Biotechnology-Derived Crops Planted in 2004 - Impacts on US Agriculture

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Introduction

The intense debate over agricultural biotechnology and its applications focused mainly on hypothetical risks and questions related to value, safety, and impacts (agronomic, economic, and environmental) of biotechnology-derived crops. The last ten years have seen many of these questions put to rest. Biotechnology-derived crops have been proven to be economically viable, environmentally sustainable, and as safe as, if not safer, than their conventional counterparts. As a matter of fact, positive impacts that stemmed from the technology served as the primary driving force for the increased adoption of these crops each year across the globe and throughout the United States as well.

Roughly 8.5 million farmers from 17 different countries planted biotechnology-derived crops on 200 million acres worldwide in 2004 (James 2005). These countries include Argentina, Australia, Brazil, Canada, China, Columbia, Germany, Honduras, India, Mexico, Paraguay, Philippines, Romania, South Africa, Spain, United States, and Uruguay. It is remarkable to note that 12 of these nations are developing countries.

The United States continues to lead the world in the research, development, and adoption of biotechnology-derived crops. American farmers planted 118 million acres of biotechnology-derived crops in 2004 (Figure 1). This accounts for 59% of the total global acreage planted to biotechnology applications in 2004. Planted acreage in the United States was mainly concentrated in three commercialized applications (herbicide-resistance, insect-resistance or Bt, and virus-resistance) and six crops (canola, corn, cotton, papaya, soybean, and squash). Approximately 75, 47, 76, 53, 85, and 10% of the total acreage of canola, corn, cotton, papaya, soybean and squash, respectively, in the United States in 2004 was planted to biotechnology-derived varieties.

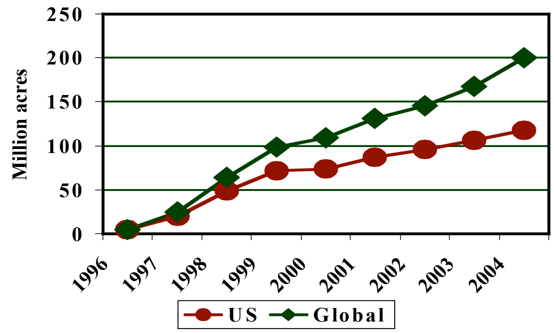
The National Center for Food and Agricultural Policy (the National Center) continues to stay at the forefront of the biotechnology debate by addressing key issues of significance to various stakeholders. Two previous reports from the National Center that assessed the agronomic, economic, and environmental impacts of biotechnology-derived crops planted in 2001 (Gianessi et al., 2002) and 2003 (Sankula and Blumenthal 2004) attracted extensive press and national attention. These reports are frequently cited in university publications, peer reviews and popular press in addition to being used in classroom curriculum. In view of the value, interest, and positive response generated from these reports, the National Center embarked on a third report which evaluated the impacts of biotechnology-derived crops based on 2004 growing season, acreage, and crop production information. The current report, therefore, is a follow-up to *Impacts on U.S. Agriculture of Biotechnology-Derived Crops Planted in 2003 - An Update of Eleven Case Studies,* released in 2004. Information generated from this report is critical to biotechnology debate and policy discussions to facilitate better-informed decision-making.

The number of biotechnology-derived crop applications (herbicide-resistant, insect-resistant or Bt, and virus-resistant) remained the same in 2004, similar to 2003. However, both the planted acreage and available applications increased in 2004. American growers increased the planting of biotechnology-derived crops on 12 million or 11% more acres in 2004, compared with 2003. Other noteworthy changes for 2004 crop season include the debut of glufosinate-resistant (Liberty Link) cotton and the phase-out of bromoxynil-resistant cotton.

The purpose of this report is to document the changes since 2003, quantify the changes, and update the impact estimates of biotechnology-derived crops planted in 2004. This 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.

The forecast for biotechnology-derived crops look bright in the United States for 2005, a year that represents two significant milestones. First, 2005 serves as the tenth anniversary of commercial planting of crops developed through biotechnology methods. Second, the cumulative one-billionth acre of biotechnology-derived crops was planted in 2005. New varieties such as Roundup Ready Flex cotton and WideStrike cotton, which are nearing commercialization, are expected to further enhance the adoption of biotechnology-derived crops in the United States.

Figure 1: Acreage planted to biotechnology-derived crops



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Method

The objective of this report is to evaluate the impacts on US agriculture of six biotechnology-derived crop cultivars that were planted in 2004. 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 our earlier reports released in 2002 and 2004. Background information for all the case studies of this report can be obtained from the earlier reports, which can be accessed at http://www.ncfap .org/whatwedo/40casestudies.php and http://www.ncfap.org/whatwedo/ biotech-us.php.

Similar to the earlier reports, states for which pest management would be impacted due to the adoption of the biotechnology-derived crop cultivars were identified and impacts were quantified. For some case studies (example: virus-resistant squash, herbicide-resistant canola, and Herculex I 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 2004.

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 2004

Trait	Crop	Resistance to	Trade name
Virus-resistant	Papaya	Papaya ring spot virus	-
Virus-resistant	Squash	Cucumber mosaic virus, Watermelon mosaic virus, Zucchini yellows mosaic virus	-
Herbicide-resistant	Soybean	Glyphosate	Roundup Ready
Herbicide-resistant	Canola	Glyphosate Glufosinate	Roundup Ready Liberty Link
Herbicide-resistant	Corn	Glyphosate Glufosinate	Roundup Ready Liberty Link
Herbicide-resistant	Cotton	Glyphosate Glufosinate Bromoxynil	Roundup Ready Liberty Link BXN
Insect-resistant	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	Bollworm/budworm Bollworm/budworm/looper/armyworm	Bollgard Bollgard II

Table 2. Case studies for which impacts were analyzed in 2004

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

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

[b]European corn borer/southwestern corn borer/black cutworm/fall armyworm/corn earworm-resistant corn (Herculex I); includes impacts due to cutworm control

[c]Rootworm-resistant corn (YieldGard Rootworm)

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

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

Virus-resistant crops

The two biotechnology-derived virus-resistant crops that were grown commercially in the United States in 2004 were still papaya and squash. The following section is an update of impacts of these crops on US agriculture in 2004.

1. Papaya

The adoption of biotechnology-derived virus-resistant papaya continued to increase in Hawaii, the primary papaya producing state, in 2004. Virus-resistant papaya varieties were planted on approximately 53% of the total acreage in 2004 (Table 1.1). This is roughly 8% higher adoption than that noted in 2003.

Hawaiian growers planted three biotechnology-derived virus-resistant papaya varieties in 2004. They include 'Rainbow', 'Sunup', and 'Laie Gold.' Rainbow variety remained most popular, accounting for 99.5% of biotechnology-derived papaya acreage and 52% of all papaya planted in 2004. The increasing market penetration and dominance of Rainbow variety is due to its ability to withstand ringspot virus infestations, higher yield potential, and yellow colored flesh preferred by papaya growers and marketers (Gonsalves 2005). Adoption of Sunup, the red-fleshed papaya variety, was less than 1% while Laie Gold, the latest biotechnology-derived papaya variety, was planted on only 12 acres in 2004 (Fitch 2005). Laie Gold is currently being grown commercially on farms smaller than 30 acres and is generally sold in higher priced niche markets. Growers are still experimenting with Laie Gold and thus adoption has not reached commercial levels yet. Adoption estimates for 2005 indicate that acres planted to Laie Gold continues to increase due to its favorable characteristics such as its sweet mango-and-coconut flavor, thick orange-yellow flesh, attractive globular shape, and higher market price (Fitch 2005).

The impacts of biotechnology-derived papaya are presented in Table 1.2. Calculations within this table, similar to the 2003 report, were based on the hypothesis that any changes in crop production since 1998 (the year when biotechnology-derived papaya varieties were first commercially planted) have resulted from the introduction of biotechnology derived virus-resistant varieties.

Per acre papaya yields continued to increase in 2004, by 7%, compared to 2003. Increased adoption of Rainbow variety and increase in bearing acreage of Rainbow has contributed to this yield increase. Planting of virus-resistant varieties has increased crop production by 11.8 million pounds in 2004 and the farm gate value of this increased production was $4.4 million.

As in 2003, papaya growers had to pay for seeds of biotechnology-derived varieties in 2004. The Papaya Administrative Committee (PAC)'s Federal Marketing Order was discontinued in 2002, and since then, the Hawaii Papaya Industry Association has set the seed costs for biotechnology-derived varieties. In 2004 and 2003, the seed and distribution costs for biotechnology-derived papaya were set at $80 an acre (Umehara 2005). Based on conventional seed costs of $32/acre (Gonsalves 2005), it is estimated that papaya growers paid a total of $56,736 to access virus-resistant varieties in 2004. Net returns, calculated by subtracting adoption costs from the value of gained production, were found to be $4.3 million in 2004 due to planting of virus-resistant varieties. Overall, biotechnology-derived papaya delivered economic benefit worth $19.7 million since its commercial introduction in 1999.

As evidenced by increased adoption in 2004, grower acceptance of biotechnology-derived papaya remains strong in spite of seed premium costs. Adoption will increase further once Japan approves importation of biotechnology-derived papaya.

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	1006
2002	2145	44	944
2003	2380	46	1095
2004	2230	53	1182

[1]Comprises of biotechnology-derived 'Rainbow' and 'Sunup' varieties; Sunup accounts for only 0.5% of the total acreage

[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	1006	14.1	50	9456	3121
2002	944	13.4	43	7552	2492
2003	1095	13.5	44	8979	2963
2004	1182	14.4	53	11820	4373
Cumulative Total				**58,155**	**19,664**

[1]Source: Hawaii Agricultural Statistics

[2]Yield increase was calculated using 1998 as base year

[3]Calculated as difference in per acre yields between 1998 and years when VR varieties were planted times acres on which VR varieties were planted

[4]Estimated cost of papaya per pound in years prior to 2004 = $0.33; cost of papaya per pound in 2004 = $0.37

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2. Squash

Biotechnology-derived virus-resistant squash is still not as widely adopted as other biotechnology-derived crops in 2004, similar to 2003. In addition to Florida and Georgia, the only states for which impacts were assessed in 2003, impacts were assessed for five additional states in this report. These states include Michigan, New Jersey, North Carolina, South Carolina, and Tennessee. Together, the above-mentioned seven states planted 69% of the total squash acreage in the United States (Tables 2.1).

