COTTON PHYSIOLOGY TODAY

Newsletter of the Cotton Physiology Education Program -- NATIONAL COTTON COUNCIL

Vol. 7, No. 4, May 1996

Cotton and Resistant Insects

Anne F. Wrona[1], Frank Carter[2], Jonathan Diehl[3], Peter Ellsworth[4], Kater Hake[5], Dick Hardee[6], Gary Herzog[7], Blake Layton[8], B. Roger Leonard[9], Jim Leser[10], Will McCarty[11], Bob Nichols[12], Jeff Silvertooth[13], Gordan Snodgrass[14], Theo Watson[15]

Knowing when and how best to treat a cotton crop for resistant insects is a dilemma faced by growers Beltwide. There are two main schools of thought about this issue, namely 1) treat to protect the crop from early season damage and 2) sacrifice some early season yield by delaying treatment to allow beneficial insect populations to build (also reducing the chances for flare-ups of secondary pests). There is seldom only one easy or right answer. In this newsletter, researchers and extension specialists from across the Cotton Belt discuss different means of managing cotton to turn a profit and, at the same time, to reduce incidences of resistance in insects.

Not all pests are resistant to insecticides. Here we focus on five pest complexes in which resistance management is an issue, discuss earliness as it relates to insecticide resistance, and indicate some ways to maintain the efficacy of the chemical tools we have available to continue to get the most "bang for the buck." We do not suggest using any one of these practices at the expense of a cotton crop.

Insecticide Resistance

Aphids, the tobacco budworm/ bollworm complex, plant bugs, pink bollworm, and silverleaf whitefly present insecticide resistance problems and accounted for over $540 million lost Beltwide in 1995, an exceptionally bad year (Table 1). It is not too surprising that the first-developed transgenic cottons target caterpillar pests when you realize that losses totaling over $334 million in 1995 were due to the budworm/bollworm complex alone.

Just what do we mean by insecticide resistance? Resistance can develop in a population of pests exposed to repeated applications of insecticide. The survivors reproduce and pass on resistance to their offspring. With repeated applications, the only surviving insects are those able to withstand doses of a product which would have proven lethal to the initial, susceptible population. Soon the only insects in a grower's field are derived from resistant stock. Susceptible insects die and resistant ones survive applications. Another insecticide "bites the dust."

[1] A.F. Wrona, National Cotton Council
[2] F.L. Carter, National Cotton Council
[3] J. Diehl, University of Arizona
[4] P.C. Ellsworth, University of Arizona
[5] K. Hake, Texas A&M University
[6] D.D. Hardee, USDA Southern Insect Management Laboratory
[7] G.A. Herzog, University of Georgia
[8] M.B. Layton, Mississippi State University
[9] B.R. Leonard, Louisiana State University Agricultural Center
[10] J.F. Leser, Texas A&M University
[11] W. McCarty, Mississippi State University
[12] R.L. Nichols, Cotton Incorporated
[13] J.C. Silvertooth, University of Arizona
[14] G.L. Snodgrass, USDA Southern Insect Management Laboratory
[15] T. Watson, University of Arizona

National Cotton Council OF AMERICA

Table 1. '95 losses due to insects in which problems with resistance to chemical treatments have been identified. Estimates of dollars lost assume $0.80 per pound. These figures do not reflect substantial economic losses that can occur as a result of reduced fiber quality. In addition to impacting yields, both whitefly and aphid infestations can produce sticky cotton which, at best, brings a discount. (Source: 1996 Beltwide Cotton Conference Proceedings [BWCCP])

	Bales Lost:	Dollars Lost:
Budworm/Bollworm	856,909	$334,194,510
Plant Bug	240,134	93,652,260
Aphids	234,756	91,554,840
Pink Bollworm	35,758	13,945,620
Silverleaf Whitefly	20,904	8,152,560
TOTAL	**1,388,461**	**$ 541,499,790**

A Look at the Cotton Plant: Earliness and Profitability

With profitable production the primary objective, the stage of development of the cotton crop must be considered when dealing with insects. Managing for earliness means the crop is in the ground for a shorter period of time. Positive spin-offs include less exposure of the crop to pests, fewer applications of pesticides, and reduced costs as a result of having the crop in the ground for less time.

Earliness is favored by selecting a fast-fruiting variety, establishing a good stand, achieving early fruit retention, protecting the crop from pests, avoiding water stress by irrigating in a timely fashion, optimizing fertilizer applications (timings and amounts), controlling the balance of vegetative and reproductive growth, and terminating the crop by stopping irrigation at the appropriate developmental stage.


