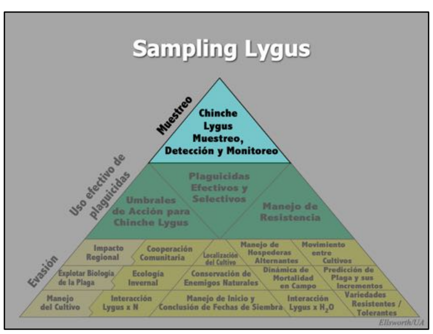
And, selective controls for Lygus, our key yield-limiting pest, were critical to the ongoing success of our program.



As damaging as Lygus are to yields, they also impact the plant in important ways that cause in greater costs and losses for growers.

Lygus damage also affects the pattern of fruiting to such extent that large gaps can sometimes be created. These gaps represent disruptions to the allocation of carbohydrates. Where normally, carbohydrates are shunted to the boll sinks, now they are redirected to the growing tip of the plant, making for a taller plant, one that is more difficult to defoliate (also because of disrupted / excess N-balance). This leads to more leaf trash in the harvest, which in turn, lowers lint turnouts and produces lint of poorer quality.

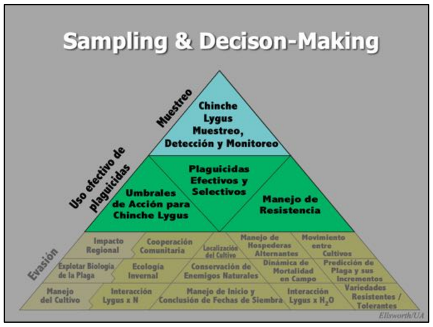
Each of these effects has been measured in our studies and represents some of the hidden costs of Lygus damage. Yield impacts can be great, but we should not forget these other losses as well.



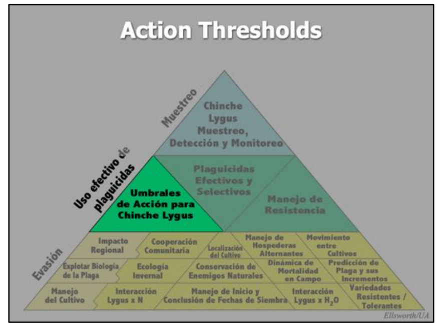
Sampling Lygus is a key element of the decision support system in our Lygus IPM program. It must be carried out deliberately and consistently from first flower to one week after cut-out (cutout = NAWF ≤ 5) or when nodes above white flower (NAWF) = 4.

Sampling Lygus depends on the right tools and techniques for capturing and counting Lygus numbers. We use a sweepnet, which is standardized as a 15 inch diameter. That sweepnet needs to be swept across the upper 12 inches of the canopy in a manner that catches Lygus.

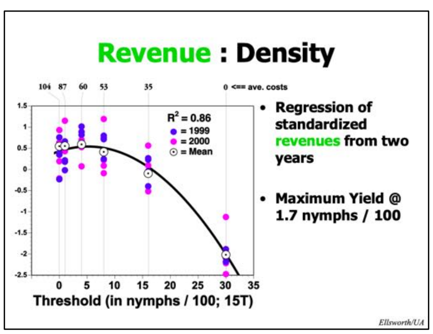
Contents are swept and pinched off to the bottom of the net and examined carefully in the field. Note how small a first instar Lygus is, just about the size of an aphid. Only the first instars have red-tipped antennae.



The upper two layers of our IPM strategy include SAMPLING and EFFECTIVE CHEMICAL USE. This is where the majority of decision-making takes place in-season by growers and pest managers.



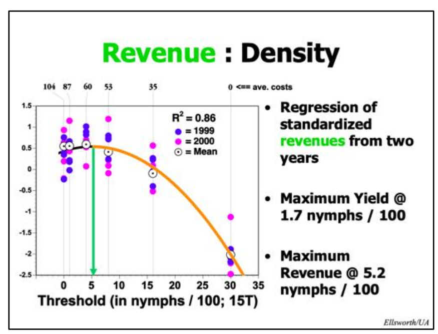
Action thresholds help limit and strategically schedule the use of our control chemistry to just the levels needed to prevent economic loss.



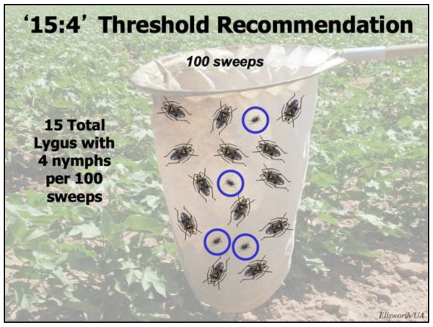
We grow money, not cotton! Any threshold needs to consider the costs of sprays along with the gains in yield possible. Value, however, is in the amount of money a grower can save or make by using a threshold.

To understand the point of diminishing return, we developed this regression that shows the relationship between standardized revenues and our tested thresholds. Each threshold here is expressed as at least 15 total Lygus with varying numbers of nymphs per 100 sweeps.

Maximum yield occurred at 15 total Lygus with ca. 1.7 nymphs per 100 sweeps. However,…



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

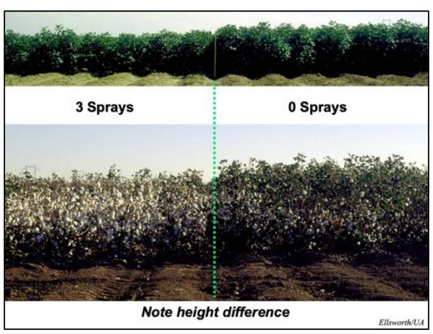


This so-called '15:4' threshold represents 15 total Lygus per 100 sweeps with at least 4 nymphs per 100 sweeps. Again, this is using the industry standard, 15 inch diameter sweep-net used by our consulting community in Arizona.

We recommend taking no more than 25 sweeps in each of 4 locations in a field for a total of 100 sweeps. Decisions made on fewer than 100 sweeps are hazardous and can easily lead to decision errors.

Our threshold counts all Lygus but focuses more on the nymph counts. Why? Because the Lygus adult cannot be reliably controlled by any chemistry and ostensibly spends more time moving and reproducing than actually feeding on the cotton plant. Thus, adults can feed and damage squares; however, from our research, the largest amount of damage is caused by nymphs and especially large nymphs. They are like the human teenagers of the Lygus world.

Triggering sprays just on Lygus adult counts is not warranted. It is always better to wait until you have confirmed that populations are resident to your field and are reproducing. Why?

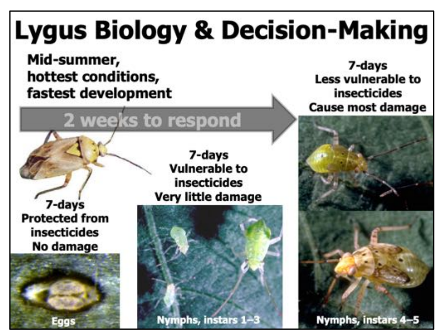


Because nymphs are the real culprit in cotton. As evidence of this, I offer this photo which demonstrates these effects occur over the shortest spatial scale. That is in adjacent rows, shown here in a commercial trial where cotton was sprayed 3 times on the left for Lygus and not at all on the right.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

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

Nymphs are plant-bound and do not move much row to row.

Adults are highly mobile. If the damage dynamic depicted here were due to this life stage, we would not see such a major distinct line of difference between the treated and untreated areas.

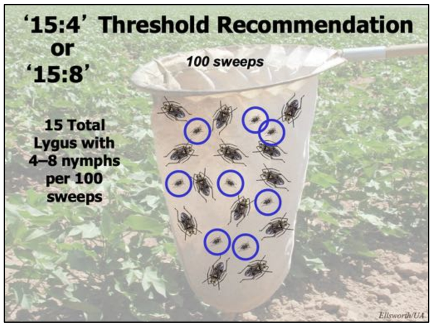


Careful and regular sampling for Lygus should prevent any "surprises".

