Impacts on US Agriculture of Biotechnology-Derived Crops Planted in 2003– An Update of Eleven Case Studies

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Introduction

One of the most revolutionary and promising pest management approaches in crop production is the development and use of biotechnology. By inserting genetic material from outside a plant's normal genome, crop varieties have been developed to resist an array of pests. As a result, these crops have been grown without using certain pesticides necessary on conventional crops (example: insect-resistant or Bt crops). In some cases, the biotechnology-derived crop provides effective control of a plant pest that is not otherwise well controlled (example: Bt crops and virus-resistant crops). Other biotechnology-derived crops are tolerant of certain herbicides that injure conventional crop varieties. Planting the biotechnology-derived herbicide-tolerant crop has made it possible to use the associated herbicide, which often provides more effective and less expensive weed control.

Available for commercial planting since 1996, the first wave of biotechnology-derived crops has been embraced with an unprecedented enthusiasm in the United States. Impressive gains have been noted in the adoption of these crops each year and planted acreage climbed to 106 million acres by 2003 (Figure 1). With three approved applications (herbicide-tolerance, insect-resistance, and virus-resistance) and a planted acreage of sixty three percent of the global total in 2003, the United States has continued as a World leader in the field of biotechnology.

Agricultural biotechnology and its applications has been a subject of vigorous debate between the proponents and opponents of the technology. Questions have been raised repeatedly about the impacts of the technology on agriculture, trade, environment, and human health. The National Center for Food and Agricultural Policy (the National Center) has played a unique role in this debate with its release of a groundbreaking study in June of 2002 that addressed some of these important issues. Findings that stemmed from this research have been used as building blocks to provide a stream of additional information contributing to the ongoing public debate about biotechnology across the world.

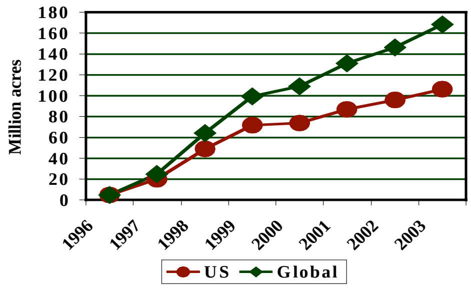
The 2002 study analyzed and estimated the impacts on US agriculture of the then commercialized biotechnology applications in addition to several potential applications on crop yield, pesticide use, and grower cost. Estimates for the 2002 report were based on 2000 or 2001 acreage information. With continued approvals of biotechnology applications that afford protection to a broader range of pest problems, the contributions and impacts of biotechnology-derived crops are expected to change. While the number of adopted biotechnology-derived crops remained unchanged since the National Center's report, the number of commercialized and adopted applications have increased by 38%. For example, biotechnology-derived crop cultivars with resistance or enhanced resistance to a broad spectrum of insect pests were introduced subsequent to the release of the National Center's report in 2002. They include Bt corn resistant to European corn borer/southwestern corn borer/black cutworm/fall armyworm/corn earworm (trade name – Herculex I), Bt corn resistant to Western, Northern, and Mexican corn rootworm (trade name – YieldGard Rootworm), and Bt cotton with resistance/enhanced resistance to bollworm/budworm/looper/armyworm pest complex (trade name – Bollgard II).

In addition, American growers have increased production of biotechnology-derived crops by 10 and 22%, respectively, in 2002 and 2003 compared to 2001, a year which was used as the basis for the National Center's 2002 study. With a technology that is planted on vast areas of the United States and one that is advancing at a rapid pace as this, it is imperative that the impacts - agronomic, economic, and environmental consequences to be specific - be assessed using the current adoption data.

The purpose of this report is to update the estimates and quantify the changes in the impacts of biotechnology-derived crops on US agriculture that have occurred since 2001. The report attempts to provide an economic perspective and establish the basis to understand why American farmers have embraced biotechnology and are likely to continue to do so. Other impacts on production practices such as tillage are also discussed.

Information specific to farm level impacts, current information in particular, is critical to the biotechnology debate and policy discussions. If policy makers and the public do not understand the current impacts the technology can provide, the technology may not be fully utilized.

Figure 1: Acreage planted to biotechnology-derived crops



Method

The objective of this study is to evaluate the impacts on US agriculture of six biotechnology-derived crop cultivars that were planted in 2003. They include papaya, squash, corn, cotton, canola, and soybean. Table 1 depicts the trait information for these crops. Information was analyzed and updated for eleven case studies (Table 2). Though there were only 6 planted biotechnology-derived crops, crops such as corn and cotton had more than one pest management trait in commercial production, which led to eleven case studies.

This report does not detail background information on each case study as the status of the pest problems and conventional pest management practices have more or less remained unchanged since the 2002 report. Background information for all the case studies of this report can be obtained from the earlier report, which can be accessed at http://www.ncfap.org/whatwedo/40casestudies.php.

Similar to the 2002 report, states for which pest management would be impacted due to the adoption of the biotechnology-derived crop cultivars were identified and impacts were calculated. For some case studies (example: virus-resistant squash, herbicide-tolerant canola, and rootworm-resistant corn), only certain states were used in the analysis. These states were those with either largest crop acreage or states where the technology could provide maximum impact in view of the significance of the pest problem. Thus, geographical analysis was limited in scope for some crops.

Similar to the method used in the earlier report, the effectiveness of the biotechnology-derived crops in controlling the target pest(s) and the resulting impacts on production practices and pest management were calculated. Impacts were identified and quantified in four categories. They include changes in production volume, value, costs, and pesticide use. The Unites States Department of Agriculture's National Agricultural Statistics Service served as valuable resource for the determination of the above impacts.

Changes in production volume were measured based on yield changes that have occurred when biotechnology-derived crops replaced existing production practices. Similarly, change in production value was calculated based on yield changes and crop prices. Changes in production costs were calculated by determining which current practices would be affected. Adoption costs associated with use of the technology (either as technology fee or seed premium or both) were considered in these calculations. Finally, changes in pesticide use were quantified when the biotechnology-derived crop cultivar has replaced or substituted current use of the target pesticides leading to either an increased or reduced usage. All the above impacts were calculated using acreage and other production information for 2003.

In addition to the above-discussed impacts, changes and new developments in pest management and other production practices that followed biotechnology-derived crops were also discussed in this report. One of these changes is increased adoption of no-tillage practices that has taken place subsequent to the widespread planting of herbicide-tolerant crop varieties. Changes in no-till acres were analyzed in this report.

University researchers and Extension Crop Specialists were surveyed to evaluate existing pest management approaches in conventional crops and to determine how biotechnology-derived crops replaced or substituted current practices. Pesticide-use information and pest-loss reports were also examined. Updated estimates, in a case study format, were sent to relevant external reviewers for comment. Comments and suggestions from the reviewers were integrated into the final version of the report.

Table 1: Biotechnology-derived crops planted in the United States in 2003

Trait	Crop	Tolerance/resistance to	Trade name
Virus-resistant	Papaya	Papaya ring spot virus	-
Virus-resistant	Squash	Cucumber mosaic virus, Watermelon mosaic virus, Zucchini mosaic virus	-
Herbicide-tolerant	Soybean	Glyphosate	Roundup Ready
Herbicide-tolerant	Canola	Glyphosate Glufosinate	Roundup Ready Liberty Link
Herbicide-tolerant	Corn	Glyphosate Glufosinate	Roundup Ready Liberty Link
Herbicide-tolerant	Cotton	Glyphosate Bromoxynil	Roundup Ready BXN
Insect-resistant	Corn Corn Corn	European corn borer/Southwestern corn borer/corn earworm European corn borer/southwestern corn borer/black cutworm/fall armyworm/corn earworm Rootworm	YieldGard Corn Borer Herculex I YieldGard-Rootworm
Insect-resistant	Cotton Cotton	Bollworm/budworm Bollworm/budworm/looper/armyworm	Bollgard I Bollgard II

Table 2. Case studies for which impacts were analyzed in 2003

Case study	Crop	Trait
1	Papaya	Virus-resistant
2	Squash	Virus-resistant
3	Canola	Herbicide-tolerant
4	Corn	Herbicide-tolerant
5	Cotton	Herbicide-tolerant
6	Soybean	Herbicide-tolerant
7	Corn	Insect-resistant (1)[a]
8	Corn	Insect-resistant (2)[b]
9	Corn	Insect-resistant (3)[c]
10	Cotton	Insect-resistant (1)[d]
11	Cotton	Insect-resistant (2)[e]

[a]European corn borer/southwestern corn borer/corn earworm-resistant corn (includes YieldGard Corn Borer and Herculex I)

[b]Rootworm-resistant corn (YieldGard Rootworm)

[c]European corn borer/southwestern corn borer/black cutworm/fall armyworm/corn earworm-resistant corn (Herculex I)

[d]Bollworm and budworm-resistant cotton (Bollgard I)

[e]Bollworm/budworm/looper/armyworm-resistant cotton (Bollgard II)

Virus-resistant crops

Virus-resistant crops that were grown on a commercial scale in the United States in 2003 are papaya and squash. Both these crops developed through biotechnology methods demonstrated value in limiting viral infestations and preventing serious yield losses. Following is an update of impacts of these two crops on US agriculture in 2003.

1. Papaya

Biotechnology-derived virus-resistant papaya continued to provide optimism to papaya growers of Hawaii, the state in which papaya is commercially produced. Biotechnology-derived papaya acreage increased steadily since its first commercial planting in 1999 and was planted on at least 37% of the total acreage each year (Table 1.1). Planted acreage of virus-resistant papaya as a percent of total acreage has increased by 7 and 9%, respectively, in 2002 and 2003, compared to 2001.

'Rainbow' and 'SunUp' were the two planted biotechnology-derived papaya varieties. While red-fleshed SunUp contributed only 1 to 2% of the planted acreage each year, Rainbow (yellow-fleshed) accounted for the majority of transgenic papaya acreage. The dominance of Rainbow is mainly due to its higher yield potential and favorable commercial characteristic that growers and marketers in Hawaii prefer, its yellow flesh. A new biotechnology-derived papaya variety, 'Laie Gold', has been developed from crosses between Rainbow and a conventional variety called Kamiya and is being field-tested in 2004 (Gonsalves et al. 2004b).

Biotechnology-derived papaya has facilitated strategic planting of conventional varieties in areas that were previously infested with the ringspot virus and also planting of conventional and biotechnology-derived varieties in close proximity to each other (Gonsalves et al. 2004b). This has resulted from the natural reduction in virus pressure due to large-scale planting of biotechnology-derived varieties. Gonsalves et al. (2004b) have also reported that the biotechnology-derived Rainbow variety produced higher yields than Kapoho, which is the leading conventional papaya variety in the US.

Impact of biotechnology-derived papaya on per acre yields and overall production is presented in Table 1.2. The calculations in Table 1.2 were based on the assumption that production changes that has occurred since 1998 were direct result of the introduction of biotechnology-derived papaya varieties. Per acre yield of papaya was improved by 44% in 2003 compared to 1998. However, yield increase in 2003 and 2002 (relative to 1998) was slightly lower than the two previous years. A drop in per acre yields in the last few years is attributed to fall in the bearing acreage of Rainbow and the slow rise in the levels of papaya ringspot virus infestation on conventional varieties (Gonsalves et al. 2004b).

Japan is a major market for American-grown papaya. Since biotechnology-derived papaya is not approved for human consumption in Japan, US papaya growers must plant conventional varieties to meet the trade requirements. Growers that planted conventional varieties had to abandon the fields prematurely in some instances as control options are practically non-existent and this has contributed to significant drop in yields (Gonsalves et al. 2004b).

Based on the changes in per acre yields since the adoption of biotechnology-derived varieties, it was calculated that virus-resistant varieties increased papaya production by 9 million pounds in 2003, the farm-gate value of which was $3.0 million (Table 1.2). A new development in 2003 is that papaya growers had to pay for seeds of biotechnology-derived varieties. Prior to 2003, growers received virus-resistant papaya seeds at no charge. The Papaya Administrative Committee (PAC)'s Federal Marketing Order was terminated in September of 2002 and the Hawaii Papaya Industry Association (HPIC) has undertaken seed distribution responsibilities since then. Seed and distribution costs of virus-resistant papaya were set at $80 per acre by the HPIC in 2003. Conventional seed costs, in contrast, were roughly $32 per acre. Therefore, papaya growers paid $48/acre or a total of $52,560 to gain access to biotechnology-derived papaya seeds in 2003. Subtracting adoption costs, improved net returns were calculated to be $2.91 million in 2003 due to planting of virus-resistant varieties. Overall, biotechnology-derived papaya has delivered economic benefits worth $15.5 million thus far to papaya growers since its availability in the market. Similar results were also reported by Gonsalves et al. (2004a).

The impact values presented in the 2002 report are higher than the ones in this report due to the fact that calculations were based on a projected adoption rate of 90%.

The impacts analyzed in this report are more realistic as actual adoption rates of biotechnology-derived varieties were used in the calculations.

Farmer's acceptance of biotechnology-derived papaya is not an issue as demonstrated by their willingness to even buy the seeds, which were available for free before 2002 (Gonsalves et al. 2004a). Adoption of virus-resistant papaya, however, may grow significantly once export markets approve the shipments of biotechnology-derived varieties. Currently, about 20% of Hawaii's papaya is exported to Japan, 11% to Canada, and the remainder is sent to the U.S. mainland or consumed locally in Hawaii (Gonsalves 2004b). Canada approved the importation of transgenic papaya in January 2003, while Japan has not granted approvals yet. Export markets are key determinants of profitability of biotechnology-derived papaya production in the US.

Table 1.1. Adoption of biotechnology-derived virus-resistant (VR) papaya in Hawaii.

Year	Planted papaya acreage	VR papaya acreage as a % of total planted acres[1,2]	VR papaya acres
	Acres	%	Acres
1999	3205	37	1186
2000	2775	42	1166
2001	2720	37	1060
2002	2145	44	944
2003	2380	46	1095

[1]Only Rainbow variety is included in the adoption figure; Sunup contributes to a minor portion of 1 to 2% each year.
[2]Source: Hawaii Agricultural Statistics.

Table 1.2. Impact of biotechnology-derived virus-resistant (VR) papaya on crop production.

Year	VR papaya acreage	Per acre yields[1]	Increase in per acre yields[2]	Increase in production due to VR varieties[3]	Value of gained production[4]
	Acres	Short ton (=2000 lb)	(%)	000lb	000$
1998	-	9.4	-	-	-
1999	1186	10.9	16	3558	1174
2000	1166	16.6	77	16790	5541
2001	1060	14.1	50	9964	3288
2002	944	13.4	43	7552	2492
2003	1095	13.5	44	8979	2963
Total				**46,843**	**15,458**

[1]Source: Hawaii Agricultural Statistics.
[2]Yield increase calculated using 1998 as base year.
[3]Calculated as difference in per acre yields between 1998 and years when VR varieties were planted x acres on which VR varieties were planted
[4]Estimated cost of papaya per pound = $0.33

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2. Squash

In the past few years, the situation of biotechnology-derived virus-resistant squash has not changed much in the United States. It is still grown primarily in the fall as a second crop when virus infestations are more prevalent. Apart from few acres of squash planted to biotechnology-derived varieties in states such as New York (Smalling 2004), Michigan (Pearman), New Jersey (Cicalese 2004), and Tennessee (Straw 2004), transgenic squash production in the United States is concentrated mostly in Georgia followed by Florida. Adoption estimates for these two states is presented in Table 2.1.

Biotechnology-derived squash varieties were planted on 2 and 17% of the total planted acreage in Florida (Simmone 2004) and Georgia (Kelley 2004; Langston 2004; Plunkett 2004), respectively, in 2003. Adoption has been lower for several reasons. Similar to years in the past, biotechnology-derived varieties available in 2003 did not carry resistance against papaya ringspot virus, a virus of significance in squash production. Lack of availability of the virus-resistance trait in the myriad squash varieties that are currently under cultivation in the United States is a second factor that limited the widespread adoption of biotechnology-derived varieties. In the last few years, several traditionally-bred varieties with tolerance to key virus problems have been introduced. As a result, these varieties are being used on more acres than the biotechnology-derived varieties. The high seed costs of biotechnology-derived varieties further hindered the adoption of transgenic squash. Seed costs of biotechnology-derived squash varieties are two to four times higher than susceptible conventional varieties. In contrast, traditionally bred varieties that have some virus-tolerance are only 50% more costly than the susceptible ones.