(Photo: A.F. Wrona).

Protecting the crop from pests early in the season is key to managing an early crop. Why? Aphids, for instance, can cause stunting of plants. Plants weakened early in the season never amount to much and certainly eliminate any chance for an early crop. An infestation of plant bugs early in the season can wipe out early fruit, again, doing away with earliness. Even more importantly, figures from Mississippi show that first position and first-formed fruits account for considerably more profit in both long and short season varieties (Table 2). Managing to retain these positions is not only critical to earliness, but also to profitability since the early-set fruit will have more value per acre (Table 2). The bulk of the crop is made on lower fruiting branches, particularly in the early season varieties.

Table 2. Values per acre by fruiting position (#1, #2, or #3) for an early season cultivar compared to a full season cultivar. (Source: J. Jenkins and J.C. McCarty, 1995)

Early Season Cultivar				Full Season Cultivar		
#3	#2	#1	NODE	#1	#2	#3
			21	$3		
			20	$11		
		$3	19	$21	$1	
		$8	18	$32	$3	
		$22	17	$47	$8	$1
	$3	$33	16	$65	$12	$1
	$8	$40	15	$73	$15	$2
$1	$10	$62	14	$79	$21	$2
$1	$12	$80	13	$86	$25	$2
$2	$14	$84	12	$79	$26	$4
$3	$22	$85	11	$69	$24	$3
$3	$33	$80	10	$77	$20	$4
$1	$31	$92	9	$75	$22	$5
$2	$32	$103	8	$68	$16	$1
$3	$29	$93	7	$38	$9	$2
	$16	$47	6	$14	$3	$1
	$3	$5	5	$1		

By treating with insecticides only when recommended thresholds have been reached, both insect pests and natural enemies are exposed less to insecticides. (Thresholds are guidelines developed through research that are useful in determining when populations of a particular insect are high enough to warrant treatment. Numbers of nymphs, eggs, and adults per leaf or per unit area have been used as thresholds. Check with your extension service for sampling procedures recommended for your area.) When treatment is necessary, using diverse materials and classes of chemistries helps delay development of resistance. For thresholds to work properly, commercial fields must be scouted in the same manner and intensity with which research plots were scouted to establish them.

Integrated pest management (IPM) uses a combination of practical methods for controlling a pest or pest complex, rather than just a single method such as insecticide treatment. Although IPM is the cornerstone of any good cotton insect management effort, it takes on additional importance when dealing with pests that have developed resistance to insecticides. Since the insect's reproductive rate, migration and host range, as well as the insecticide's persistence, specificity, and intensity of use influence how rapidly insecticide resistance develops, employing IPM can often delay development of resistance.

Deciding which management approach to use is a bit of a gamble, like many aspects of farming. Here we briefly review the biology and describe specific resistance problems of five pest complexes which torment producers and challenge us all to derive better means of treating them.

Aphids (*Aphis gossypii*)

Figure 1. Cotton aphids (Photo: D. Hardee)

Cotton aphids (*Aphis gossypii)* are present in all cotton-growing areas of the world where they colonize a wide range of hosts. Colonies are made up of individuals of different colors: shades of green, brown, yellow, orangey yellow, and even white. Size varies up to the size of the head of a pin (Figure 1). Aphids migrate into cotton fields as winged adults. Females produce living young (nymphs) without mating. In about 5 days at 80°F, these nymphs become adults which produce even more colonies on the undersides of leaves.

Their economic importance as cotton pests stems from 1) direct damage as a result of sucking nutrients from plants, and 2) indirect damage caused either by honeydew (sugary wastes) which contaminates lint (sticky cotton) or by transmission and spread of diseases, particularly viruses.

Since the mid-1980's, aphids have increased in severity and have become a problem earlier in the season. Heavy infestations can cause significant decreases in lint yields. Plants suffer considerable stress, they are small and less branched, and boll shedding results in yield loss. Much of the increasing problems caused by aphids are a result of natural enemies being eliminated by frequent sprays of all classes of insecticides for early season cotton insects. While natural enemies are destroyed by these early sprays, resistant aphid populations rapidly build up, as it takes them only 5 days to complete their life cycle. More than 60 generations can be produced in one growing season. Consequently, these insects can develop resistance much more rapidly than other insects with longer life cycles.

