BT COTTON: OPPORTUNITIES AND CHALLENGES

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Abstract

For the first time in 30 years, major new insect pest management technologies will be available to cotton producers. Transgenic *Bt* cotton varieties, eradication of the boll weevil and new insecticides offer opportunities and challenges for cotton producers, crop consultants, researchers, extension and industry personnel, and society. They offer opportunities to reduce insect injury and increase yields for producers currently suffering from sever chronic, infestations of bollworm, tobacco budworm, pink bollworm, and boll weevil; as well as other caterpillar pests such as cabbage looper, saltmarsh caterpillar and cotton leaf perforator. Producers, consultants, scientists, EPA, environmental interest groups, and society are hopeful that *Bt* cottons will reduce the current use of conventional synthetic insecticides. These reductions should provide the opportunities to: (1) improve natural biological control of cotton pests, (2) reduce human/wildlife hazards due to exposure to insecticides, and (3) reduce risks of environmental contamination from synthetic insecticides.

The major challenges that accompany these technologies are how to: (1) integrate them into current insect pest management (IPM)/cotton crop production systems; (2) delay the development of insect resistance to these technologies, especially *Bt* cotton; (3) evaluate and manage natural biological control and; (4) how to suppress insect pests not controlled by *Bt* cotton without disrupting natural biological control. These new IPM technologies offer great opportunity, however, because of our inexperience in their use, they also offer great risk of financial loss. Due to our inexperience and the risk involved, it is recommended that consultants and producers carefully evaluate and test these new technologies in their crop production system to become confident that these new IPM methods will improve insect control and farm profit.

Introduction

Bt cotton has certainly stirred up cotton producers, university researchers and extension specialists, and the cotton seed and agrichemical industries unlike any new product that I have seen! Many excellent written and spoken presentations have been made over the last 3 or 4 years on the virtues and short comings of this new insect management technology (Benedict et al., 1996; Bradley, 1995; Luttrell and Herzog, 1994; Watson, 1995).

Why all the interest in *Bt* cotton? After all, it is just another method to apply insecticide! It kills some caterpillar pests of cotton just like other currently used insecticides. In fact, the insecticide produced by the first commercially available *Bt* cottons, from Delta and Pine Land and Hartz Seed Companies (licensed by Mansanto Company under the tradename, Bollgard™ gene), produce the same insecticidal protein, CryIA(c), as is found in many of the biological insecticides like Dipel that have been used to control caterpillar pests for more than 35 years (Navon, 1993). Today, I want to briefly discuss some of the reasons why I think there is so much interest in *Bt* cottons, and some of the opportunities and challenges that they offer cotton producers.

I think a major reason for the unusual interest is because *Bt* cotton is a novel way to control insects. It is novel because the *Bt* cotton plant produces the insecticide throughout the plant, all day, everyday of the cotton plant's life. It can't be washed off, and the sun and other environmental factors can't reach it to break it down like many conventional synthetic and biological insecticides. This plant produced insecticide is truly unique because it is not produced in an industrial chemical synthesis plant or sold in a 5-gallon container or applied as a foliar spray with a machine. Rather, the CryIA(c) insecticide is produced by the *Bt* plant, sold as cotton seed in a bag, and the cotton plant makes its own application to every plant cell as it grows. (This plant synthesis has been called this bioproduction.) In addition the CryIA(c) protein in *Bt* cotton is nontoxic to man, domesticated animals, wildlife and the environment.

Opportunities and Challenges

1. What is the greatest opportunity that this technology has to offer?

Possibly the greatest opportunity is to use *Bt* cotton to increase profit and yield for growers that are making four or more insecticide applications and spending $30 or more per acre to control bollworm, tobacco budworm, or pink bollworm, and still not obtaining good insect control (Table 1). (These are the target insects that *Bt* cotton was developed to control.) There are geographic areas of the U.S. and the world that have had to quit growing cotton due to high insect control costs and yields so low that cotton production was unprofitable. For example, producers in Southern California and areas of Texas and Arizona have quit growing cotton because of the costs due to the pink bollworm. With *Bt* cotton these producers now have the opportunity to again produce cotton. *Bt* cotton technology is especially attractive for those producers across the cotton belt that are fighting tobacco budworms that are resistant to conventional insecticides. Last season (1995) producers in the hill region of Mississippi

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experienced high infestations of insecticide resistant tobacco budworms (Mike Williams, personal communication). In spite of more than 8 applications, costing greater than $80/A they still lost an estimated 23% of their potential yield—for these producers *Bt* cotton is technology "to-die-for".

