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Bt Cotton Requires Vigilant Management

Growers, cotton specialists, entomologists and industry representatives highlight both the good and bad of the 1996 Bt cotton season and offer insights that will impact decision-making in 1997. The authors, participants in a panel discussion of Bt cotton at this year's Beltwide Cotton Conferences in New Orleans, all agree that Bt cotton requires vigilant management (Figure 1). Here we present a synopsis of their comments and tips for the 1997 production year.

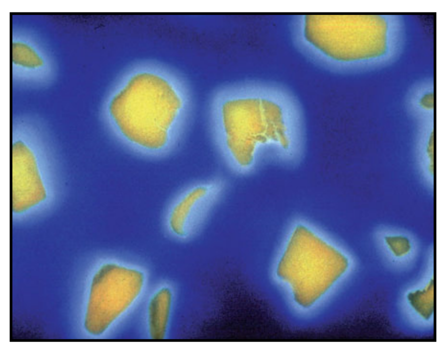
K Gully

Figure 1. Although Bt cotton required no insecticide applications in some parts of the Cotton Belt, it required vigilant management everywhere it was grown.

Bt Cotton is a Novel Tool

The development of cotton varieties takes many years as outlined in the last issue of *Cotton Physiology Today*, "Varieties: Development and Selection." Bt cotton which contains the Bollgard® gene is but one of the arsenal of new tools brought to the cotton industry through genetic engineering.

Bacillus thuringiensis, a soil bacterium, produces a protein (Figure 2) which is toxic when eaten by certain caterpillar pests. A great advantage of this toxin is its selectivity. Beneficial insects are not harmed.



R Deaton

Figure 2. Crystallized protein from *Bacillus thuringiensis* which is toxic to caterpillar pests.

INSIDE:

The Cotton Physiology Education Program (CPEP), now in its ninth year, is funded by a grant to the Cotton Foundation by BASF, makers of Pix®, the original plant regulator. CPEP's mission is to discover and communicate more profitable methods of producing cotton.

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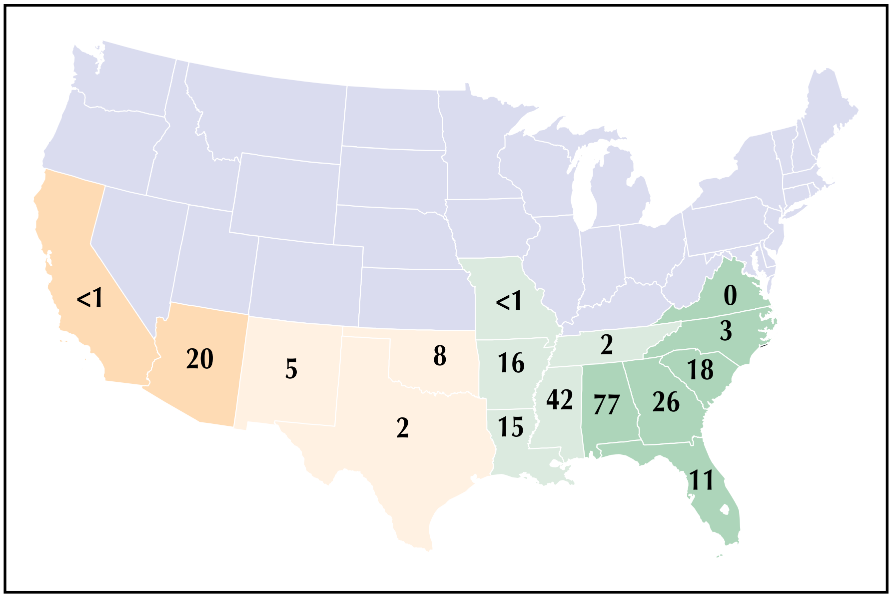
Molecular biologists clipped DNA from the bacterium, *Bacillus thuringiensis*, and successfully inserted it into the DNA of cotton cells. Plants were regenerated from these transformed cells and produced the same toxin. In 1996, two cotton varieties debuted that contained Monsanto's Bollgard® gene.

Over 1.8 million acres were planted to these new varieties, NuCOTN 33^B and NuCOTN 35^B. Use varied by state and reflected the pest populations growers needed to combat (Figure 3, Table 1). Greatest effectiveness was expected on tobacco budworm (Figure 4).