Budworm/Bollworm (Heliothine species)

Figure 2. Bollworm (Photo: NCC)

Tobacco budworm (*Heliothis virescens*) and bollworm (*Helicoverpa zea*) are found on a very wide range of wild and cultivated plants throughout the world. Females attract males with sex hormones (pheromones) which they release in the early morning hours. Adult moths lay eggs, usually at night, on young leaves and terminals of the plant. Females lay between 1,000 and 3,000 eggs which hatch in 2 to 4 days. If not controlled, caterpillars (larvae) may reach 2 inches in length. (At 3 days of age or older they are very difficult to control.) They feed directly on squares, blooms, and bolls of cotton (Figure 2). The larvae mature in 12 to 16 days. Mature larvae drop to the ground, burrow into the soil and pupate for 10 to 14 days before emerging as moths. (Larvae entering a resting stage (diapause) to survive adverse conditions such as cold winter temperatures or hot, dry summer conditions will pupate longer.) Potentially three or more generations can be produced in one cotton season.

Although the bollworm has been a pest since the 1820's, the tobacco budworm did not become a pest until the 1930's. Both insects became increasingly important as pests of cotton with the widespread use of synthetic insecticides for control of the boll weevil. These insecticides greatly reduced the predator and parasite populations which had kept tobacco budworm and bollworm under control. Since the 1950's these insects, particularly tobacco budworm, have developed resistance to most of the carbamate, organochlorine, organophosphate, and pyrethroid insecticides used for their control.

Pink Bollworm (*Pectinophora gossypiella*)

Figure 3. Pink bollworm (Photo: NCC)

The pink bollworm is one of the most serious pests of cotton in much of the tropics and subtropics. Like the previous caterpillar pests (insect order Lepidoptera), female moths attract their mates with pheromones. Eggs are laid singly or in small groups in sheltered locations on the plant (leaf axils, undersides of leaves, squares, and more frequently beneath the calyx of young bolls). Between 200 and 300 eggs are laid by each female. Eggs hatch into larvae in 4 to 8 days. Newly emerged larvae can bore into a boll in less than 24 hours. These larvae must feed immediately or they die (Figure 3). In 14 to 21 days, larvae pupate in silk cocoons formed inside damaged bolls, on the ground, or in the soil.

Of the three to five generations produced in a year, the first feeds mainly in squares and flowers; later generations feed in bolls. Characteristic rosetting of blooms occurs when larvae spin together developing flower petals. Entry holes into bolls are rarely visible, but larvae mine through the developing lint, severing fibers, on their way to the seed on which they feed. Their activity is associated with boll rot fungi and elevated levels of aflatoxin production. Populations peak in August or September. Overwintering larvae diapause starting in mid-September, pupate in late winter and spring, and produce adults which emerge over an extended period of time. Those adults that emerge when fruiting cotton is available are the ones that initiate the new year's infestations.

The pink bollworm was the major pest of cotton in the desert Southwest for many years, at times destroying more than half the crop unless control measures were imposed. The heavy use of pyrethroid insecticides against the whitefly has provided the selection pressure necessary for populations of pink bollworm to develop resistance to this class of insecticides. Fortunately, they are still susceptible to the organophosphate and carbamate insecticides. Cultural measures which adversely affect pink bollworm populations continue to be the foundation for a good resistance management program against this insect. Cultural practices will be even more important as transgenic *Bt* cottons are grown.

Plant Bug (*Lygus* species)

Plant bugs (*Lygus hesperus, L. lineolaris,* and others) are serious pests of cotton and many other cultivated crops grown in the United States (Figure 4). Plant bugs that increase in numbers on wild hosts and other crops provide a ready reservoir for migrations into cotton. In cotton, plant bugs have few parasites and predators that attack them. Control is almost exclusively by insecticides including carbamates, organophosphates, and pyrethroids. Strip cutting of alfalfa and maintaining good sanitation through timely elimination of weeds contribute to plant bug control, too. For instance, destroying weed hosts at early square may worsen infestations of plant bugs.

Figure 4. Lygus (Photo: P.C. Ellsworth)

Plant bugs overwinter as adults in a reproductive diapause. In cotton, eggs are laid in flowers, buds, bracts, and nodes. In about 8 days, the eggs hatch into nymphs which develop for about 11 days. Each generation takes about 20 to 30 days. Several generations are produced in a year, but usually not more than three develop on cotton. Plant bugs feed by inserting their mouth parts into the tender plant parts and sucking sap. Feeding on squares and small bolls usually causes them to shed.