Growers have planted biotechnology-derived squash varieties in 2003 as an insurance against yield losses from fall plantings. The impacts of planting biotechnology-derived virus-resistant squash in Georgia and Florida compared to planting conventional varieties are presented in Table 2.2. It is assumed that squash growers would experience complete crop failure (conventional) and lose their entire fall-planted squash production, as virus infestations are particularly heavy during this season. Therefore, it is assumed that growers that planted biotechnology-derived varieties in 2003 restored their yields to original levels. In aggregate, this would translate to a gained production of 24 million pounds in Georgia and Florida together, which was valued at $6.99 million.

Seed costs of squash varieties have increased considerably in 2003 compared to years before. While conventional squash seed costs were $79 per acre, biotechnology-derived varieties cost $315 (Kelley 2004; Plunkett 2004). As a result, adoption costs were higher in 2003 compared to 2001. Assuming that squash growers in Georgia and Florida paid a premium of $0.43 million in seed costs, the net benefit of planting biotechnology-derived varieties was $6.56 million in 2003.

Table 2.1. Production[1] and adoption of biotechnology-derived squash varieties in 2003.

State	Area harvested	Production	Value	Acreage planted to virus-resistant squash	Adoption
	Acres	Million lb	1000$	Acres	% of total
FL	10,000	140	52,640	200[2]	2
GA	9,500	124.4	34,832	1,615[3]	17
Total	**19,500**	**264.4**	**87,472**	**1,815**	**19**

[1]Source: National Agricultural Statistics Service, Vegetables 2003 Summary.
[2]Source: Simmone 2004.
[3]Source: Kelley 2004; Langston 2004; Plunkett 2004.

Table 2.2 Impacts of biotechnology-derived virus-resistant squash.

State	Acreage planted to virus-resistant squash	Adoption costs[1]	Yield advantage[2]	Gain in value	Net gain
	Acres	$	Million lb	000$	000$
FL	200	47,200	2.8	1,053	1,006
GA	1615	381,140	21.2	5,936	5545
Total	**1,815**	**428,340**	**24.0**	**6,989**	**6,561**

[1]Adoption costs = added seed costs due to biotechnology-derived virus-resistant squash compared to conventional squash. Average seed costs of conventional and biotechnology-derived squash varieties were $79 and 315 per acre, respectively, in 2003. Therefore, adoption costs were $236 per acre.
[2]Yield advantage was calculated based on production and virus-resistant squash adoption information from Table 2.1.

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Herbicide-tolerant crops

Herbicide-tolerant crops (canola, corn, cotton, and soybean) have experienced the most widely used application of agricultural biotechnology in the US. Adoption has increased steadily since they were first commercialized. While soybean has been the most predominantly planted herbicide-tolerant crop, corn has been adopted at a slightly slower pace. With the end of the moratorium and the approval of imports of herbicide-tolerant corn into the European Union, herbicide-tolerant corn adoption is projected to increase significantly in the next few years. Herbicide-tolerant crops are adopted so very enthusiastically as these crops have simplified weed management, thereby increasing the overall crop production efficiency of growers and reducing reliance on intense herbicide use. Following is an update on the economic, agronomic, and environmental impact of herbicide-tolerant crops for the year 2003.

3. Canola

North Dakota planted about 90% of the total US canola acreage in 2003. Planted acreage dropped by 25% in 2003, compared to 2002 and 2001 (Table 3.1). Excessive moisture and cool and damp weather during planting season prevented the usual number of acres from being planted in 2003. Also, higher price for alternative crops such as soybean, peas, and barley is another reason for the decrease in canola acreage in 2003.

Approximately 75% of North Dakota's canola acreage was planted with biotechnology-derived herbicide-tolerant cultivars in 2003 (Coleman 2003; Jenks 2003). This is roughly 7% higher adoption than in 2001 and 2002. Acreage trends since 1999 indicate that the availability of biotechnology-derived varieties is the main reason for the expanded canola acreage in North Dakota.

North Dakota’s canola growers increased their adoption of glufosinate-tolerant (LibertyLink) canola since 2001 while acres planted to glyphosate-tolerant (Roundup Ready) canola have decreased significantly during the same period (Table 3.2). Higher adoption of glufosinate-tolerant canola is due to the awareness and increased knowledge about the trait, availability of the trait in high yielding varieties, and also due to a greater choice of varieties (Coleman 2003).

Comparative analysis of weed management programs in conventional and biotechnology-derived varieties is presented in Table 3.3. On average, canola growers have spent about $38 for weed management in conventional varieties in 2003. In contrast, weed management costs inclusive of technology fee were about $24 and $29 in glyphosate-tolerant and glufosinate-tolerant canola, respectively. Therefore, weed management costs were reduced by 37 and 24%, in glyphosate- and glufosinate-tolerant canola, respectively, compared to conventional varieties in 2003. Weed management costs in herbicide-tolerant canola included costs associated with the herbicide use, herbicide application, seed premium, and technology fee.

Based on the above, it is estimated that North Dakota canola growers have saved a total of $8.98 million on weed management costs by planting herbicide-tolerant varieties in 2003. Similar to years before, canola growers that planted biotechnology-derived varieties were also able to reduce the herbicide use in transgenic canola. Use of herbicide active ingredients was reduced by 0.05 lb and 0.66 lb per acre in glyphosate and glufosinate-tolerant canola, respectively (Table 3.3). Across the state, this represents a reduction of 0.16 million pounds in herbicide use.

In spite of increased adoption of biotechnology-derived canola varieties in 2003, impact estimates reported in this study were lower than the ones noted in the 2002 report. This is mainly due to overall reduction in acreage planted to canola in North Dakota in 2003 and slight modification in the method of impact assessment. Planted herbicide-tolerant canola acreage was 20% lower in 2003 compared to 2001 (910,000 acres in 2001 versus 728,000 acres in 2003) due to an overall reduction in planted canola acreage. Additionally, unlike the 2002 report where impacts for glyphosate-tolerant and glufosinate-tolerant canola were averaged, impacts were calculated separately for glyphosate and glufosinate-tolerant varieties in 2003. Weed management system utilizing glufosinate-tolerant canola is 21% costlier than glyphosate-tolerant canola. Thus, drop in planted canola acreage and costs associated with glufosinate-tolerant canola are the reasons for lower economic impact in 2003, compared to 2001. Higher adoption rate of glufosinate-tolerant canola further reduced the economic impact in 2003.

Biotechnology-derived canola varieties provided effective control of problem weeds at a reduced cost in 2003 (compared to conventional varieties), similar to that noted in 2002 report. Growers have embraced the herbicide-tolerant canola varieties very enthusiastically due to increased ease in controlling problem weeds such as wild mustard, kochia, and Canada thistle (Jenks 2003). Control of these weeds is costly with the available conventional options and necessitates the use of numerous herbicides. Both glyphosate- and glufosinate-tolerant canola varieties provide weed control equivalent to that achieved with conventional herbicides but with the use of one or two herbicides only and at a reduced rate and cheaper cost.

Table 3.1. Canola Production in North Dakota[1]

Year	Acres	Production	Value
	000	million lb	million $
1987	0	0	---
1992	16	22	---
1997	376	427	---
1998	800	1147	117
1999	855	1085	81
2000	1270	1650	108
2001	1300	1799	158
2002	1300	1427	151
2003	970	1354	134

[1]Source: National Agricultural Statistics Service.

Table 3. 2. Adoption of biotechnology-derived herbicide-tolerant (HT) canola in North Dakota[1]

Year	Total HT canola	Roundup Ready canola	Liberty Link canola	HT canola acreage
	---------------- Percent adoption -------------------			000 acres
1999	25	24	1	214
2000	50	48	2	635
2001	70	67	3	910
2002	70	56	14	910
2003	75	55	20	728

[1]Source: Coleman 2003; Jenks, 2003.

Table 3.3. Comparison of weed management costs in various canola systems in North Dakota in 2003[1]

Herbicides	$/lb ai		Lb ai/A		$/A	
Conventional canola						
Ethafluralin (PRE)	9.31		0.94		8.77	
Quizalofop (POST) +	159		0.056		8.75	
Clopyralid (POST) or Ethametsulfuron (POST)	167[1]	661[2]	0.09[1]	0.014[2]	15.00[1]	9.25[2]
Totals			1.09	1.01	$32.52[1]	$26.77[2]
2 applications @ $4.00/application/A					$8.00/A	
Total weed management costs in conventional canola					$40.52[1]	$34.77[2]
Average weed control costs in conventional canola					**$37.65**	
Glyphosate-tolerant canola						
Seed premium					$5.00	
Technology Fee plus 1.0 lb ai/A glyphosate					$15.00	
Application cost (1 application)					$4.00	
Total cost					**$24.00**	
Glufosinate-tolerant canola						
Seed premium					$7.0	
Technology fee					$0.0	
0.37lb ai/A glufosinate ($14.35) + 0.023 lb ai/A quizalofop ($3.59)					$17.94	
Application cost (1 application)					$4.0	
Total cost					**$28.94**	
Average weed control costs in transgenic canola					**$26.47**	

[1]Source: Coleman 2003; Jenks, 2003. For the purpose of this analysis, a single program is selected, as above, from several suggested alternative programs.

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[1] Clopyralid
[2] Ethametsulfuron

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4. Corn

Biotechnology-derived herbicide-tolerant corn adoption was 14% in 2003. This represents a 75% increase in corn acreage on which biotechnology-derived varieties were planted, compared to 2001. Adoption was highest in South Dakota followed by Utah (Table 4.1). Adoption estimates shown in Table 4.1 are based on the USDA's published estimates and estimates provided by the Weed Specialists.

In general, adoption of biotechnology-derived herbicide-tolerant corn is comparatively lower than other herbicide-tolerant crops due to issues surrounding transgenic corn exports to the European Union and non-availability of trait in suitable varieties. Adoption of herbicide-tolerant corn has been highest in states where export issues were trivial due to local consumption. Adoption in Iowa, Illinois, and Indiana, where the majority of corn acreage is concentrated, is low in 2003 similar to 2001, as much of the corn produced in these states is exported. However, after five years of a de facto moratorium of biotechnology-derived crops due to public opposition, the European Commission authorized the import and processing of herbicide-tolerant corn for use in animal feed or industrial purposes in July of 2004. As a result, biotechnology-derived corn acreage is predicted to increase in 2005 in these key corn-producing states. Adoption is projected to increase across the US in the next few years, as the herbicide-tolerant trait will be integrated into varieties suitable for various geographical regions.

Both glyphosate- and glufosinate-tolerant corn varieties were planted in 2003 in the United States. However, adoption of glufosinate-tolerant corn has been low in several states and insignificant in some states compared to glyphosate-tolerant corn. Competitive pricing of glyphosate, good seed distribution systems, and effectiveness of glyphosate in controlling weeds were the major driving forces behind the rapid increase in the adoption of glyphosate-tolerant corn compared to glufosinate-tolerant corn. Glyphosate-tolerant corn acreage is expected to increase further in the next few years once seed companies develop better performing/high yielding herbicide-tolerant corn hybrids stacked with Bt genes. Impacts were calculated for glyphosate-tolerant corn only in view of its dominant market share.

The survey of Corn Weed Specialists has indicated that the niche for glyphosate-tolerant corn in 2003, similar to that noted in years before, was in the control of specific problem weeds such as Johnsongrass, Bermudagrass, crabgrass, burcucumber, bindweed, and herbicide-resistant weeds such as kochia and pigweed. Glyphosate-tolerant corn is an excellent choice in a dryland production system, where crop competes poorly with weeds and weed control from soil-applied herbicides is dependent upon timely rainfall events that are needed for herbicide incorporation. Herbicide carryover concerns have been alleviated since herbicide-tolerant corn use in states such as Pennsylvania where, for example, conventional herbicides used in corn injure alfalfa grown in rotation. In some states such as Delaware, herbicide-tolerant corn was deemed to be a good fit, for the same reason as above, in fields where vegetables are grown.

As noted in the 2002 report, glyphosate-tolerant varieties continued to replace the previously-used herbicide programs in conventional corn in two ways: 1) by facilitating the use of reduced rates of soil-applied preemergence herbicides followed by a postemergence application of glyphosate for problem weed management or 2) substitution of the conventional herbicides used in a total postemergence program with glyphosate. The first substitution scenario was used in the calculation of 2003 impacts, as this is the most widely used weed management program in glyphosate-tolerant corn as cited by Weed Specialists.

Herbicide substitutions facilitated by glyphosate-tolerant corn have resulted in a grower cost saving of $10.15 per acre in 2003, in spite of seed premium costs ($6/A) associated with transgenic varieties (Table 4.2). This estimate is based on the comparison of a standard program of acetochlor + atrazine (premix) applied premergence followed by a postemergence application of primisulfuron + dicamba. Substituting the above program with reduced rates of preemergence herbicides followed by glyphosate applications, corn growers have reduced their overall herbicide use by almost 1.0 pound per acre. This implies an aggregate reduction of 9.43 million lb across the country (Table 4.3). Similarly, weed management costs (seed premium costs included) were reduced by almost 100 million dollars due to the adoption of herbicide-tolerant varieties in 2003. This resulted in 72% more increase in grower returns and 62% more reduction in pesticide use in 2003, compared to the estimates reported in our 2002 report.

Another significant impact of herbicide-tolerant corn has been the increased adoption of no-tillage production practices in the United States. No-till corn acres increased by 9% and 14% in 2000 and 2002, respectively, compared to 1998 (the year when glyphosate-tolerant corn was first introduced for commercial planting) (based on the data from Conservation Technology Information Center's website). No-till corn acreage is expected to go up significantly in 2005 as adoption is expected to increase in principal corn producing states in the midwest. No-till production is beneficial in protecting soil from erosion, increasing soil-organic matter, improving precipitation-storage efficiency, reducing fuel usage, reducing tractor hours, and increasing the number of crop options for dryland rotations. Herbicide-tolerant corn will enable all the above environmental and economic benefits of no-till as its use is compatible with conservation tillage practices.

Table 4.1. Adoption of herbicide-tolerant (HT) corn in the United States in 2003

State	Harvested acres[1]	Adoption of HT corn[2]	HT corn acres	Source
	000A	%	000A	
AZ	45	22	10	Clark
AR	350	17	60	Talbert
CA	130	10	13	Canevari
CO	940	10	94	Westra
CT	17	20	3	Himelstein
DE	160	13	21	VanGessel
ID	50	27	14	Morishita
IL	11050	5	553	USDA[3]
IN	5450	8	436	USDA
IA	12000	12	1440	USDA
KS	2650	22	583	USDA
KY	1090	8	87	Green
MA	15	9	1	Bhowmik
MD	400	22	88	Ritter
MI	2050	17	349	USDA
MN	6650	22	1463	USDA
MO	2800	10	280	USDA
NC	640	10	64	York
ND	1250	24	300	Zollinger
NE	7750	16	1240	USDA
NJ	67	8	5	Majek
NY	460	20	92	Stachowski
OH	3150	3	95	USDA
OK	200	30	60	Medlin
PA	900	11	99	Curran
SD	4100	41	1681	USDA
TN	650	10	65	Hayes
TX	1600	16	256	Baughman
UT	13	38	5	Evans
VA	275	14	39	Hagood
VT	45	8	4	Assigned
WI	2850	11	314	USDA
WY	48	15	7	Miller
Total	**71,759**	**14**	**9,821**	

[1]Source: National Agricultural Statistics Service. 2003 Acreage.
[2]A major percent of this acreage is Glyphosate-tolerant.
[3]Source: National Agricultural Statistics Service. 2004 Prospective Plantings.