Efficacy starts with understanding these biological facts which are based in close monitoring and knowing how much time a grower has to respond to Lygus infestations.

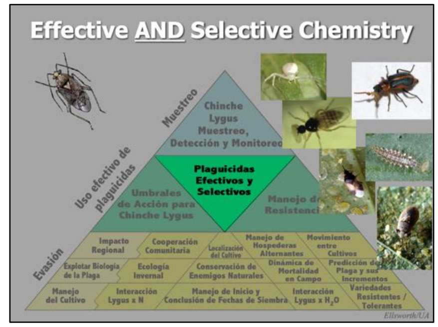
Bear in mind that the response time one has to react is entirely based on how well a pest manager scouts a field and detects the activities first of adults arriving (and staying) in a field and then later in detecting the hatching of 1^{st} instars.

But, in general, under the hottest summer conditions, eggs take 1 week to develop and cannot be controlled until they hatch. Even then, it takes 1 week for the small nymphs (less damaging) to develop into the most damaging life stage of Lygus, the large nymphs. Thus, a grower has up to 2 weeks to respond to a population that is arrived in their fields before spraying.



This so-called '15:4' threshold represents 15 total Lygus per 100 sweeps with at least 4 nymphs per 100 sweeps. However, the revenue curves were such that economics were close to maximum even at 8 nymphs per 100 sweeps. Our PCAs use this knowledge to determine whether they need to be at the low end or upper end of this threshold. Many have simply adopted the 15:8 threshold as their best approach to controlling Lygus and have done very well.

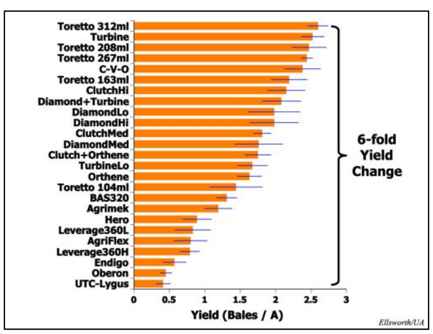
Manejo Integrado de Chinche Lygus Chihuahua Cotton Congress, March 6, 2020



Central to this layer of management is EFFECTIVE & SELECTIVE CHEMISTRY.

Every grower understands that he/she wants to only use products that work, those that kill the target. What's different in this system is that we place a heavy emphasis not only on chemical efficacy but also on chemical selectivity or safety towards beneficials in our system.

Manejo Integrado de Chinche Lygus Chihuahua Cotton Congress, March 6, 2020

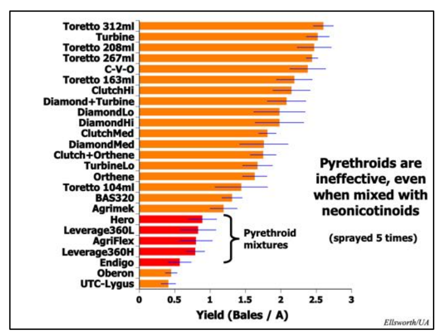


We have many years of data on dozens of products proposed for Lygus control. But I will share with you a typical trial done and highlight the yield results. Many products were tested here. Lygus pressure was very extreme. There is a 6-fold increase in yield when this cotton was protected from damaging Lygus populations in this trial.

Products were sprayed 3–5 times depending on when they reached or exceeded the action threshold.

[This trial was with Bt cotton and there were no other yield-limiting pests present.]

Manejo Integrado de Chinche Lygus Chihuahua Cotton Congress, March 6, 2020

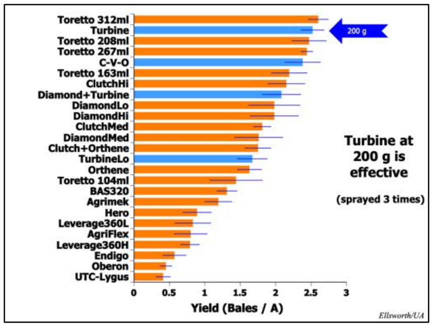


Let's start with the ones that didn't perform.

The red bars show all the pyrethroid containing treatments. None performed well, despite being sprayed 5 times (2 more than any other material).

Note, too, that Orthene is off 1 bale (more than half the yield lost). This is not due to poor Lygus control; Lygus control was good. This is due to the defoliation that occurred due to mites which broke out after destroying their natural enemies (most likely Western Flower Thrips, an important mite predator in our system).

Pyrethroids and neonicotinoids do NOT control Lygus ever in our system. What's worse? They kill the beneficials needed to keep whiteflies and mites and other pests under control.



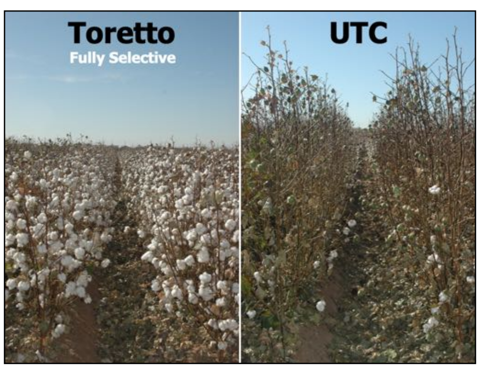
The flonicamid containing treatments, on the other hand, were highly effective and protective of the beneficials present when the 200 g rate of Turbine was used. And, it was sprayed just 3 times.

Likewise, sulfoxaflor (e.g., Toretto) has performed very well and is similarly safe to beneficials, and does not require the very high rate at the top of the trial here. Toretto can be used at 250 ml per hectare to maximum effect on Lygus.

Turbine and Toretto are our standards for Lygus control in Arizona cotton.

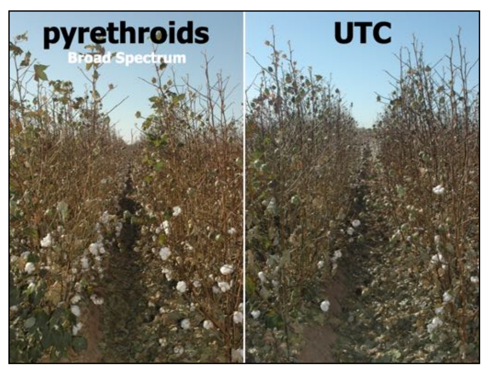
Carbine / Turbine has continued to perform outstanding in control of Lygus and protection of yield. Note the height differences.

It is our Lygus control standard and was adopted in over 80% of all Lygus applications made in Arizona cotton and in over 90% of the first applications made for Lygus (2006-2012).

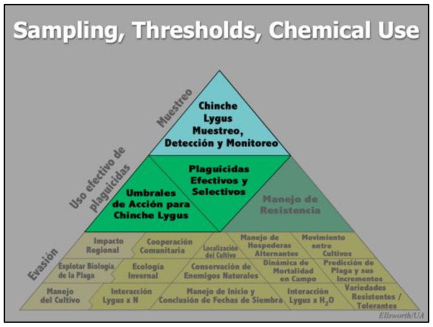


However, sulfoxaflor (Transform / Toretto) has given us new opportunities and flexibility in Lygus control while enjoying some whitefly suppression. Note the huge difference in plant heights. When Lygus are not controlled, fruiting positions (and fruit) are lost. Then all the energy the plant produces goes into unproductive vertical growth. Tall cotton is a telltale sign of Lygus injury many times.

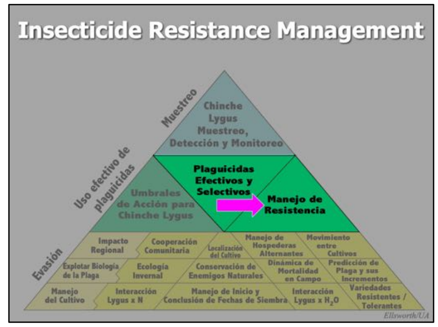
Transform was registered for use in Arizona for the first time in 2013. Since then, almost all Lygus applications are either with Transform or Carbine, or a rotation of these two effective and selective products.