Pyrethroid resistance in some tarnished plant bug (*L. lineolaris*) populations can be high enough to cause control failures. First documented in the Mississippi Delta in 1993, the resistance was the result of 10 years of pyrethroid use to control various insect pests. Tarnished plant bugs resistant to one pyrethroid were found to be resistant to all pyrethroids. In several states, they also displayed higher levels of resistance to other classes of insecticides including organophosphates, carbamates, and cyclodienes.

Silverleaf whitefly (*Bemisia argentifolii*)

The silverleaf whitefly (*Bemisia argentifolii*) is a tiny sap-sucking insect related to aphids (Figure 5). Many wild, horticultural, and crop plants serve as hosts for these insects. Football-shaped eggs are laid on the undersides of leaves where they develop into nymphs that feed by sucking sap. Their waste products are excreted as a clear, sugary liquid (honeydew) that falls onto lower plant parts, often producing sticky lint. Adults feed on plants the same way as nymphs, but produce less honeydew. Whereas nymphs can move very little, adults can be carried long distances in the wind and easily infest additional fields. In warm weather, their life cycle is completed in 14 to 23 days. In desert areas of the West, 12 to 15 generations can be produced in a year, moving from winter vegetables to melons to cotton. Like aphids, whiteflies can develop resistance much more rapidly than other insects with longer life cycles.

Figure 5. Silverleaf whitefly (Photo: S. Bauer, USDA-ARS)

Whiteflies require a living host and have no special overwintering stage. They continue to develop and reproduce through the winter, albeit slowly, on hosts other than cotton. Because whitefly eggs and nymphs are on the undersides of leaves, chemical control is difficult. Unless insecticides are rotated, their short life cycle can result in several generations being exposed to the same insecticide (up to 12 applications) over the course of a season. Heavy use of insecticides for whitefly control presents the risk of also increasing resistance in other pests, such as the pink bollworm and plant bug.

Control and Management

A general theme runs throughout our discussion so far — namely, repeated exposure of insects to the same class of insecticides has resulted in populations resistant to the chemical tools we have available to fight them. We have all heard it said that if any organisms would likely survive a nuclear holocaust, it would be the insects. Their resilience is truly remarkable. If that is our challenge, how best do we continue to grow crops and prolong the useful life of the chemical tools available to us? In the discussion that follows, researchers from across the Cotton Belt have contributed their insights on a region by region basis.

West (AZ, CA)

Plant bugs and aphids cause the most damage in the West (Figure 6). However, in parts of the region such as the desert areas of Arizona and the Imperial Valley of California, the silverleaf whitefly and pink bollworm are the resistant insects of most concern. Effective management for all four of these pests requires using cultural controls, sampling routinely for insects, and following action thresholds. When chemical controls are needed, efficacious materials should be selected carefully to avoid repeated exposure of pests to the same material or class of chemistry.

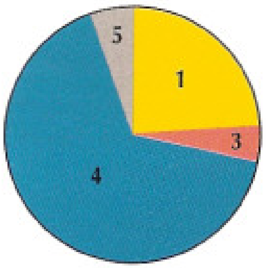


Figure 6. '95 losses in the West due to insects in which resistance problems have been identified (Source: 1996 BWCCP)

Lygus hesperus presents a constant threat to cotton in the West. Because plant bugs migrate into cotton from other host plants, problems often can be avoided by timely management in the alfalfa, safflower, or surrounding weeds that serve as hosts. Specifically, strip-cutting or block-cutting alfalfa located near cotton has been shown to effectively reduce migration into cotton and lessen its damage. Thresholds for treatment of *Lygus* are based on sweep net samples in conjunction with plant mapping to determine damage. To prolong their usefulness, insecticides effective for treating whiteflies should be avoided when treating *Lygus*.

Aphids may attack cotton from the seedling stage throughout the season to harvest. Some researchers argue that populations occurring before first square do not harm yield or quality and might be important in sustaining beneficial insects in the field and in reducing outbreaks of secondary pests later in the season. Others remind you that stunting plants early, as a result of feeding by high populations of aphids, markedly reduces vigor and eliminates the possibility of an early crop. Management decisions need to take into account the density of the population of insects, as well as the uniformity of its distribution, or lack thereof, throughout a field. Perhaps treating only the sections of the field with high populations would provide a viable solution and compromise for this quandary.