Table 4.2. Herbicide substitution analysis in biotechnology-derived herbicide-tolerant (HT) corn

Program	Herbicide rate	Herbicide costs
	lb ai/A	$/A
Conventional corn		
Preemergence		
Premix of Acetochlor + Atrazine[1]	2.61	22.24
followed by		
Postemergence		
Premix of Primisulfuron + Dicamba[2]	0.15	10.10
Total for conventional program	**2.76**	**32.34**
Herbicide-tolerant corn		
Acetochlor/atrazine[1]	1.3	11.12
Followed by		
Glyphosate[3]	0.5	5.07
Seed costs/technology fee		6.0
Total for HT program	**1.8**	**22.19**
Difference		
Conventional to Herbicide Tolerant	**-0.96**	**-10.15**

[1]Trade name: Harness Xtra
[2]Trade name: North Star
[3]Trade name: Roundup

Table 4.3. Impacts of herbicide-tolerant (HT) corn in 2003

State	Harvested acres	Adoption of HT corn	HT corn acres	Reduction in Herbicide Use[1]	Reduction in Production Costs[2]
	000A	%	000A	000lb ai	000$
AR	45	22	10	10	102
AZ	350	17	60	58	609
CA	130	10	13	13	132
CO	940	10	94	90	954
CT	17	20	3	3	31
DE	160	13	21	20	213
ID	50	27	14	13	142
IL	11050	5	553	531	5613
IN	5450	8	436	419	4425
IA	12000	12	1440	1382	14616
KS	2650	22	583	560	5918
KY	1090	8	87	84	883
MA	15	9	1	1	10
MD	400	22	88	85	893
MI	2050	17	349	335	3542
MN	6650	22	1463	1404	14850
MO	2800	10	280	269	2842
NC	640	10	64	61	650
ND	1250	24	300	288	3045
NE	7750	16	1240	1190	12586
NJ	67	8	5	5	51
NY	460	20	92	88	934
OH	3150	3	95	91	964
OK	200	30	60	58	609
PA	900	11	99	95	1005
SD	4100	41	1681	1614	17062
TN	650	10	65	62	660
TX	1600	16	256	246	2598
UT	13	38	5	5	51
VA	275	14	39	37	396
VT	45	8	4	4	41
WI	2850	11	314	301	3187
WY	48	15	7	7	71
Total	**71,759**	**14**	**9,821**	**9,429**	**99,685**

[1]Calculated at 0.96 lb ai/A

[2]Calculated at $10.15/A

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5. Cotton

Weed management in cotton is often complicated due to its slow early growth and sensitivity to herbicides, resulting in limited options when compared with other row crops. As a result, conventional cotton requires a combination of mechanical, manual, and chemical control methods. Weed management has become simpler since the introduction of herbicide-tolerant cotton as few herbicide applications replaced a multitude of control methods. Additionally, early-season crop injury is substantially reduced or eliminated. This has been reflected in the rapid rate of adoption of biotechnology-derived cotton varieties.

Cotton acres planted with biotechnology-derived herbicide-tolerant varieties have increased steadily reaching 74% of the total planted acreage in 2003 (Table 5.1). This accounts for a 25% increase in acreage in 2003 compared to 2001. While acreage planted to bromoxynil-tolerant (BXN) cotton fell by 50% compared to 2001, growers planted 29% more acres to glyphosate-tolerant (RR) cotton during this period. Adoption of BXN cotton was highest in states such as Arkansas and Louisiana where morning glory is a severe problem.

The adoption of bromoxynil-tolerant cotton has slid down in the US in 2003 for various reasons. Deficiencies associated with the BXN system, such as the inability of bromoxynil to control certain broadleaf weeds (example: sicklepod) and its lack of activity on grass weeds, were the main contributing factors for the poor and declining adoption of BXN cotton. Restrictions placed by the Environmental Protection Agency on bromoxynil and lack of availability of stacked varieties (herbicide- and insect-resistance together) further limited its adoption.

Unlike the 2002 report in which herbicide use in conventional cotton and impact assessments due to herbicide-tolerant varieties were evaluated based on the data from National Agricultural Statistics Service, survey responses from Weed Specialists were used in 2004 to obtain the most realistic picture of herbicide programs that were replaced in conventional cotton with glyphosate and bromoxynil-based weed management programs. The names of the cotton Weed Specialists that specified the management programs were listed in the References section. The most widely used weed management program in conventional cotton along with herbicide use rate and cost for each of the producing states is detailed in Table 5.2. Representative weed management programs in RR and BXN cotton in various states is presented in Table

5.3. The impact of biotechnology-derived varieties on herbicide use and weed management costs was calculated based on the information presented in Tables 5.2 and 5.3. Calculations related to impacts on number of herbicide applications, tillage, and hand weeding operations were based on the 2002 report.

Biotechnology-derived herbicide-tolerant varieties have led to a new era for weed management in cotton. The primary advantage of herbicide-tolerant cotton for growers was the increased ease in applying the postemergence over the top herbicides with excellent crop safety. Production costs have also decreased as growers have made fewer trips across fields applying herbicides, made fewer cultivation trips, and performed fewer handweeding operations. Thus, cotton growers have adopted the biotechnology-derived varieties in 2003 as a way to reduce production costs as in the years before.

Similar to 2001, significant reductions have been observed in overall herbicide use, herbicide costs, number of herbicide applications, tillage, and handweeding operations in 2003 (Tables 5.4 and 5.5). Though seed premium and technology fee costs increased crop production expenses (Table 5.6), savings from other weed management costs have more than offset these increased costs. The overall net impact of herbicide-tolerant cotton on US agriculture has been a reduction in production costs of $221 million (Table 5.7) and pesticide use of 9.6 million pounds (Table 5.4). This represents 67% higher net returns in 2003 due to biotechnology-derived cotton varieties compared to 2001. Similarly, herbicide use continued to decrease by 56% in 2003 compared to 2001, mainly due to expanded cotton acreage in 2003.

A weed management system that was available to growers for the first time in 2004 is biotechnology-derived glufosinate-tolerant cotton (trade name: Liberty Link cotton). The Liberty Link Cotton system, developed by Bayer CropScience (formerly Aventis), received full registration in November of 2003. Similar to glyphosate-tolerant cotton, the Liberty Link cotton allows the over the top applications of a non-selective herbicide called glufosinate (trade name: Ignite). Each management system (BXN, Roundup Ready, or Liberty Link) has limitations and careful planning is necessary to alleviate weed escapes. For example, glufosinate provides better control of morningglory but less control of palmer amaranth and grass weeds compared to glyphosate while morning glory control with glyphosate is poor to marginal (based on crop growth stage). Similarly, bromoxynil used in conjunction with BXN cotton has no activity on grasses.

A second-generation glyphosate-tolerant cotton called Roundup Ready Flex cotton is due for commercial release in the next few years. The first generation of glyphosate-tolerant cotton provided very good vegetative tolerance but marginal reproductive tolerance. Thus, any glyphosate applications beyond the 5-leaf stage caused crop loss if the application was not directed. The use of Roundup Ready Flex cotton will extend the window of application for glyphosate and allow the use of its postemergence applications beyond the 5-leaf stage, with the additional benefit of higher use rates. This will provide growers additional flexibility when timely herbicide application is delayed by environmental conditions. Roundup Ready Flex cotton may further increase grower efficiency as herbicide applications are combined with other applications of insecticide, plant growth regulators, and other topical applications. Herbicide-tolerant cotton acreage is expected to increase when Roundup Ready Flex cotton is commercially available.

Significant gains have been noted in the cotton acres planted with no-tillage practices since the introduction of herbicide-tolerant cotton varieties (Table 5.8). The increase in percentage of no-till acreage has been higher in cotton than any other crop. For example, no-till cotton acres were increased by 300% in 2002, while increases were 14 and 45% in corn and soybean, respectively. The above estimates are based on the information compiled by the Conservation Technology Information Center. A study conducted by Doane Marketing Research (2002) for the Cotton Foundation also indicated similar trends in no-till cotton acreage during the period from 1997 to 2002.

Several reasons have been cited for the dramatic increase in no-till cotton acreage. These include adoption of herbicide-tolerant crops which enable the over the top herbicide applications, enhanced awareness in growers of the benefits of conservation tillage practices, increase in fuel prices, access to better no-till equipment, and availability of better herbicides to control weeds in no till fields. However, biotechnology-derived cotton is by far the leading reason for this increase in no-till production practices in cotton. In fact, 79% of the cotton growers surveyed by the Doane Marketing Research have responded that herbicide-tolerant cotton has enabled them to successfully incorporate no-till production into their farming operations. The

Doane study also indicated that conservation tillage practices, such as no-till, result in about $20 savings in fuel and labor per acre. Assuming that the entire no-till cotton acreage in 2002 (1.9 million acres) was planted to herbicide-tolerant varieties, fuel and labor cost savings was estimated to be $38 million.

Table 5.1. Herbicide-tolerant (HT) cotton adoption in 2003[1]

State	Planted acreage[2]	RR[3] adoption	BXN[4] adoption	Total HT acres	RR acres	BXN acres	Total HT acres
	000 acres	%	%	%	000A	000A	000A
Alabama	525	93	1	94	488	5	493
Arizona	218	52	2	54	113	4	117
Arkansas	980	82	5	87	804	49	853
California	700	30	6	36	210	42	252
Florida	94	99	0	99	93	0	93
Georgia	1300	91	0.5	92	1183	7	1190
Louisiana	525	70	4	74	368	21	389
Mississippi	1110	85	1	86	944	11	956
Missouri	400	90	2	92	360	8	368
New Mexico	62	80	0	80	50	0	50
North Carolina	810	87	1	88	705	8	713
Oklahoma	180	95	5	100	171	9	180
South Carolina	220	98	0	98	216	0	216
Tennessee	560	90	0	90	504	0	504
Texas	5620	60	2	62	3372	112	3484
Virginia	89	32	2	34	29	2	31
US	**13,393**	**72**	**2**	**74**	**9,610**	**278**	**9,889**

[1]Source: Estimates provided by Weed Specialists listed in the References section.
[2]Source: National Agricultural Statistics Service. 2003 Acreage.
[3]RR = Biotechnology-derived glyphosate-tolerant or Roundup Ready cotton
[4]BXN = Biotechnology-derived bromoxynil-tolerant cotton

Table 5.2. Typical weed management programs in various cotton growing states of the US in 2003 as suggested by University Weed Specialists across the Cotton Belt[1]

State	Standard weed management program[2] (lbai/A)					Total ai used	Cost of herbicide program
	PPI	PRE	POST	POST-DIR	Post-Dir/Layby	Lb ai/A	$/A
AL		Fluometuron (1.5)	Pyrithiobac (0.05)		Prometryn (0.5) + MSMA (2.0)	4.1	42.1
AZ	Pendimethalin (1.5)		Pyrithiobac (0.11) + MSMA (2.0)	Prometryn (0.5)	Diuron (1.3) + Carfentrazone (0.024)	5.4	54.5
AR	Pendimethalin (0.6)	Fluometuron (0.5)	Pyrithiobac (0.063)	MSMA (2.0)	Prometryn (1.0)	4.2	42.4
CA	Trifluralin (1.0)		Pyrithiobac (0.063)	MSMA (2.0)	Glyphosate (1.0)	6.1	63.9
FL	Pendimethalin (0.75)	Fluometuron (1.5)	Prometryn (0.75) + MSMA (2.0)			5.0	30.0
GA	Pendimethalin (0.75)	Fluometuron (1.0) + Pyrithiobac (0.043)	Trifloxysulfuron (0.0047)		Diuron (1.0) + MSMA (2.0)	4.8	42.7
LA		Pendimethalin (0.75) + fluometuron (0.75)	Pyrithiobac (0.063)	Fluometuron (0.75) + MSMA (2.0)	Diuron (1.0)	5.3	45.4
MS	Pendimethalin (1.0)		Pyrithiobac	Prometryn fb[3] MSMA		4.1	44.9
MO		Fluometuron (1.2)	Clethodim (0.09)	Fluometuron (1.0) + MSMA (1.5)	Diuron (1.0) + MSMA (1.5)	6.3	46.0
NM	Trifluralin (0.5)			Diuron (0.5) + DSMA (3.6)		4.6	13.3
NC	Pendimethalin (0.75)	Fluometuron (1.0)	Pyrithiobac (0.07)	Prometryn (0.75)	MSMA (2.0) + Prometryne (0.5)	5.1	56.6
OK	Pendimethalin (0.63)			Fluometuron (1.0) fb[3] prometryn (0.8)	Diuron (0.75)	3.2	37.0
SC	Pendimethalin (0.83)	Fluometuron (1.0)	Pyrithiobac (0.063)	Prometryn (1.0)	MSMA (2.0)	4.9	44.0
TN	Trifluralin (0.75)	Fluometuron (1.4)	Pyrithiobac (0.06) +Clethodim (0.125)	Diuron (1.0) + MSMA (2.0)		5.3	45.3
TX	Trifluralin (1.0) Pendimethalin (0.75)	Prometryn (1.5) Prometryn (1.0)	Prometryn (1.5) + MSMA (1.0)			3.4	29.4
VA	Pendimethalin (0.63)	Fluometuron (1.0)		Prometryn (0.8)	Diuron (0.75)	3.2	37.0
US average						**4.68**	**42.16**

[1]Specialists that specified the weed management programs for their respective states are listed in the References section.
[2]PPI = preplant incorporated; PRE = preemergence; POST = postemergence; POST-DIR = post-directed
[3]fb=followed by.

Table 5.3a. Typical weed management programs in biotechnology-derived glyphosate-tolerant cotton as suggested by University Weed Specialists across the Cotton Belt [1]

Herbicide program	Herbicide rates (Lb ai/A)	Total lb ai/A	Program costs $/A
1. Trifluralin preemergence followed by glyphosate before 4th leaf followed by glyphosate + diuron as layby treatments	0.75 + 1.0 + 0.5 + 0.75	3.0	21.30
2. Three postemergence applications of glyphosate	1.0 + 1.0 + 1.0	3.0	29.97
3. Two postemergence applications of glyphosate followed by diuron + MSMA as layby treatments	1.0 + 0.5 + 1.0 + 2.0	4.5	22.50
4. Pendimethalin premergence followed by 2 postemergence applications of glyphosate followed by carfentrazone + prometryn as layby treatments	0.75 + 0.75 + 0.75 + 0.024 + 0.5	2.8	24.93
Average		**3.3**	**24.6**

[1]Specialists that specified the weed management programs for their respective states are listed in the References section.

Table 5.3b. Typical weed management programs in biotechnology-derived bromoxynil-tolerant cotton as suggested by University Weed Specialists across the Cotton Belt

Herbicide program	Herbicide rates (Lb ai/A)	Total lb ai/A	Program costs $/A
1. Pendimethalin (premergence) followed by bromoxynil postemergence followed by fluometuron or MSMA post-directed followed by diuron as layby treatment[1]	0.85 + 0.5 + 1 or 2 + 1	3.9	28.8
2. Trifluralin (preplant incorporated) followed by fluometuron (preemergence) followed by bromoxynil (postemergence) followed by diuron (layby)[2]	1.0 + 1.0 + 0.5 + 1.0	3.5	28.8
Average		**3.7**	**28.8**

[1]Source: Miller 2004.
[2]Wilcut et al. 2003.