Adoption estimates of biotechnology-derived virus-resistant varieties for various states were presented in the Table 2.2. Biotechnology-derived squash varieties accounted for 22, 17, 20, 15, 15, 10, and 2% of the total planted acreage in Florida, Georgia, New Jersey, South Carolina, Tennessee, North Carolina, and Michigan, respectively, in 2004. Averaged across the United States, this represents an adoption of 10%. Similar to the years before, higher seed costs and the lack of resistance to key virus problems such as papaya ringspot virus are the primary reasons for the low adoption of biotechnology-derived varieties in the United States.

The average seed cost for conventional squash was $208 per acre in 2004 while biotechnology-derived seeds cost $369 per acre (Coffey 2005; Ludwick 2005). Thus, seed costs for biotechnology-derived varieties were 78% higher compared to conventional varieties. In spite of high seed costs, squash growers planted biotechnology-derived varieties in 2004, primarily as an insurance against yield losses.

Table 2.3 presents the data on the impacts of biotechnology-derived squash varieties in the seven states listed above. It is assumed that squash growers would experience complete conventional crop failure (if not planted with biotechnology-derived varieties) and lose their entire squash production. Therefore, it is assumed that growers that planted biotechnology-derived varieties in 2004 restored their yields to original levels. The impact of biotechnology-derived virus-resistant squash is a gained production of 64 million pounds, valued at $20.2 million. Based on the assumption that American squash growers paid a premium of $0.95 million in seed costs, the net benefit of planting biotechnology-derived varieties was $19.25 million in 2004.

Table 2.1. Acreage and production of US squash in 2004[1]

State[2]	Area planted	Production	Value
	Acres	Million lb	000$
FL	10500	133.9	45392
GA	12000	115	33350
MI	7200	112	16240
NJ	3200	32.7	12066
NC	3900	30	9000
SC	1400	14.2	3918
TN	1200	9.5	2116
Total	**39,400**	**447.3**	**122,082**
US total	**56,900**	**775.6**	**222,718**

[1]Source: National Agricultural Statistics Service, Vegetables 2004 Summary
[2]California, New York, Ohio, Oregon, & Texas have squash acreage, however they were not included in this report

Table 2.2. Adoption of biotechnology-derived virus-resistant squash varieties in 2004

State	Area planted	Adoption of virus-resistant squash	Acreage planted to virus-resistant squash	Source[1]
	Acres	% of total	Acres	
FL	10500	22	2310	Olson
GA	12000	17	2040	Kelley
MI	7200	2	144	Zandstra
NJ	3200	20	640	Vanquicken
NC	3900	10	390	Schultheis
SC	1400	15	210	Boyhan
TN	1200	15	180	Straw
Total/ Average	**39,400**	**15**	**5,914**	
US Total/ Average	**56,900**	**10[2]**		

[1]Affiliations for the specialists that provided adoption estimates for biotechnology-derived varieties are listed in the References section
[2]The adoption of biotechnology-derived squash in 2003 was misreported 19% in our earlier report. It should have been 3%

Table 2.3. Impacts of biotechnology-derived virus-resistant squash in 2004

State	Acreage planted to virus-resistant squash	Adoption costs[1]	Yield advantage[2]	Gain in value	Net gain
	Acres	$	Million lb	000$	000$
FL	2310	371910	29.4	9986	9614
GA	2040	328440	19.6	5670	5342
MI	144	23184	2.2	325	302
NJ	640	103040	6.7	2413	2310
NC	390	62790	3	900	837
SC	210	33810	2.1	588	554
TN	180	28980	1.4	317	288
Total	**5,914**	**952,154**	**64.4**	**20,199**	**19,247**

[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 $208 and $369 per acre, respectively, in 2004. Therefore, adoption costs were $161 per acre

[2]Yield advantage was calculated based on production and virus-resistant squash adoption information from Tables 2.1 and 2.2, respectively

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Herbicide-resistant crops

The number of biotechnology-derived herbicide-resistant crops planted in the United States remained the same during 2003 and 2004. Planted crops were still canola, corn, cotton, and soybean. Similar to previous years, herbicide-resistant crops were planted on largest crop acreage of the United States compared to other applications. Soybean continued to be the dominant crop among all the biotechnology-derived crops, with about 85% adoption in 2004. Whereas herbicide-resistant canola and cotton were planted on 75 and 77% of the national acreage, herbicide-resistant corn represented 21% of the total US acreage. With the European Unions' approval of glyphosate-resistant corn for use in food products, in addition to feed ingredients, in October 2004, it is projected that herbicide-resistant corn acreage will increase significantly in the next few years. The rapid and widespread adoption of herbicide-resistant crops is mainly due to enhanced simplicity and flexibility of weed management by these crops. Following is an update on the economic, agronomic, and environmental impact of herbicide-resistant crops planted in 2004.

3. Canola

North Dakota remained the dominant canola producing state in the United States in 2004, planting approximately 90% of the national canola acreage. Sixteen other states including Minnesota and Montana planted roughly 85,000 acres of canola in 2004 (National Agricultural Statistics Service: Acreage).

North Dakota's canola acreage continued to slide from its 2001/2002 high of 1.3 million acres to 0.78 million acres in 2004 (Table 3.1). Compared to 2003, 20% fewer acres were planted to canola in 2004. Excessively wet weather in the key growing areas of North Dakota was the primary reason for the drop in canola acreage in 2004, similar to 2003 (Coleman 2005; Jenks 2005).

The adoption of biotechnology-derived herbicide-resistant canola has remained unchanged in North Dakota since 2003, at about 75% (Coleman 2005; Jenks 2005; Table 3.2). However, the total number of acres planted to herbicide-resistant varieties was reduced by 20% in 2004 compared to 2003. This reduction in herbicide-resistant canola acreage is proportional to the drop (20%) in total canola acres planted in North Dakota.

While there was a slight decline in the acreage planted to glyphosate-resistant (Roundup Ready) canola varieties, from 55% in 2003 to 50% in 2004, plantings of glufosinate-resistant (Liberty Link) canola increased to 25% in 2004, from 20% in 2003 (Table 3.2). The steady increase in the market share of glufosinate-resistant canola has been a trend since 2002 and was attributed to the availability of the trait in high yielding varieties, awareness and increased knowledge about the Liberty Link trait, and also due to a greater choice of varieties (Coleman 2005).

Both glyphosate and glufosinate provided viable weed management options to North Dakota canola growers due to their broad-spectrum of activity, convenient postemergence-based programs, and economic control of problem weeds. As in the years past, in addition to reasons mentioned above, North Dakota canola growers have planted biotechnology-derived herbicide-resistant varieties to control difficult weeds such as kochia, Canada thistle, wild buckwheat, wild oat, and yellow foxtail and seed contaminants such as wild mustard that may cause price discounts or rejection in the market. A comparison of weed control programs in conventional, glyphosate-resistant, and glufosinate-resistant canola is presented in Table 3.3.

A typical weed management program in conventional canola (that could provide control comparable to the program in herbicide-resistant canola), on an average, costs $39 per acre in 2004. In contrast, weed management costs in glyphosate-resistant and glufosinate-resistant canola, inclusive of technology fee, were about $24 and $28 per acre, respectively. Growers of glyphosate-resistant and glufosinate-resistant canola, therefore, reduced their weed management costs by 38 and 28%, respectively, compared to growers of conventional canola in 2004. Weed management costs in herbicide-resistant canola included costs associated with the herbicide use, herbicide application, seed premium (for both varieties), and technology fee (for glyphosate-resistant canola only).

Overall, canola growers saved $7.9 million on weed management costs using herbicide-resistant varieties in 2004. Similar to previous years, growers were also able to reduce the herbicide use in biotechnology-derived canola. Use of herbicide active ingredients per acre was 0.72 and 0.7 lb lower in glyphosate-resistant and glufosinate-resistant canola, respectively, compared to conventional canola (Table 3.3). Across the state, this represented a reduction of 0.42 million pounds in herbicide use in 2004.

Expectations are high for 2005 planting season. Planting trends indicate that North Dakota growers have planted canola on 1.0 million acres in 2005, an increase of 28% over 2004 (Coleman 2005). It is expected that agronomic and economic impacts will be higher in 2005 as large proportion of the canola would have been planted with biotechnology-derived herbicide-resistant varieties.

Table 3.1. Canola production in North Dakota in 2004

Year	Acres planted[1]	Production[2]	Value[3]
	000A	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	1403	149
2003	970	1354	143
2004	780	1223	136

[1]Source: National Agricultural Statistics Service. 2005 Acreage
[2]Source: National Agricultural Statistics Service. 2005 Crop Production
[3]Source: National Agricultural Statistics Service. 2005 Crop Value

Table 3.2. Adoption of biotechnology-derived herbicide-resistant (HR) canola in North Dakota in 2004[1]

Year	Total HR canola	Glyphosate-resistant[2] canola	Glufosinate-resistant[3] canola	HR canola acreage
	---------------------Percent adoption		----------------------	000A
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
2004	75	50	25	585

[1]Source: Coleman 2005; Jenks 2003
[2]Roundup Ready
[3]Liberty Link

Table 3.3. Comparison of weed management costs in various canola systems in North Dakota in 2004[1]

Conventional canola[2]			
Herbicides	**$/lb ai/A**	**Lb ai/A**	**$/A**
Ethafluralin (PRE) fb[3]	$8.78	0.94	$8.25
Quizalofop (POST)+	$145.54	0.056	$8.15
Clopyralid (POST)	$160.00	0.09	$14.40
Total		1.09	$30.80
Application cost (2 applications)			$8.00
Total weed management costs in conventional canola			$38.80
Glyphosate-resistant canola			
Seed premium			$5.00
Technology Fee plus 0.375lb ai/A glyphosate			$15.00
Application cost (1 application)			$4.00
Total cost			$24.00
Glufosinate-resistant canola			
Seed Premium			$7.00
Technology fee			$0.00
0.37 lb ai/A glufosinate ($13.51) + 0.023 lb ai/A quizalofop ($3.35)			$16.86
Application cost (1 application)			$4.00
Total cost			$27.86

[1]Sources: Brian Jenks of North Dakota State University for herbicide rate and cost information; Barry Coleman of Northern Canola Growers Association for technology fee and seed premium cost information
[2]For the purpose of this analysis, a single program is selected, as above, from several suggested alternative programs
[3]Followed by

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4. Corn

Biotechnology-derived herbicide-resistant varieties were planted on 21% of the total corn acreage of the United States in 2004. Adoption increased by 70% in 2004 compared with 2003. Texas ranked first in the adoption of herbicide-resistant hybrids (65%) in 2004 followed by South Dakota (51%), Colorado (50%) and Utah (50%) (Table 4.1). However, planted acreage was greatest in major producing states in the Corn Belt such as Illinois, Iowa, and Nebraska.