In recent years the silverleaf whitefly has become the pest causing most damage in much of Arizona and in the Imperial Valley of California. Whitefly populations are at their lowest in winter and early spring when they begin to move into cotton from preferred hosts such as melons. Prompt and thorough destruction of crop residues denies the whitefly host material upon which to reproduce. As temperatures warm, whitefly populations increase exponentially. The more of the cotton fruiting cycle that is completed **before** the whiteflies escalate in number, the better.

Implementing a cotton production strategy that achieves crop earliness is key to managing whiteflies in the arid West. Although the climate of this region may accommodate a growing season of 250 days, managing for earliness may mean using only 130 to 150 days from planting to the last irrigation. In Arizona, this is what is meant by a short season approach and is least likely to produce sticky cotton.

1	Aphids
2	Budworm/Bollworm
3	Pink Bollworm
4	Plant Bug
5	Silverleaf Whitefly

If two new insect growth regulators (IGRs) are approved in 1996, the Southwest Whitefly Resistance Management Working Group will recommend a three-stage program in which each IGR may be used only once. Treatment with pyrethroid insecticides is delayed until the end of the season. No single insecticide is used more than twice in a season. Registration of these IGRs will provide an opportunity to diversify insecticide use while delaying use of broad spectrum insecticides.

Again, cultural control is an integral part of resistance management for the pink bollworm. Timely termination of irrigation and plow down will limit the number of diapausing larvae. Sterile moths have been released early in the season to prevent mating and thereby delay the onset of infestations in new cotton crops in the San Joaquin and Imperial valleys of California. Additionally, *Bt* cotton effectively controls pink bollworm and other caterpillar pests. Both *Bt* cotton and pheromone mating disruption programs enhance resistance management. They limit the need for insecticide applications, while reducing exposure of both pests and natural enemies to insecticides other than *Bt*.

Southwest (NM, OK, TX)

Budworm/bollworm, aphids, and pink bollworm are the resistant insects causing the most damage in the Southwest (Figure 7). Short season production practices are one of the key components of resistance management for most insects in the Southwest. Shortening the growing season minimizes the number of pest generations that is exposed to insecticides. In so doing, a greater number of insects remains susceptible to insecticides.

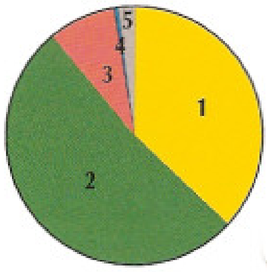


Figure 7. '95 losses in the Southwest due to insects in which resistance problems have been identified (Source: 1996 BWCCP)

Cultural practices that can help to shorten a season include planting narrow row cotton, using short season varieties, planting in a window of favorable weather, using moderate plant densities and avoiding maturity-delaying high densities, irrigating in a timely fashion, applying only enough nitrogen fertilizer to achieve realistic yield goals, balancing vegetative and reproductive growth to promote early cutout (using growth regulators as needed), and using harvest aids to limit the numbers of diapausing insects. Active plant monitoring helps to catch potential pest problems so that appropriate pest control measures can be taken to insure that early season fruit are retained.

Neither the pink bollworm nor the silverleaf whitefly has developed resistant populations in this region. However, both of these pests cause significant yield loss (Figure 7), and their infestations can result in a marked increase in insecticide use. Use of cultural practices promoting earliness have minimized both population increases of these pests and insecticide use.

Lower Rio Grande Valley producers have minimized whitefly problems by maintaining a short growing season, limiting insecticide use for all pests (thereby conserving natural enemies), and managing whiteflies on alternate hosts. Key management components include plowing up vegetable hosts immediately following harvest, avoiding planting cotton next to other whitefly hosts, planting smooth leaf varieties, planting early to avoid growing cotton late summer when the greatest whitefly populations occur, maximizing insecticide coverage by including 1 to 2% oil in the tank, and plowing under stalks as soon after harvest as is feasible.

In some years, Far West Texas and the adjacent cotton growing area in New Mexico require multiple applications of insecticide for pink bollworm control. Cultural practices often minimize pest populations and reduce the number of applications as well as the likelihood of resistance developing. These practices include winter tillage which destroys overwintering pink bollworms, winter or spring irrigation which forces them out of diapause and leaves many dead of starvation (as a result of having no host plants to eat), September crop termination which reduces the number of diapausing larvae, and early season use of mating disruption products.