Table 5.4a. Impacts of glyphosate-tolerant (Roundup Ready/RR) cotton on herbicide use and weed management costs in 2003

State	Planted acreage	RR acres	Conventional program		Per acre impacts on		Aggregate Impacts on	
	000 acres	000A	Herbicide use (lb ai/A)	Program cost ($/A)	Herbicide use[1] (lb ai/A)	Costs[2] ($/A)	Herbicide use (000 lb)	Weed management costs (000$)
AL	525	488	4.1	42.1	-0.8	- 17.5	-390	-8540
AZ	218	113	5.4	54.5	-2.1	-29.9	-237	-3379
AR	980	804	4.2	42.4	-0.9	-17.8	-724	-14311
CA	700	210	6.1	63.9	-2.8	-39.3	-588	-8253
FL	94	93	5.0	30.0	-1.7	-5.4	-158	-502
GA	1300	1183	4.8	42.7	-1.5	-18.1	-1775	-21412
LA	525	368	5.3	45.4	-2.0	-20.8	-736	-7654
MS	1110	944	4.1	44.9	-0.8	-20.3	-755	-19163
MO	400	360	6.3	46.0	-3.0	-21.4	-1080	-7704
NM	62	50	4.6	13.3	-1.3	11.3	-65	565
NC	810	705	5.1	56.6	-1.8	-32.0	-1269	-22560
OK	180	171	3.2	37.0	0.1	-12.4	17	-2120
SC	220	216	4.9	44.0	-1.6	-19.4	-346	-4190
TN	560	504	5.3	45.3	-2.0	-20.7	-1008	-10433
TX	5620	3372	3.4	29.4	-0.1	-4.8	-337	-16186
VA	89	29	3.2	37.0	0.1	-12.4	3	-360
US	**13,393**	**9,610**	**4.68**	**42.16**	**-0.98**	**-15.21**	**-9,448**	**-146,202**

[1]Average herbicide use in RR cotton = 3.3 lb ai/A
[2]Average cost of weed management program in RR cotton = $24.6/A

Table 5.4b. Impacts of bromoxynil-tolerant (BXN) cotton on herbicide use and weed management costs in 2003

State	Planted acreage	BXN acres	Conventional program		Per acre impacts on		Aggregate impacts on	
	000 acres	000 A	Herbicide use (lb ai/A)	Program cost ($/A)	Herbicide use[1] (lb ai/A)	Costs[2] ($/A)	Herbicide use (000 lb)	Weed management costs (000$)
AL	525	5	4.1	42.1	-0.4	-13.3	-2	-67
AZ	218	4	5.4	54.5	-1.7	-25.7	-7	-103
AR	980	49	4.2	42.4	-0.5	-13.6	-25	-666
CA	700	42	6.1	63.9	-2.4	-35.1	-101	-1474
FL	94	0	-	-	-	-	-	-
GA	1300	7	4.8	42.7	-1.1	-13.9	-8	-97
LA	525	21	5.3	45.4	-1.6	-16.6	-34	-349
MS	1110	11	4.1	44.9	-0.4	-16.1	-4	-177
MO	400	8	6.3	46.0	-2.6	-17.2	-21	-138
NM	62	0	-	-	-	-	-	-
NC	810	8	5.1	56.6	-1.4	-27.8	-11	-222
OK	180	9	3.2	37.0	0.5	-8.2	5	-74
SC	220	0	-	-	-	-	-	-
TN	560	0	-	-	-	-	-	-
TX	5620	112	3.4	29.4	0.3	-0.6	34	-67
VA	89	2	3.2	37.0	0.5	-8.2	1	-16
US	**13,393**	**278**	**4.68**	**42.16**	**-0.62**	**-12.4**	**-173**	**-3,450**

[1]Average herbicide use in BXN cotton = 3.7 lb ai/A
[2]Average cost of weed management program in BXN cotton = $28.8/A

Table 5.5. Impact of herbicide-tolerant (HT) cotton on other weed management costs in 2003

State	HT cotton Adoption		Tillage		Herbicide Application		Handweeding		
	%	000A	#/A[1]	(000$)[2]	Trips/A[3]	(000$)[4]	000A[5]	Hours/A[6]	(000$)[7]
AL	94	493	-2.0	-4437	0	0	37	-1.0	-333
AZ	54	117	-2.5	-1316	-1	-468	56	-4.0	-2016
AR	87	853	-1.0	-3839	-2	-6824	392	-2.0	-7056
CA	36	252	-2.5	-2835	-1	-1008	252	-8.0	-18144
FL	99	93	-2.0	-837	-1	-372	0	0	0
GA	92	1190	-1.0	-5355	-1	-4760	65	-2.5	-1463
LA	74	389	-1.0	-1751	-2	-3112	79	-2.5	-1778
MS	86	956	-1.0	-4302	-2	-7648	111	-2.5	-2498
MO	92	368	-1.0	-1656	-1	-1472	80	-2.5	-1800
NM	81	50	-3.0	-675	0	0	0	0	0
NC	88	713	-2.5	-8021	-1	-2852	8	-1.0	-72
OK	100	180	-1.0	-810	-1	-720	36	-6	-1944
SC	98	216	-2.5	-2430	-2	-1728	22	-1.0	-198
TN	90	504	-1.0	-2268	-2	-4032	56	-2.5	-1512
TX	62	3484	-1.0	-15678	-1	-13936	843	-1.5	-15174
VA	34	31	-2.5	-349	-1	-124	0	0	0
US	**73**	**9,889**	**-1.7**	**-56,559**	**-1.4**	**-49,056**	**2037**	**-2.84**	**-49,943**

[1,5,6]Based on the National Center for Food and Agricultural Policy's 2002 report.
[2]Calculated at $4.50/A for each tillage
[3]As suggested by Cotton Weed Specialists
[4]Calculated at $4.00/A for each application
[7]Calculated at $9.0/hr of handweeding times the number of acres on which handweeding is estimated reduced based on 2003 wage rate.

Table 5.6. Adoption costs of herbicide-tolerant (HT) cotton in 2003

	HT cotton acres	Bromoxynil-tolerant cotton		Glyphosate-tolerant cotton		Adoption costs[1]		
	(000A)	Adoption	Acreage	Adoption	Acreage	BXN	RR	Total
		%	(000A)	%	(000A)	(000$)		
AL	493	1	5	93	488	35	4148	4183
AZ	117	2	4	52	113	28	961	989
AR	853	5	49	82	804	343	6834	7177
CA	252	6	42	30	210	630	3150	3780
FL	93	0	0	99	93	0	791	791
GA	1190	0.5	7	91	1183	49	10056	10105
LA	389	4	21	70	368	147	3128	3275
MS	956	1	11	85	944	77	8024	8101
MO	368	2	8	90	360	56	3060	3116
NM	50	0	0	80	50	0	425	425
NC	713	1	8	87	705	56	5993	6049
OK	180	5	9	95	171	63	1454	1517
SC	216	0	0	98	216	0	1836	1836
TN	504	0	0	90	504	0	4284	4284
TX	3484	2	112	60	3372	784	28662	29446
VA	31	2	2	32	29	14	247	261
US	**9,889**	**2**	**278**	**71**	**9,610**	**2,282**	**83,053**	**85,335**

[1]Assumptions on adoption costs based on surveys of Extension Specialists: Technology fee for RR cotton in CA = $15.00; Other states = $8.50; There is no technology fee for BXN cotton; however, the seed costs of BXN cotton are $15 higher in CA and $7.0 higher in other states compared to conventional cotton.

Table 5.7. Summary of weed management cost changes in cotton due to biotechnology-derived herbicide-tolerant varieties in 2003

State	Herbicide Costs	Application Costs	Adoption Costs	Tillage costs	Hand weeding costs	Total
	000$/year					
AL	-8607	0	4183	-4437	-333	-9194
AZ	-3437	-468	989	-1316	-2016	-6248
AR	-14977	-6824	7177	-3839	-7056	-25519
CA	-9727	-1008	3780	-2835	-18144	-27934
FL	-502	-372	791	-837	0	-920
GA	-21509	-4760	10105	-5355	-1462	-22981
LA	-8003	-3112	3275	-1751	-1778	-11369
MS	-19340	-7648	8101	-4302	-2498	-25687
MO	-7842	-1472	3116	-1656	-1800	-9654
NM	-565	0	425	-675	0	-815
NC	-22782	-2852	6049	-8021	-72	-27678
OK	-2194	-720	1517	-810	-1944	-4151
SC	-4190	-1728	1836	-2430	-198	-6710
TN	-10433	-4032	4284	-2268	-1260	-13709
TX	-16253	-13936	29446	-15678	-11389	-27810
VA	-376	-124	261	-349	0	-588
US	**-150,737**	**-49,056**	**85,335**	**-56,559**	**-49,943**	**-220,967**

Table 5.8. Impact of biotechnology-derived herbicide-tolerant varieties on no-till cotton acreage in the United States.

Year	No-till acreage (Million acres)	No-till acreage as a % of total	% Increase in no-till acreage based on 1996
1996	0.51	3.4	-
1997	0.53	3.7	4
1998	0.67	4.9	31
2000	1.35	8	166
2002	2.03	14	300

Source: Conservation Technology Information Center.

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6. Soybean

The adoption track record of biotechnology-derived soybean represents the most rapid case of technology adoption in the history of agriculture. First available for commercial planting in 1996, herbicide-tolerant soybean was planted on 82% of the total US soybean acreage in 2003. This indicates a significant leap from 1996 when only 7% of the acres were planted to herbicide-tolerant soybean.

Herbicide-tolerant varieties were planted on at least 70% of total planted acreage in every soybean producing state in the US in 2003 (Table 6.1). Unlike other herbicide-tolerant crops such as corn, the adoption level is spread fairly uniformly across the major soybean-producing states. South Dakota has the highest adoption rate of 91% followed by the northeastern states such as New York, New Jersey, and West Virginia, which planted 90% of their soybean acreage to biotechnology-derived soybean. States such as Tennessee, Michigan, North Dakota, and Ohio, which had the lowest adoption rates, still have every three out of four acres planted to herbicide-tolerant varieties.

Weed management in soybean production has changed radically since the widespread adoption of glyphosate-tolerant soybean. It has become simpler, more flexible, and less costly with the use of herbicide-tolerant varieties. Simplicity in weed management has resulted from the replacement of multiple treatments of conventional herbicides with one to two treatments of a single broad-spectrum herbicide. This has led to a net reduction in the number of herbicide applications and trips across the field. Herbicide-tolerant soybean added remarkable flexibility in managing weeds as it facilitated herbicide applications at later stages of both crop and weed growth. Soybean growers have clearly realized the benefits from glyphosate-tolerant varieties, as evidenced by increased adoption each year.

Another major reason for the rapid expansion of soybean acreage in the US is the effectiveness of and lower cost associated with the weed management programs in glyphosate-tolerant soybean. Since glyphosate, the herbicide associated with herbicide-tolerant soybean, is competitively priced, soybean weed management has become cheaper than the conventional alternatives. Table 6.2 lists the alternative herbicides used in conventional soybean along with their costs and use rates.

A survey of Weed Specialists was conducted in 2003 to obtain data on the herbicide programs that soybean growers have used in a conventional soybean system to achieve weed control equivalent to that provided by glyphosate in an herbicide-tolerant soybean system if glyphosate-tolerant soybean is not available. Alternative herbicide programs had to rely on herbicides alone without the need for additional cultivation similar to glyphosate-tolerant soybean. The herbicide replacement scenarios provided by the Specialists are denoted in Table 6.3. The surveys indicated that growers had to use 2 to 4 herbicide active ingredients to effectively replace glyphosate. Per acre herbicide use rates and cost estimates of weed management programs in glyphosate-tolerant and conventional soybean systems are presented in Table 6.4.

Table 6.5 represents the production costs associated with glyphosate-tolerant soybean including the seed premium costs ($7/acre). The aggregate impacts due to the replacement of alternative programs with glyphosate-based programs are simulated in Table 6.6. Comparative analyses indicate that on average glyphosate-tolerant soybean programs used 1.05 lb ai/A at a cost of $17.66 per acre in 2003. Alternative programs, on the other hand, used 0.34 lb ai/A (24%) more herbicide active ingredients at an additional cost of $20.04 (53% higher). Overall, American soybean growers saved $1.2 billion on weed management costs due to a switch to glyphosate programs in 2003, in spite of added costs due to seed premiums. This represents a further reduction in weed management costs of 19% than that noted in 2001. Additionally, soybean growers have reduced herbicide use by 0.34 lb per acre or 20 million pounds nationally in 2003.

Average use rates for suggested representative herbicide programs in conventional soybean were 1.39 and 1.52 lb ai/A in 2003 and 2001, respectively. Therefore, herbicide use reduction in 2003 was 30% lower than that calculated in the 2002 report. Weed populations and environmental conditions that influence weed management, management programs used to control weeds, herbicide prices and weed management recommendations are in constant flux; therefore alternative herbicide programs suggested by the Weed Specialists have changed since 2001 and this accounts for the differential. Regardless, herbicide-tolerant soybean accounted for significant reduction in herbicide use in 2003.

A major consequence of the adoption of herbicide-tolerant soybean is an increase in no-till acreage. In 1995, one year before the commercialization of glyphosate-tolerant soybean, approximately 27% of the total full-season soybean acres in the United States were under no-till production (Table 6.7). With the increasing acreage of glyphosate-tolerant soybean, no-till acres also are on the rise. By 2002, about 33% of the total soybean acreage in the United States was planted using no-tillage production practices (Conservation Technology Information Center). This represents a 45% increase in the no-till soybean acreage since the introduction of glyphosate-tolerant soybean and 10% increase since 2000 (Figure 6.1). Surveys by the agencies such as American Soybean Association (2002) and Conservation Technology Information Center showed that growers that are already using no-tillage are leaving more residues on the soil than before following the introduction of glyphosate-tolerant soybean. No-till farming practices aid in decreased soil erosion, dust, and pesticide run-off and in increased soil moisture retention and improved air and water quality.

Table 6.1. Adoption of glyphosate-tolerant (RR) soybean in the United States in 2003

State	Area harvested[1]	RR adoption	RR acres	Source[1, 2]
	000A	%	000A	
AL	175	75	131	Everest
AR	2850	84	2394	NASS
DE	185	80	148	VanGessel
FL	10	87	9	Brecke
GA	170	84	143	Prostko
IL	10550	77	8124	NASS
IN	5350	88	4708	NASS
IA	10350	84	8694	NASS
KS	2600	87	2262	NASS
KY	1100	80	880	Green
LA	870	84	731	Griffin
MD	475	77	366	Ritter
MI	2090	73	1526	NASS
MN	7500	79	5925	NASS
MS	1310	89	1166	NASS
MO	4900	83	4067	NASS
NE	4650	86	3999	NASS
NJ	98	90	88	Majek
NY	142	90	128	Stachowski
NC	1360	85	1156	York
ND	3050	74	2257	NASS
OH	4380	74	3241	NASS
OK	175	77	135	Medlin
PA	365	81	296	Curran
SC	460	87	400	Murdoch
SD	4050	91	3686	NASS
TN	1150	70	805	Hayes
TX	210	85	179	Baughman
VA	510	80	408	Hagood
WV	16	90	14	Chandran
WI	1580	84	1327	NASS
Total	**72,681**	**82**	**59,393**	

[1]Source: National Agricultural Statistics Service. 2003 Acreage.
[2]Affiliations of Weed Specialists that provided the adoption information are listed in the References section.

Table 6.2. Use rates and costs for alternative soybean herbicides in 2003

Trade name	Common Name	Rate (formulated product/A)	Rate (Lb ai/A)	Cost[1] ($/A)
Assure II	Quizalofop	8 oz	0.1	8.73
Authority	Sulfentrazone	4 oz	0.19	6.8
Boundary	Metribuzin + s-Metolachlor	1.25 pt	1.22	12.02
Canopy	Chlorimuron + Metribuzin	4 oz	0.19	7.15
Canopy XL	Sulfentrazone + Chlorimuron	6 oz	0.21	11.96
Classic	Chlorimuron	0.67 oz	0.01	7.9
Dual II Magnum	S-Metolachlor	1.5 pt	1.43	19.77
FirstRate	Cloransulam	0.3 oz	0.016	8.03
Flexstar	Fomesafen	1 pt	0.24	12.44
Fusion	Fluazifop + Fenoxaprop	10 oz	0.21	11.98
Harmony GT	Thifensulfuron	0.5 oz	0.024	5.89
Poast	Sethoxydim	1.0 pt	0.19	8.88
Prowl	Pendimethalin	3.6 pt	1.5	9.49
Pursuit	Imazethapyr	1.44oz	0.063	16.91
Pursuit Plus	Imazethapyr + Pendimethalin	2.5 pt	0.94	15.6
Python	Flumetsulam	1.0 oz	0.053	9.5
Raptor	Imazamox	5 oz	0.039	21.66
Reflex	Fomesafen	1.5 pt	0.375	18
Select	Clethodim	8 oz	0.125	13.97
Sencor	Metribuzin	0.5 lb	0.38	10.4
Squadron	Imazaquin + Pendimethalin	3 pt	0.88	14.07
Storm	Acifluorfen + Bentazon	1.5 pt	0.75	16.89
Synchrony	Chlorimuron + Thifensulfuron	0.5 oz	0.013	5.0
Treflan	Trifluralin	2.0 pt	1.0	6.97
Ultra blazer	Acifluorfen	1.5 pt	0.375	14.51
Roundup UltraMAX	Glyphosate	26 oz	1.0	10.14

[1]Herbicide costs were calculated based on the 2003 Herbicide Price List compiled by Brent Pringnitz of Iowa State University.