Corn growers planted two biotechnology-derived herbicide-resistant cultivars in 2004, as in 2003. They were glyphosate-resistant (trade name: Roundup Ready corn and Roundup Ready corn 2) and glufosinate-resistant (trade name: Liberty Link) corn. Among the two, glyphosate-resistant corn was the dominant cultivar in 2004, with about 18% adoption. Glufosinate-resistant corn was planted on 3% of 2004's planted corn acreage. Lower adoption of glufosinate-resistant corn is due to high price differential between glufosinate and glyphosate and also due to the ineffectiveness of glufosinate in controlling specific weeds in corn production such as nutsedge, pigweeds, and certain grasses.

Unlike other herbicide-resistant crops, adoption of biotechnology-derived herbicide-resistant corn was low in 2004, similar to 2003. Reasons for this low adoption include non-availability of the trait in hybrids suited to various geographic locations, availability of effective alternative weed management programs, and trade restrictions in export markets. Most available hybrids were bred for midwest region of the United States and were not fully suited for the southeast-growing region (Prostko 2005). However, in midwestern states such as Iowa, Illinois, and Indiana, adoption remains low at only 18, 7 and 10%, respectively. Issues involving the export of biotechnology-derived corn are the primary reason for the low adoption in those states (Nafziger 2005).

In July 2004 the European Commission approved the import, processing, and use in animal feed of glyphosate-resistant corn (NK 603) in the European Union (EU). In October of the same year, the EU authorized the use of NK 603 as a single trait in food ingredients and products. Prior to this approval, the NK 603 or Roundup Ready Corn 2 was marketed under the Market Choices Certification Mark (MCCM). The MCCM identifies hybrids that are fully approved for food and feed use in the United States and

Japan but not in the EU. The EU approval of NK 603 allowed for discontinued use of MCCM in single trait hybrids. Therefore, it is predicted that the adoption of herbicide-resistant corn will increase in the midwestern states in the near future.

The niche for herbicide-resistant corn in 2004, as in 2003, was in the control of specific difficult to control weeds such as Johnsongrass, Bermudagrass, crabgrass, burcucumber, bindweed, and herbicide-resistant weeds such as kochia and pigweed for which conventional weed control programs have weaknesses. Besides being cost-effective (Table 4.2), weed management programs in herbicide-resistant corn enhanced flexibility in timing herbicide applications because glyphosate and glufosinate can be applied at later crop growth stages.

A survey of Crop Specialists (names listed in Reference section) in 2004 suggested two major options for weed management in biotechnology-derived corn. The first and most widely used option is the use of half rate of a preemergence herbicide followed by either glyphosate or glufosinate as postemergence. The second approach involves a total postemergence-based program with either one or two applications of glyphosate or glufosinate or tankmix applications of glyphosate or glufosinate with atrazine.

Weed control strategies in biotechnology-derived herbicide-resistant corn, unlike soybean, necessitate the use of preemergence residual herbicides in addition to postemergence applications of glyphosate/glufosinate. Residual herbicide applications are needed in corn due to its earlier time of planting and its greater susceptibility to early season weed competition compared with soybean. As a result, preemergence residual herbicides (at half-rates) have become the basis of weed management programs in biotechnology-derived corn.

Comparative weed management programs and costs associated with glyphosate-resistant, glufosinate-resistant, and conventional corn are presented in Table 4.2. Weed management costs in 2004 were 26% and 24% lower in glyphosate-resistant and glufosinate-resistant corn, respectively, compared to conventional corn. Typical weed management program in conventional corn included premix applications of acetochlor + atrazine (preemergence) followed by a post-emergence application of primisulfuron + dicamba. Substitution of the above program with half rate of preemergence applications of acetochlor + atrazine applications followed by glyphosate or glufosinate have led to reduction in herbicide use of 1.1 and 1.4 lb ai/acre, respectively. Overall, biotechnology-derived glyphosate- and glufosinate-resistant corn reduced the herbicide use in corn by 18.5 million pounds (15.2 and 3.3 million pounds, respectively) in 2004 (Tables 4.3, 4.4, and 4.5). Furthermore, herbicide substitutions facilitated by the use of both glyphosate-resistant and glufosinate-resistant corn have resulted in grower cost savings of $139 million due to lower costs associated with herbicide programs in herbicide-resistant corn. In comparison to 2003, grower returns were 39% higher and pesticide use was 51% lower in 2004 due to increased adoption of herbicide-resistant corn varieties.

Similar to years since the first commercial use of herbicide-resistant corn, no-till corn acreage has increased significantly in 2004 also. No-till corn acres increased by 20% in 2004, 14% in 2002, and 9% in 2000 (based on the data from Conservation Technology Information Center's website; Table 4.6). The positive impacts from no-till production (such as reduced fuel use, soil erosion, runoff of pesticides and water, global warming potential, and greenhouse gas emissions and improved wild life habitat) will only increase as the adoption of herbicide-resistant crops continue to increase.

Table 4.1. Adoption of biotechnology-derived herbicide-resistant (HR) corn in the United States in 2004

State	Total corn acres planted[1]	Adoption of RR[2] corn	RR corn acreage	Adoption of LL[3] corn	LL corn acreage	Total adoption of HR corn	Total HR corn acreage	Source
	000A	%	000A	%	000A	%	000A	
AZ	53	6	3	0	0	6	3	Clay
AR	320	40	128	3	10	43	138	Kelley
CA	540	40	216	1	5	41	221	Lanini
CO	1200	40	480	10	120	50	600	Meyer
DE	160	10	16	3	5	13	21	VanGessel
GA	335	18	60	2	7	20	67	Prostko
ID	230	33	76	0	0	33	76	Morishita
IL	11750	6	705	1	118	7	823	NASS[4]
IN	5700	7	399	3	171	10	570	NASS[4]
IA	12700	14	1778	4	508	18	2286	NASS[4]
KS	3100	28	868	1	31	29	899	NASS[4]
KY	1210	13	157	0	0	13	157	Martin
LA	420	24	101	1	4	25	105	Ferguson
MA	20	14	3	1	0.2	15	3	Barlow
MD	490	22	108	1	5	23	113	Ritter
MI	2200	13	286	5	110	18	396	NASS[4]
MN	7500	21	1575	7	525	28	2100	NASS[4]/Gunsolus
MS	460	30	138	0	0	30	138	Poston
MO	2950	15	443	2	59	17	502	NASS[4]
NC	820	16	131	4	33	20	164	York
ND	1800	22	396	3	54	25	450	Zollinger
NE	8250	19	1568	0	0	19	1568	NASS[4]
NJ	86	10	9	3	3	13	12	VanGessel
NM	125	20	25	0	0	20	25	McWilliams
NY	980	19	186	1	10	20	196	Hahn
OH	3350	4	134	1	34	5	168	NASS[4]
OK	250	25	63	15	38	40	101	Medlin
PA	1400	14	196	1	14	15	210	Lingenfelter
SC	315	39	123	1	3	40	126	Norsworthy
SD	4650	45	2093	6	279	51	2372	NASS[4]
TN	680	20	136	1	7	21	143	Hayes
TX	1830	60	1098	5	92	65	1190	Baumann
UT	55	50	28	0	0	50	28	Griggs
VA	500	17	85	3	15	20	100	Hagood
VT	95	12	11	0	0	12	11	Giguere
WV	48	32	15	3	1	35	16	Chandran
WI	3600	13	468	3	108	16	576	NASS[4]
WY	90	30	27	0	0	30	27	Miller
Total/Average	**80,262**	**18**	**14,332**	**3**	**2,369**	**21**	**16,701**	

[1]Source: National Agricultural Statistics Service. 2005 Acreage
[2]RR = Glyphosate-resistant or Roundup Ready corn
[3]LL = Glufosinate-resistant or Liberty Link corn
[4]Source: National Agricultural Statistics Service: 2005 Acreage

Table 4.2. Herbicide substitution analysis[1] in biotechnology-derived herbicide-resistant (HR) corn

Program	Herbicide rate	Herbicide costs
	lb ai/A	$/A
Conventional corn		
Premix of Acetochlor + Atrazine[2] as PRE followed by	3.22	22.40
Premix of Primisulfuron + Dicamba[3] as POST	0.15	10.24
Total for conventional program	**3.37**	**32.64**
Glyphosate-resistant (Roundup Ready or RR) corn		
Acetochlor/atrazine[2] as PRE followed by	1.61	11.20
Glyphosate[4] as POST	0.7	7.05
Seed premium costs/technology fee		6.0
Total for RR program	**2.31**	**24.25**
Glufosinate-resistant (Liberty Link or LL) corn		
Acetochlor/atrazine[2] as PRE followed by	1.61	11.20
Glufosinate[5] as POST	0.37	13.63
Seed premium costs/technology fee		0
Total for LL program	**1.98**	**24.83**
Difference		
Conventional to RR	**-1.06**	**-8.39**
Conventional to LL	**-1.39**	**-7.81**

[1]Based on the survey of Weed Specialists (listed in References section) in 2004
[2]Trade name: Harness Xtra
[3]Trade name: North Star
[4]Trade name: Roundup
[5]Trade name: Liberty