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



So far, we've talked about sampling plans and action thresholds as key tools in properly using and timing chemical controls. However, there is another critical element of EFFECTIVE CHEMICAL USE, …



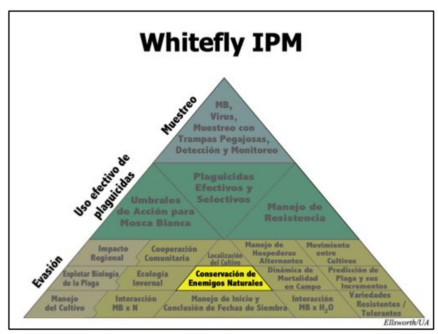
Stewardship of effective and especially selective chemistry demands a program of resistance management that will help us preserve the usage of all chemistry for generations to come.

These products are too valuable to lose because of overuse. It is everyone's responsibility to use these products consistent with a resistance management plan.

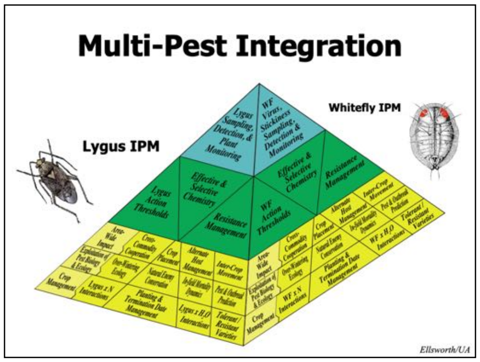
Any time we talk about resistance management in our cotton system, we have to reflect on the disasters in whitefly control that occurred now more than 25 years ago. Whitefly populations were overwhelming and part of this was due to the serious resistances present in those populations. The lessons we learned during that time inform our recommendations for all cotton resistance management.

No class or single active ingredient should be used more than twice per season. This is critically important for valuable chemistries, like Carbine and Transform (Turbine and Toretto) that are central to our Lygus IPM plan.

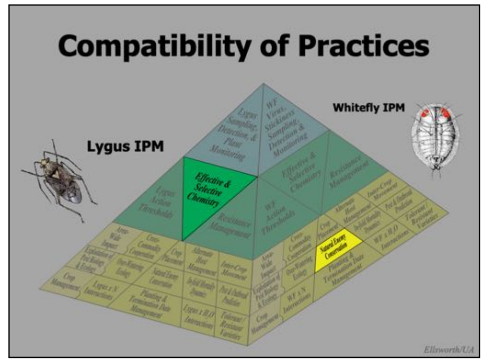
In the end, we never have perfect data or perfect inference when it comes to resistance management. However, there is a prudent course that we follow in AZ that is now more manageable because of the diversity of effective and selective approaches that we have and the small number of times we spray.



Our past experiences (and research) with whiteflies have taught us that natural enemy conservation is central to our success in our whitefly IPM plan.



Continued durability and stability of our system depends on the full integration of practices over the range of pests that growers face in cotton. In our case that means making sure that our Lygus IPM and Whitefly IPM plans are fully integrated and compatible.



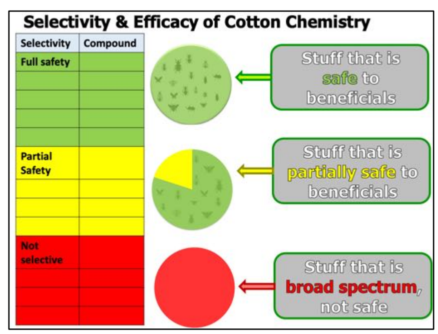
It is important that the management practices used for one pest are compatible with those of a second pest. Take for example the chemistries used in the control for Lygus. Some Lygus chemistries are broad-spectrum, e.g., acephate. These broad-spectrum chemistries are damaging to the natural enemies that are important for controlling whiteflies. With the introduction of selective Lygus chemistries in 2006 we are better able to conserve the natural enemies needed to manage whiteflies and all secondary pests more efficiently, e.g., mites, aphids, various lepidopteran pests.

This is an excellent example of when the conservation of natural enemies is neglected.

What happened here? Inappropriate selection and use of a broad-spectrum Lygus insecticide (acephate, Orthene) destroyed the natural enemy complex. Only this time, whiteflies did not resurge nearly as much as did two-spotted spider mites. The resulting stress on the plants defoliated the entire plot right down to the row. In contrast 3 sprays of selective products or no sprays at all, UTC, resulted in conserved natural enemies that were critical in maintaining <u>natural</u> control of spider mites.

We do very specific research, like the non-target study shown here, that screens each new insecticide for its safety to beneficials and this gives us the confidence to categorize products as to selectivity in our system.

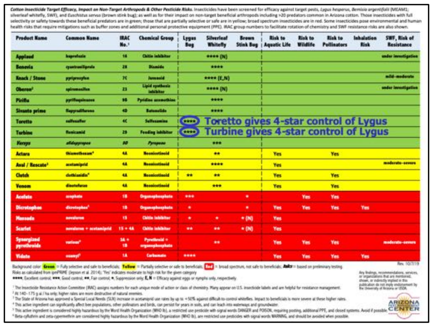
11F32NTO, 2011 large plot study, 3 sprays at roughly 2 week intervals; effects visible prior to 3rd spray. This is a non-target study.



The use of selective insecticides is so important to our system, we organize our chemical use guidelines around this stop light metaphor, where the green box includes all the products that have been tested as safe to beneficials in our cotton system, yellow is the stuff that is partially safe to beneficials and red is the stuff that is non-selective or broad spectrum and not safe to beneficials.

There can always be those scenarios where and when non-selective products are needed precisely because of their broad-spectrum control of arthropod pests for which we have no selective alternatives.

We'll talk more about this in my talk that follows about whitefly IPM.

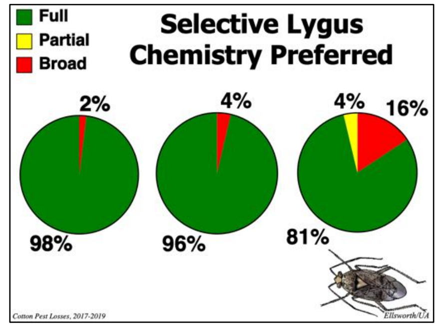


Let’s look at this chart for Lygus control.

Carbine and Transform (Turbine and Toretto) are “4-star” materials in terms of their efficacy in controlling Lygus. And, they are fully selective or safe to beneficials.

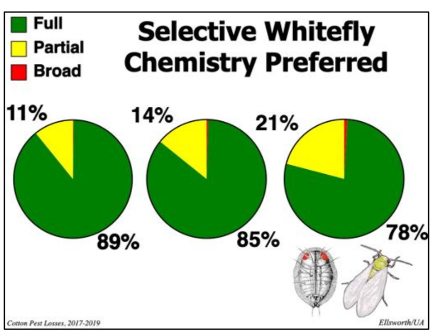
Belay (Clutch) is no longer used in Arizona cotton. It was only a 2-star material in terms of efficacy and only partially selective. Worse, it has very significant hazards to pollinators and aquatic life. This is the major reason it is no longer used in Arizona cotton.

There are broad spectrum controls for Lygus but they are generally not as effective and always more damaging to natural enemies. Plus, they carry with them significant environmental and human health hazards that we should try to avoid.