Table 6.3. Soybean herbicide program that would provide weed control equivalent to glyphosate[1]

State	Conventional program	Source[2]
AL	Squadron fb[3] Storm + Select	Everest
AR	Squadron fb Storm + Select	Talbert
DE	Canopy XL + Dual II Magnum fb Reflex + Poast (POST program at half rate)	VanGessel
FL	Prowl + Sencor fb Classic	Brecke
GA	Treflan + Sencor fb Classic	Prostko
IL	Boundary fb Flexstar + Fusion	Hager
IN	Dual II Magnum + Pursuit fb Storm	Bauman
IA	Boundary fb Flexstar + Select	Owen
KS	Boundary fb FirstRate + Select-	Peterson
KY	Canopy XL fb Select	Green
LA	Squadron fb Storm + Select	Griffin
MD	Dual II Magnum + Canopy XL	Ritter
MI	Canopy XL fb Flexstar + Assure	Sprague
MN	Boundary fb Fusion + Reflex	Gunsolus
MS	Squadron fb Storm + Select	Poston
MO	Boundary fb Flexstar + Fusion	Kendig
NE	Pursuit Plus + Ultra Blazer	Martin
NJ	Dual II Magnum + Canopy XL	Majek
NY	Dual II Magnum + Python + Sencor	Stachowski
NC	Storm + Select	York
ND	Flexstar + Raptor	Zollinger
OH	Canopy XL fb Flexstar + Select	Loux
OK	Boundary fb Flexstar + Fusion	Medlin
PA	Dual II Magnum + Canopy XL	Curran
SC	Classic fb FirstRate + Assure	Murdoch
SD	Authority fb FirstRate + Select	Wrage
TN	Squadron fb Flexstar + Select	Hayes
TX	Treflan + Prowl fb Ultra Blazer + Select	Baughman
VA	Canopy XL + Dual II Magnum	Hagood
WV	Dual II Magnum + Canopy XL	Chandran
WI	Raptor	Boerboom

[1]Survey respondents specified several alternative programs that would be equally effective. For the purpose of this analysis, a single program is selected as above.
[2]Affiliations of Weed Specialists that provided the above information are listed in the References section.
[3]fb = followed by.

Table 6.4. Comparative herbicide costs and use rates in glyphosate-tolerant and conventional soybean[1]

State	Glyphosate-tolerant soybean		Conventional soybean	
	$/A	lb ai/A	$/A	lb ai/A
AL	17.14	1.0	44.93	1.76
AR	17.14	1.0	44.93	1.76
DE	17.14	1.0	45.17	1.91
FL	17.14	1.0	27.79	1.89
GA	20.09	1.0	25.27	1.39
IL	17.14	1.0	36.44	1.67
IN	17.14	1.0	53.57	2.24
IA	17.14	1.0	38.43	1.59
KS	27.28	2.0	38.43	1.59
KY	17.14	1.0	25.93	0.34
LA	27.28	2.0	44.93	1.76
MD	17.14	1.0	31.73	1.64
MI	17.14	1.0	33.13	0.55
MN	17.14	1.0	42.00	1.81
MS	17.14	1.0	44.93	1.76
MO	17.14	1.0	36.44	1.67
NE	17.14	1.0	30.11	1.30
NJ	17.14	1.0	31.73	1.64
NY	17.14	1.0	39.67	1.86
NC	17.14	1.0	30.86	0.88
ND	17.14	1.0	34.10	0.28
OH	17.14	1.0	38.37	0.58
OK	17.14	1.0	36.44	1.67
PA	17.14	1.0	31.73	1.64
SC	17.14	1.0	24.66	0.13
SD	17.14	1.0	28.80	0.33
TN	17.14	1.0	40.48	1.25
TX	17.14	1.0	44.94	2.99
VA	17.14	1.0	31.73	1.64
WV	17.14	1.0	31.73	1.64
WI	17.14	1.0	21.66	0.04

[1]Roundup Ready program costs = Seed costs + herbicide program costs; Roundup Ready seed premium costs = $7/A; Cost of Roundup UltraMAX = $10.14/lb ai/A. Herbicide applications in glyphosate-tolerant soybean comprised of one timely application of glyphosate at 1 lb ai/A or 2 split applications or glyphosate tankmixed with herbicides such as Classic. Alternative program costs and rates are based on specified product alternatives in Table 6.3 and product costs and rates in Table 6.2.

Table 6.5. Production costs of glyphosate-tolerant (RR) soybean in 2003							
State	**RR soybean acreage**	**Herbicide use**		**Technology Fee[1]**	**Herbicide Cost[2]**	**Total cost**	**Cost/A**
	000A	lb ai/A	000 lb/yr.	000$	000$	$	$/A
AL	131	1.0	131	917	1328	2245	17.14
AR	2394	1.0	2394	16758	24275	41033	17.14
DE	148	1.0	148	1036	1501	2537	17.14
FL	9	1.0	9	63	91	154	17.14
GA	143	1.0	143	1001	1827	2828	20.09
IL	8124	1.0	8124	56868	82377	139245	17.14
IN	4708	1.0	4708	32956	47739	80695	17.14
IA	8694	1.0	8694	60858	88157	149015	17.14
KS	2262	2.0	4524	15834	45873	61707	27.28
KY	880	1.0	880	6160	8923	15083	17.14
LA	731	2.0	1462	5117	14825	19942	27.28
MD	366	1.0	366	2562	3711	6273	17.14
MI	1526	1.0	1526	10682	15474	26156	17.14
MN	5925	1.0	5925	41475	60080	101555	17.14
MS	1166	1.0	1166	8162	11823	19985	17.14
MO	4067	1.0	4067	28469	41240	69708	17.14
NE	3999	1.0	3999	27993	40550	68543	17.14
NJ	88	1.0	88	616	892	1508	17.14
NY	128	1.0	128	896	1298	2194	17.14
NC	1156	1.0	1156	8092	11722	19814	17.14
ND	2257	1.0	2257	15799	22886	38685	17.14
OH	3241	1.0	3241	22687	32864	55551	17.14
OK	135	1.0	135	945	1369	2314	17.14
PA	296	1.0	296	2072	3001	5073	17.14
SC	400	1.0	400	2800	4056	6856	17.14
SD	3686	1.0	3686	25802	37376	63178	17.14
TN	805	1.0	805	5635	8163	13798	17.14
TX	179	1.0	179	1253	1815	3068	17.14
VA	408	1.0	408	2856	4137	6993	17.14
WV	14	1.0	14	98	142	240	17.14
WI	1327	1.0	1327	9289	13456	22745	17.14
Total	**59,393**	**1.05**	**62,386**	**415,751**	**632,971**	**1,048,721**	**17.66**

[1]Calculated at $7/A

[2]Calculated at $10.14/lb ai/A

Table 6.6. Aggregate impacts of glyphosate-tolerant (RR) soybean in 2003					
	RR soybean acreage	**Changes in**			
State		**Production costs**		**Herbicide use**	
	000A	$/A	000$	lb ai/A	000 lb
AL	131	-27.79	-3640	-0.76	-100
AR	2394	-27.79	-66529	-0.76	-1819
DE	148	-28.03	-4148	-0.91	-135
FL	9	-10.65	-96	-0.89	-8
GA	143	-5.18	-741	-0.39	-56
IL	8124	-19.3	-156793	-0.67	-5443
IN	4708	-36.43	-171512	-1.24	-5838
IA	8694	-21.29	-185095	-0.59	-5129
KS	2262	-11.15	-25221	0.41	927
KY	880	-8.79	-7735	0.66	581
LA	731	-17.65	-12902	0.24	175
MD	366	-14.59	-5340	-0.64	-234
MI	1526	-15.99	-24401	0.45	687
MN	5925	-24.86	-147296	-0.81	-4799
MS	1166	-27.79	-32403	-0.76	-886
MO	4067	-19.3	-78493	-0.67	-2725
NE	3999	-12.97	-51867	-0.3	-1200
NJ	88	-14.59	-1284	-0.64	-56
NY	128	-22.53	-2884	-0.86	-110
NC	1156	-13.72	-15860	0.12	139
ND	2257	-16.96	-38279	0.72	1625
OH	3241	-21.23	-68806	0.42	1361
OK	135	-19.3	-2606	-0.67	-90
PA	296	-14.59	-4319	-0.64	-189
SC	400	-7.52	-3008	0.87	348
SD	3686	-11.66	-42979	0.67	2470
TN	805	-23.34	-18789	-0.25	-201
TX	179	-27.8	-4976	-1.99	-356
VA	408	-14.59	-5953	-0.64	-261
WV	14	-14.59	-204	-0.64	-9
WI	1327	-4.52	-5998	0.96	1274
Total	**59,393**	**20.04**	**1,190,158**	**0.34**	**-20,059**

Table 6.7. Trends in no-till full-season soybean acreage in the US[a].

U.S. soybean acreage	1995	1996	1997	1998	2000	2002
	-------------------------------- Million acres --------------------------------------					
Total	58.8	60.6	65.1	66.6	70.0	69.8
No-till	15.9	16.2	17.9	19.0	21.5	23.1
No till as a % of total	27	27	28	29	31	33
% Increase in no-till acreage	-	2	13	20	35	45

[a]Data is not available for 1999.

Source: Conservation Technology Information Center.

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Insect-resistant crops

Insect-resistant (Bt) crops offered numerous advantages to growers in corn and cotton insect pest management. A major benefit of insect-resistant crops has been an increase in crop yields due to enhanced levels of and season-long insect control, which reduce yield losses. Reduction in insecticide use due to Bt crops was also significant based on the 2002 report. Besides the above grower rewards, Bt crops have eliminated the scouting needs for key insect pest problems, improved the timeliness of insect control, eliminated the need for specialized equipment to treat second generation pest problems in the later crop growth stages, and reduced the potential insecticide exposure to applicators. The benefits realized by the growers correlated positively to adoption levels each year, except for the years when predicted target insect infestation levels were lower. Following is a discussion on how insect pest management and crop production were impacted in corn and cotton due to various Bt applications in 2003. Impact estimates from 2003 were compared to 2002 findings and new developments since the 2002 report were discussed.

Corn

The adoption of biotechnology-derived insect-resistant corn reached 29% in 2003, 38% higher than that in 2001. This encompasses the different applications of insect-resistant corn that are currently under commercial cultivation. They include Bt corn resistant to corn borer (trade names: YieldGard Corn Borer and Herculex I), Bt corn resistant to rootworm (trade name – YieldGard Rootworm), and black cutworm (BCW)/fall armyworm (FAW)-resistant corn (trade name – Herculex I). Two genetic transformation events, Bt11 and Mon 810, each with same endotoxin, are currently marketed as YieldGard Corn Borer for resistance against corn borers.

Impacts of Bt corn were analyzed separately based on the target pest it controls. Accordingly, three case studies were developed. They are case study 7, which details impacts due to European corn borer control (both YieldGard Corn Borer and Herculex I included), case study 8, with impacts due to corn rootworm and case study 9, with impacts due to black cutworm and fall armyworm control using Bt varieties (Herculex I alone).

7. Corn borer-resistant corn (IR-1)

Acreage planted to Bt corn resistant to corn borers increased from 8% of the total planted acreage in 1997 to 26 percent in 1999, and then fell to 19 percent in 2000 and 2001, before climbing up to 30 percent in 2003 (Table 7.1). Since the outlook for ECB populations vary each year, fluctuations is expected in future adoption also, similar to that observed in past years.

Herculex I corn accounted for less than 1% of total planted corn acreage and 2% of the total Bt Corn Borer acres planted in 2003 (Table 7.2). Thus, about 98% of total corn borer-resistant Bt corn acreage in 2003 was planted to YieldGard Corn Borer varieties (Bt11 and MON 810 events together).

Bt corn impact estimates for 2003 were calculated using the same methodology used in the 2002 report. Yield impacts due to corn borers were calculated based on the premise that high infestations usually lead to significant yield losses while low infestations do not. Information on corn borer impacts on yield during a ‘low’ and a ‘high’ infestation year were obtained from the 2002 report. This information was the result of a survey of entomologists who specified the number of years during which infestation was high in a 10-year period.

The survey information on corn borer infestation levels for 36 states is shown in Table 7.3. Yield losses in ‘high’ infestation years are typically much higher in the Plains states and in other states where SWCB is the primary pest (CO, KS, OK, KY, TX). It appears that Alabama is the only state where no yield loss typically occurs due to corn borers (all years are classified as ‘low’ during which the average yield loss is zero).

Table 7.4 displays state-by-state estimates of the aggregate impacts on corn production volume, value, and production costs of current adoption of Bt corn during a ‘low’ and’ high’ borer infestation year. These estimates compare impacts of Bt Corn Borer corn adoption to an untreated situation where insecticides are not used for borer control. Growers who planted Bt Corn Borer corn are assumed to gain 100% of the lost yield in this situation. Based on the comparisons to an untreated scenario, total production increase on current Bt Corn Borer corn acreage is estimated to range between 101 and 314 million bushels during a low and high year, respectively. In 2003, Bt Corn Borer technology cost \$9/A and a bushel of corn was valued at \$2.45. Thus, the total value of the increased production is estimated at \$246 and \$770 million in a low and high year, respectively. Subtracting the Bt Corn Borer corn technology costs, the net benefit of Bt corn was estimated at \$54 and \$578 million or \$2.52 and \$27.0 per acre in low and high years, respectively.

Simulations involving the use of insecticides on current Bt Corn Borer corn acreage are presented in Table 7.5. This table shows state-by-state estimates of potential per acre yield and value increase that resulted from using insecticides in a 'high' infestation year. Insecticides provide 80% control of corn borers at an average cost of \$14/A. Insecticide use is simulated for only high infestation years because in no state does insecticide use return more than the \$14/A cost in a low year. Except for Indiana and Mississippi, an insecticide application in a high year has increased total production value in all the states in 2003. Insecticide use analysis in a high year indicated that 7.84 million pounds of insecticide will be used and net income would increase by \$318 million.

The impacts of adoption of Bt Corn Borer corn during a typical year out of a normal 10-year cycle are displayed in Table 7.6. The increase in production volume, value, and costs for a low infestation year are based on use of Bt Corn Borer corn. For high infestation years, the impact of Bt Corn Borer corn is calculated as the difference between volume, value and cost resulting from planting of Bt Corn Borer corn minus the amounts that would result from use of insecticides. Thus in a high year, growers gain an extra 20% yield from Bt Corn Borer corn which they would not gain from using insecticides. Bt Corn Borer corn is credited with lowering production costs during a high infestation year because Bt corn costs less than insecticides.

The production volume, value and the production cost estimates for low and high years are weighted by the number of low and high years expected in a normal 10-year cycle to compute estimates for a typical year. Insecticide use is assumed to occur only in high years. The use of insecticides in a typical year is calculated as the product of the number of high years times the estimated insecticide use in a high year divided by ten. The net value of Bt Corn Borer corn adoption during a typical year out of ten is calculated as the difference between the increase in production value and the increase in production costs.

Based on the planted acreage of 21 million acres in 2003, it was calculated that Bt Corn Borer corn resulted in an increased production of 84 million bushels or 4.7 billion pounds of corn valued at $205 million. The net value of Bt Corn Borer corn was estimated at $147 million. Without the use of Bt Corn Borer corn, approximately 3.6 million pounds of insecticides would be used in a typical year. The above estimates imply that corn growers produced 33% more yields, used 39% less insecticides, increased monetary gains by 18% in 2003, compared to 2001.

Based on 98 and 2% acreage contribution of the YieldGard Corn Borer and Herculex I, respectively, to the total Bt Corn Borer acres planted in 2003, it was determined that the YieldGard Corn Borer and Herculex I corn varieties increased the production volume by 4.6 and 0.09 billion pounds, respectively in 2003. The use of YieldGard Corn Borer corn resulted in a reduction of insecticides used for corn borer control by 3.55 million pounds, while the use of Herculex I resulted in a 0.07million pound reduction.

An indirect benefit noted with YieldGard Corn Borer corn was reduction in the outburst of podworm (referred to as earworm in corn) infestations in rotational crops such as soybean and fall vegetables. Research in the mid-Atlantic region consistently showed that corn earworm suppression in YieldGard Corn Borer corn (especially event Bt 11) is significantly better than the Herculex I corn (Dively 2004). In the mid-Atlantic area, use of YieldGard Corn Borer hybrids reduced the recruitment of earworm moths from corn by 90% or more and delayed emergence by 2 weeks. Thus, the risks of podworm outbreaks in soybean and several vegetable crops during the fall were significantly reduced. This has resulted in substantial indirect savings to farmers.