Most areas of the Southwest do not experience problems with tobacco budworms until late in the season. The key to resistance management of this pest is, again, to utilize a short season. Early infestations are usually first treated with ovicides and *Bt* products to avoid elimination of natural enemies. Later in the season insecticides other than pyrethroids are used. *Bt* cottons can reduce the potential for resistance in some areas. However, most of the cotton acreage in the Southwest cannot justify the use of this technology at current costs.

Since aphids became a more frequent pest in the late 1980's, resistance to several insecticides has been documented. Resistance levels vary greatly between areas, and even within areas. Few insecticides remain that provide consistent long-term control. Although the fungus, *Neozygites fresenii,* has reduced aphid populations in some years, natural enemies do not consistently prevent aphids from reaching economically damaging levels.

Specific practices that help to minimize aphid resistance stem from field research and observations. Usually growers can significantly reduce aphid numbers and the need to spray by planting smooth leaf varieties, planting into fields with high levels of residues remaining from grain crops, avoiding excessive nitrogen fertilization by using results of soil and tissue tests to schedule applications and amounts, minimizing the early use of pesticides, and applying insecticides only when aphid numbers exceed 50 per leaf. Planting a uniform, solid stand to achieve adequate density for the region will minimize hot spots attractive to aphids. Since resistance problems are intensified by applications of sublethal rates of insecticides, applying insecticides at recommended rates helps to avoid increasing populations of resistant insects. Achieving full canopy coverage also helps insure effective control.

Mid-South (AR, LA, MO, MS, TN)

In the Mid-South, tobacco budworm, cotton aphid and tarnished plant bug are the resistant insects of concern (Figure 8). General integrated pest management (IPM) strategies that are useful in managing these pests include the following: 1) use of fast fruiting varieties, 2) use of transgenic resistant varieties, 3) use of economic thresholds in conjunction with scouting, 4) timely application of insecticides as needed, and 5) management for early crop maturity. Many of the cultural practices promoting earliness also apply to this region.

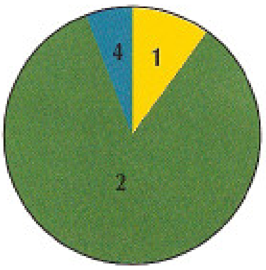


Figure 8. '95 losses in the Mid-South due to insects in which resistance problems have been identified (Source: 1996 BWCCP)

Transgenic *Bt* cotton provides a useful new tool for growers to use to combat tobacco budworm and bollworm. Unfortunately, in conventional, non-transgenic cotton, no new classes of foliar insecticides are registered for use against tobacco budworm for 1996.

Managing with a goal of producing an early-maturing crop will help reduce the number of tobacco budworm generations attacking the crop or exposed to insecticide. Avoiding unnecessary applications of insecticides before first bloom and using varied chemistries in tank mixes thereafter will help slow further development of resistance. Insecticide treatments are most effective against eggs and 1 to 2-day-old larvae, so timing applications to target these stages is advisable. Terminating insecticide treatments as soon as most of the crop is safely past developmental stages incurring damage from these pests is essential to reduce selection pressure. Fall, winter, or early spring tillage destroys a high proportion of pupae that may be overwintering in fields.

Tarnished plant bugs are most damaging during the period of crop development between early square and first bloom, even though they may often be a late season pest as well. Scouting with a sweep net twice a week and monitoring early square retention provides information needed to determine when insecticide applications are required.

Cotton aphids have become increasingly important in recent years because of their resistance to insecticides. Several naturally occurring organisms help in controlling aphids. A fungus (*Neozygites fresenii*) destroys cotton aphid populations throughout much of the Mid-South in early to mid July. When selecting insecticides to use on aphids, growers need to consider what classes of insecticide have been used on the field already, and try to use a material from the least-used class of chemistry. Usually systemic materials perform better than contact insecticides. Effective coverage is important.

The Mid-South Insecticide Resistance Management Plan (IRMP) provides guidelines on managing resistant pests in this region. IRMP is designed to spread the risk of control failures among all available insecticides and reduce the probability of severe yield loss. To preserve the efficacy of the pyrethroids and organophosphates against bollworm and tobacco budworm, growers are advised not to spray these products during pre-bloom (planting to late June or early July). Treatments should be applied only as needed to control damaging levels of all pests. Following early bloom (early July to crop termination), medium rates of pyrethroids are advised as the first choice to control a broad spectrum of pests including boll weevil, tarnished plant bug, cotton aphid, tobacco budworm, and bollworm. Tank mixes containing additional insecticides in combination with a pyrethroid should improve control of tobacco budworm. Consult extension agents for a more detailed plan.