Table 1. Planted Bt acreage by state in 1996. USDA

	Thousand Acres
WEST	
Arizona	156
California	1
	157
SOUTHWEST	
New Mexico	3
Oklahoma	22
Texas	118
	143
MID-SOUTH	
Arkansas	156
Louisiana	138
Mississippi	440
Missouri	<1
Tennessee	10
	745
SOUTHEAST	
Alabama	430
Florida	11
Georgia	358
North Carolina	21
South Carolina	48
Virginia	0
	868



USDA

Figure 3. Percent of each state's cotton acreage planted to Bt cotton in 1996.

T Kerby

Figure 4. Demonstration field in Mississippi hill country run by Delta and Pine Land Company. Bt cotton (left) was not sprayed in spite of extremely high pressure. Tobacco budworm ravaged conventional cotton (right) which was treated with insecticides.

Grower Views of Highlights of 1996 Season

In Arizona, Ron Rayner planted 40% of his acreage to Bt cotton, variety NuCOTN 33[B]. He describes his experience as both outstanding and incredible. Not only were his costs $100 per acre less for Bt (license fee included) than for conventional cotton, but his yields averaged 1 bale more per acre for Bt than for conventional cotton.

In addition to having no pink bollworm or other bollworm activity in his Bt cotton, a definite bonus for this Arizona grower was not needing to spray for other pests. Neither the whitefly nor lygus reached levels that would trigger treatment according to University of Arizona guidelines. Beneficials, particularly spiders, were present in high numbers and played an important role in reducing numbers of insect pests.

Growers in the Southern Rolling Plains of Texas were in their second full year of boll weevil eradication. With the weevils under control, the bollworm and budworm were the next two most prevalent pests to tackle in 1996. The availability of Bt varieties was well-timed for these growers.

For Kenneth Gully, worms were not much of a problem until very late season in 1996. Over 100% egg lay (more than 1 egg on each of 100 plants scouted) was recorded by mid July. Because of extremely hot and dry conditions at that time, only 40% of these eggs hatched and survived in conventional cotton. In Bt cotton, only about 10% survived and very little damage occurred.

K Gully

Figure 5. Texas Bt cotton was planted skip-row and stripper-harvested.

Because of limited availability of irrigation water, Kenneth used a skip-row pattern for his Bt cotton in 1996. He supplemented 8 inches of rainfall with 7 inches of irrigation water. He stripper harvested a quite uniform crop (Figure 5). In 1997, he will use a solid row pattern and, again, will irrigate all of his Bt acreage.

In Louisiana, Billy Guthrie found that Bt cotton gave 100% control of tobacco budworm. However, when extensive corn acreage started drying down, bollworms moved into the cotton and he needed to spray an average of 2.5 times with synthetic pyrethroids. Even so, his costs were $15 to $20 less per acre to grow Bt cotton which yielded 5 to 100 pounds more than conventional cotton.

Georgia grower Bob McLendon irrigated his Bt cotton acreage. It required only 1.4 sprays for fall armyworm, whereas his conventional cotton was sprayed 6.24 times for fall armyworm, tobacco budworm and bollworm. He made 100 pounds more lint per acre on his Bt cotton and it cost him $14.36 less to produce per acre. These factors added together to make Bt cotton $55.16 more profitable for him than conventional cotton. Success with Bt cotton for the grower-panelists is reflected in their 1997 planted acreages which increased significantly (Table 2).

Table 2. Growers from each of the four regions of the U.S. Cotton Belt have increased the acreages of their farms planted to Bt cotton in 1997.

	Bt as % of Total Farm Acreage 1996	1997	Change from 1996	Comments
West - Ron Rayner	38%	95%	Up 57%	Irrigated
Southwest - Kenneth Gully	60%	96%	Up 36%	Irrigated
Mid-South - Billy Guthrie	50%	70%	Up 20%	
Southeast - Bob McLendon	79%	90%	Up 11%	Irrigated