Table 4.3. Impacts of herbicide-resistant Roundup Ready (RR) corn in 2004

State	Total corn acres planted	RR corn acreage	Impacts due to RR corn: Reduction in herbicide use[1]	Impacts due to RR corn: Reduction in weed management costs[2]
	000A	000A	000 lb ai	000$
AZ	53	3	3	25
AR	320	128	136	1074
CA	540	216	229	1812
CO	1200	480	509	4027
DE	160	16	17	134
GA	335	60	64	503
ID	230	76	81	638
IL	11750	705	747	5915
IN	5700	399	423	3348
IA	12700	1778	1885	14917
KS	3100	868	920	7283
KY	1210	157	166	1317
LA	420	101	107	847
MA	20	3	3	25
MD	490	108	114	906
MI	2200	286	303	2400
MN	7500	1575	1670	13214
MS	460	138	146	1158
MO	2950	443	470	3717
NC	820	131	139	1099
ND	1800	396	420	3322
NE	8250	1568	1662	13156
NJ	86	9	10	76
NM	125	25	27	210
NY	980	186	197	1561
OH	3350	134	142	1124
OK	250	63	67	529
PA	1400	196	208	1644
SC	315	123	130	1032
SD	4650	2093	2219	17560
TN	680	136	144	1141
TX	1830	1098	1164	9212
UT	55	28	30	235
VA	500	85	90	713
VT	95	11	12	92
WV	48	15	16	126
WI	3600	468	496	3927
WY	90	27	29	227
Total	**80,262**	**14,332**	**15,195**	**120,246**

[1]Calculated at 1.06 lb ai/A based on Table 4.2

[2]Calculated at $8.39/A based on Table 4.2

Table 4.4. Impacts of herbicide-resistant Liberty Link (LL) corn in 2004

State	Total corn acres planted	LL corn acreage	Impacts due to LL corn: Reduction in herbicide use[1]	Impacts due to LL corn: Reduction in weed management costs[2]
	000A	000A	000 lb ai	000$
AR	320	10	14	78
CA	540	5	7	39
CO	1200	120	167	937
DE	160	5	7	39
GA	335	7	10	55
IL	11750	118	164	922
IN	5700	171	238	1336
IA	12700	508	706	3967
KS	3100	31	43	242
LA	420	4	6	31
MD	490	5	7	39
MI	2200	110	153	859
MN	7500	525	730	4100
MO	2950	59	82	461
NC	820	33	46	258
ND	1800	54	75	422
NJ	86	3	4	23
NY	980	10	14	78
OH	3350	34	47	266
OK	250	38	53	297
PA	1400	14	19	109
SC	315	3	4	23
SD	4650	279	388	2179
TN	680	7	10	55
TX	1830	92	128	719
VA	500	15	21	117
WV	48	1	1	8
WI	3600	108	150	843
Total	**69,674**	**2,369**	**3,294**	**18,502**

[1]Calculated at 1.39 lb ai/A based on Table 4.2
[2]Calculated at $7.81/A based on Table 4.2

Table 4.5. Aggregate impacts of herbicide-resistant (HR) corn in 2004[1]

State	Total corn acres planted	HR corn acreage	Impacts due to HR corn: Reduction in herbicide use	Impacts due to HR corn: Reduction in weed management costs
	000A	000A	000 lb ai	000$
AZ	53	3	3	25
AR	320	138	150	1152
CA	540	221	236	1851
CO	1200	600	676	4964
DE	160	21	24	173
GA	335	67	74	558
ID	230	76	81	638
IL	11750	823	911	6837
IN	5700	570	661	4684
IA	12700	2286	2591	18884
KS	3100	899	963	7525
KY	1210	157	166	1317
LA	420	105	113	878
MA	20	3	3	25
MD	490	113	121	945
MI	2200	396	456	3259
MN	7500	2100	2400	17314
MS	460	138	146	1158
MO	2950	502	552	4178
NC	820	164	185	1357
ND	1800	450	495	3744
NE	8250	1568	1662	13156
NJ	86	12	14	99
NM	125	25	27	210
NY	980	196	211	1639
OH	3350	168	189	1390
OK	250	101	120	826
PA	1400	210	227	1753
SC	315	126	134	1055
SD	4650	2372	2607	19739
TN	680	143	154	1196
TX	1830	1190	1292	9931
UT	55	28	30	235
VA	500	100	111	830
VT	95	11	12	92
WV	48	16	17	134
WI	3600	576	646	4770
WY	90	27	29	227
Total	**80,262**	**16,701**	**18,489**	**138,748**

[1]Includes impacts from glyphosate-resistant and glufosinate-resistant corn from Tables 4.3 and 4.4

Table 4.6. Impact of biotechnology-derived herbicide-resistant varieties on no-till corn 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	13.17	16.8	-
1997	13.7	17.3	4
1998	13.2	16.4	0.3
2000	14.35	17.9	9
2002	15.0	19.1	14
2004	15.82	19.7	20

Source: Conservation Technology Information Center

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5. Cotton

The United States planted 13.7 million acres of cotton in 2004. Of these, biotechnology-derived herbicide-resistant (HR) cotton represented 79%. American cotton growers planted 9% more acres to herbicide-resistant varieties in 2004 compared to 2003. Except for Arizona, California, New Mexico, and Texas, adoption of biotechnology-derived herbicide-resistant varieties was more than 90% in the rest of the cotton producing states of the United States (Table 5.1). Planted HR cotton acreage was highest in Texas (3.6 million acres) followed by Georgia (1.3 million acres) and Mississippi (1.1 million acres).

Three biotechnology-derived herbicide-resistant cotton cultivars were planted in 2004. These include glyphosate-resistant (Roundup Ready or RR), bromoxynil-resistant (BXN), and glufosinate-resistant (Liberty Link or LL) cotton. Glufosinate-resistant cotton is the new tool added to the weed management arsenal of cotton in November 2003. Glufosinate-resistant cotton was first planted on a commercial scale in 2004. Glufosinate-resistant cotton, as the name suggests, is developed to be resistant to the herbicide glufosinate.

Glyphosate-resistant cotton remained the dominant variety among all biotechnology-derived herbicide-resistant varieties in 2004 (Table 5.1). It was planted on 10.6 million acres (or 77% of the total) in 2004. This represents 10% higher acreage compared to 2003. Glufosinate-resistant cotton was planted on 152,000 acres or 1% of total acreage in 2004 (Table 5.1). Adoption of glufosinate-resistant cotton was low and was only significant (around 2% or slightly higher) in Texas, Virginia and Mississippi because of the low introductory year seed supplies.

Adoption of bromoxynil-resistant cotton, on the other hand, continued to slide down and was planted on only 30,000 acres or 0.22% of total acres in 2004. The adoption of bromoxynil-resistant declined over 900% since 2003. The reason for this decline is due to the lack of stacked varieties, the lack of broad-spectrum weed control with bromoxynil and restrictions placed on the use of bromoxynil by the Environmental Protection Agency (Sankula 2004). Bromoxynil-resistant cotton is due to be withdrawn from the market in 2005.

While both glyphosate and glufosinate are post-emergence, non-residual, non-selective, over-the-top herbicides, there are several contrasts between glyphosate and glufosinate based weed management systems. Whereas glyphosate can be applied over-the-top (broadcast) only up to 4-5 leaf stage of cotton (precision post-direct equipment must be used after this stage), glufosinate has a larger over-the-top application window and can be applied up to 70 days prior to harvest (Lemon et al. 2004). Hence, timing of herbicide applications is more flexible with glufosinate-resistant cotton (Culpepper 2003). However, unlike glyphosate, glufosinate is not effective against nutsedge, grasses, and pigweeds. Control of morning glory, smartweed, and hemp sesbania, on the other hand, is superior with glufosinate compared to glyphosate. Another major difference between the two systems is that glyphosate is used as repeated and as-needed applications until lay-by while glufosinate is used in more of a pre-planned, traditional type program. Regardless the differences, the availability of glyphosate and glufosinate-resistant cotton systems serve as valuable tools in managing weed resistance and population shifts due to their diverse mechanisms of action.

A survey was conducted in 2004 to identify the herbicide programs that were replaced in conventional cotton with glyphosate, glufosinate, 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 states is detailed in Table 5.2. Representative weed management programs in RR, LL, 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 National Center's 2002 report.

Biotechnology-derived herbicide-resistant varieties have led to a new era for weed management in cotton. The primary advantage of herbicide-resistant 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 2004 as a way to reduce production costs, as in the years before.

Similar to 2003, significant reductions have been observed in overall herbicide use and herbicide costs (Tables 5.4 and 5.5); number of herbicide applications; tillage; and handweeding operations in 2004 (Table 5.6). Though seed premium and technology fee costs increased crop production expenses (Table 5.7), savings from other weed management costs have more than offset these increased costs. The overall impact of herbicide-resistant cotton on US agriculture has been a reduction in crop production costs of $264 million (Table 5.8) and pesticide use of 14.0 million pounds (Table 5.5). This represents 19% higher net returns in 2004 compared with 2003. Similarly, herbicide use continued to decrease by 46% in 2004 compared to 2003, mainly due to expanded acreage of biotechnology-derived herbicide-resistant cotton in 2004 (9%).

The second generation glyphosate-resistant cotton, referred to as Roundup Ready Flex cotton, is fully approved by the regulatory agencies in the United States in 2005. Approval in key export markets is expected by the end of 2005. Roundup Ready Flex cotton will be offered for planting for the 2006 crop season as a single-trait product. Efforts are also in progress to market Roundup Ready Flex cotton stacked with Bollgard II trait to expand the protection against other key cotton pest problems. Roundup Ready Flex cotton possesses both vegetative and reproductive tolerance to glyphosate and can be applied over-the-top from cotton emergence through seven days prior to harvest with out any concern for crop injury unlike the first generation cotton on which glyphosate applications cannot be made past 4-leaf stage. Roundup Ready Flex cotton, once planted, will enhance the flexibility in timing herbicide applications, facilitate co-applications of herbicides, insecticides and plant growth regulators, and reduce the reliance on specialized equipment used for post-directed sprays.

A major impact of crop biotechnology in the United States has been increase in the adoption of no-till production practices. No-till crop acres rose significantly in soybean, corn, and cotton; however, percent increase in no-till acreage has been higher in cotton than any other crop. For example, no-till cotton acres were increased by 371% in 2004 compared with 1996 (Table 5.9), while increases were 20 and 64% 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-resistant 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 herbicide-resistant 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-resistant 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 2004 (2.4 million acres) was planted to herbicide-resistant varieties, fuel and labor cost savings were estimated to be $48 million.