Southeast (AL, FL, GA, NC, SC, VA)

Tobacco budworms, tarnished plant bugs, and aphids present potential resistance problems for growers in the Southeast (Figure 9). Silverleaf whitefly presents resistance problems in isolated patches that account for little acreage and do not show on the pie chart.

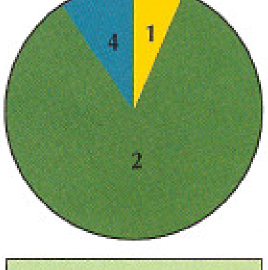


Figure 9. '95 losses in the Southeast due to insects in which resistance problems have been identified (Source: 1996 BWCCP)

Historically, areas of the Lower Coastal Plain have used more insecticide than most other areas of the Cotton Belt. In spite of high usage, this area was not the first to encounter insecticide resistance problems. Low levels of pyrethroid resistance in tobacco budworm were confirmed in northern Alabama as long ago as 1990. Central Alabama was ravaged by high populations of resistant tobacco budworms in 1994, and most of that state's cotton crop was devastated in 1995. Northern Florida and the western edge of Georgia had some isolated pyrethroid resistance problems in 1995. Other areas of the Southeast have managed to maintain tobacco budworm populations that are still susceptible to this important class of chemistry.

A possible explanation for the delay in the onset of resistance in tobacco budworm may simply be the diversity of agriculture in the Southeast. Until recently, cotton occupied only a very small portion of the land in this region. Other crops, pastures, swamps, and timberlands offered opportunity for populations of tobacco budworm to develop without being exposed to pyrethroids. Although high numbers of sprays were once utilized for control of tobacco budworm in cotton, the limited cotton acreage meant only a portion of each generation of tobacco budworm was exposed to these sprays.

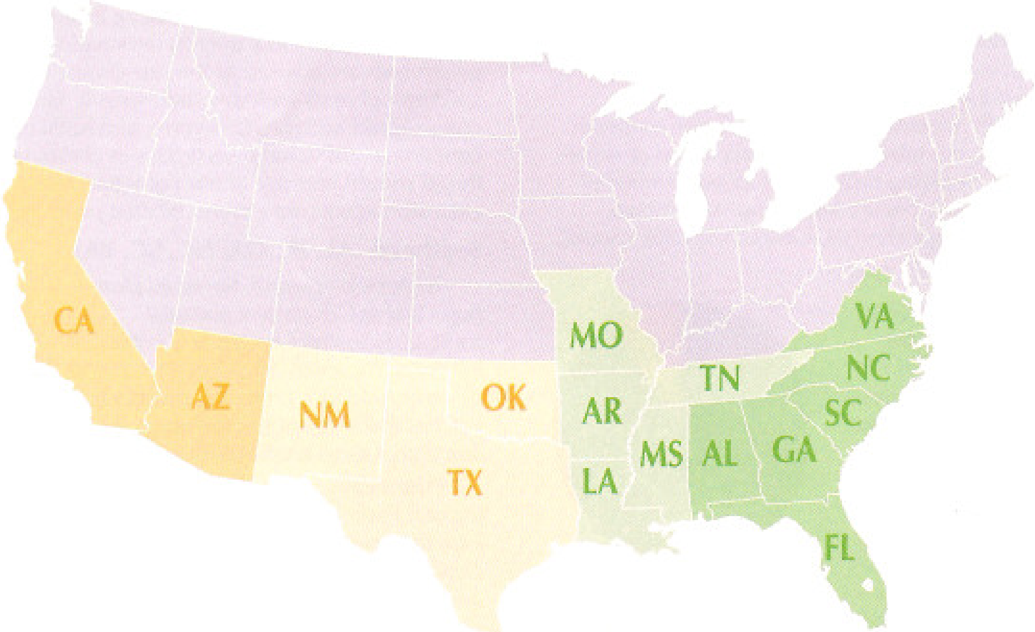
Resistance in tobacco budworm populations to the pyrethroid insecticides has been a potential threat in the Southeast for a number of years, and particularly now that there has been such a significant increase in cotton acreage. Judicious use of the new transgenic *Bt* cottons should help delay further development of tobacco budworm populations resistant to pyrethroids in the Southeast.

Cotton aphids infest cotton each season. Populations can reach extremely high numbers. With the exception of some areas of northern Alabama, cotton aphid control is still good throughout the Southeast with insecticides such as systemic organophosphates. Unfortunately, early treatments for aphids often result in later explosions of secondary pest problems. For instance, the beet armyworm is more destructive in the absence of natural enemies killed by early season treatments for aphids. Losses to the beet armyworm are often greater than losses to aphids — a tough reality.