A stacked-version of YieldGard Corn Borer and YieldGard Rootworm traits has been developed by Monsanto to provide broad-spectrum protection against both corn borers and corn rootworms. The trade name for this stacked product is YieldGard Plus. Registration for YieldGard Plus was obtained in November of 2003. Thus, YieldGard Plus was not planted in 2003 as approvals were obtained after field season ended.

YieldGard Plus received Japanese approval during the summer of 2004 so will be available in 2005.

Table 7.1. Adoption of Bt corn resistant to corn borers in 2003

State	Harvested acres	Adoption of Bt corn[1]	Bt Acreage[1]	Source[2,3]
	000A	%	000A	
AL	210	8	17	Flanders
AR	340	35	119	Studabaker
AZ	22	75	17	Clark
CO	850	35	298	Peairs
CT	30	15	5	Robert Durgy
DE	170	35	60	Whalen
GA	330	9	30	Buntin
IL	10950	24	2628	USDA
IN	5550	9	500	USDA
IA	12100	37	4477	USDA
KS	2700	30	810	USDA
KY	1130	30	339	Bessin
LA	480	37	178	Baldwin
MA	22	5	1	DMR
MD	450	35	158	Dively
MI	2050	21	431	USDA
MN	6550	38	2489	USDA
MS	530	42	223	Parker
MO	2850	33	941	USDA
NE	7650	41	3137	USDA
NJ	67	40	27	Bamka
NM	40	55	22	Carpenter
NY	430	7	30	Smith
NC	660	15	99	VanDuyn
ND	1250	20	250	Glogoza
OH	3200	6	192	USDA
OK	170	65	111	Royer
PA	900	25	225	Calvin
SC	300	37	111	Sheppard
SD	4100	51	2091	USDA
TN	630	22	139	Patrick
TX	1750	27	473	Porter
VA	275	10	28	Youngman
VT	96	16	15	DMR
WV	27	25	7	DMR
WI	2900	23	667	USDA
Total	**71,759**	**30**	**21,345**	

[1]Includes YieldGard Corn Borer and Herculex I corn.
[2]Source: National Agricultural Statistics Service. 2003 Acreage.
[3]Affiliations of Entomologists that provided the adoption information are listed in the References section.

Table 7.2. Adoption of Cry1F (Herculex I) corn in the US in 2003.

State	Adoption (Acres)	Adoption as a % of total planted acres	Adoption as a % of total Bt acres
CO	12881	1.2	4.32
DE	76	0.05	0.13
IA	155721	1.3	3.48
IL	12221	0.11	0.47
IN	2671	0.05	0.53
KS	18824	0.7	2.32
MD	931	0.2	0.59
MI	3570	0.16	0.83
MN	44723	0.6	1.8
MO	60411	2.1	6.42
ND	9959	0.7	3.98
NE	74424	0.92	2.37
NJ	18	0.02	0.07
NM	577	0.44	2.62
NY	177	0.02	0.59
OH	271	0.01	0.14
OK	1240	0.54	1.12
PA	170	0.01	0.08
SD	44569	1.01	2.13
TX	16941	0.93	3.58
VA	122	0.03	0.44
WI	11979	0.32	1.8
WV	36	0.08	0.51
WY	38	0.05	-
Total	**472,512**	**0.6**	**2**

Source: Dow AgroSciences’s 2003 planted acreage information.

Table 7.3. Corn borer incidence and yield impacts[1, 2]

State	Yield loss (bu/A)		Number of years out of 10	
	Low	High	Low	High
AL	0.0	8.0	10	0
AR	5.0	30.0	5	5
AZ	7.0	23.0	5	5
CO	7.0	23.0	5	5
CT	3.0	11.0	5	5
DE	3.9	11.2	5	5
GA	5.0	11.0	9	1
IL	4.0	10.0	5	5
IN	3.0	7.0	6	4
IA	5.0	11.0	5	5
KS	5.0	40.0	5	5
KY	2.2	18.9	5	5
LA	4.0	30.0	7	3
MA	3.0	11.0	5	5
MD	8.0	26.0	6	4
MI	4.0	12.0	3	7
MN	4.5	13.0	6	4
MS	2.5	5.5	5	5
MO	5.0	30.0	5	5
NE	5.0	11.0	7	3
NJ	5.0	9.0	3	7
NM	7.0	23.0	5	5
NY	3.0	11.0	5	5
NC	5.0	11.0	2	8
ND	5.0	11.0	7	3
OH	2.0	12.0	8	2
OK	8.0	18.0	5	5
PA	3.3	11.5	7	3
SC	3.0	10.0	8	2
SD	5.0	15.0	5	5
TN	5.0	11.0	7	3
TX	8.0	40.0	2	8
VA	3.0	15.0	9	1
VT	3.0	11.0	5	5
WV	3.0	15.0	9	1
WI	4.0	12.0	3	7

[1]Includes European and Southwestern corn borer.
[2]Information is based on the National Center for Food and Agricultural Policy's 2002 report.

Table 7.4. Aggregate impacts of Bt Corn Borer corn adoption[1]

State	Bt acreage	Production volume increase				Production value increase[2]				Bt cost[3]	Total net value	
		Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*		*Low*	*High*
	000 A	Bu/A		000 Bu/Year		$/A		000$/Year		000 $/Year	000 $/Year	
AL	17	0.0	8.0	0	136	0.00	19.60	0	333	153	-153	180
AR	119	5.0	30.0	595	3570	12.25	73.50	1458	8747	1071	387	7676
AZ	17	7.0	23.0	119	391	17.15	56.35	292	958	153	139	805
CO	298	7.0	23.0	2,086	6,854	17.15	56.35	5,111	16,792	2,682	2,429	14,110
CT	5	3.0	11.0	15	55	7.35	26.95	37	135	45	-8	90
DE	60	3.9	11.2	234	672	9.56	27.44	573	1,646	540	33	1,106
GA	30	5.0	11.0	150	330	12.25	26.95	368	809	270	98	539
IL	2,628	4.0	10.0	10,512	26,280	9.80	24.50	25,754	64,386	23,652	2,102	40,734
IN	500	3.0	7.0	1,500	3,500	7.35	17.15	3,675	8,575	4,500	-825	4,075
IA	4,477	5.0	11.0	22,385	49,247	12.25	26.95	54,843	120,655	40,293	14,550	80,362
KS	810	5.0	40.0	4,050	32,400	12.25	98.00	9,923	79,380	7,290	2,633	72,090
KY	339	2.2	18.9	746	6,407	5.39	46.31	1,827	15,697	3,051	-1,224	12,646
LA	178	4.0	30.0	712	5,340	9.80	73.50	1,744	13,083	1,602	142	11,481
MA	1	3.0	11.0	3	11	7.35	26.95	7	27	9	-2	18
MD	158	8.0	26.0	1,264	4,108	19.60	63.70	3,097	10,065	1,422	1,675	8,643
MI	431	4.0	12.0	1,724	5,172	9.80	29.40	4,224	12,671	3,879	345	8,792
MN	2,489	4.5	13.0	11,201	32,357	11.03	31.85	27,441	79,275	22,401	5,040	56,874
MS	223	2.5	5.5	558	1,227	6.13	13.48	1,366	3,005	2,007	-641	998
MO	941	5.0	30.0	4,705	28,230	12.25	73.50	11,527	69,164	8,469	3,058	60,695
NE	3,137	5.0	11.0	15,685	34,507	12.25	26.95	38,428	84,542	28,233	10,195	56,309
NJ	27	5.0	9.0	135	243	12.25	22.05	331	595	243	88	352
NM	22	7.0	23.0	154	506	17.15	56.35	377	1,240	198	179	1,042
NY	30	3.0	11.0	90	330	7.35	26.95	221	809	270	-50	539
NC	99	5.0	11.0	495	1,089	12.25	26.95	1,213	2,668	891	322	1,777
ND	250	5.0	11.0	1,250	2,750	12.25	26.95	3,063	6,738	2,250	813	4,488
OH	192	2.0	12.0	384	2,304	4.90	29.40	941	5,645	1,728	-787	3,917
OK	111	8.0	18.0	888	1,998	19.60	44.10	2,176	4,895	999	1,177	3,896
PA	225	3.3	11.5	743	2,588	8.09	28.18	1,819	6,339	2,025	-206	4,314
SC	111	3.0	10.0	333	1,110	7.35	24.50	816	2,720	999	-183	1,721
SD	2,091	5.0	15.0	10,455	31,365	12.25	36.75	25,615	76,844	18,819	6,796	58,025
TN	139	5.0	11.0	695	1,529	12.25	26.95	1,703	3,746	1,251	452	2,495
TX	473	8.0	40.0	3,784	18,920	19.60	98.00	9,271	46,354	4,257	5,014	42,097
VA	28	3.0	15.0	84	420	7.35	36.75	206	1,029	252	-46	777
VT	15	3.0	11.0	45	165	7.35	26.95	110	404	135	-25	269
WV	7	3.0	15.0	21	105	7.35	36.75	51	257	63	-12	194
WI	667	4.0	12.0	2,668	8,004	9.80	29.40	6,537	19,610	6,003	534	13,607
Total	**21345**			**100,466**	**314,219**			**246,143**	**769,838**	**192,105**	**54,038**	**577,733**

[1]Compared to an untreated scenario

[2]Calculated at $2.45/Bushel

[3]Calculated at $9.00/Acre

Table 7.5. Aggregate impacts of simulated insecticide use for corn borer control in a high infestation year

State	Bt acreage	Production increase				Insecticide cost[3]	Total net value		Insecticide use
		Volume		Value					
	1000 A	Bu/A[1]	000 Bu/Yr	$/A[2]	000 $/Yr	000 $/Yr	$/A	000 $/Yr	Lb/Yr[4]
AL	17	6.40	109	15.68	267	238	1.68	29	6,460
AR	119	24.00	2856	58.80	6998	1666	44.80	5332	45,220
AZ	17	18.40	313	45.08	767	238	31.08	529	6,460
CO	298	18.40	5,483	45.08	13,434	4,172	31.08	9,262	113,240
CT	5	8.80	44	21.56	108	70	7.56	38	1,900
DE	60	8.96	538	21.95	1,317	840	7.95	477	22,800
GA	30	8.80	264	21.56	647	420	7.56	227	11,400
IL	2,628	8.00	21,024	19.60	51,509	36,792	5.60	14,717	998,640
IN	500	5.60	2,800	13.72	6,860	0	0.00	0	0
IA	4,477	8.80	39,398	21.56	96,524	62,678	7.56	33,846	1,701,260
KS	810	32.00	25,920	78.40	63,504	11,340	64.40	52,164	307,800
KY	339	15.12	5,126	37.04	12,558	4,746	23.04	7,812	128,820
LA	178	24.00	4,272	58.80	10,466	2,492	44.80	7,974	67,640
MA	1	8.80	9	21.56	22	14	7.56	8	380
MD	158	20.80	3,286	50.96	8,052	2,212	36.96	5,840	60,040
MI	431	9.60	4,138	23.52	10,137	6,034	9.52	4,103	163,780
MN	2,489	10.40	25,886	25.48	63,420	34,846	11.48	28,574	945,820
MS	223	4.40	981	10.78	2,404	0	0.00	0	0
MO	941	24.00	22,584	58.80	55,331	13,174	44.80	42,157	357,580
NE	3,137	8.80	27,606	21.56	67,634	43,918	7.56	23,716	1,192,060
NJ	27	7.20	194	17.64	476	378	3.64	98	10,260
NM	22	18.40	405	45.08	992	308	31.08	684	8,360
NY	30	8.80	264	21.56	647	420	7.56	227	11,400
NC	99	8.80	871	21.56	2,134	1,386	7.56	748	37,620
ND	250	8.80	2,200	21.56	5,390	3,500	7.56	1,890	95,000
OH	192	9.60	1,843	23.52	4,516	2,688	9.52	1,828	72,960
OK	111	14.40	1,598	35.28	3,916	1,554	21.28	2,362	42,180
PA	225	9.20	2,070	22.54	5,072	3,150	8.54	1,922	85,500
SC	111	8.00	888	19.60	2,176	1,554	5.60	622	42,180
SD	2,091	12.00	25,092	29.40	61,475	29,274	15.40	32,201	794,580
TN	139	8.80	1,223	21.56	2,997	1,946	7.56	1,051	52,820
TX	473	32.00	15,136	78.40	37,083	6,622	64.40	30,461	179,740
VA	28	12.00	336	29.40	823	392	15.40	431	10,640
VT	15	8.80	132	21.56	323	210	7.56	113	5,700
WV	7	12.00	84	29.40	206	98	15.40	108	2,660
WI	667	9.60	6,403	23.52	15,688	9,338	9.52	6,350	253,460
Total	**21345**		**251,375**		**615,872**	**288,708**		**317,900**	**7,836,360**

[1]Calculated at 80% of the increase attributed to Bt Corn Borer corn

[2]Calculated at $2.45/Bushel

[3]Calculated at $14/Acre

[4]Calculated at 0.38 lb ai/Acre

Table 7.6. Aggregate impacts of Bt Corn Borer corn adoption: typical year

State	# Years out of 10		Production volume increase			Production value increase			Production cost			Net value	Insecticide use
	Low	High	Low[1]	High[2]	Typical[3]	Low	High	Typical	Low	High	Typical	Typical	Typical
			000 Bu/Year			000 $/Year			000 $/Year			000 $/Year	Lb ai/Year
AL	10	0	0	27	0	0	66	0	153	-85	153	-153	0
AR	5	5	595	714	655	1458	1749	1604	1071	-595	238	1366	22610
AZ	5	5	119	78	99	292	191	242	153	-85	34	208	3230
CO	5	5	2,086	1,371	1,729	5,111	3,358	4,235	2,682	-1490	596	3639	56,620
CT	5	5	15	11	13	37	27	32	45	-25	10	22	950
DE	5	5	234	134	184	573	329	451	540	-300	120	331	11,400
GA	9	1	150	66	142	368	162	347	270	-150	228	119	1,140
IL	5	5	10,512	5,256	7,884	25,754	12,877	19,316	23,652	-13140	5256	14060	499,320
IN	6	4	1,500	700	1,180	3,675	1,715	2,891	4,500	4500	4500	-1609	0
IA	5	5	22,385	9,849	16,117	54,843	24,131	39,487	40,293	-22385	8954	30533	850,630
KS	5	5	4,050	6,480	5,265	9,923	15,876	12,900	7,290	-4050	1620	11280	153,900
KY	5	5	746	1,281	1,014	1,827	3,139	2,483	3,051	-1695	678	1805	64,410
LA	7	3	712	1,068	819	1,744	2,617	2,006	1,602	-890	854	1152	20,292
MA	5	5	3	2	3	7	5	6	9	-5	2	4	190
MD	6	4	1,264	822	1,087	3,097	2,013	2,663	1,422	-790	537	2126	24,016
MI	3	7	1,724	1,034	1,241	4,224	2,534	3,041	3,879	-2155	-345	3386	114,646
MN	6	4	11,201	6,471	9,309	27,441	15,855	22,807	22,401	-12445	8463	14344	378,328
MS	5	5	558	246	402	1,366	601	984	2,007	2007	2007	-1024	0
MO	5	5	4,705	5,646	5,176	11,527	13,833	12,680	8,469	-4705	1882	10798	178,790
NE	7	3	15,685	6,901	13,050	38,428	16,908	31,972	28,233	-15685	15058	16914	357,618
NJ	3	7	135	49	75	331	119	183	243	-135	-22	204	7,182
NM	5	5	154	101	128	377	248	313	198	-110	44	269	4,180
NY	5	5	90	66	78	221	162	192	270	-150	60	132	5,700
NC	2	8	495	218	273	1,213	534	670	891	-495	-218	888	30,096
ND	7	3	1,250	550	1,040	3,063	1,348	2,549	2,250	-1250	1200	1349	28,500
OH	8	2	384	461	399	941	1,129	979	1,728	-960	1190	-212	14,592
OK	5	5	888	400	644	2,176	979	1,578	999	-555	222	1356	21,090
PA	7	3	743	518	676	1,819	1,267	1,653	2,025	-1125	1080	573	25,650
SC	8	2	333	222	311	816	544	762	999	-555	688	73	8,436
SD	5	5	10,455	6,273	8,364	25,615	15,369	20,492	18,819	-10455	4182	16310	397,290
TN	7	3	695	306	578	1,703	749	1,417	1,251	-695	667	750	15,846
TX	2	8	3,784	3,784	3,784	9,271	9,271	9,271	4,257	-2365	-1041	10312	143,792
VA	9	1	84	84	84	206	206	206	252	-140	213	-7	1,064
VT	5	5	45	33	39	110	81	96	135	-75	30	66	2,850
WV	9	1	21	21	21	51	51	51	63	-35	53	-2	266
WI	3	7	2,668	1,601	1,921	6,537	3,922	4,707	6,003	-3335	-534	5240	177,422
Total:			**100,468**	**62,844**	**83,780**	**246,145**	**153,965**	**205,259**	**192,105**	**96,603**	**58,661**	**146,598**	**3,622,046**

[1]Low: Aggregate increase from Bt Corn Borer corn compared to untreated.