Research has shown that *Bt* cotton is very effective in controling the target pests. Yield data for *Bt* cottons in nine highly infested large plot tests (5 to 25 acres per plot) in Texas (1995) averaged 23% more (range 10 to 34%), 175 lbs. of lint/A, (range 53 to 326 lb/A) compared to the sprayed parent non-*Bt* varieties DPL5415 and 5690 (Pigg, 1995) (Table 2). The *Bt* cottons evaluated were Delta and Pine Land NuCOTN33B and NuCOTN35B. Also research data from my program at Texas A&M showed a 14% increase in yield (157 lbs./A) with *Bt* cotton (Coker 312 background) compared to the sprayed non-*Bt* parent variety, Coker 312, over five years of testing (Table 3). This was surprising because the Bt cottons in my program were not agronomically competitive with commercial varieties, especially the Bt lines evaluated in 1990 and 1991. However in three North Carolina small plot trials the Coker 312 *Bt* cotton only yielded 4% higher, 109 lbs. of lint/A, compared with the sprayed non-*Bt* Coker 312 parent (Mahaffey et al., 1994). The primary insect pest in the North Carolina studies was the bollworm which is harder to kill with the CryIA(c) insecticide in *Bt* cotton, but easier to kill with conventional synthetic insecticides, than the tobacco budworm.

These yield increases with *Bt* cotton were only achieved in studies where tobacco budworm/bollworm infestations injured 20 to 60% of the flower buds and bolls. Producers and consultants should keep in mind that *Bt* cotton technology will not pay for itself if the field is not infested with tobacco budworm, bollworm, or pink bollworm. So my advice is use it only where you know you are really going to need it! Where it should increase yield and profit due to insect infestation in 8 out of 10 years. Where you expect an infestation of bollworm, tobacco budworm or pink bollworm that would cost more than $30/A in insecticides and yield losses. In the absence of an infestation of one of the target pests, the current *Bt* cottons appear to yield equal or slightly superior to the parent varieties (i.e., DPL5415 or 5690) (Roy Parker, personal communication).

2. Where else could a cotton producer use this technology to advantage?

The most obvious is to control the target caterpillar pests—bollworm, tobacco budworm, and pink bollworm, in situations where they are difficult to control now. For example, (1) along waterways or near lakes where there is restricted use of synthetic insecticides or synthetic insecticides cannot be applied at all; (2) in restricted areas around homes and businesses where foliar sprays cannot be applied; (3) in the areas where boll weevil eradication is being conducted, and outbreaks of secondary caterpillar pests are expected. Another possible use would be (4) in areas where outbreaks of beet armyworms and/or fall armyworms are a problem due to killing of natural enemies with sprays of synthetic insecticides to control bollworm, tobacco budworm, or pink bollworm. If *Bt* cotton is used to control the bollworm and tobacco budworm, and no mid or late season conventional synthetic insecticides are used, the natural enemies of beet armyworm and fall armyworm should keep these armyworms under control, in most situations, with no additional cost to the grower.

3. What other opportunities for a producer does this *Bt* technology provide?

(1) It reduces the amount of time a producer and his employees are involved in purchasing, transporting, mixing, and spraying insecticides for caterpillar control; (2) frees up producer and employee time for other crop production related activities; (3) reduces risk of insecticide related accidents and law suits; (4) eliminates need to respray due to rain wash-off and insecticide degradation; and (5) provides peace of mind and reduced risk of crop loss from tobacco budworm, bollworm, and pink bollworm.

4. Does *Bt* cotton provide any control of insect pests other than tobacco budworm, bollworm and pink bollworm?

Yes, but only for a limited number of caterpillar pests. It provides good to excellent control (approximately 85% or better kill) of cotton leaf perforator, European corn borer, saltmarsh caterpillar, and cabbage looper. It also provides some control (approximately 25 to 50% kill) of soybean looper and beet armyworm, but little control of fall armyworm. Several new insecticides, as yet unregistered, appear to work well against armyworms. These insecticides are selective in that they kill armyworms but do not kill all beneficial insects. How easy the new insecticides are on beneficial insects, has yet to be fully determined. These selective insecticides are “Tracer” (DowElanco) and “Confirm” (Rohm and Haas). They should be compatible with *Bt* cotton in an Integrated Pest Management (IPM) approach to preserving beneficials.