Table 5.1. Herbicide-resistant (HR) cotton adoption in the United States in 2004[1]

State	Planted cotton acreage[2]	RR[3] cotton adoption	LL[4] cotton adoption	BXN[5] cotton adoption	Total HR cotton adoption	RR cotton acres	LL cotton acres	BXN cotton acres	Total HR cotton acres
	000A	%	%	%	%	000A	000A	000A	000A
AL	550	92.96	0.12	0.0	93.08	511	0.7	0.0	512
AZ	220	71.00	0.03	2.73	73.76	156	0.1	6.0	162
AR	950	98.42	0.11	0.84	99.37	935	1.0	8.0	944
CA	560	49.73	0.0	1.78	51.51	278	0.0	10.0	288
FL	105	92.28	0	0.0	92.28	97	0.0	0.0	97
GA	1330	94.81	0.45	0.0	95.26	1261	6.0	0.0	1267
KS	120	96.33	0.0	0.0	96.33	116	0.0	0.0	116
LA	500	98.74	0.17	0.0	98.91	494	0.9	0.0	495
MS	1100	97.53	1.95	0.0	99.48	1073	21.5	0.0	1095
MO	400	93.95	0.93	0.51	95.39	376	3.7	2.0	382
NM	60	49.36	0.0	0.0	49.36	30	0.0	0.0	30
NC	720	95.33	0.69	0.03	96.05	686	5.0	0.2	691
OK	190	93.69	0.37	0.0	94.06	178	0.7	0.0	179
SC	240	98.99	0.23	0.0	99.22	238	0.6	0.0	239
TN	570	97.52	0.42	0.0	97.94	556	2.4	0.0	558
TX	6000	58.71	1.78	0.07	60.56	3523	106.8	4.2	3634
VA	85	94.78	2.92	0.0	97.7	81	2.5	0.0	84
Total/ Average	**13,700**	**77.29**	**1.11**	**0.22**	**78.64**	**10,589**	**151.9**	**30.4**	**10,773**

[1]Source: Agricultural Marketing Service. Cotton Varieties Planted, United States, 2004 Crop
[2]Source: National Agricultural Statistics Service. 2004 Acreage
[3]RR = Biotechnology-derived glyphosate-resistant or Roundup Ready cotton
[4]LL = Biotechnology-derived Liberty Link cotton
[5]BXN = Biotechnology-derived bromoxynil-resistant cotton

Table 5.2. Typical weed management programs in various cotton growing states of the US in 2004 as suggested by University Weed Specialists across the Cotton Belt[1]

State	Standard weed management program[2] (lb ai/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 (0.063)		Prometryn (0.5) + MSMA (2.0)	4.1	47.45
AZ	Pendimethalin (1.5)		Pyrithiobac (0.063) + MSMA (2.0)	Prometryn (0.5)	Diuron (1.3) + Carfentrazone (0.024)	5.4	56.61
AR	Pendimethalin (0.6)	Fluometuron (0.5)	Pyrithiobac (0.063)	MSMA (2.0)	Prometryn (1.0)	4.2	45.82
CA	Trifluralin (1.0)		Pyrithiobac (0.063)	MSMA (2.0)	Glyphosate (1.0)	6.1	46.79
FL	Pendimethalin (0.75)	Fluometuron (1.5)	Prometryn (0.75) + MSMA (2.0)			5.0	31.35
GA	Pendimethalin (0.75)	Fluometuron (1.0) + Pyrithiobac (0.043)	Pyrithiobac (0.043) + MSMA (0.75)		Diuron (1.0) + MSMA (2.0)	5.6	58.3
KS	Pendimethalin (1.0)	Fluometuron (1.0)	Clethodim (0.125)	Prometryn (0.75)	Diuron (1.0) + MSMA (2.0)	5.9	44.42
LA		Pendimethalin (0.75) + fluometuron (0.75)	Pyrithiobac (0.063)	Fluometuron (0.75) + MSMA (2.0)	Diuron (1.0)	5.3	50.17
MS	Pendimethalin (1.0)		Pyrithiobac (0.063)	Prometryn (0.5) fb[3] MSMA (2.0)	Diuron (1.0) + MSMA (1.5)	6.1	47.7
MO		Fluometuron (1.2)	Clethodim (0.09)	Fluometuron (1.0) + MSMA (1.5)	Diuron (1.0) + MSMA (1.5)	6.3	47.56
NM	Trifluralin (0.5)	Fluometuron (1.0)		Diuron (1.0) + MSMA (2.0)		4.5	23.39
NC	Pendimethalin (0.75)	Fluometuron (1.0)	Pyrithiobac (0.07)	Prometryn (0.75)	MSMA (2.0) + Prometryne (0.5)	5.1	55.71
OK	Pendimethalin (0.63)			Fluometuron (1.0) fb[3] prometryn (0.8)	Diuron (0.75)	3.2	23.0
SC	Pendimethalin (0.83)	Fluometuron (1.0)	Pyrithiobac (0.063)	Prometryn (1.0)	MSMA (2.0)	4.9	51.77
TN	Trifluralin (0.75)	Fluometuron (1.4)	Pyrithiobac (0.06) + Clethodim (0.125)	Diuron (1.0) + MSMA (2.0)		5.3	63.75
TX	Trifluralin (1.0)		Pyrithiobac (0.063) + MSMA (0.75)	Prometryn (1.5) + MSMA (1.0)		3.4	51.55
VA	Pendimethalin (0.63)	Fluometuron (1.0)		Prometryn (0.8)	Diuron (0.75)	3.2	23.18
Average						**4.92**	**45.21**

[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-resistant 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[2] before 4th leaf followed by glyphosate + diuron as layby treatments	0.75 + 1.0 + 0.5 + 0.75	3.0	22.69
2. Three postemergence applications of glyphosate	1.0 + 1.0 + 1.0	3.0	28.71
3. Two postemergence applications of glyphosate followed by diuron + MSMA as layby treatments	1.0 + 0.5 + 1.0 + 2.0	4.5	24.42
4. Pendimethalin preemergence 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	27.35
Average		**3.3**	**25.79**

[1]Specialists that specified the weed management programs for their respective states are listed in the References section
[2]Roundup WeatherMax formulations used in the calculations

Table 5.3b. Typical weed management programs in biotechnology-derived glufosinate–resistant 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. Pendimethalin premergence followed by 2 postemergence applications of glufosinate (early to mid POST and late POST) followed diuron + MSMA as layby treatments	0.75 + 0.42 + 0.42 + 0.75 + 2.0	4.34	44.82
2. Two postemergence applications of glufosinate (at 2-leaf followed by 5-6 leaf stages) followed by diuron + MSMA as layby treatments	0.42 + 0.42 + 0.75 + 2.0	3.59	39.94
3. Glufosinate at 2-leaf stage followed by glufosinate + metolachlor at 5-6 leaf stage followed by diuron + MSMA as layby treatments	0.42 + 0.21 + 0.9 + 0.75 + 2.0	4.28	45.84
4. Pendimethalin premergence followed by 2 postemergence applications of glufosinate (early to mid POST and late POST to layby)	0.75 + 0.42 + 0.42	1.59	35.82
5. Three glufosinate applications (early POST, mid POST, layby)	0.42 + 0.42 + 0.21	1.05	38.68
Average		**2.97**	**41.02**

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

Table 5.3c. Typical weed management programs in biotechnology-derived bromoxynil-resistant 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	31.64
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	35.0
Average		**3.7**	**33.32**

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

Table 5.4a. Impacts of glyphosate-resistant (Roundup Ready/RR) cotton on herbicide use and weed management costs in 2004

State	Planted acreage	RR acres	Conventional program		Impacts on		Aggregate impacts on	
	000A	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	550	511	4.1	47.45	-0.8	-21.66	-409	-11068
AZ	220	156	5.4	56.61	-2.1	-30.82	-328	-4808
AR	950	935	4.2	45.82	-0.9	-20.03	-842	-18728
CA	560	278	6.1	46.79	-2.8	-21.00	-778	-5838
FL	105	97	5.0	31.35	-1.7	-5.56	-165	-539
GA	1330	1261	5.6	58.30	-2.3	-32.51	-2900	-40995
KS	120	116	5.9	44.42	-2.6	-18.63	-302	-2161
LA	500	494	5.3	50.17	-2.0	-24.38	-988	-12044
MS	1100	1073	6.1	47.70	-2.8	-21.91	-3004	-23509
MO	400	376	6.3	47.56	-3.0	-21.77	-1128	-8186
NM	60	30	4.5	23.39	-1.2	2.40	-36	72
NC	720	686	5.1	55.71	-1.8	-29.92	-1235	-20525
OK	190	178	3.2	23.00	0.1	2.79	18	497
SC	240	238	4.9	51.77	-1.6	-25.98	-381	-6183
TN	570	556	5.3	63.75	-2.0	-37.96	-1112	-21106
TX	6000	3523	3.4	51.55	-0.1	-25.76	-352	-90752
VA	85	81	3.2	23.18	0.1	2.61	8	211
US	**13,700**	**10,589**	**4.92**	**45.21**	**-1.32**	**-25.09**	**-13,934**	**-265,662**

[1]Average herbicide use in RR cotton = 3.3 lb ai/A (from Table 5.3a)
[2]Average cost of weed management program in RR cotton = $25.79/A (from Table 5.3a)

Table 5.4b. Impacts of glufosinate-resistant (Liberty Link/LL) cotton on herbicide use and weed management costs in 2004

State	Planted acreage	LL acres	Conventional program		Impacts on		Aggregate impacts on	
	000A	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	550	0.7	4.1	47.45	-1.13	-6.43	-0.8	-4.5
AZ	220	0.1	5.4	56.61	-2.43	-15.59	-0.2	-1.6
AR	950	1.0	4.2	45.82	-1.23	-4.80	-1.2	-4.8
CA	560	0.0	6.1	46.79	-3.13	-5.77	0.0	0.0
FL	105	0.0	5.0	31.35	-2.03	9.67	0.0	0.0
GA	1330	6.0	5.6	58.30	-2.63	-17.28	-15.8	-103.7
KS	120	0.0	5.9	44.42	-2.93	-3.40	0.0	0.0
LA	500	0.9	5.3	50.17	-2.33	-9.15	-2.1	-8.2
MS	1100	21.5	6.1	47.70	-3.13	-6.68	-67.3	-143.6
MO	400	3.7	6.3	47.56	-3.33	-6.54	-12.3	-24.2
NM	60	0.0	4.5	23.39	-1.53	17.63	0.0	0.0
NC	720	5.0	5.1	55.71	-2.13	-14.69	-10.7	-73.5
OK	190	0.7	3.2	23.00	-0.23	18.02	-0.2	12.6
SC	240	0.6	4.9	51.77	-1.93	-10.75	-1.2	-6.5
TN	570	2.4	5.3	63.75	-2.33	-22.73	-5.6	-54.6
TX	6000	106.8	3.4	51.55	-0.43	-10.53	-45.9	-1124.6
VA	85	2.5	3.2	23.18	-0.23	17.84	-0.6	44.6
US	**13,700**	**151.9**	**4.92**	**45.21**	**-1.08**	**-9.83**	**-163.9**	**-1,492.6**