Cotton Specialists Comment on Developmental Differences

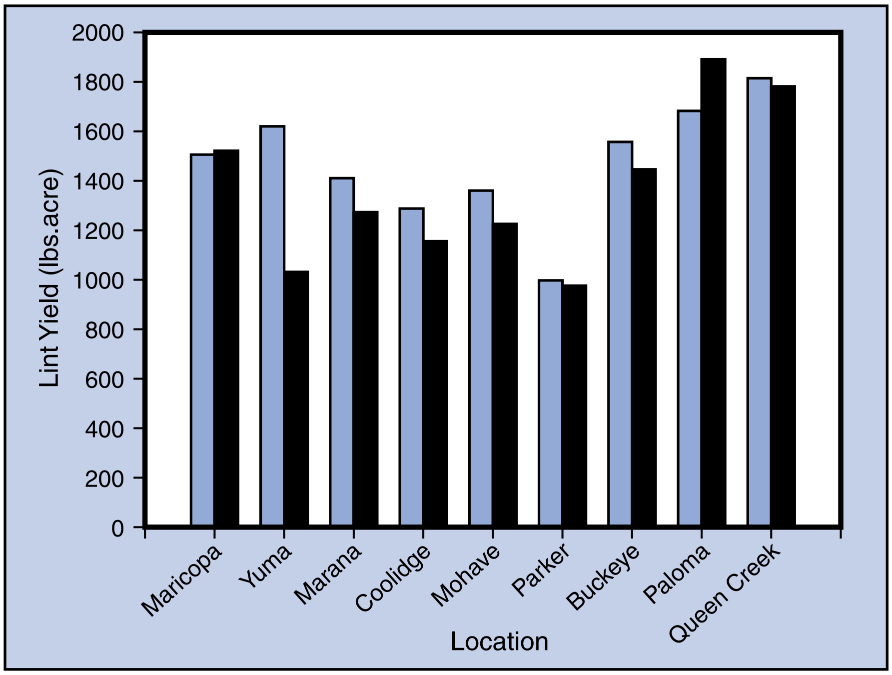
In Arizona, NuCOTN 33^B was compared to its recurrent parent, Deltapine 5415 in replicated trials in six distinct growing regions across the state. Growth, development, and yield were monitored at all locations. Except for the Maricopa and Paloma locations, NuCOTN 33^B out-yielded Deltapine 5415 (Figure 6). Differences in yield were attributed to differences in insect damage, primarily from the pink bollworm which thrived in conventional cotton.

Plant vigor was assessed by measuring the height of a plant in inches and dividing it by the number of main stem nodes to obtain height to node ratios. Fruit retention was measured as percent of first position fruit retained. These two varieties are very similar agronomically as seen in their responses at two of the locations (Figure 7). The responses measured at Paloma Ranch were typical. At Yuma, NuCOTN 33^B showed more vigorous growth potential than its parent.

The sharp dip in fruit retention seen at 2,000 heat units accumulated after planting at the Yuma location corresponds to a period in early July of 1996 when nighttime temperatures and humidities increased substantially. The cotton was at peak bloom and unable to photosynthesize enough during the day to compensate for its high respiration rates at night. It was consuming photosynthate faster than it was manufacturing it. Consequently, fruit dropped because of an inadequate supply of photosynthate to the developing bolls.

In the Mid-South, NuCOTN 33^B was the primary Bt cotton variety planted. It matured later than most conventional varieties grown in this region. However, because NuCOTN 33^B did not lose early-set fruit to worms, it matured a little earlier than expected. Bt cotton had two vegetative growth spurts. The first was early season in response to favorable June temperatures. The second was after a fruit shed in early August during a cloudy period.

Typical of varieties that mature mid-season, NuCOTN 33^B produced a lot of vegetative growth. This Bt variety grew taller later in the season than the varieties growers in this region are used to planting. Consequently growers applied more Pix® to Bt cotton late season than to their conventional varieties.



J. Silvertooth

Figure 6. Yield of NuCOTN 33^B compared to its recurrent parent, Deltapine 5415 at nine locations in Arizona. NuCOTN 33^B DPL 5415