[2]High: Difference between aggregate increase from Bt corn and aggregate increase from insecticide use.

[3]Typical: Low and High aggregate values weighted by the number of low and high years.

[4]Insecticide use: Use in high year weighted by the number of high years divided by 10.

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8. Rootworm-resistant corn (IR-2)

Corn rootworm is an economically important insect pest of corn, costing growers millions of dollars each year in insecticides and lost crop yields. Excellent rootworm-control products have fallen by the wayside as corn rootworm has developed resistance to various insecticides. In addition to insecticide use, crop rotation is the most widely used cultural method to manage corn rootworms. Since a variant of the corn rootworm became the first pest ever to develop a way of foiling crop rotations, corn growers have been seeking a breakthrough in corn rootworm management. Biotechnology was deemed to offer exciting new possibilities and was expected to mark a new era for corn rootworm management in the United States.

The Environment Protection Agency approved biotechnology-derived rootworm-resistant corn (event MON863, YieldGard Rootworm^{TM}) developed by Monsanto in February of 2003, just in time for the planting season. Monsanto's MON 863 event produces a Cry3Bb1 protein which specifically targets the midgut lining of larval corn rootworms. Another event developed by Dow AgroSciences, Pioneer Hi-Bred, and Mycogen Seeds is still pending registration. The toxin in the Dow AgroSciences' product is a binary protein (Cry34Ab1 and Cry35AB1) produced by the PS-149-B1 strain of *Bacillus thuringiensis*.

A stacked-version of YieldGard Corn Borer and YieldGard Rootworm traits has been developed by Monsanto to provide broad-spectrum protection against both corn borers and corn rootworms (trade name: YieldGard Plus). Monsanto obtained the registration for YieldGard Plus in November of 2003. Thus, YieldGard Plus was not planted in 2003 as approvals were obtained after field season ended. YieldGard Plus received Japanese approval during the summer of 2004 so will be available in 2005.

Biotechnology-derived corn rootworm-resistant hybrids (YieldGard Rootworm corn) were planted on about 0.5% of the total planted corn acreage in 2003 (Table 8.1). Seed supply was limited in 2003, due to it being an introductory year. Iowa, Nebraska, and Illinois planted 43, 15, and 10% of the total seed supply in 2003. Adoption is expected to increase rapidly in next few years, as more seed becomes available to growers. Planting data from 2004 indicated that growers have already planted YieldGard Rootworm corn on 3 million acres, a ten-fold increase compared with 2003.

Adoption was highest in Iowa (1.2% of the total planted acreage) followed by Michigan (0.9%) and Nebraska (0.7%) in 2003.

YieldGard Rootworm corn hybrids offered excellent root protection in the 2002 and 2003 university trials. The consistency of YieldGard Rootworm corn hybrids was 100% whereas insecticide use was only 63% consistent in protecting roots against economic damage based on these trials (Rice 2004). However, information is sparse on yield response of YieldGard Rootworm corn hybrids. Most of the field research with Bt Rootworm corn hybrids in 2003 has focused on root injury. However, limited information that is available indicates that Bt Rootworm hybrids yielded 1.5 to 4.5% higher relative to a soil insecticide treatment in Iowa (Rice 2004). In Wisconsin, yield from Bt Rootworm corn hybrids was higher than the trial average in 40% of the experiments where soil insecticides were applied at planting in 2003 (Lauer 2004). For analytical purposes, a 3% improvement in yield has been assumed due to Bt Rootworm corn hybrids in 2003.

Table 8.2 depicts the impacts of YieldGard Rootworm corn on crop production and crop value in 2003. Based on 3% yield gain due to Bt Rootworm technology, corn growers across the US were able to improve their yields by 86 million pounds in 2003. The value of this gained production was $3.77 million.

Corn growers use both seed treatments (insecticides such as thiamethoxam, clothianidin, imidacloprid, and tefluthrin) and soil insecticides (bifenthrin, chlorethoxyfos, chlopyriphos, ethoprop, fipronil, phorate, tefluthrin , and tebupirimphos + cyfluthrin) for corn rootworm larval control in conventional corn. Seed treatments for rootworm control are a relatively new technology (first marketed in 1999). The insecticides most commonly applied for control of corn rootworms were chlorpyriphos and tefluthrin.

A survey of corn entomologists indicated that on average growers applied 0.66lb ai/A of insecticides at a cost of $13/A in 2003 (Burger 2004; Olson 2004; Parker 2004; Peairs 2004; Sloderbeck 2004). Based on this assumption, it was calculated that growers that planted Bt Rootworm corn hybrids have applied 225,000 pounds fewer insecticides in 2003.

Corn growers have spent $17/A to gain access to the rootworm technology in 2003 (Reiss 2004). Thus, adoption costs, based on Bt Rootworm corn acreage in 2003, were $5.8 million. Overall, net economic gain from rootworm technology was $2.4 million in 2003, despite the added adoption costs and planted acreage of only 0.5% of the total.

In spite of the use of YieldGard Rootworm corn hybrids, insecticide treatments may still be needed to lessen the risk of damage caused by secondary pests, especially if their frequency of occurrence continues to increase. This may either be in the form of current soil insecticides applied at planting, or in the form of an insecticide treatment coating the seed. New seed-coated insecticides that offer protection against corn rootworms such as thiamethoxam (trade name: Crusier) and clothianidin (trade name: Poncho) were introduced in 2003 offering growers more options for management of insect pests in corn. Bt Rootworm corn seed coated with insecticides for protection against secondary pests may increase the adoption of biotechnology-derived corn rootworm-resistant hybrids. If the cost and effectiveness of insecticide-treated YieldGard Rootworm corn seed is still comparable to the current cost of a soil insecticide application, the convenience of having soil insect protection in and on the seed without having to apply a soil insecticide at planting will increase further adoption of YieldGard Rootworm corn hybrids in the United States.

Table 8.1. Adoption of YieldGard Rootworm corn in 2003

State	Harvested Acres[1]	Adoption of YieldGard Rootworm corn[2]	YieldGard Rootworm corn acreage
	000A	%	Acres
Colorado	850	0.4	3211
Illinois	10950	0.4	40000
Indiana	5550	0.6	35179
Iowa	12100	1.2	144743
Kansas	2700	0.4	10056
Michigan	2050	0.9	18416
Minnesota	6550	0.3	18987
Missouri	2850	0.2	5145
Nebraska	7650	0.7	51117
Ohio	3200	0.1	1821
South Dakota	4100	0.03	1379
Wisconsin	2900	0.4	10185
Total		**0.5**	**340,239**

[1]National Agricultural Statistics Service. 2003 Acreage.
[2]Percent adoption of YieldGard Rootworm corn is based on DMR's 2003 estimates.

Table 8.2. Impacts of YieldGard Rootworm corn on crop yield and value in 2003

State	Corn yield in 2003	Yield gain due to YieldGard Rootworm corn [1]		Value of gained production[2]	YieldGard Rootworm corn acreage	Yield gain due to YieldGard Rootworm corn	Value of gained production from Bt acreage
	Bu/A	Bu/A	Lb/A	$/A	Acres	Lb	$
Colorado	135	4.1	230	10.12	3,211	738,530	32,495
Illinois	164	4.9	274	12.06	40,000	10,960,000	482,400
Indiana	146	4.4	246	10.82	35,179	8,654,034	380,637
Iowa	157	4.7	263	11.57	144,743	38,067,409	1,674,677
Kansas	120	3.6	202	8.88	10,056	2,031,312	89,297
Michigan	126	3.8	213	9.37	18,416	3,922,608	172,558
Minnesota	146	4.4	246	10.82	18,987	4,670,802	205,439
Missouri	108	3.2	179	7.88	5,145	920,955	40,543
Nebraska	146	4.4	246	10.82	51,117	12,574,782	553,086
Ohio	156	4.7	263	11.57	1,821	478,923	21,069
South Dakota	111	3.3	185	8.14	1,379	255,115	11,225
Wisconsin	129	3.9	218	9.59	10,185	2,220,330	97,674
Total/Average			**252**	**11.06**	**340,239**	**85,494,800**	**3,761,100**

[1]A 3% yield gain was assumed due to planting of YieldGard Rootworm corn.
[2]Price of corn in 2003 = $2.45/bushel or 4.4 cents/lb.

Table 8.3. Overall impacts of YieldGard Rootworm corn in 2003

State	Yield-Gard Root-worm corn acres	Gain in crop yield[1]	Gain in crop value [1]	Adoption costs[2]	Reduction in insecticide costs[3]	Net economic impact	Reduction in insecticide use[4]
	Acres	Lb	$	$	$	$	lb ai/yr
Colorado	3,211	738,530	32,495	54,587	41,743	19,651	2,119
Illinois	40,000	10,960,000	482,400	680,000	520,000	322,400	26,400
Indiana	35,179	8,654,034	380,637	598,043	457,327	239,921	23,218
Iowa	144,743	38,067,409	1,674,677	2,460,631	1,881,659	1,095,705	95,530
Kansas	10,056	2,031,312	89,297	170,952	130,728	49,073	6,637
Michigan	18,416	3,922,608	172,558	313,072	239,408	98,894	12,155
Minnesota	18,987	4,670,802	205,439	322,779	246,831	129,491	12,531
Missouri	5,145	920,955	40,543	87,465	66,885	19,963	3,396
Nebraska	51,117	12,574,782	553,086	868,989	664,521	348,618	33,737
Ohio	1,821	478,923	21,069	30,957	23,673	13,785	1,202
South Dakota	1,379	255,115	11,225	23,443	17,927	5,709	910
Wisconsin	10,185	2,220,330	97,674	173,145	132,405	56,934	6,722
Total	**340,239**	**85,494,800**	**3,761,100**	**5,784,063**	**4,423,107**	**2,400,144**	**224,557**

[1]Calculations on crop yield and value were detailed in Table 8.2.
[2]Adoption costs of Yieldgard Rootworm corn in 2003 = $17/A.
[3]Average cost of insecticides used for rootworm control = $13/A.
[4]Average insecticide use rate for rootworm control = 0.66 lb ai/A.

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9. Corn borer/cutworm/armyworm-resistant corn (IR-3)

A biotechnology-derived insect-resistance trait that was in its first season of commercial availability in 2003 was Bt corn marketed under the trade name Herculex I. Dow AgroSciences, in cooperation with Pioneer Hi-Bred International, Inc., developed this corn. American corn growers gained access to the Herculex I corn in the 2003 planting season even though regulatory clearances were obtained in 2001. Herculex I received United States Department of Agriculture's approval in June 2001 (USDA 2001). A preliminary approval was granted by the Environmental Protection Agency in May 2001, and re-registration was granted in late 2001 (US-EPA 2001). Food and Drug Administration consultation was finalized in May 2001 (US-FDA 2001). Dow AgroSciences committed to not commercialize Herculex I corn until food, feed and import approval is granted by Japan, one of the export markets for US corn. Herculex I received full approval in Japan in mid 2002 (Dow AgroSciences News Center 2002).

Herculex I expresses the Cry1F insecticidal protein, a different protein from the one expressed by the YieldGard Corn Borer corn (Cry1Ab). The Herculex I offers similar protection against corn borers (European and southwestern) and corn earworm and also expands protection to include black cutworm and fall armyworm (Babcock and Bing 2001).

With a 2003 registration amendment by the Environmental Protection Agency, Herculex I is now approved to provide built-in protection against western bean cutworm, an increasingly problematic pest in the last few years (Rice 2003). Once found primarily in Colorado and other western states, this highly damaging pest now infests corn in Iowa, Kansas, Minnesota, Nebraska and South Dakota, and continued marching eastward lately.

The adoption of Herculex I corn accounted for only 0.6% of the total planted corn in 2003 due to limited seed supplies (Table 9.1). This is equivalent to 2% of the total planted Bt crop acreage in the US in 2003.

The resulting impacts due to cutworm and armyworm control by Herculex I trait is presented in Table 9.2. Impacts are estimated to be incremental to those provided due to corn borer control (Case study 7). Impacts of Herculex I corn on black cutworm control were estimated for states where economically damaging levels of infestation occurs. Fall armyworm impacts were not assessed in this case study as adoption of Herculex I in the southern states such as Georgia, where losses due to the pest are significant, was negligible.

In order to assess the incremental value of Herculex I corn on black cutworm control, several assumptions were made. It was assumed that impacts would vary depending on the level of pest management. Growers will achieve increased yields on infested acreage that is not currently treated with insecticides. On acreage that is currently treated, it is assumed that the impact would be a reduction in insecticide use and related costs.

Previous research has indicated that black cutworm infestations result in a yield loss of 12% when left untreated and insecticide use will narrow yield loss by 2% (Santos and Shields 1998). Based on these findings, it was assumed that Herculex I corn would improve corn yields by 10% due to improved cutworm control.

It was assumed that Cry1F protein is as effective as the currently available foliar insecticides for black cutworm. Survey of corn entomologists indicated that the cost of an insecticide treatment for black cutworm varies between $5 and $16 per acre, depending on the product and rate used (Baldwin 2004; Bessin 2004; Buntin 2004; Dively 2004; Flanders 2004; Nuessly 2004; Parker 2004). A $10 per acre treatment cost was assumed. The insecticide use reduction is calculated assuming current application rates of 0.15 lb/acre, the average of application rates for recommended foliar insecticides used for cutworm control.

It was also assumed that adoption costs for Herculex I for black cutworm control in 2003 to be $1/acre. Clearly, if a grower switches from YieldGard Corn Borer corn to Herculex I corn for black cutworm control, the additional cost will be the difference in the technology fees between the two products ($9 for YieldGard Corn Borer versus $10 for Herculex I).

It is estimated that the value of increased production from planting Herculex I on acreage infested with black cutworm in 2003 was worth approximately $7.3 million/year. On acreage that is currently treated, growers have saved $3 million on insecticides. Net monetary gain was $10 million/yr.

Table 9.1. Adoption of Cry1F (Herculex I) corn in the US in 2003.

State	Adoption[1] (Acres)	Adoption as a % of total planted acres[2]	Adoption as a % of total Bt acres
CO	12881	1.2	4.32
DE	76	0.05	0.13
IA	155721	1.3	3.48
IL	12221	0.11	0.47
IN	2671	0.05	0.53
KS	18824	0.7	2.32
MD	931	0.2	0.59
MI	3570	0.16	0.83
MN	44723	0.6	1.8
MO	60411	2.1	6.42
ND	9959	0.7	3.98
NE	74424	0.92	2.37
NJ	18	0.02	0.07
NM	577	0.44	2.62
NY	177	0.02	0.59
OH	271	0.01	0.14
OK	1240	0.54	1.12
PA	170	0.01	0.08
SD	44569	1.01	2.13
TX	16941	0.93	3.58
VA	122	0.03	0.44
WI	11979	0.32	1.8
WV	36	0.08	0.51
WY	38	0.05	-
Total	**472,512**	**0.6**	**2**

[1]Estimates from Dow AgroSciences

[2]Calculated based on the National Agricultural Statistics Service: 2003 Acreage data.

Table 9.2. Impacts of Cry1F (Herculex I) corn due to black cutworm control in 2003 in selected states with economically damaging levels.