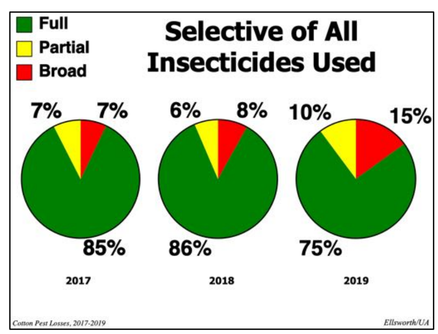
Pest managers are actively choosing one or both of the fully selective products to control Lygus in Arizona cotton. On rare occasion, and for a variety of reasons, some sprays are made with non-selective materials, perhaps as they try to control some other pest for which there are no selective or partially selective options.

2018 results were similar to 2017; however, 2019 shows an unfortunate trend with 20% of Lygus sprays being made with partially or non-selective materials. Worse, some of these products used are ineffective and not recommended for Lygus control. We are still investigating this trend. However, it appears that the fiscal climate is so poor that some thought they could “cut corners” and fall back on these “cheaper” materials. This, in fact, was not a good decision, as I will discuss in my next talk.



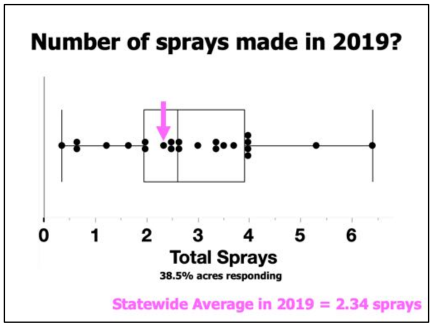
We can also examine the whitefly control products used by Arizona pest managers and see that the vast majority are fully selective materials. Almost no broad spectrum products are used for whitefly control.

However, in 2019, there was a decrease in usage of fully selective materials and an increase in partially selective products.



This trend can be seen over the full range of insect control products used by our growers. There was a doubling in the amount of partially selective and non-selective materials used in 2019.

We will pause here for questions about Lygus IPM and continue our discussion about whitefly IPM by completing an analysis of chemical use by growers in 2019 and how their choices impacted the number of sprays made.

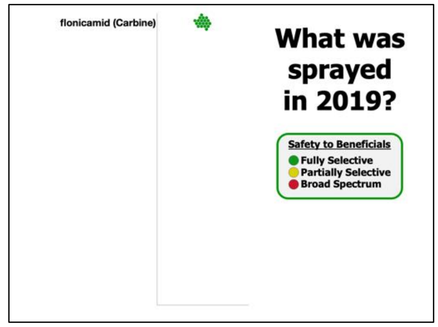


Let's continue by reviewing the spraying behaviors of pest control advisors to the cotton industry in 2019.

This chart shows the number of sprays made to cotton for arthropod pest control in Arizona. There is a wide range of responses, some around a 0.5 sprays season-long while some over 5 sprays.

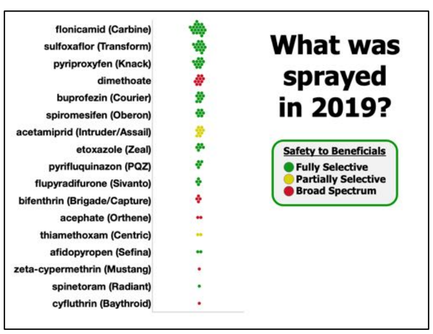
The statewide average was 2.34 sprays.

This diversity could be due to differences in pest pressures or other factors.



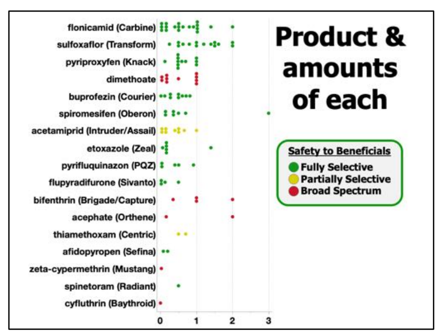
Each product sprayed by our growers can be ranked and categorized as to selectivity to beneficials.

Among all insecticides used, Carbine (or Turbine) by more pest control advisors.



This was followed by our other fully selective Lygus control chemical, Transform (or Toretto).

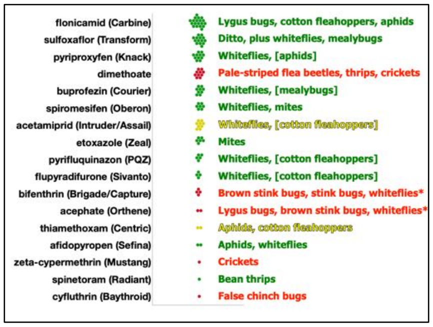
However, you can see that there are 'yellow' and 'red' products in use in 2019. Let's look closer.



Here we can see what they sprayed and how frequently they sprayed each product. Most products were sprayed less than one time, meaning it was sprayed on only a fraction of a pest control advisor's acreage. But some, like Oberon were used as much as 3 times, which would exceed our recommended practice of limiting chemistry to no more than 2 non-consecutive uses (i.e., to support resistance management goals).

And, there were some broad spectrums that were used in only the smallest fraction of acreage like cyfluthrin on just a few acres. In this case, there were false chinch bugs invading a field edge that needed to be controlled.

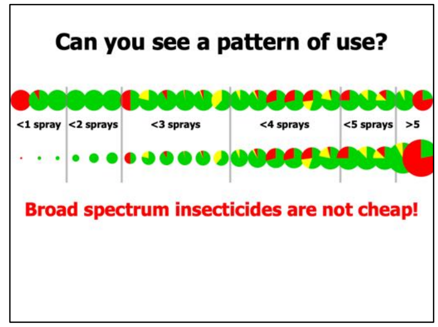
We don't always have a selective chemical control for all pests.



This shows us the targets listed by each pest control advisor for each product they used (those in brackets are additional targets known to be impacted by a product's use).

Dimethoate was used by more people on more acres this past year, in part because of the weak seed and poor germination and early growth conditions that we had in 2019. This is a natural tendency thought to 'help' the cotton along and prevent any excessive damage due to flea beetles or thrips. However, there is a risk to this use pattern because of its harsh effects on natural enemies.

Other targets are unusual (e.g., crickets and false chinch bugs) and pest control advisors have to do the best they can with the available tools.



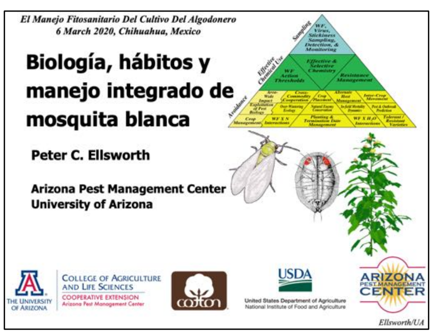
In the top chart, we see the distribution of products by their selectivity. Can you see any pattern here? Does it seem like there is somewhat more yellow and red as you move to the right?

Turns out the fewest total sprays were made by the PCAs on the left end and the most by PCAs on the right end of this chart.

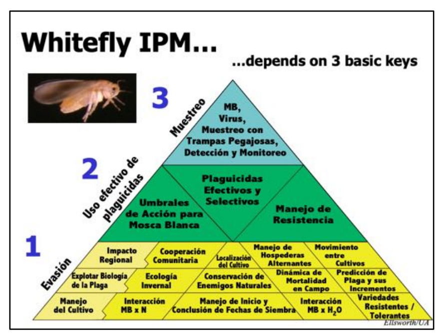
If we re-scale the pies to reflect the number of sprays each pest control advisor made, we quickly see the pattern: more 'yellow' and 'red' products seem to be related to more spraying in general.

Is this coincidence? Or is this the natural enemy destruction that leads to additional primary pest and secondary pest sprays?