[1]Average herbicide use in LL cotton = 2.97 lb ai/A (Table 5.3b)
[2]Average cost of weed management program in LL cotton = $41.02/A (Table 5.3b)

Table 5.4c. Impacts of bromoxynil-resistant (BXN) cotton on herbicide use and weed management costs in 2004

State	Planted acreage	BXN acres	Conventional program		Impacts on		Aggregate impacts on	
	000A	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	550	0.0	4.1	47.45	-0.4	-14.13	0.0	0.0
AZ	220	6.0	5.4	56.61	-1.7	-23.29	-10.2	-139.7
AR	950	8.0	4.2	45.82	-0.5	-12.50	-4.0	-100.0
CA	560	10.0	6.1	46.79	-2.4	-13.47	-24.0	-134.7
FL	105	0.0	5.0	31.35	-1.3	1.97	0.0	0.0
GA	1330	0.0	5.6	58.30	-1.9	-24.98	0.0	0.0
KS	120	0.0	5.9	44.42	-2.2	-11.10	0.0	0.0
LA	500	0.0	5.3	50.17	-1.6	-16.85	0.0	0.0
MS	1100	0.0	6.1	47.70	-2.4	-14.38	0.0	0.0
MO	400	2.0	6.3	47.56	-2.6	-14.24	-5.2	-28.5
NM	60	0.0	4.5	23.39	-0.8	9.93	0.0	0.0
NC	720	0.2	5.1	55.71	-1.4	-22.39	-0.3	-4.5
OK	190	0.0	3.2	23.00	0.5	10.32	0.0	0.0
SC	240	0.0	4.9	51.77	-1.2	-18.45	0.0	0.0
TN	570	0.0	5.3	63.75	-1.6	-30.43	0.0	0.0
TX	6000	4.2	3.4	51.55	0.3	-18.23	1.3	-76.6
VA	85	0.0	3.2	23.18	0.5	10.14	0.0	0.0
US	**13,700**	**30.4**	**4.92**	**45.21**	**-1.39**	**-15.92**	**-42.4**	**-484.0**

[1]Average herbicide use in BXN cotton = 3.7 lb ai/A (Table 5.3c)
[2]Average cost of weed management program in BXN cotton = $33.32/A (Table 5.3c)

Table 5.5. Overall impact[1] of herbicide-resistant cotton on herbicide use and weed management costs in 2004

State	Total HR Acreage	Impacts on	
	000 A	Herbicide use 000 lb	Weed management costs 000 $
AL	512	-410	-11073
AZ	162	-338	-4949
AR	944	-847	-18833
CA	288	-802	-5973
FL	97	-165	-539
GA	1267	-2916	-41099
KS	116	-302	-2161
LA	495	-990	-12052
MS	1095	-3071	-23653
MO	382	-1146	-8239
NM	30	-36	72
NC	691	-1246	-20603
OK	179	18	510
SC	239	-382	-6190
TN	558	-1118	-21161
TX	3634	-397	-91953
VA	84	7	256
US	**10,773**	**-14,141**	**-267,640**

[1]Includes the impacts of Roundup Ready, Liberty Link, and BXN cotton, together

Table 5.6. Impact of herbicide-resistant (HR) cotton on other weed management costs in 2004

State	HR cotton Adoption		Tillage		Herbicide Application		Handweeding		
	%	000A	#/A[1]	000$[2]	Trips/A[3]	000$[4]	000A[5]	Hours/A[6]	000$[7]
AL	93	512	-2.0	-4608	0	0	39	-1.0	-359
AZ	74	162	-2.5	-1823	-1	-648	44	-4.0	-1619
AR	99	944	-1.0	-4248	-2	-7552	380	-2.0	-6992
CA	52	288	-2.5	-3240	-1	-1152	288	-8.0	-21197
FL	92	97	-2.0	-873	0	0	0	0.0	0
GA	95	1267	-1.0	-5702	-1	-5068	67	-2.5	-1541
KS	96	116	-1.0	-522	-2	-928	12	-2.0	-221
LA	99	495	-1.0	-2228	-1	-1980	75	-2.5	-1725
MS	100	1095	-1.0	-4928	-1	-4380	110	-2.5	-2530
MO	95	382	-1.0	-1719	-1	-1528	80	-2.5	-1840
NM	49	30	-3.0	-405	0	0	0	0.0	0
NC	96	691	-2.5	-7774	-2	-5528	7	-1.0	-64
OK	94	179	-1.0	-806	0	-0	4	-6.0	-221
SC	99	239	-2.5	-2689	-2	-1912	24	-1.0	-221
TN	98	558	-1.0	-2511	-1	-2232	57	-2.5	-1311
TX	61	3634	-1.0	-16353	0	-0	900	-1.5	-12420
VA	98	84	-2.5	-945	-1	-336	0	0.0	0
US	**79**	**10,773**	**-1.7**	**-61,374**	**-1.0**	**-33,244**	**2,087**	**-2.3**	**-52,261**

[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 $9.20/hr (based on farm labor wage rates reported by NASS) of handweeding times the number of acres on which handweeding is estimated reduced

Table 5.7. Adoption costs[1] of herbicide-resistant (HR) cotton in 2004

State	Total HR cotton Acreage	Glyphosate-resistant cotton acreage	Adoption costs of glyphosate-resistant cotton	Glufosinate-resistant cotton acreage	Adoption costs of glufosinate-resistant cotton	Bromoxynil-resistant cotton acreage	Adoption costs of bromoxynil-resistant cotton	Total adoption costs of HR cotton
	000A	000A	000$	000A	000$	000 A	000$	000$
AL	512	511	7154	0.7	10	0.0	0	7164
AZ	162	156	2184	0.1	1	6.0	42	2227
AR	944	935	13090	1.0	14	8.0	56	13160
CA	288	278	3892	0.0	0	10.0	70	3962
FL	97	97	1358	0.0	0	0.0	0	1358
GA	1267	1261	17654	6.0	84	0.0	0	17738
KS	116	116	1624	0.0	0	0.0	0	1624
LA	495	494	6916	0.9	13	0.0	0	6929
MS	1095	1073	15022	21.5	301	0.0	0	15323
MO	382	376	5264	3.7	52	2.0	14	5330
NM	30	30	420	0.0	0	0.0	0	420
NC	691	686	9604	5.0	70	0.2	1	9675
OK	179	178	2492	0.7	10	0.0	0	2502
SC	239	238	3332	0.6	8	0.0	0	3340
TN	557	556	7784	2.4	34	0.0	0	7818
TX	3634	3523	49322	106.8	1495	4.2	29	50846
VA	84	81	1134	2.5	35	0.0	0	1169
US	**10,772**	**10,589**	**148,246**	**151.9**	**2,127**	**30.4**	**212**	**150,585**

[1]Assumptions on adoption costs are based on surveys of Extension Specialists and chemical company representatives; technology fee for glyphosate-resistant = $14.00/acre; there is no technology fee for Liberty Link and bromoxynil-resistant cotton; however, seed premium costs for Liberty Link and bromoxynil-resistant cotton are $14.00 and $7.00 per acre, respectively

Table 5.8. Summary of weed management cost changes in cotton due to biotechnology-derived herbicide-resistant varieties in 2004[1]

State	Herbicide costs	Application costs	Adoption costs	Tillage costs	Hand weeding costs	Total
	000$/year					
AL	-11073	0	7164	-4608	-359	-8876
AZ	-4949	-648	2227	-1823	-1619	-6812
AR	-18833	-7552	13160	-4248	-6992	-24465
CA	-5973	-1152	3962	-3240	-21197	-27600
FL	-539	0	1358	-873	0	-54
GA	-41099	-5068	17738	-5702	-1541	-35672
KS	-2161	-928	1624	-522	-221	-2208
LA	-12052	-1980	6929	-2228	-1725	-11056
MS	-23653	-4380	15323	-4928	-2530	-20168
MO	-8239	-1528	5330	-1719	-1840	-7996
NM	72	0	420	-405	0	87
NC	-20603	-5528	9675	-7774	-64	-24294
OK	510	0	2502	-806	-221	1985
SC	-6190	-1912	3340	-2689	-221	-7672
TN	-21161	-2232	7818	-2511	-1311	-19397
TX	-91953	0	50846	-16353	-12420	-69880
VA	256	-336	1169	-945	0	144
US	**-267,640**	**-33,244**	**150,585**	**-61,374**	**-52,261**	**-263,934**

[1]Compiled based on data from Tables 5.5, 5.6, and 5.7

Table 5.9. Impact of biotechnology-derived herbicide-resistant 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
2004	2.40	18	371

Source: Conservation Technology Information Center

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6. Soybean

Nearly 85% of the US soybean acreage in 2004 was planted to biotechnology-derived herbicide-resistant varieties (Table 6.1). Planted acreage of herbicide-resistant soybean increased by 4.62 million acres or 8% in 2004 compared with 2003. The adoption of herbicide-resistant soybean leaped from 7% to 85% between 1996 (the first year of commercial planting) and 2004, denoting the most rapid adoption of any new agricultural technology.

All the thirty-one states analyzed in this report planted at least 75% or more of their soybean acres to biotechnology-derived herbicide-resistant varieties in 2004 (Table 6.1). While adoption in twenty-eight states exceeded 80%, thirteen states had an adoption rate of over 90%. Adoption of herbicide-resistant soybean was greatest in Florida (99%) followed by Alabama (95%), South Dakota (95%), and West Virginia (95%). However, number of acres planted to biotechnology-derived soybean in 2004 was highest in Iowa (8.7 million acres) followed by Illinois (8.1 million acres).