State	Adoption[1]	Production gain on untreated acres[2]	Value of gained production[3]	Reduction in insecticide use[4]	Reduction in insecticide costs[5]	Adoption costs[6]	Net impact
	Acres	000Bu	000$	Lb ai/A	000$	000$	000$
IA	155721	2476	6190	23358	1557	156	7591
IL	12221	0	0	1833	122	12	110
IN	2671	0	0	401	27	3	24
KS	18824	232	580	2824	188	19	749
MO	60411	0	0	9062	604	60	544
OH	271	4	10	41	3	0.3	13
TX	16941	188	470	2541	169	17	622
PA	170	2	5	26	2	0.2	7
	267,230	**2,902**	**7,255**	**40,086**	**2,672**	**268**	**9,660**

[1]Adoption was negligible in southern states such as LA, MS, and KY.
[2]A 10% yield increase is assumed on acres untreated currently.
[3]Yield increase times average price per bushel (=$2.50)
[4]Calculated at 0.15lb ai/A
[5]Calculated at $10/A
[6]Seed premium costs for Herculex I corn = $10/A. Since seed premium costs for YieldGard Corn Borer corn that provides control of borers is 9$, it is assumed that additional costs that the growers would have to pay for black cutworm and fall armyworm control would be $1/acre.

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10. Bollworm and budworm-resistant cotton (IR - I or Bt - I or Bollgard I)

Bt cotton continued to provide the arsenal for the control of the key lepidopteran pest problems (bollworms and budworms) in its production in 2003 as in the years since its first commercial planting in 1996. Across the cotton growing states, adoption averaged 46% in 2003 (Table 10.1). This represents an increase of approximately 19% in 2003, compared to 2001. Growth in the adoption of Bt-I cotton reflects the confidence of growers in biotechnology-derived varieties to improve crop yields and reduce production costs.

Hudson et al. (2003) calculated the economic comparisons of Bt and non-Bt cotton varieties based on multi-location and multi-year trials. These comparisons have included yields (volume and value), insect control costs, number of insecticide applications and changes in net revenue. State-by-state per-acre impact estimates for Bt cotton provided by Hudson et al. served as the basis for the 2003 impact assessment of Bt - I cotton in this report. Per-acre estimates were used to calculate aggregate impact estimates by state and are presented in Table 10.2. For California and Missouri, for which state-specific data could not be located, aggregate estimates were calculated based on a neighboring state.

Analysis indicated that Bt cotton was associated with significantly higher yields and reduced pesticide use for all the states in 2003. Production costs increased in 10 of the 16 cotton-producing states due to added costs associated with the technology fee. However, increased returns due to improved yields offset the increased production costs in all these states. In aggregate, Bt - I cotton produced 363 million more pounds of cotton lint valued at $182 million, reduced production costs by $9.5 million, and reduced insecticide use by 3.2 million pounds compared to conventional cotton. This represents 96% higher increase in lint production, 85% higher increase in net value, and 71% more reduction in insecticide use in 2003 compared to the estimates calculated in the 2002 report for 2001 (see www.ncfap.org). Averaged across various cotton growing states, insecticide applications were reduced by at least two, which translated to time, labor, and energy savings for cotton growers.

The need for supplemental remedial insecticide applications to fully control pests such as cotton bollworm has been a minor drawback for Bollgard I cotton. Bollgard I cotton has been consistently efficacious on tobacco budworm and pink bollworm. However Bollgard I provides only suppression of cotton bollworm, loopers, armyworms, and other minor lepidopteran cotton pests. As a result, growers may have to spray for these pest problems under certain circumstances, especially during bloom stage.

In 2003, about 74% of the US cotton crop was infested with the bollworm/budworm pest complex of which 86% were bollworms (Williams 2003). Bt cotton acreage sprayed for bollworms is presented in Table 10.3. Approximately 52% of the Bollgard cotton acreage was sprayed with insecticide applications to control bollworms in 2003 (Williams 2003). Number of insecticide applications for bollworm control in Bt cotton averaged 0.54 per acre in 2003. A second version of Bt cotton (Bollgard II) with enhanced resistance to key cotton pest problems was developed by Monsanto and was planted on a limited commercial scale in 2003. Bollgard II cotton will eliminate the need for additional insecticide sprays for bollworm control. The impact of Bollgard II on pest management in 2003 is presented in the next case study (Case study 11).

Table 10.1. Adoption of Bollgard I cotton in the US in 2003

State	Planted acreage[1]	Bollgard I cotton adoption[2]	
	000 acres	% of total	000 acres
Alabama	525	62	326
Arizona	218	77	168
Arkansas	980	82	804
California	700	21	147
Florida	94	82	77
Georgia	1300	64	832
Louisiana	525	74	389
Mississippi	1110	85	944
Missouri	400	66	264
New Mexico	62	35	22
North Carolina	810	72	583
Oklahoma	180	59	106
South Carolina	220	23	51
Tennessee	560	91	510
Texas	5620	15	843
Virginia	89	71	63
US	**13,393**	**46**	**6,129**

[1]National Agricultural Statistics Service: 2003 Acreage.
[2]Based on the cotton planting data from the US Agricultural Marketing Service.

Table 10.2. Aggregate impact of Bollgard I cotton in 2003[1]

State	Production						
	Bt Acres (000)	Volume (000lb)	Value (000$)	Costs (000$)	Net economic value (000$)	Change in insecticide use (Lb ai/yr)[4]	Applications (#/A)
Alabama	326	9128	4564	1255	3309	-163000	-2.0
Arizona[2]	168	11760	5880	247	5633	-84000	-2.0
Arkansas	804	62712	31356	-6038	37394	-462300	-2.3
California[2]	147	10290	5145	216	4929	-73500	-2.0
Florida	77	2156	1078	297	781	-38500	-2.0
Georgia	832	23296	11648	3203	8445	-416000	-2.0
Louisiana	389	26063	13032	-2322	15354	-223675	-2.3
Mississippi	944	63248	31624	-5636	37260	-542800	-2.3
Missouri	264	20592	10296	-1983	12279	-151800	-2.3
ew Mexico[2]	22	1540	770	32	738	-11000	-2.0
rth Carolina	583	20988	10494	3883	6611	-218625	-1.5
Oklahoma[3]	106	8268	4134	-796	4930	-60950	-2.3
uth Carolina	51	1836	918	340	578	-19125	-1.5
Tennessee	510	39780	19890	-3830	23720	-293250	-2.3
Texas	843	59010	29505	1239	28266	-421500	-2.0
Virginia	63	2268	1134	420	714	-23625	-1.5
Total	6,129	362,935	181,468	-9,473	190,941	-3,203,650	-2.0

[1]Calculated based on Hudson et al., 2003.
[2]Calculated with per-acre impact estimates for Texas.
[3]Calculated with per-acre estimates for Arkansas, Missouri, and Tennessee.
[4]Calculated at 0.25 lb ai/A/application based on average insecticide use rate in conventional cotton.

Table 10.3. Bollgard I cotton acreage sprayed for bollworm control in 2003[1].

State	Acreage sprayed for bollworm control
AL	55,000
AZ	141
AR	755,000
CA	0
FL	100
GA	350,000
KS	0
LA	327,600
MS	570,000
MO	189,120
NM	0
NC	402,500
OK	24,900
SC	0
TN	5,000
TX	68,018
VA	60,000
Total	3,147,379

[1]Williams 2003.

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11. Cotton (IR -II/Bt - II/BollGard II)

A new development in 2003 in cotton insect management was the commercialization of Bollgard II cotton. Bollgard II cotton received final regulatory clearance in December 2002 facilitating its commercial launch in 2003, in time for the 2003 planting season (Mills and Shappley 2004).

Bollgard II is the second generation of insect-protected cotton developed by Monsanto. Bollgard II offers enhanced protection against cotton bollworm, fall armyworm, beet armyworm, and soybean looper while maintaining control of tobacco budworm and pink bollworm (similar to that provided by the Bollgard I). Bollgard II contains two Bt genes, Cry1Ac and Cry2Ab, compared to the single gene (Cry1Ac) in its predecessor, Bollgard I. The presence of two genes in Bollgard II provides cotton growers with a broader spectrum of insect control, enhanced control of certain pests, and increased defense against the development of insect resistance. Presence of the Cry2Ab gene in addition to the Cry1Ac in Bollgard II cotton provides a second, independent high insecticide dose against the key cotton pests. Therefore, Bollgard II is viewed as an important new element in the resistance management of cotton insect pests.

Dow AgroSciences used a similar gene stacking or gene combination strategy in the development of their Bt cotton (trade name: WideStrike) with efficacy against a wide range of caterpillar pests. The WideStrike cotton, which expresses Cry1Ac and Cry1F proteins, offers season-long protection against a broad- spectrum of cotton pests such as cotton bollworm, tobacco budworm, pink bollworm, beet armyworm, fall armyworm, yellow-striped armyworm, cabbage looper and soybean looper (Dow Agrosciences 2003). The USDA’s Animal and Plant Health Inspection Service registered WideStrike cotton in mid 2004 (AgServ 2004). While pre-market consultation with the Food and Drug Administration is still pending, approval from the Environmental Protection Agency is expected by the end of 2004.

Another Bt cotton that is anticipated to be available for cotton growers in the near future is Vip cotton developed by Syngenta. Vip cotton contains a vegetative insecticidal protein (Vip) derived from the *Bacillus thuringiensis* bacterium (Syngenta 2003). Field tests have indicated that Vip protein provides broad spectrum, full season control of major lepidopteran and spodopteran pests. Unlike Bt cotton, which is an endotoxin, Vip protein, is an exotoxin and thus differs structurally, functionally, and biochemically from Cry protein. As a result, the mode of action of Vip protein is different than Cry protein. The availability of WideStrike and Vip cottons along with Bollgard II could aid in bolstering insect resistance management in cotton due to their diverse modes of action in addition to providing growers with a wide choice of pest management tools.

Bollgard II cotton was planted on a limited basis on about 31,000 acres in the introductory year of 2003 (Table 11.1). The mid-south region that includes Arkansas, Tennessee, Missouri, Mississippi, and Louisiana planted about 50% of the total planted acreage in the United States (Mills and Shappley 2004). Adoption across the country represents only 0.24% of the total planted cotton acreage. However, adoption is expected to increase significantly in 2004 and years thereafter. Bollgard I cotton will be phased out of commercial production in future in the US once Bollgard II seed supply is abundant to meet the growers planting needs.

Several multi-year and multi-site studies have been conducted in the cotton-belt to assess the agronomic and yield performance of Bollgard II cotton in comparison to Bollgard (Baker et al. 2004; Mills and Shappely 2004; Mullins and Hudson 2004). Research findings indicated that Bollgard II enhanced insecticidal activity against pests on which Bollgard was weakest. The enhanced control with the Bollgard II of the principal cotton bollworm/budworm complex and control of secondary lepidopteran insect pests (such as the armyworms and loopers) has resulted in increased yield and reduced insecticide use in the US.

Multi-location studies conducted by Mullins and Hudson (2004) in 2003 were the basis for the impact assessments of Bollgard II in this report. These studies have indicated that Bollgard II cotton averaged 0.6 fewer insecticide applications, 19 pounds more lint yields, and $14.63 more economic returns per acre compared to Bollgard I cotton. In comparison to the conventional non-Bt cotton, the Bollgard II averaged 3.6 fewer insecticide applications, $16.86 less insecticide costs, 74 pounds more lint yields, and $39.69 more economic returns per acre in 2003. Impacts were analyzed based on the conclusions drawn from Bollgard II and non-Bt cotton. Estimates on insecticide use in Bollgard II cotton were made based on the National Center's 2002 report.

Bollgard II cotton has provided similar agronomic advantages as its predecessor which included improved insect control as reflected by increased yields, reduction in input costs, and reduced pesticide use and sprays (Table 11.2). However, yield improvement and pesticide use reduction, as noted above, is higher with Bollgard II compared to Bollgard (Baker et al. 2004; Mills and Shappely 2004; Mullins and Hudson 2004).

It is estimated that Bollgard II has increased cotton production by 2.3 million pounds with a value of $1.5 million in 2003. (Table 11.2). Cotton growers made 0.11 million fewer trips across the field, which represent significant labor, time and fuel savings in addition to reduced equipment wear and tear. The reduction in insecticide use of 38,223 pounds led to $0.52 million savings on insecticide costs. With the Bollgard II cotton planted on only 30,677 acres in 2003, American cotton growers have increased their net returns by $1.2 million or $39.69 per acre compared to standard practices used in conventional cotton.

Table 11.1. Adoption of Bollgard II cotton in the United States in 2003

State	Planted acreage[1]	Bollgard II adoption[2]	
	000 acres	%	acres
Alabama	525	0	0
Arizona	218	0.07	153
Arkansas	980	0.08	784
California	700	0	0
Florida	94	0.49	461
Georgia	1300	1.44	18720
Louisiana	525	0.57	2993
Mississippi	1110	0.52	5772
Missouri	400	0	0
New Mexico	62	0	0
North Carolina	810	0.13	1053
Oklahoma	180	0.09	0
South Carolina	220	0.26	572
Tennessee	560	0	0
Texas	5620	0	0
Virginia	89	0.19	169
US	**13,393**	**0.23**	**30,677**

[1]National Agricultural Statistics Service: 2003 Acreage.
[2]Based on the cotton planting data from the US Agricultural Marketing Service.

Table 11.2. Aggregate impacts of Bollgard II cotton in 2003[1]

State	Bollgard II adoption	Increase in cotton production	Increase in production value	Reduction in the number of insecticide sprays	Reduction in insecticide costs	Reduction in insecticide use	Economic advantage
	Acres	Lb	$	#	$	Lb	$
AZ	153	11322	7359	551	2580	191	6073
AR	784	58016	37710	2822	13218	977	31117
FL	461	34114	22174	1660	7772	574	18297
GA	18720	1385280	900432	67392	315619	23325	742997
LA	2993	221482	143963	10775	50462	3729	118792
MS	5772	427128	277633	20779	97316	7192	229091
NC	1053	77922	50649	3791	17754	1312	41794
SC	572	42328	27513	2059	9644	713	22703
VA	169	12506	8129	608	2849	211	6708
Total	**30,677**	**2,270,098**	**1,475,564**	**110,437**	**517,214**	**38,224**	**1,217,572**

[1]Impacts were calculated based on Mullins and Hudson, 2003. Accordingly, assessments, as compared to conventional non-Bt cotton, were as follows: reduction in total number of insecticide sprays in Bt-II cotton = 3.6/acre (1.6 for bollworms/budworms and 2.0 for armyworms and loopers); reduction in insecticide costs = $16.86/acre; gain in lint yields per acre = 74 lb; net economic advantage/acre = $39.69; cost of 1 lb of cotton = $0.65; insecticide use was calculated at 0.25 and 0.423 lb ai/A for bollworm/budworm and armyworms/soybean loopers, respectively.

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Conclusions

Crop biotechnology has revolutionized American agriculture by helping to meet one of the key goals of production agriculture: improving yields with the use of minimal inputs. Applications of agricultural biotechnology have also offered profitable and durable solutions for pest management, while maintaining the sustainability of agriculture in the United States. While control of key insect pests that resulted in increased yields and reduced insecticide use were the reasons for the success of Bt crops, increased ease and flexibility of weed management afforded by herbicide-tolerant crops enhanced their adoption.

The findings of this study have documented that the already significant contributions of biotechnology to US agriculture that were observed in 2001 have continued into 2003. Positive impacts have come in the form of increased yields, improved insurance against pest problems, reduced pest management costs and pesticide use, and overall increase in grower returns. American growers have increased crop production by 5.3 billion pounds and net returns by $1.9 billion in 2003 due to the adoption of biotechnology-derived crop varieties. This corresponds to a 41% increase in production volume and a 27% increase in net economic impact in 2003 compared to 2001. Pesticide use reduction was 46.4 million pounds in 2003. Every state that planted biotechnology-derived canola, corn, cotton, soybean, papaya, or squash realized production gains and economic benefits.

Overall, it has been illustrated in 2003, similar to years before, that biotechnology-derived crops have provided reliable and flexible alternatives to traditional pest management choices, have reduced the total amount of input costs in farming, and have improved crop yields. These benefits all translated to direct economic benefits to farmers. Impacts were greater in 2003 compared to 2001 due to increased adoption of biotechnology-derived crops.