5. Does *Bt* cotton provide any environmental benefits?

EPA, Sierra Club, Audubon Society, other special interest groups, the general public, and many extension and research scientists hope that the use of *Bt* cotton will replace some of the conventional synthetic insecticides currently used for control of "the big three," tobacco budworm, bollworm, and pink bollworm. Further, it is hoped that as conventional synthetic insecticide use is decreased, due to use of *Bt* cotton and new selective insecticides, that the natural enemies of all insect pests of cotton will become more effective. Thus, further reducing the need for conventional insecticides to control the cotton insects not controlled by *Bt* cotton. Eradication of the boll weevil should also reduce usage of conventional synthetic insecticide. Reducing the amount and use of conventional synthetic insecticides also could reduce potential problems with contamination of run-off water and of ground water, hazards from spray drift, and hazards to wildlife and society. However, this view may be unrealistic. We will know in 2-5 years whether current synthetic insecticides are really reduced, or just replaced by new, more expensive, selective insecticides.

6. Is there an opportunity to improve the effectiveness of beneficial insects with *Bt* cotton?

As discussed under 5, if the frequency of use and amounts of conventional broad spectrum synthetic insecticides are really reduced with *Bt* cotton production, then the effectiveness of natural enemies in controlling all cotton pests has the potential to improve. With reduced conventional synthetic insecticide use there should also be opportunities to use new biological control methods, such as release of new types of natural enemies into cotton fields to compliment our current natural enemies and provide more effective control of cotton pests. Some scientists feel the use of *Bt* cotton and eradication of boll weevil may provide our first real opportunity to begin practicing IPM of cotton insects! However, as Dr. Bradley has pointed out (Bradley, 1995), there is much we need to know regarding sampling for pests and natural enemies, making treatment decisions, managing insect resistance to insecticides, and integrating new and old insect control methods with current production practices, before we can truly practice cotton IPM.

Allow me to digress for a moment! Methods of cotton production and insect pest management are changing this year. They have been changing slowly since man began to farm cotton hundreds or possibly thousands of years ago. But now we are in a time of very rapid transition. We cannot be certain what form these changes will take in the next five years or what all the opportunities will be. The cotton production system of tomorrow is further complicated because we have many new and promising herbicides, selective insecticides, and genetically engineered insect and herbicide resistant varieties coming to commercial cotton production. They will all play a part in the system of cotton production that we adopt over the next few years. We have had little change in insect management for 30 years, and now suddenly it almost seems everything in the entire cotton production system is changing. My recommendation to producers is that they work closely with consultants and other reliable sources of information, and carefully evaluate these new technologies on a limited area before adopting them on the entire farm. They are expensive and if a producer doesn't need them, he/she could be spending thousands of dollars unnecessarily.

7. What are the greatest challenges of using this *Bt* gene technology?

One of the greatest challenges is (1) for the producer to decide whether he/she needs this *Bt* cotton anywhere on the farm. This decision must be made at planting or earlier—before the producer has an economic insect infestation of one of the "big three" insects to control. A wrong decision could be expensive. There are two types of wrong decisions: first the producer could decide not to grow *Bt* cotton and his field become infested with insecticide resistant tobacco budworms which he can't control well with currently registered insecticides, resulting in a sizable crop loss. There is a new, as yet unregistered insecticide called "Pirate" (American Cyanamid), which will control resistant tobacco budworms but it also is expensive. Two applications of Pirate could cost as much as *Bt* cotton. The second type of wrong decision is that the producer could decide to purchase and grow *Bt* cotton and then no insect infestation develop. This decision can result in a loss of about $34/A for insect control he did not need ($34/A is the total for seed premium, $6/bag, and the gene technology license fee, $32/A).