The simplicity, flexibility, safety, and economics of the weed management program based on glyphosate has positively influenced the adoption of herbicide-resistant soybean in the United States in 2004, similar to years before. Using glyphosate as the primary herbicide in soybean, growers realized greater flexibility in timing herbicide applications, simplicity with less confusion of herbicide mixes and rates, effective control of perennial and other problem weeds, excellent crop safety, and economic weed control. For these reasons, adoption of glyphosate-resistant soybean has been rapid than any other new technologies in the history of agriculture.

Herbicides used for weed management in soybean along with their costs are presented in Table 6.2. A survey of soybean specialists offered many different weed management programs that could be used in conventional soybean. The most typical of these programs, which could provide weed control equivalent to that of glyphosate in herbicide-resistant soybean, is presented in Table 6.3. A majority of these programs in conventional soybean featured a preemergence application (using 1 – 2 herbicides) followed by one postemergence application (with 1 – 2 herbicides). On the other hand, herbicide applications in glyphosate-resistant soybean were comprised of one timely application of glyphosate alone at 0.95 lb ai/A in most states (Table 6.4). In only 3 states

(Mississippi, Ohio, and Tennessee), 2 applications of glyphosate (at 0.75 or 0.95 lb ai/A each) were routinely used in glyphosate-resistant soybean.

Comparative herbicide use rates and associated costs for weed management in conventional and herbicide-resistant soybean are presented in Table 6.4. Weed management costs associated with glyphosate-resistant soybean are presented in Table 6.5. Weed management costs included seed premium costs of $8/acre. There has been a slight increase (14%) in seed premium costs in 2004 compared with 2003. Table 6.6 represents changes in herbicide applications along with resulting grower cost savings due to glyphosate-resistant soybean in 2004. Analysis indicated that soybean growers that planted glyphosate-resistant varieties reduced the overall number of herbicide applications by 0.4 million, which translated to cost savings of $187 million.

The aggregate impacts of replacing herbicide programs in conventional soybean with glyphosate-based programs are simulated in Table 6.7. On average, glyphosate-resistant soybean programs used 1.03 lb ai/A at a cost of $18.38 per acre in 2004. Conventional herbicide programs, on the other hand, used an additional 0.35 lb ai/A or 25% more herbicide active ingredients at an additional cost of $21.42. Overall, American soybean growers saved $1.37 billion on weed management costs due to a switch to glyphosate programs in 2004, in spite of added costs due to seed premiums. This represents a further reduction in weed management costs of 14% than that noted in 2003. Additionally, soybean growers have reduced herbicide use by 0.35 lb ai per acre or 22.4 million pounds nationally in 2004.

A significant impact of the adoption of herbicide-resistant soybean is an increase in no-till acreage. In 1995, one year before the commercialization of glyphosate- resistant soybean, approximately 27% of the total full-season soybean acres in the United States were under no-till production (Table 6.8). With the increasing acreage of glyphosate-resistant soybean, no-till acres also are on the rise. By 2004, about 36% of the total soybean acreage in the United States was planted using no-tillage production practices (Conservation Technology Information Center). This represents a 64% increase in the no-till soybean acreage since the introduction of glyphosate- resistant 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-resistant (RR) soybean in the United States in 2004

State	Area harvested[1] 000A	RR adoption %	RR acres 000A	Source[1, 2]
AL	210	95	200	Burmester
AR	3200	92	2944	NASS
DE	210	85	179	VanGessel
FL	19	99	19	Brecke
GA	280	90	252	Prostko
IL	9950	81	8060	NASS
IN	5550	87	4829	NASS
IA	10200	85	8670	Owen
KS	2800	87	2436	NASS
KY	1310	82	1074	Helmkamp
LA	1100	90	990	Ferguson
MD	500	90	450	Kenworthy
MI	2000	75	1500	NASS
MN	7300	82	5986	NASS
MS	1670	90	1503	Shaw
MO	5000	92	4600	NASS
NE	4800	92	4416	NASS
NJ	105	85	89	Majek
NY	175	82	144	Blackson
NC	1530	85	1301	York
ND	3750	75	2813	Zollinger
OH	4450	76	3382	NASS
OK	320	90	288	Ballard
PA	430	84	361	Curran
SC	540	87	470	Pavlisek
SD	4150	95	3943	NASS
TN	1210	90	1089	Hayes
TX	290	85	247	Chittendon
VA	540	82	443	Zobell
WV	19	95	18	Chandran
WI	1600	82	1312	NASS
Total	**75,208**	**85**	**64,008**	

[1]Source: National Agricultural Statistics Service: 2005 Acreage
[2]Affiliations for the Crop Specialists that provided the soybean adoption information are listed in the References section

Table 6.2. Use rates and costs for soybean herbicides in 2004

Trade name	Common Name	Rate (formulated product/A)	Rate (Lb ai/A)	Cost[1] ($/A)
Assure II	Quizalofop	8 oz	0.1	8.43
Authority	Sulfentrazone	4 oz	0.19	6.95
Boundary	Metribuzin + s-Metolachlor	1.25 pt	1.22	12.56
Canopy	Chlorimuron + Metribuzin	4 oz	0.19	7.79
Canopy XL	Sulfentrazone + Chlorimuron	6 oz	0.21	11.62
Classic	Chlorimuron	0.67 oz	0.01	8.84
Dual II Magnum	S-Metolachlor	1.5 pt	1.43	20.64
FirstRate	Cloransulam methyl	0.3 oz	0.016	8.10
Flexstar	Fomesafen	1 pt	0.24	12.81
Fusion	Fluazifop + Fenoxaprop	10 oz	0.21	11.75
Gangster	Flumioxazin + Cloransulam methyl	2.4 oz	0.08	14.35
Harmony Extra	Thifensulfuron	0.5 oz	0.024	6.43
Poast	Sethoxydim	1.0 pt	0.19	8.61
Prowl	Pendimethalin	3.6 pt	1.5	9.72
Pursuit	Imazethapyr	1.44oz	0.063	16.49
Pursuit Plus	Imazethapyr + Pendimethalin	2.5 pt	0.94	16.07
Python	Flumetsulam	1.0 oz	0.053	9.8
Raptor	Imazamox	5 oz	0.039	20.8
Reflex	Fomesafen	1.5 pt	0.375	17.76
Scepter	Imazaquin	2.8 oz	0.12	8.14
Select	Clethodim	8 oz	0.125	11.77
Sencor	Metribuzin	0.5 lb	0.38	10.38
Squadron	Imazaquin + Pendimethalin	3 pt	0.88	13.84
Storm	Acifluorfen + Bentazon	1.5 pt	0.75	16.20
Synchrony	Chlorimuron + Thifensulfuron	0.5 oz	0.013	5.16
Treflan	Trifluralin	2.0 pt	1.0	6.75
Ultra blazer	Acifluorfen	1.5 pt	0.375	12.84
Roundup WeatherMAX	Glyphosate	22 oz	0.95	9.57

[1]Herbicide costs were calculated based on the 2004 Herbicide Price List compiled by the University of Tennessee. The Herbicide Price List price list can be accessed from http://weeds.utk.edu/05Rcmanual/Price list.pdf

Table 6.3. 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 II	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 II	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 + Ultra Blazer	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 for 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-resistant (Roundup Ready) and conventional soybean[1]

State	Glyphosate-resistant soybean		Conventional soybean	
	$/A	lb ai/A	$/A	lb ai/A
AL	17.57	0.95	41.81	1.76
AR	17.57	0.95	41.81	1.76
DE	17.57	0.95	45.45	1.92
FL	17.57	0.95	28.94	1.89
GA	17.57	0.95	25.97	1.39
IL	17.57	0.95	37.12	1.67
IN	17.57	0.95	53.33	2.24
IA	17.57	0.95	37.14	1.59
KS	17.57	0.95	32.43	1.36
KY	17.57	0.95	23.39	0.34
LA	17.57	0.95	41.81	1.76
MD	17.57	0.95	32.26	1.64
MI	17.57	0.95	32.86	0.55
MN	17.57	0.95	42.07	1.81
MS	27.14	1.90	41.81	1.76
MO	17.57	0.95	37.12	1.67
NE	17.57	0.95	28.91	1.32
NJ	17.57	0.95	32.26	1.64
NY	17.57	0.95	40.82	1.86
NC	17.57	0.95	27.97	0.83
ND	17.57	0.95	33.61	0.28
OH	27.14	1.90	36.20	0.58
OK	17.57	0.95	37.12	1.67
PA	17.57	0.95	32.26	1.64
SC	17.57	0.95	25.37	0.13
SD	17.57	0.95	26.82	0.33
TN	22.36	1.43	38.42	1.25
TX	17.57	0.95	41.08	3.00
VA	17.57	0.95	32.26	1.64
WV	17.57	0.95	32.26	1.64
WI	17.57	0.95	33.64	0.41

[1]Roundup Ready program costs = Seed costs + herbicide program costs; Roundup Ready seed premium costs = $8/A; Cost of Roundup WeatherMax = $9.57/ 0.95lb ai; herbicide applications in glyphosate-tolerant soybean comprised of one timely application of glyphosate at 0.95 lb ai/A or 2 applications of 0.72 or 0.95 lb ai/A each. Alternative program costs and rates are calculated based on Tables 6.2 and 6.3

Table 6.5. Production costs associated with glyphosate-resistant (RR) soybean in 2004