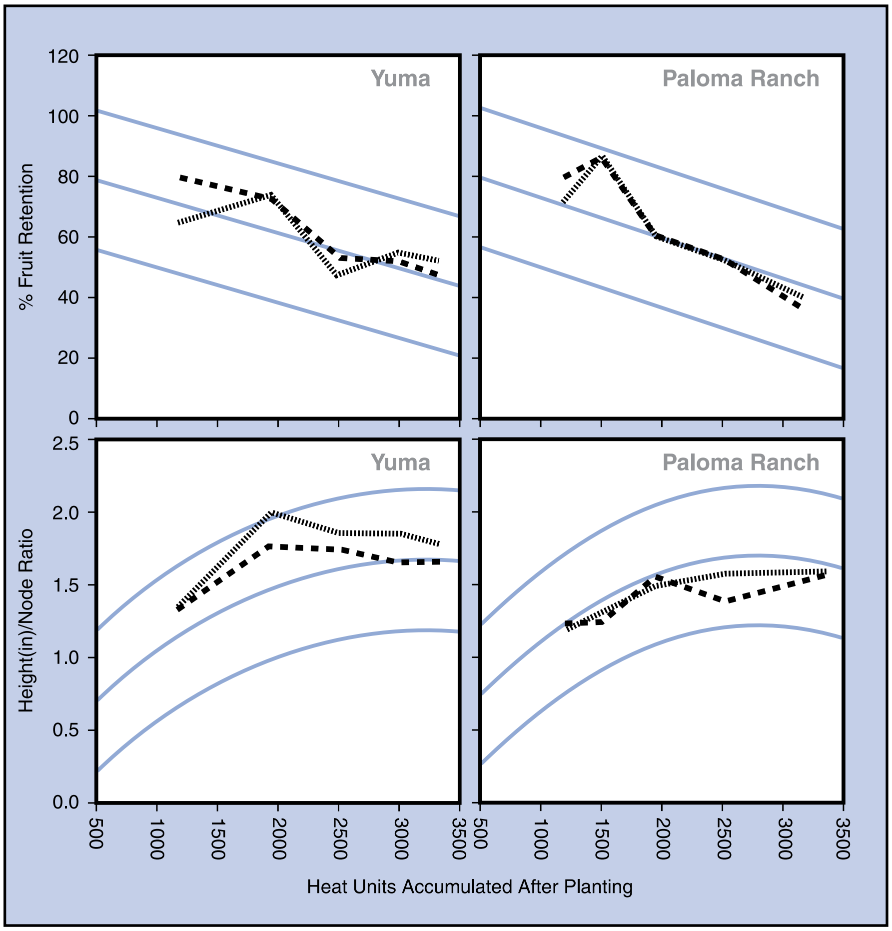
Mid-South growers planting NuCOTN 33B or 35B again in 1997 need to watch for several things. First, plant populations need to be carefully controlled. Keep populations in the 40,000 to 45,000 range. Roughly three to four plants per row foot in a 38 or 40 inch row provides this density. Denser plantings will tend to increase vegetative growth and increase the number of barren plants in the field.

Second, plant into warm, moist soil to facilitate rapid emergence and seedling development. Use an appropriate fungicide and an in-furrow systemic insecticide.

Third, carefully choose the rate of nitrogen fertilizer to apply. In many cases, total nitrogen may be reduced for Bt varieties. Mid- and full-season varieties tend to produce rank growth as nitrogen rates are increased. Make decisions on a field by field basis. A rough recommendation is to use about 50 pounds per bale of realistic yield goal.

Fourth, according to Will McCarty, rate and timing decisions for using Pix® plant growth regulator need to be made on a field by field basis. Consider delaying first applications to NuCOTN 33B and 35B varieties until a few days after pin head square. If the cotton is growing vigorously, McCarty suggests that 6 to 8 ounces is an appropriate rate. At first bloom, depending on growth rate, apply another 10 to 12 ounces. Another similar application may be required 10 to 14 days later. The trick is to prevent rank vegetative growth and to keep fruit on the plant. Using heavier rates earlier in the season may be the way to do this.

In North Carolina, crops usually have at least 90% square retention as they go into early bloom. Very light plant bug pressure, absence of the boll weevil, and usually light June budworm populations account for this high retention. As a result, a compact crop on only four to nine nodes is typical. This pattern will also be possible to achieve in the Mid-South as boll weevil eradication spreads to that region, too.