As in the Mid-South, the naturally occurring fungus, *Neozygotes fresnii,* consistently eliminates most of the aphid problems, once aphid populations have reached a certain density (usually mid-summer). Most state extension specialists in the Southeast have recommended that growers be patient and wait for the fungus to eliminate aphid problems.

Although elimination of sprays for the boll weevil were expected to cause plant bugs to become a bigger problem in the Southeast, they have not. Isolated problems with plant bugs do occur and treatments seem to be effective. At this time there is no indication that tarnished plant bug populations in the Southeast have resistance to the commonly used pesticides.

Although silverleaf whitefly could potentially present a significant problem throughout the Southeast, to date it has not done so. Populations of silverleaf whitefly occur at damaging levels only in isolated and sporadic sites in the Southeast. Those areas are in Florida and regions adjacent to the Florida panhandle. Many of the heavily infested vegetable-growing areas of Florida are not in proximity to cotton growing areas. Few insecticides have been used to control silverleaf whitefly in cotton. Resistance is not yet a primary concern.



Conclusions

At best, insect resistance management remains a tough call. We have repeatedly shown examples of pesticides being used to control one pest and, at the same time, reducing the susceptibility of another pest, destroying beneficials, or causing problems with secondary pests. We have also presented data documenting the contribution of early-set fruit to overall yield and fiber quality. Under the principles of integrated crop management, each component of a cotton production program needs to be evaluated as to how it will affect other components and, ultimately, the profitability of a crop. Fertility management, variety selection, tillage, plant density, growth regulator use, water management, insect control, disease and nematode management, harvest aid use — all are important components of integrated crop management. Producers must strike a balance between both viewpoints discussed here to maximize sustained profitablity.

What's in the Research Pipeline?

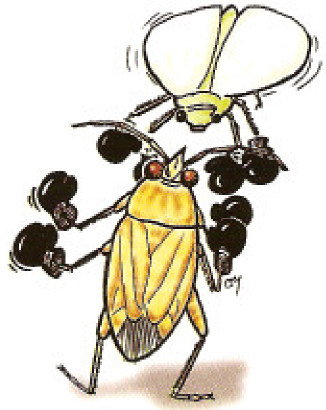
New classes of insecticides are being developed that show promise as tools to help manage several of the pests mentioned here. These newer chemistries have more specificity than the older "broad spectrum" materials. However, this selectivity can be a two-edged sword. On the one hand, we may be able to conserve beneficial insects with more targeted materials. On the other hand, more than one pest may call for treatment, and a selective material may not adequately control all pests present. Tank mixes may be required and could prove more costly to growers. These new chemistries are needed and welcomed, but will require wise husbanding to break the cycle of having insects develop resistance to them, too.

Transgenic *Bt* cotton is an outstanding tool for management of several serious Lepidopteran pests. Needed is research to maximize its effectiveness and, again, delay development of resistant pests. Research aimed at putting genes coding for different *Bt* toxins into new transgenic cottons may be a viable means of delaying development of resistance. Further expansion of host plant resistance research looks promising. As an alternative approach in Far West Texas and Arizona, nematodes of the genus, *Steinernema,* are being evaluated as biological control agents for soil-inhabiting, diapausing pink bollworms.

Research aimed at the best times to spray for pests has the potential to reduce the rate at which pesticide resistance develops. The industry continues to search for new, active compounds effective in controlling insects and other pests. Research on alarm pheromones, juvenile hormones (basis for developing IGRs), and biological control involving parasites, predators and pathogens have far-reaching applications in helping us to combat insects.

Researchers in Texas are testing a relay strip cropping system which uses canola followed by sorghum (winter and spring hosts, respectively). Aphids feed on these crops and, in turn, are fed upon by lady beetles which move into cotton when aphids appear there. This crop sequencing plan shows great promise in providing a reservoir of beneficials to assist in controlling aphids in cotton.

For more information on future developments, the National Academy of Sciences' world wide web site contains a recent report from the National Research Council's Board on Agriculture. To obtain this report, point your web browser to http://www.nas.edu.



The Cotton Physiology Education Program is supported by a grant to the Cotton Foundation from BASF Agricultural Products, makers of Pix® plant regulator, and brought to you as a program of the National Cotton Council in cooperation with state extension services.