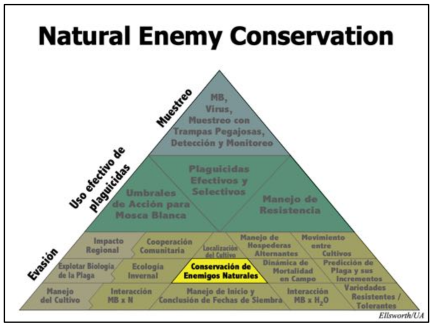
The conclusion is clear. Broad spectrum products are not necessarily "cheap" options, if they lead to more sprays!



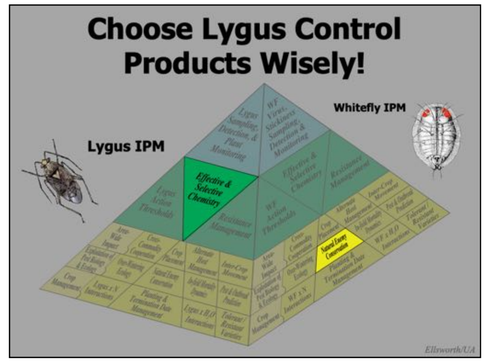
In this talk, I'll want to highlight some of the key attributes of our whitefly IPM plan including our newest biological control informed thresholds that we debuted in Arizona and Mexico in 2019.



We are all familiar with the IPM pyramid. There are three key components to successfully managing whiteflies. This includes avoidance, effective chemical use, and sampling. What I will be teaching today is how to use the resources already available to you in the field and how you can capitalize on those resources by removing uncertainty in decision-making while saving you money.

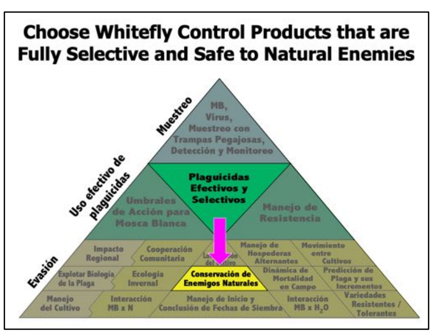


As we have already mentioned, natural enemy conservation is a central tactic of our whitefly IPM plan.

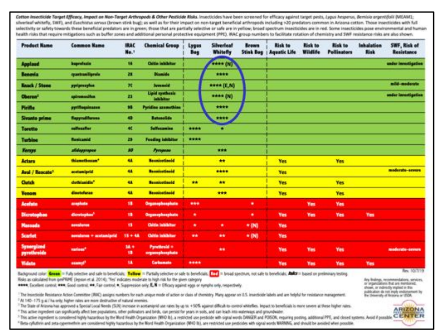


Once again, the Lygus chemical controls we use can have a direct influence in our ability to conserve this free source of pest control in our system, one that is so key to whitefly management.

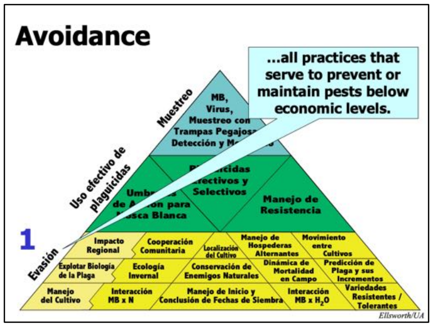
So, choose your Lygus chemical control products very wisely!



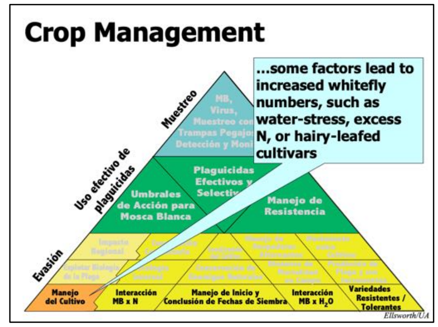
Likewise, every effort should be made to choose a fully selective whitefly control product, one compatible with natural enemy conservation.



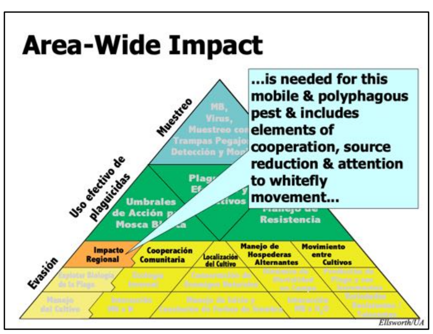
There are many to choose from in Arizona. There are easily 6 excellent choices for whitefly control.



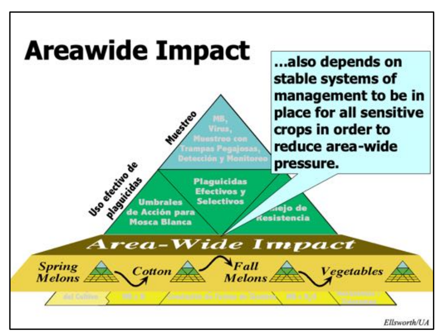
Practice the fundamentals of 'AVOIDANCE'. These practices help prevent or maintain pests below economic levels so that spraying is not necessary.



'AVOIDANCE' includes 3 layers, the base layer being 'CROP MANAGEMENT'. There are many cultural controls that contribute to preventing whitefly problems. Do not place your cotton under water stress, avoid hairy-leafed varieties, and don't over fertilize with Nitrogen, as these are all risk factors that favor whitefly development.



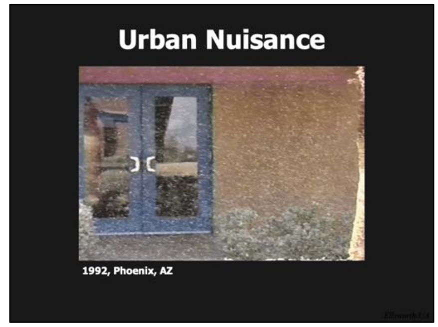
'AREA-WIDE IMPACT' is fundamental to such a mobile and polyphagous pest. These tactics include the human ones of communicating, cooperating and coordinating activities with your neighbors.



For example, in Arizona, each season's crop serves as a potential source for the crop that follows. We have much temporal and spatial overlap of spring melons, cotton, fall melons and winter vegetables. There needs to be stable systems of management in place for all sensitive crops in a region. This will lower area-wide pressure.

None of these things were in place in the early 1990s, when whiteflies broke out into biblical proportions.

This video reviews the terrible conditions that were at play in the early 1990s in Arizona. Here you can see the heavy infestation of cotton that was typical for central Arizona in 1992. This was an agricultural disaster, and not one that was going to be easily recovered from using just insecticides.



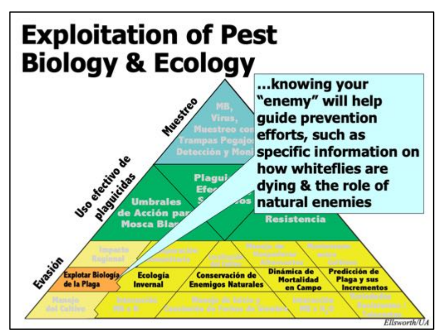
This was the scene we were facing when the invasive B-biotype came to Arizona (MEAM1). The numerical pressure was overwhelming and impacting not only agricultural areas, but also Arizona's largest city, Phoenix, as seen here on the campus of a local college.

The urban friction caused was substantial, where residents had to wear masks just to jog or ride a bike in the fall of 1992. An optometrist reported multiple occurrences where whiteflies were impacted on the corneas of patients and had to be removed surgically.

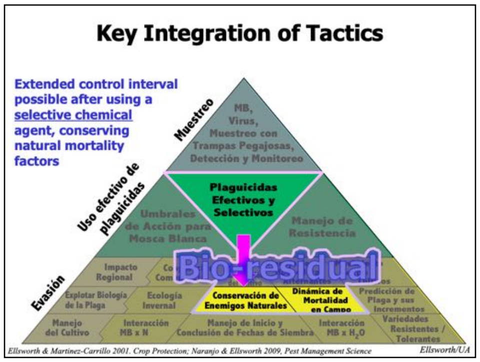
This scene has colored everything we do in cotton IPM in AZ since.