J. Silvertooth

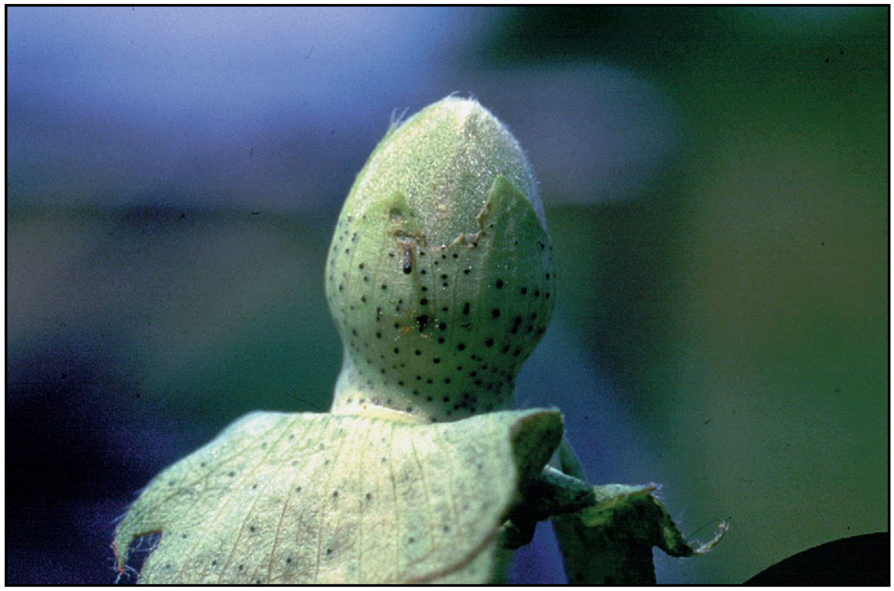
Figure 7. Height to node ratios and percent fruit retention plotted as a function of heat units accumulated after planting for DPL 5415 and NuCOTN 33B grown at Yuma and Paloma, Arizona. ▪ ▪ ▪ DPL 5415 ııııııııı NuCOTN 33B

Entomologists Discuss Scouting, Thresholds and Treatments

Bt cotton was so effective on tobacco budworm that the insect was completely absent in Bt fields. However, although bollworm larval populations were much reduced in Bt cotton, enough of them survived that a pyrethroid application was required to prevent yield losses in many situations. Obviously, bollworms are not as susceptible to the Bt endotoxin as are tobacco budworms (Figure 8).

Survival of bollworms on Bt cotton appeared to be related to plant phenological stage and perhaps plant stress at the time of the bollworm moth flight. In North Carolina, the major bollworm moth flight occurred in mid-to-late July when most cotton fields were in peak flower, apparently the most susceptible plant growth stage. Pollen provided a potential food source for boll worms to establish in cotton containing the Bollgard® gene.

Stress from too much rainfall, cloudy weather, or drought conditions also seemed to affect bollworm survival on Bt cotton. The fact that a varying, but often significant, proportion of the bollworm population survived on Bt cotton is cause of great concern to some entomologists. Most of the resistance models assume a "high dose strategy," enough endotoxin present to kill larvae (Figure 9). That assumption is being questioned by some after the first year of commercial growing of Bt cotton. The present refugia plan may not be adequate to effectively delay resistance development in the bollworm.



R Deaton

Figure 9. Bt cotton square with worm that died from feeding.

Bollworm numbers were higher throughout the Cotton Belt during 1996. Their increased numbers contributed to bollworm survival on Bt cotton. There is probably greater potential for bollworm populations developing to damaging levels in Bt cotton fields in most years than some entomologists previously thought. According to J.R. Bradley, every year that Bt cottons have been evaluated in North Carolina, bollworms have reduced yields. These tests, conducted under conditions of high bollworm numbers, demonstrated that Bt cotton was highly resistant, but not immune to the bollworm.

Fall armyworm and beet armyworm were present at such low levels in North Carolina in 1996 that their damage potential to Bt cotton is unknown. However, results from small plots conducted in previous years suggest that fall armyworm will pose a problem to Bt cotton when its numbers are high.

R Deaton

Figure 8. Cotton boll with worm damage.

Stinkbugs and plant bugs were also present in low numbers, but their populations were higher in non-sprayed Bt cotton than in sprayed conventional cotton. Stinkbugs are expected to become more of an economic problem as the acreage of Bt cotton increases. Insecticides normally applied to control bollworm and tobacco budworm also control stinkbugs.

Plant bugs are also predicted to increase in Bt cotton, especially during the period when cotton fields are typically being sprayed for caterpillar control. The economic significance of plant bug feeding on small bolls in Bt cotton is a question which will only be answered in time.

Beneficial insects fared better in Bt cotton than in sprayed conventional cotton. However, in small plots predaceous species were reduced in number in Bt cotton in comparison to populations in conventional cotton that had not been sprayed. Numbers of beneficial insects will be directly correlated to prey numbers.