Another challenge is (2) how to control insect pests of cotton that *Bt* cotton does not control (Bacheler and Mott, 1995; Bradley, 1995; Turnipseed et al., 1995). These insect and mite pests that are not affected by the insecticidal CryIA(c) protein in the *Bt* cotton plant are thrips, aphids, boll weevils, some armyworms, stink bugs, plant bugs, white flies, and spider mites. These are called non-target pests of *Bt* cotton. In the past many of these non-target pests have been suppressed coincidentally by the synthetic foliar insecticides applied to control bollworm, tobacco budworm, boll weevil, or pink bollworm. Some scientists and consultants predict that when these synthetic insecticide applications stop, due to boll weevil eradication and use of *Bt* cottons, that insecticide applications for the non-target insects will increase to the point, where producers will be spraying almost as frequently as they are now for bollworm, tobacco budworm, and pink bollworm. I hope this is not true! As discussed earlier, the use of *Bt* cotton is expected to increase the effectiveness of beneficial insects and suppress non-target pests, resulting in few additional synthetic insecticide sprays being required. Evidence from cotton producing states where the boll weevil has been eradicated show that the most likely outcome, of using *Bt* cotton and/or boll weevil eradication to control target pests, will be a reduction in foliar synthetic insecticide use (Luttrell and Herzog 1994). However, the maximum value-added by beneficial insects and diseases of insects in *Bt* cotton, can only be realized as consultants and producers are willing and able to evaluate and use them in managing their cotton crop. The challenge for all of us is to better use our beneficial insects and diseases of insects than ever before.

If we assume that with *Bt* cotton, beneficial insects become more effective in suppressing all cotton pests, then a great challenge is (3) to develop sampling methods for beneficial insects, and treatment thresholds which include beneficial insects. These natural enemies of cotton pests could become a more valuable resource for producers if we can develop rapid practical ways to measure their ability to control pests and include this information in the process for determining the need-to-control a particular pest infestation.

The last challenge I want to mention is critical to maintaining the long-term use of *Bt* cottons (i.e., greater than 10 years). The challenge is (4) to manage *Bt* cotton in such a way that the target insects do not develop resistance to the CryIA(c) insecticidal protein (Gould et al. 1995, Tabashnik, 1994). The development of insect resistance to an insecticide works like this: the insecticidal protein is present in a fairly high dose in every cell of the plant, all season long, resulting in intense selection taking place in *Bt* cotton fields for those individual caterpillars that have the ability to feed on the toxin, yet survive and become reproductive adults. Those resistant adults in turn mate with each other and thus can pass on to their offspring this ability, to feed on the toxin and survive. In each subsequent generation more individual caterpillars that feed on *Bt* cotton will be resistant to the *Bt* insecticide. This selection process continues over a number of years (maybe 5 to 10years) until the *Bt* cotton no longer controls the target insect pests and is useless technology for insect management in cotton. The cotton production areas of the U.S. where we might first expect tobacco budworm to become resistant to *Bt* cotton are those same production areas where *Bt* cotton is most needed today; that is, where the most synthetic insecticides applications are currently being used, and resistance in tobacco budworm is already occurring to current synthetic insecticides (Kanga et al., 1995).

Monsanto is developing a number of tactics to delay the development of resistance to the CryIA(c) insecticide in *Bt* cotton (Deaton, 1995). One of these methods is the use of a non-*Bt* refuge crop. This method works by producing CryIA(c) insecticide susceptible moths in the refuge that mate with any CryIA(c) resistant moths that may develop in the *Bt* cotton. The offspring of this mating of a resistant and susceptible moth should be susceptible to the CryIA(c) insecticide in *Bt* cotton plants and thus die when they feed on *Bt*. I can't emphasize how important it is to carry out one of the refuge options as required by Monsanto and the EPA. We all have much to loose if resistance develops to the insecticidal protein in *Bt* cotton.

Conclusion

I hope you can clearly see from this presentation that *Bt* cotton, boll weevil eradication and new selective insecticides offer many new opportunities for cotton producers to reduce insect injury, and improve cotton yields and farm income. However, *Bt* cotton alone is not the sole answer to all cotton insect problems, but I think we can agree that it offers a great economic opportunity to those producers whose cotton crop has been frequently and severely reduced by attacks from tobacco budworm, bollworm, and pink bollworm. This is also the first time in nearly 30 years when several new insect management technologies, (i.e., *Bt* cotton and new selective insecticides) will have a major influence on the way we manage insect pests of cotton. The challenges are to manage these insecticides so they are effective for a long time, and to develop integrated pest management systems that realize the greatest benefits from all these new technologies. Finally, I urge that cotton producers, consultants, researchers, extension specialists, and industry personnel all work together to meet these challenges so we can all profit from the opportunities offered by these new insect management technologies.