Our largest challenge was contamination of markets where buyers applied broad scale penalties to our region's production, whether or not that production was actually "sticky".

Honeydew deposited by nymphs and adults fell onto exposed lint where it then hosted sooty mold fungi that discolored and weakened fibers, but most of all it prevented the processing of fiber, bringing mills to costly stand-stills for million-dollar cleanings of all equipment.



All this experience is why we place such a heavy emphasis on tactics that take advantage of the biology and ecology of our system. In particular, we have to maximize the free biological control that is possible when we take action to conserve natural enemies in our cotton system.



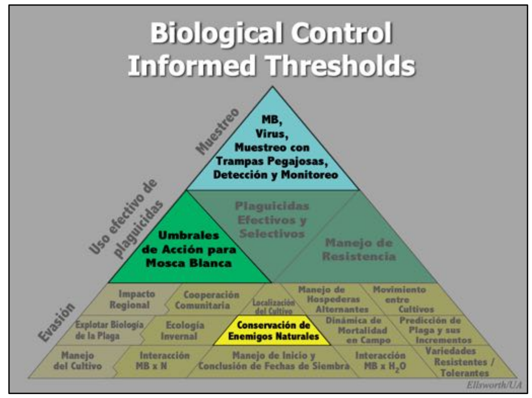
There are two key concepts to master when trying to become an effective manager of whiteflies in desert cotton.

The first is 'bio-residual'.

Selective chemistry supports all of natural enemy conservation.

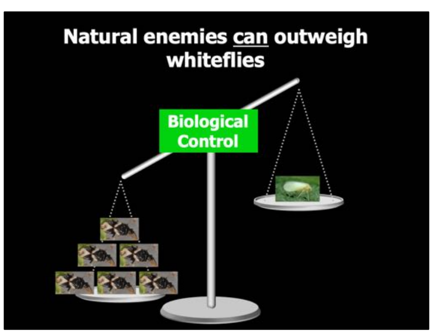
The role and function of predators and natural mortalities in whiteflies in cotton and the integration of these mortality factors with fully selective insecticides is key to our plan's success. The two combined give us access to an extended suppressive interval known as bio-residual (sensu Ellsworth & Martinez-Carrillo 2001).

This integration of chemical and biological control tactics is key to the sustainably of our IPM system and its future resilience when new potential pests enter the system.

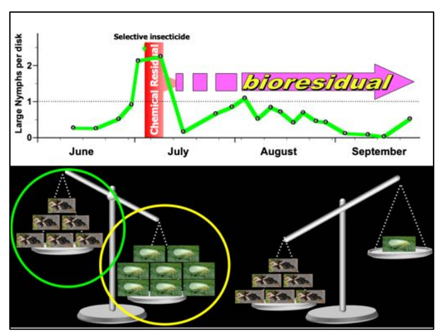


The other concept is an advanced one: Biological Control Informed Thresholds. Or, put another way, using information about natural enemy levels to make better decisions on whether or not to spray whiteflies.

The upper two layers of our IPM strategy include SAMPLING and THRESHOLDS, as key elements of the decision support system. These two things act together in order to develop decision-support for pest sprays, but are decidedly pest centric. In our system, we have integrated sampling and thresholds for both pest <u>and</u> natural enemies!



Natural enemy populations can and do outweigh whitefly populations throughout much of the season. It is only when they don't that chemical control is needed. And then, the choice should be to use a product that is safe to the natural enemies that are still present. This chemical control can then reduce pest populations to a level that allows natural enemies to once again outweigh and suppress pests.

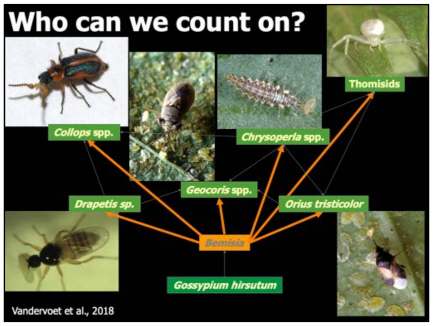


Let's examine the system at work.

Once whiteflies exceed threshold, they have reached levels that outweigh the natural enemies.

(left) This is how the system looks like when we sprayed. Lots of whiteflies, but not a proportional number of predators to provide biocontrol.

But even though the chemical residual is short, perhaps 7-12 days, whiteflies remain below threshold for weeks thereafter. Why? Because the number of natural enemies finally outweighed the number of whiteflies, achieving successful, functioning biocontrol. This extended period of whitefly control due to natural enemies and other natural factors after a selective insecticide application is called Bioresidual.



One or more of these six predators dominates cotton-whitefly food web. Dr. Tim Vandervoet's (former student) work definitively confirmed that these are in fact the key predators that we should be counting in our cotton fields.

Drapetis is a small empidid fly that feeds exclusively on whitefly adults (not eggs or nymphs) and other insects.

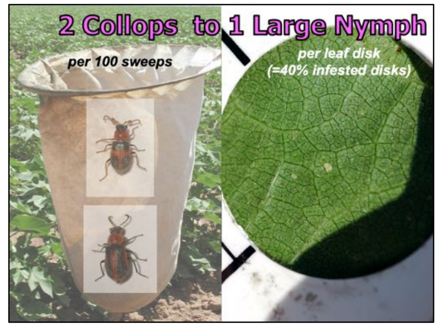
Collops beetle, two different species.

Big-eyed bugs, two different species.

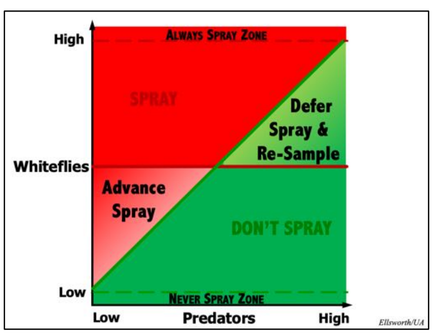
Green lacewing larvae (adults don't feed).

Crab spiders (though other spiders can also be present in large numbers).

Minute Pirate bugs.

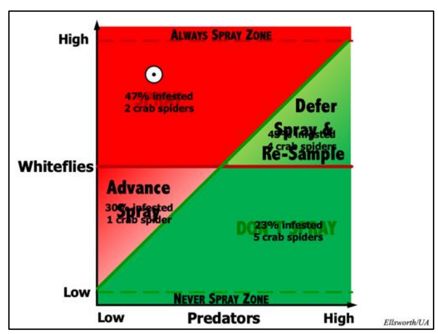


The way this works is the scout sweeps the field and maintains counts of the target predator, in this case, *Collops* beetles (either of two species, *C. vittatus* and *C. quadrimaculatus*) and compares this to the density of large nymphs per 3.88 sq cm leaf disk. The standard threshold is 1 large nymph per disk or 40% infested disks. In this case, at least 2 Collops per 100 sweeps would be needed to defer a spray.

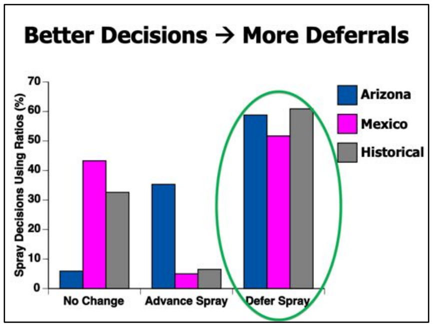


Whitefly levels can be below, above, or at threshold. When whiteflies are very low, you know that you never need to spray; when whitefly levels are very high, you know that you have to spray no matter what. They're just too high.