HC Lambert

Figure 10. Bollworm larva, about 4 days old, feeding under dried bloom tag.

In 1997, scouting in Bt cotton will require much more attention be paid to what is happening well down into the plant canopy. Bollworms tend to move down the plant rapidly after egg hatch and are most often found feeding within flowers or on small bolls — especially small bolls with bloom tags (Figure 10). The typical terminal and upper plant focus of scouting must change in Bt cotton during periods of bollworm moth flight and larval development. Bollworm larvae spend very little time in the terminal of a cotton plant, particularly in Bt cotton.

There is strong evidence that the egg threshold that has been used as the trigger for applying insecticides for bollworms in North Carolina for more than 10 years is inappropriate for Bt cotton. During peak bollworm moth flight from field corn, an egg threshold will still be used. However, it will be a much higher threshold (i.e. 75-100 eggs/100 terminals or 20 eggs/100 fruit) than that recommended for conventional cotton. The egg threshold will be used only to determine when to make the first insecticide application. Any subsequent applications will be based on 6% fruit damage or 3% live larvae of 1/8 inch or larger on fruit. Pyrethroids must be applied before substantial boll damage from bollworms occurs, or yield potential will be compromised.

In the Brazos River Bottoms of Texas, the main insect pest is the boll weevil, not the cotton bollworm or tobacco budworm. Growers usually treat three to five times for boll weevil early and then stop for the rest of the season and let the beneficial populations build. In areas where the weevil is not as troublesome, growers let beneficials build by using softer early treatments for aphids, fleahoppers and lygus.

Using Bt cotton allows growers in weevil-infested areas to use more aggressive over-wintering treatments without fearing a bollworm outbreak in the absence of beneficials, which are eliminated along with the weevils. Where weevils are not a problem, beneficials thrive and aid in control.

In the absence of treatments for boll weevils, fleahopper and lygus become major pests. In 1996, numbers of tobacco budworms and beet armyworms were reduced in Bt cotton. When bollworms reached an economic threshold in Bt cotton, pyrethroids were very effective.

In the Mid-South, Bt cotton gave 100% control of tobacco budworms. However, in mid July, cotton bollworm pressure was intense (egg counts above 200 per 100 terminals). Many eggs were laid down in the canopy. Consultants observed eggs (Figure 11) and young larvae (Figure 9) associated with dried blooms adhering to young bolls.

HC Lambert

Figure 11. Cotton bollworm egg laid on dried bloom tag.

Worms hatched and infested small bolls in damaging levels. Two pyrethroid insecticide applications were required. NuCOTN 33[B] varieties treated based on worm egg-lay, rather than on damaged fruit, yielded better.

Because Bt cotton was not being treated on a regular basis for worms, both boll weevils and plant bugs were a constant threat. Their numbers increased rapidly in July and August and left much cotton with the "buggy whip" configuration. Intense insect pressure removed fruit from top positions. This top fruit is needed for the longer season varieties, like NuCOTN 33[B], to achieve optimum yields.

Very few fields developed a useful beneficial population because of the intensity with which producers had to treat for boll weevils and plant bugs at pinhead square. In areas where boll weevil eradication has been in existence for some time (such as parts of the Southeast), beneficial populations can build in numbers to overcome heavy bollworm pressure in Bt cotton.

In Alabama, the first caterpillar infestations occurred in June when cotton was squaring. They were almost entirely tobacco budworm, *Heliothis virescens*. No survivors were reported on Bt cotton. Foliar sprays of registered insecticides applied to control budworms in conventional cotton were no more effective than beneficial insects in untreated plots. Very few budworms occurred during the remainder of the season.

Bollworm (*Helicoverpa zea*) numbers peaked at two points in the season — mid-to-late July and again in early September. The mid-to-late July populations came from maturing corn. Beneficial insects dramatically reduced the number of bollworm escapes in Bt cotton, as compared to conventional cotton, in which beneficial numbers had been suppressed by insecticides.

Where foliar insecticide applications were made to both Bt and conventional cotton for control of bollworms in July, August and September, the results were good to excellent. Pyrethroids at mid-label rates gave equal to or better results than the newer chemistries under development. Foliar Bt's oversprayed on Bt cotton did not reduce the number of escaped bollworms compared to untreated plots.