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Table 1. Annual cotton yields, losses and costs of control for caterpillars (Lepidoptera) controlled by Bollgard *Bt* cotton in the USA (Average of 1992-1994).

	Cotton production region				All
Measurements	Southeast	Midsouth	Southwest	West	USA
Acres harvested x 1 million	1.80	4.08	4.98	1.55	12.40
Yield in bales per acre	1.41	1.46	1.01	2.47	1.31
Yield, total bales x 1 million	2.57	5.99	4.94	3.95	17.45
---------------- Estimates for *Bt* Cotton Controlled Lepidoptera----------------					
No. applications per acre	3.81	3.26	1.02	0.83	2.81
Total acre applic. x 1 million	6.43	13.55	1.73	0.36	22.06
$ costs for control per acre	27.72	33.13	9.77	8.88	24.31
$ costs for control x 1 million	46.65	137.57	15.55	3.60	203.38
$ crop loss above control costs x 1 million	35.03	68.80	16.38	5.34	125.54
$ Total loss x 1 million	81.68	205.37	31.93	8.94	328.92

* Data estimates from Beltwide Cotton Conference, 1992-1994. Lepidoptera controlled with *Bt* were bollworm, tobacco budworm, pink bollworm, cabbage looper, cotton leaf perforator, and saltmarsh caterpillar.

Table 2. Yields and yield differences between unsprayed *Bt* varieties and sprayed non-*Bt* varieties in large plot tests on farms in Texas. Conducted by the Texas Agricultural Extension Service and DPL, 1995.

Farm	Variety*	Lint yield (lbs/A)	Yield difference (lbs/A)
1. J. Conn	NUCOTN33B	949	+202
	DPL5415	747	
2. D. Schernick	NUCOTN35B	553	+53
	DPL5690	500	
3. D&H Swanberg	NUCOTN33B	422	+93
	DPL5415	329	
4. D&H Swanberg	NUCOTN35B	432	+96
	DPL5690	336	
5. H.L. Keller	NUCOTN33B	1,518	+295
	DPL5415	1,223	
6. B. Beakley	NUCOTN33B	801	+111
	DPL5690	690	
7. B. Beakley	NUCOTN33B	793	+79
	DPL5415	714	
8. T. Lombardo	NUCOTN33B	1,497	+316
	DPL5690	1,181	
9. T. Lombardo	NUCOTN33B	1,411	+326
	DPL5415	1,085	
Average	*Bt* varieties	931	+175
	Non-*Bt* varieties	756	(+23%)

*The NUCOTN33B and NUCOTN35B are *Bt* cotton varieties and were not sprayed for caterpillar pests, whereas DPL 5415 and 5690 are non-*Bt* varieties and were sprayed one or more times, depending upon the location, with insecticides to control caterpillar pests.

Table 3. Yields and yield differences in 5 years of small plot tests in Texas conducted by the Texas Agricultural Experiment Station, 1990-1994 (Benedict et al. 1996).

Test/Year	Variety*	Lint yield (lbs/A)	Yield difference (lbs/A)
1990	*Bt* Coker 312	1,169	-119
	Non-*Bt* Coker 312	1,288	
1991	*Bt* Coker 312	1,534	-65
	Non-*Bt* Coker 312	1,599	
1992	*Bt* Coker 312	2,007	+443
	Non-*Bt* Coker 312	1,564	
1993	*Bt* Coker 312	683	+266
	Non-*Bt* Coker 312	417	
1994	*Bt* Coker 312	840	+257
	Non-*Bt* Coker 312	583	
Average	*Bt* Coker 312	1,247	+156
	Non-*Bt* Coker 312	1,090	(+14%)

*The *Bt* Coker 312 indicates Coker 312 breeding lines with the *Bt* gene present, CryIA(c), and were not sprayed for caterpillar pests. Whereas Non-*Bt* Coker 312 was the parent of the *Bt* lines but without the *Bt* gene. The Non-*Bt* Coker 312 variety was sprayed 4 to 8 times with synthetic pyrethroids to control caterpillar pests. Both bollworms and tobacco budworms infested these tests. Tobacco budworms in 1993 and 1994 were resistant to pyrethroids. Yields for the *Bt* Coker 312 were the average of three breeding lines in each year.