How do things change when you consider predator numbers? The green line represents these new predator thresholds, a ratio actually, where predator numbers needed increases as whitefly levels increase. So when whiteflies are higher than threshold, but predators are also high, you can probably safely defer your spray and re-sample in a few days. This saves you money. Conversely, when whitefly numbers are low but approaching threshold <u>and</u> numbers of predators are also low, biocontrol is compromised and you will want to advance your spray. This prevents whitefly damage and also saves you money by making your control efficient.

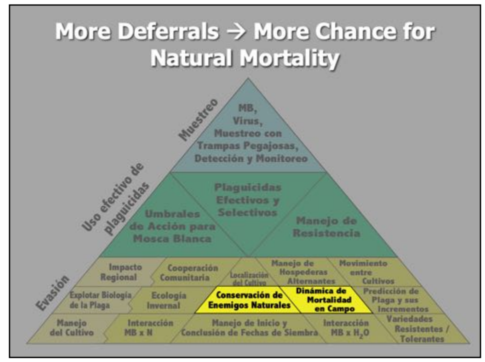


Let's work through a hypothetical example…



Delaying, or deferring, sprays can have very large impacts on both producers' costs (by potentially cutting the number of sprays down over the course of the season), and by maintaining natural enemy impacts (Ellsworth and Martinez Carrillo 2001, and Naranjo et al. 2002). Similarly, controlling whiteflies early, when biocontrol is not functioning can reduce management costs season-long and prevent unnecessary damage.

Based on our surveys of Mexican and Arizona cotton fields and our own historical data from research trials, we can see that using biological control informed threshold via predator : prey ratios should, on average, lead to more decisions to defer sprays.

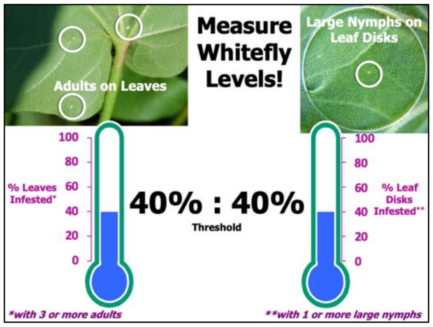


More deferrals opens up windows in time when biological control can continue to function as well as other, sometimes significant, mortality factors, like…

Haboobs are large dust fronts that occur in arid climates influenced by monsoonal air flows. Wind speeds are typically 25–50 mph and cause dust to abrade the leaf surface, scouring off eggs and nymphs when windspeeds are high. This is a natural source of mortality.

While we cannot count on this happening in every field every year, there are always some fields each year that are impacted by these summer weather systems.

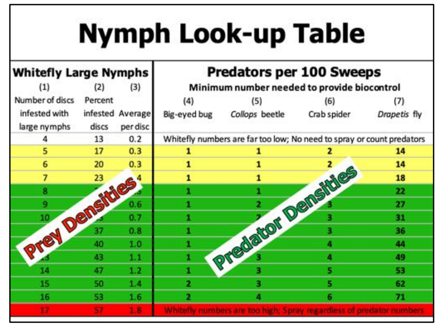
Use of biological control informed thresholds lead, on average, to more decisions to defer sprays, more time for natural whitefly mortality to proceed with greater chance for major weather events that would lessen the need to spray at all as a result.



Sampling whiteflies is necessary to their proper management. There are two stages of whiteflies to sample and both measurements should be taken whenever decision-making is critical. I have seen numerous situations where either one or the other measurement has been insufficient to understand the whitefly dynamics present in the field. Fields with few adults may actually be harboring disproportionately large nymph populations. This happens especially when there have been prior sprays, rains or dust fronts (haboobs) in the field. Other times, large nymph counts are very low but adults are quite high. This is very common in scenarios where immigration is occurring when cotton is next to a source field like spring melons.

Leaves with 3 or more adults on them are considered 'infested'. 40% infested leaves is the base, pest-centric threshold. 3.88 sq. cm leaf disks with 1 or more large nymphs are considered 'infested'. 40% infested leaf disks is the base, nymph threshold.

Thermometer adapted from http://www.showeet.com/16/03/2010/charts-and-diagrams/thermometer-free-diagram/



Nymph Look-up Table

Whitefly Large Nymphs (1) Number of discs infested with large nymphs	(2) Percent infested discs	(3) Average per disc	Predators per 100 Sweeps, Minimum number needed to provide biocontrol: (4) Big-eyed bug	(5) *Collops* beetle	(6) Crab spider	(7) *Drapetis* fly
4	13	0.2	Whitefly numbers are far too low; No need to spray or count predators			
5	17	0.3	1	1	2	14
6	20	0.3	1	1	2	14
7	23	[illegible]	1	1	[illegible]	18
8	[illegible]	[illegible]	1	1	[illegible]	22
9	[illegible]	0.6	1	2	3	27
10	[illegible]	0.7	1	[illegible]	3	31
[illegible]	37	0.8	1	[illegible]	3	36
[illegible]	40	1.0	1	[illegible]	4	44
[illegible]	43	1.1	1	3	4	49
14	47	1.2	1	3	5	53
15	50	1.4	2	3	5	62
16	53	1.6	2	4	6	71
17	57	1.8	Whitefly numbers are too high; Spray regardless of predator numbers			

The standard pest-centric threshold is actually based on both large nymph and adult numbers.

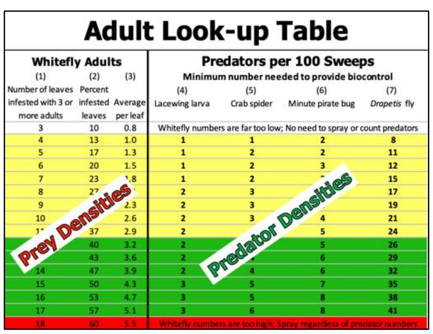
We published in English and Spanish look-up tables where once a pest manager knows the whitefly (prey) density, they can determine the predator density that indicates whether biological control is still functioning.

In the IPM Short, "Counting Whiteflies & Predators", there are two tables to help interpret your count data. This is the whitefly large nymphs and predators table.

Publication available at:

https://cals.arizona.edu/crops/cotton/files/PredatorToPreyRatios.pdf

In Spanish at,
https://cals.arizona.edu/crops/cotton/files/PtoPlaminateSpanish.pdf

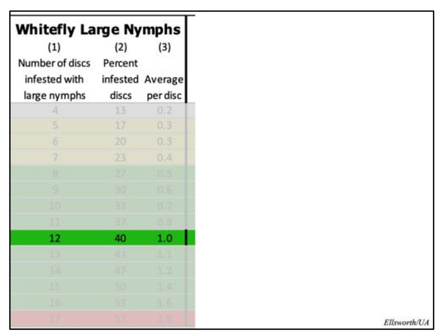


Adult Look-up Table

Whitefly Adults (1) Number of leaves infested with 3 or more adults	(2) Percent infested leaves	(3) Average per leaf	Predators per 100 Sweeps, Minimum number needed to provide biocontrol: (4) Lacewing larva	(5) Crab spider	(6) Minute pirate bug	(7) *Drapetis* fly
3	10	0.8	Whitefly numbers are far too low; No need to spray or count predators			
4	13	1.0	1	1	2	8
5	17	1.3	1	2	2	11
6	20	1.5	1	2	3	12
7	23	[illegible]	1	2	[illegible]	15
8	[illegible]	[illegible]	2	3	[illegible]	17
9	[illegible]	2.3	2	3	[illegible]	19
10	[illegible]	2.6	2	3	4	21
[illegible]	37	2.9	2	[illegible]	5	24
[illegible]	40	3.2	2	[illegible]	5	26
[illegible]	43	3.6	2	[illegible]	6	29
14	47	3.9	2	4	6	32
15	50	4.3	3	5	7	35
16	53	4.7	3	5	8	38
17	57	5.1	3	6	8	41
18	60	5.5	Whitefly numbers are too high; Spray regardless of predator numbers			

Because whitefly thresholds depend on measuring both whitefly large nymphs and whitefly adults, there are two different tables. This one is for adult Bemisia and predators.