Orius, the minute pirate bug, was the most important predator over much of the state. Populations of 45,000 per acre were recorded. In the northern part of the state, *Geocoris*, big-eyed bug, was the most common predator. A shift from *Orius* to *Geocoris* was noted in several other areas in late season (early September).

Beet armyworm, *Spodoptera exigua*, was less likely to occur at economic levels on Bt cotton because of the reduced use of insecticides, higher numbers of beneficials (especially *Cotesia*), and the suppression by 30 to 60% of beet armyworms by Bt cotton itself. Based on one year's observations, aphids may also be a reduced pest on Bt cotton because of the presence of greater numbers of beneficials.

Fall armyworm, *Spodoptera frugiperda*, was a significant economic pest in the Gulf Coast area of Alabama and throughout most of the Coastal Plain of the Southeast. Because fall armyworms do not feed on as many fruit per larva, both bollworms and tobacco budworms cause much greater damage on a per caterpillar basis.

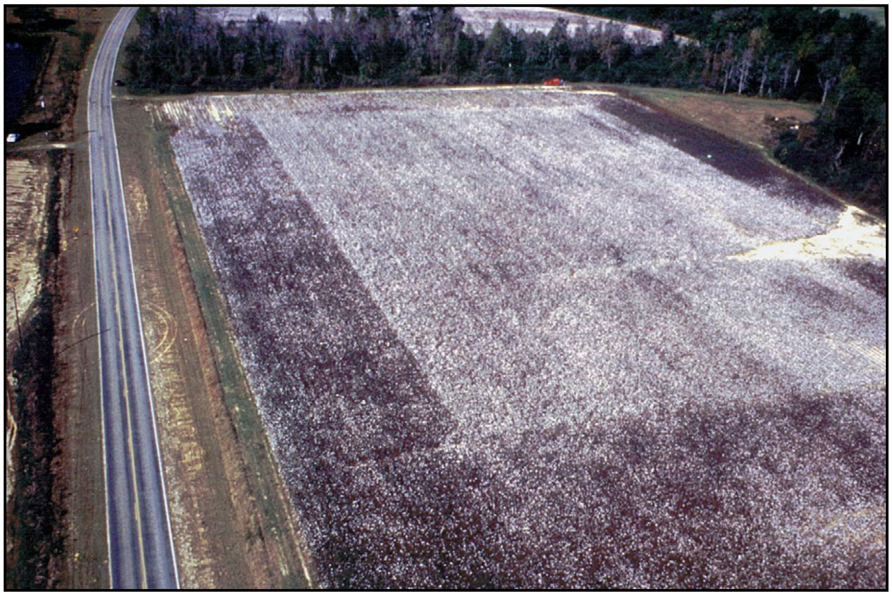
No currently registered insecticide or combination gave over 30 to 50% control of the fall armyworm infestation that occurred in July. In future seasons, populations are likely to increase. New products and approaches are needed to control this pest which infested over 1 million acres of cotton in 1996.

Any beneficials that remain during the mid-to-late July period when fall armyworms occur will provide a significant level of suppression. In 1996, pirate bugs were most often found inside boll bracts low on the plant and inside red blooms where early instar fall armyworms occur. *Orius* tends to search the entire plant better than most beneficials.

Industry Representatives Look Back and to the Future

Over the last 3 years, staff of Delta and Pine Land Company compared NuCOTN varieties to their recurrent parents across the Cotton Belt. In these trials, varieties were planted to a minimum of four rows the length of the field and farmed according to the cooperator's management practices. In 1994 and 1995, only the recurrent parents were sprayed for heliothine pests, but NuCOTN varieties were not (Figure 12). However, in 1996, all plots were sprayed. Efforts were focused on agronomic comparisons of the varieties.

Results of the trials from 79 locations (22, 28, and 29 in 1994, 1995, and 1996, respectively) are averaged over all 3 years (Table 3). Yield, fiber quality, and plant growth data are compared for NuCOTN and the recurrent parent. Significance of the orthogonal contrast is given in the last column.



T Kerby

Figure 12. Bt cotton field bordered by rows of conventional cotton in 1994 demonstration prior to regulatory approval. Field was not sprayed for Heliothine pests.