Through these two tables, pest managers can elect to use 1 or more of the 8 thresholds available for 1 or more of the 6 key predators.

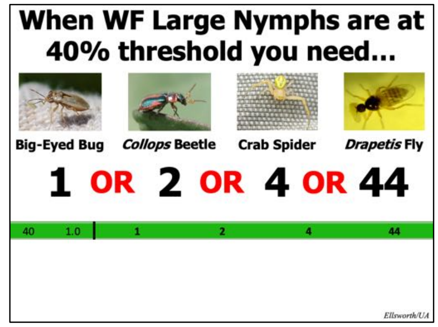


Whitefly Large Nymphs (1) Number of discs infested with large nymphs	(2) Percent infested discs	(3) Average per disc
4	13	0.2
5	17	0.3
6	20	0.3
7	23	0.4
8	27	0.5
9	30	0.6
10	33	0.7
11	37	0.8
12	40	1.0
13	43	1.1
14	47	1.2
15	50	1.4
16	53	1.6
17	57	1.8

The normal threshold for large nymphs is 40% of leaf discs infested with 1 or more live, large nymphs (3rd or 4th instars). That's 12 leaves infested out of 30 total, and is equivalent to an average of 1 per disc.

ge Nymphs (2) Percent infested discs	(3) Average per disc	Predators per 100 Sweeps — Minimum number needed to provide biocontrol (4) Big-eyed bug	(5) *Collops* beetle	(6) Crab spider	(7) *Drapetis* fly
13	0.2	Whitefly numbers are far too low; No need to spray or count predators			
17	0.3	1	1	2	14
20	0.3	1	1	2	14
23	0.4	1	1	2	18
27	0.5	1	1	2	22
30	0.6	1	2	3	27
33	0.7	1	2	3	31
37	0.8	1	2	3	36
40	**1.0**	**1**	**2**	**4**	**44**
43	1.1	1	3	4	49
47	1.2	1	3	5	53
50	1.4	2	3	5	62
53	1.6	2	4	6	71
57	1.8	Whitefly numbers are too high; Spray regardless of predator numbers			

There are 4 predator thresholds to go with your large nymph counts, one for big-eyed bug (specifically Geocoris pallens), one for Collops beetle (either species, C. vittatus or C. quadrimaculatus), one for crab spider, and one for Drapetis fly.



Only one of the predator species needs to be at or above threshold, which are 1, 2, 4, or 44 *G. pallens, Collops, Misumenops celer*, or *Drapetis*, per 100 sweeps, respectively, in order to defer a spray in favor of continued biocontrol.

Whitefly Adults (1) Number of leaves infested with 3 or more adults	(2) Percent infested leaves	(3) Average per leaf	Predators per 100 Sweeps — Minimum number needed to provide biocontrol (4) Lacewing larva	(5) Crab spider	(6) Minute pirate bug	(7) *Drapetis* fly
3	10	0.8	Whitefly numbers are far too low; No need to spray or count predators			
4	13	1.0	1	1	2	8
5	17	1.3	1	2	2	11
6	20	1.5	1	2	3	12
7	23	1.8	1	2	3	15
8	27	2.1	2	3	4	17
9	30	2.3	2	3	4	19
10	33	2.6	2	3	4	21
11	37	2.9	2	3	5	24
12	40	3.2	2	4	5	26
13	43	3.6	2	4	6	29
14	47	3.9	2	4	6	32
15	50	4.3	3	5	7	35
16	53	4.7	3	5	8	38
17	57	5.1	3	6	8	41
18	60	5.5	Whitefly numbers are too high; Spray regardless of predator numbers			

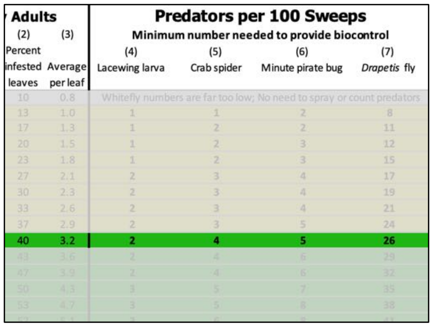
Ellsworth/UA

There is a table for adult Bemisia and predators, too.

Whitefly Adults (1) Number of leaves infested with 3 or more adults	(2) Percent infested leaves	(3) Average per leaf
3	10	0.8
4	13	1.0
5	17	1.3
6	20	1.5
7	23	1.8
8	27	2.1
9	30	2.3
10	33	2.6
11	37	2.9
12	**40**	**3.2**
13	43	3.6
14	47	3.9
15	50	4.3
16	53	4.7

Ellsworth/UA

The adult threshold is 40% of leaves infested with 3 or more whiteflies (12 out of 30 here), which is equivalent to 3.2 adults per leaf…

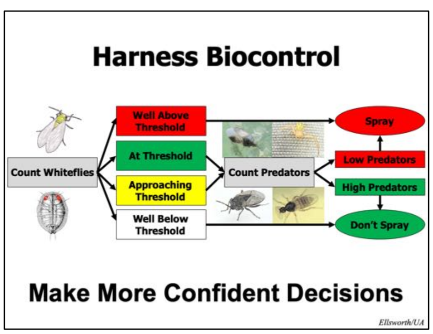


Adults (2) Percent infested leaves	(3) Average per leaf	Predators per 100 Sweeps — Minimum number needed to provide biocontrol (4) Lacewing larva	(5) Crab spider	(6) Minute pirate bug	(7) *Drapetis* fly
10	0.8	Whitefly numbers are far too low; No need to spray or count predators			
13	1.0	1	1	2	8
17	1.3	1	2	2	11
20	1.5	1	2	3	12
23	1.8	1	2	3	15
27	2.1	2	3	4	17
30	2.3	2	3	4	19
33	2.6	2	3	4	21
37	2.9	2	3	5	24
40	**3.2**	**2**	**4**	**5**	**26**
43	3.6	2	4	6	29
47	3.9	2	4	6	32
50	4.3	3	5	7	35
53	4.7	3	5	8	38

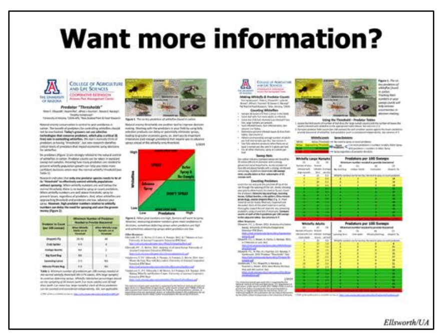
There are 4 predator thresholds to go with whitefly adult densities.

As with the nymphs, you only need to satisfy one of the predator thresholds. Note that the predators and the number of predators needed are different from the species and levels needed for the nymphs.

These thresholds were the subject of Dr. Tim Vandervoet's dissertation research in our program.



To summarize, our decision flow depicted helps growers make much more confident control decisions.



https://cals.arizona.edu/crops/cotton/files/PtoPlaminateSpanish.pdf

https://cals.arizona.edu/crops/cotton/files/PtoPlaminate.pdf

https://cals.arizona.edu/crops/cotton/files/wfBIT.pdf

https://cals.arizona.edu/crops/cotton/files/PredatorToPreyRatios.pdf

Thanks to support from FMC, we have a Spanish language, laminated 'visor guide' that can be kept in your truck so that you can consult these tables any time.

This is available on-line at:

https://cals.arizona.edu/crops/cotton/files/PtoPlaminateSpanish.pdf

Manejo Integrado de Chinche Lygus Chihuahua Cotton Congress, March 6, 2020

I'd like to close with thanks to the funding organizations and other supporters and collaborators that have been instrumental to our research and Extension programs.

Special thanks to FMC for supporting my attendance to this Congress and for their excellent translation services.