Table 3. Comparison of NuCOTN 33 B and 35 B with their recurrent parents at 79 test locations from 1994 to 1996. T Kerby

	DP5415	NuCOTN33B	DP5690	NuCOTN 35 B	Recurrent Parent	NuCOTN	Contrast p
Agronomy							
Yield, lbs/acre	943	1080	898	997	921	1039	0.002
Turnout, %	36.5	35.9	35.5	34.8	36.1	35.4	0.010
Quality							
Length, inches	1.109	1.110	1.101	1.113	1.105	1.112	0.611
Strength	29.6	29.2	30.7	30.6	30.2	29.9	0.261
Micronaire	4.44	4.34	4.36	4.32	4.40	4.33	0.245
Leaf grade	2.8	2.9	3.0	3.0	2.9	3.0	0.662
Grade index	96	95	96	95	96	95	0.427
Mapping							
Final height, inches	39.2	40.1	42.6	43.0	40.9	41.5	0.547
Total nodes	21.1	21.5	22.1	22.1	21.6	21.8	0.536
Vegetative nodes	5.2	5.2	5.4	5.4	5.3	5.3	0.730
Height to node ratio	1.87	1.87	1.94	1.95	1.91	1.91	0.930
% FP1 Retention, Bottom 5	42.5	48.0	40.9	45.0	41.7	46.5	0.011
% FP1 Retention, 95% zone	49.4	55.8	50.2	55.2	49.8	55.5	0.000
# Nodes, 95% zone	17.8	18.1	18.7	18.5	18.3	18.3	0.867

Gin turnout percentage was reduced by 0.7 for both NuCOTN 33^B and 35^B compared to their recurrent parents. This difference occurred as a result of an increase in seed size for the NuCOTN varieties, and not as a result of trash or moisture differences. Both leaf grade and grade index were very similar for NuCOTN and the recurrent parents.

The increased seed size for NuCOTN varieties resulted in better vigor ratings during emergence than those for the recurrent parents. NuCOTN varieties and their recurrent parents were equivalent in fiber length, strength, and micronaire.

Final plant height, number of nodes, height to node ratio, and number of vegetative nodes before the first fruiting branch were the same for NuCOTN varieties and their recurrent parents. However, NuCOTN varieties retained significantly more bolls on the primary fruiting sites (first position) on the first five fruiting branches, as well as on all the effective fruiting branches (95% zone) than their recurrent parents.

Height to node ratios alone do not suggest more growth potential for NuCOTN varieties because they retained more early season bolls. They were able to maintain growth rates similar to those of their recurrent parents while carrying a larger boll load. Although many consultants and growers felt Pix® would not be necessary based upon the boll load they observed on NuCOTN varieties, these results suggest the NuCOTN varieties require a boll load that is approximately 10% greater than that of their recurrent parents to achieve the same level of growth control. Earliness of NuCOTN varieties was approximately the same as that of their parents. The node where 95% of the harvestable bolls was set was equal for NuCOTN and its parents (i.e. 18.3).

The agronomic performance of NuCOTN varieties, relative to that of their recurrent parents, was not affected by year. While NuCOTN varieties got most of the attention in 1996, the number of varieties with Bollgard® will increase in 1997. Modules of Bollgard® cotton will increase across the Cotton Belt (Figure 13).

Stoneville Pedigreed Seed inserted the Bollgard® gene into ST 474, their highest yielding variety. In 1997, this new Bt variety, BG+BXN 4740, has been entered into every state variety trial, except for Virginia.

Deltapine and Paymaster could have 13 varieties with Bollgard® and an additional 8 varieties with both Bollgard® and Roundup Ready®. Before they will be released, these new varieties are going through the same testing as did NuCOTN 33^B and 35^B.

T Kerby

Figure 13. Harvested cotton containing Monsanto's Bollgard® gene.

Conclusions

In spite of a few problems that occurred in 1996, the first year Bt cotton was grown commercially, growers are planting more acreage to Bt cotton this year than ever before. Resistance management, important to maintain Bollgard®'s long-term value, received outstanding implementation by growers in 1996. Scouting was, and will continue to be, particularly critical for managing Bt cotton in order to get the most from the technology. Scouting must focus on locating small bollworm larvae in the plant interior before they cause yield loss. The new Bt cotton technology is great, but it must be combined with other tools, such as insecticides, to achieve maximum yield potential.

Mention of a specific product does not imply endorsement of it over any other product.

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