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$	000$	$/A
AL	200	0.95	190	1600	1914	3514	17.57
AR	2944	0.95	2797	23552	28174	51726	17.57
DE	179	0.95	170	1432	1713	3145	17.57
FL	19	0.95	18	152	182	334	17.57
GA	252	0.95	239	2016	2412	4428	17.57
IL	8060	0.95	7657	64480	77134	141614	17.57
IN	4829	0.95	4588	38632	46214	84846	17.57
IA	8670	0.95	8237	69360	82972	152332	17.57
KS	2436	0.95	2314	19488	23313	42801	17.57
KY	1074	0.95	1020	8592	10278	18870	17.57
LA	990	0.95	941	7920	9474	17394	17.57
MD	450	0.95	428	3600	4307	7907	17.57
MI	1500	0.95	1425	12000	14355	26355	17.57
MN	5986	0.95	5687	47888	57286	105174	17.57
MS	1503	1.90	2856	12024	28767	40791	27.14
MO	4600	0.95	4370	36800	44022	80822	17.57
NE	4416	0.95	4195	35328	42261	77589	17.57
NJ	89	0.95	85	712	852	1564	17.57
NY	144	0.95	137	1152	1378	2530	17.57
NC	1301	0.95	1236	10408	12451	22859	17.57
ND	2813	0.95	2672	22504	26920	49424	17.57
OH	3382	1.90	6426	27056	64731	91787	27.14
OK	288	0.95	274	2304	2756	5060	17.57
PA	361	0.95	343	2888	3455	6343	17.57
SC	470	0.95	447	3760	4498	8258	17.57
SD	3943	0.95	3746	31544	37735	69279	17.57
TN	1089	1.43	1557	8712	15633	24345	22.36
TX	247	0.95	235	1976	2364	4340	17.57
VA	443	0.95	421	3544	4240	7784	17.57
WV	18	0.95	17	144	172	316	17.57
WI	1312	0.95	1246	10496	12556	23052	17.57
Total	**64,008**	**1.03**	**65,974**	**512,064**	**664,519**	**1,176,583**	**18.38**

[1]Calculated at $8/A
[2]Calculated at $9.57/ 0.95 lb ai/A

Table 6.6. Reduction in herbicide applications and application costs due to glyphosate-resistant (RR) soybean

State	RR soybean acreage	Herbicide applications in conventional soybean[1]	Herbicide applications in RR soybean[2]	Reduction in herbicide applications in RR soybean	Application cost savings due to RR soybean
	000A	#/acre	#/acre	#/acre	000$[3]
AL	200	2	1	1	800
AR	2944	2	1	1	11776
DE	179	2	1	1	716
FL	19	2	1	1	76
GA	252	2	1	1	1008
IL	8060	2	1	1	32240
IN	4829	2	1	1	19316
IA	8670	2	1	1	34680
KS	2436	2	1	1	9744
KY	1074	2	1	1	4296
LA	990	2	1	1	3960
MD	450	1	1	0	0
MI	1500	2	1	1	6000
MN	5986	2	1	1	23944
MS	1503	2	2	0	0
MO	4600	2	1	1	18400
NE	4416	1	1	0	0
NJ	89	1	1	0	0
NY	144	1	1	0	0
NC	1301	1	1	0	0
ND	2813	1	1	0	0
OH	3382	2	2	0	0
OK	288	2	1	1	1152
PA	361	1	1	0	0
SC	470	2	1	1	1880
SD	3943	2	1	1	15772
TN	1089	2	2	0	0
TX	247	2	1	1	988
VA	443	1	1	0	0
WV	18	1	1	0	0
WI	1312	1	1	0	0
Total	**64,008**	**1.68**	**1.10**	**0.58**	**186,748**

[1]Data from Table 6.3
[2]Data from Table 6.4
[3]Herbicide application costs = $4.00/acre

Table 6.7. Aggregate impacts of glyphosate-resistant (RR) soybean in 2004

	RR soybean acreage	Changes in			
State		**Production costs**		**Herbicide use**	
	000A	$/A	000$[1]	lb ai/A	000 lb
AL	200	-28.24	-5648	-0.81	-162
AR	2944	-28.24	-83139	-0.81	-2385
DE	179	-31.88	-5707	-0.97	-174
FL	19	-15.37	-292	-0.94	-18
GA	252	-12.4	-3125	-0.44	-111
IL	8060	-23.55	-189813	-0.72	-5803
IN	4829	-39.76	-192001	-1.29	-6229
IA	8670	-23.57	-204352	-0.64	-5549
KS	2436	-18.86	-45943	-0.41	-999
KY	1074	-9.82	-10547	0.61	655
LA	990	-28.24	-27958	-0.81	-802
MD	450	-14.69	-6611	-0.69	-311
MI	1500	-19.29	-28935	0.40	600
MN	5986	-28.5	-170601	-0.86	-5148
MS	1503	-14.67	-22049	0.14	210
MO	4600	-23.55	-108330	-0.72	-3312
NE	4416	-11.34	-50077	-0.37	-1634
NJ	89	-14.69	-1307	-0.69	-61
NY	144	-23.25	-3348	-0.91	-131
NC	1301	-10.4	-13530	0.12	156
ND	2813	-16.04	-45121	0.67	1885
OH	3382	-9.06	-30641	1.32	4465
OK	288	-23.55	-6782	-0.72	-207
PA	361	-14.69	-5303	-0.69	-249
SC	470	-11.8	-5546	0.82	385
SD	3943	-13.25	-52245	0.62	2445
TN	1089	-16.06	-17489	0.18	196
TX	247	-27.51	-6795	-2.05	-506
VA	443	-14.69	-6508	-0.69	-306
WV	18	-14.69	-264	-0.69	-12
WI	1312	-16.07	-21084	0.54	708
Total	**64,008**	**-21.42**	**-1,371,091**	**-0.35**	**-22,404**

[1]Includes cost savings due to herbicide use (Table 6.5) and herbicide application (Table 6.6)

Table 6.8. Trends in no-till full-season soybean acreage in the United States[a]

U.S. soybean acreage	1995	1996	1997	1998	2000	2002	2004
.	------------------------------- Million acres --------------------------------------						
Total	58.8	60.6	65.1	66.6	70.0	69.8	71.42
No-till	15.9	16.2	17.9	19.0	21.5	23.1	26.02
No till as a % of total	27	27	28	29	31	33	36
% Increase in no-till acreage	-	2	13	20	35	45	64

[a]Data is not available for 1999

Source: Conservation Technology Information Center

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Insect-resistant crops

Three applications of Bt corn (YieldGard Corn Borer, Herculex I, and YieldGard Rootworm) and 2 applications of Bt cotton (Bollgard and Bollgard II) were in commercial production in 2004, as in 2003. Since the first planting of insect-resistant/Bt crops, growers noted that the most substantial impact of has been improvement in crop yields. Unlike conventional insecticides, Bt crops offered in-built, season-long, and enhanced pest protection, which translated to gained yields. Another significant impact of insect-resistant crops has been the reduction in insecticide use targeted for key pests because Bt crops eliminate the need for insecticide applications. Reduction in overall insecticide use and number of insecticide sprays has led to a reduction in overall input costs for the adopters of Bt crops. Other benefits from Bt crops include reduced scouting needs, pesticide exposure to applicators, and energy use. The agronomic and economic impacts from Bt corn and cotton for 2004 crop season are analyzed and discussed in the following case studies.

7. Corn borer-resistant corn (YieldGard Corn Borer & Herculex I/IR-I)

Biotechnology-derived corn borer-resistant corn was planted on 22.4 million acres in 2004 (Table 7.1). This represents an adoption of 28% across the country. Adoption was highest in New Jersey at 53% followed by Nebraska (47%). Iowa, at 4.3 million acres, has the largest planted acreage of corn borer-resistant corn in 2004 (Table 7.1).

Two varieties of biotechnology-derived corn offered protection against European corn borer (ECB) and southwestern corn borer (SWCB) in 2004, similar to 2003. These include YieldGard Corn Borer and Herculex I. While YieldGard Corn Borer corn was planted on roughly 21 million acres in 2004, Herculex I corn was planted on about 1.5 million acres in 2004 (Table 7.2). Thus, YieldGard Corn Borer and Herculex I corn represented 93 and 7%, respectively, of the total acreage planted to corn borer-resistant varieties in 2004. Adoption of Herculex I corn increased 341% since 2003, while YieldGard Corn Borer acres remained the same during this period.

Case study 7 represents the impacts due to ECB and SWCB control from YieldGard Corn Borer and Herculex I. Impacts from YieldGard Corn Borer and Herculex I were calculated together in view of their target pests, ECB and SWCB. Bt corn impact estimates for 2004 were calculated using the same methodology used in our earlier reports. 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 2001 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 costs based on current adoption of Bt corn during a 'low' and' high' borer infestation year. These estimates compare impacts of Bt corn adoption to an untreated situation where insecticides are not used for borer control. Growers who planted Bt 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 acreage is estimated to range between 106 and 327 million bushels during a low and high year, respectively. In 2004, Bt corn borer technology cost was $9/A and a bushel of corn was valued at $2.45. Thus, the total value of the increased production is estimated to be $259 and $801 million in a low and high year, respectively. Subtracting the technology fee costs, the net benefit of planting Bt corn was estimated to be $58 and $600 million or $2.58 and $26.82 per acre in low and high years, respectively.

Simulations involving the use of insecticides on current Bt corn acreage are presented in Table 7.5. This table shows state-by-state estimates of potential per acre yield and value 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 net economic returns in all the states in 2004. Insecticide use analysis in a high year indicated that 8.5 million pounds of insecticide will be used and net income would increase by $328 million.

The impacts of the adoption of Bt 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 (Table 7.4). For high infestation years, the impact of Bt corn is calculated as the difference between volume, value and cost resulting from the planting of Bt corn (Table 7.4) minus the amounts that would result from use of insecticides (Table 7.5). Thus in a high year, growers gain an extra 20% yield from Bt corn which they would not gain from using insecticides. Bt 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 adoption during a typical year is calculated as the difference between the increase in production value and the increase in production costs.

Based on the planted acreage of 22.4 million acres in 2004, it was calculated that Bt corn resulted in an increased production of 88.3 million bushels or 4.95 billion pounds of corn valued at $216 million. Net returns due to Bt corn were estimated to be $156 million. Without the use of Bt corn, approximately 3.83 million additional pounds of insecticides would be used in a typical year. The above estimates imply that corn growers produced 6% more yields, lowered insecticide use by 6%, and increased monetary gains by 6% in 2004, compared to 2003, due to expanded Bt acreage in 2004.

Based on 93 and 7% acreage contribution of the YieldGard Corn Borer and Herculex I, respectively, to the total Bt corn acres planted in 2004, it was determined that the YieldGard Corn Borer and Herculex I corn varieties increased the production volume by 4.6 and 0.35 billion pounds, respectively in 2004. The use of YieldGard Corn Borer resulted in 3.6 million pounds reduction in insecticide use, while the use of Herculex I resulted in a 0.3million pound reduction.

Table 7.1. Adoption of Bt corn resistant to corn borers in 2004

State	Planted acres[1]	Bt acreage[2,3]	Adoption of Bt corn[2]
	000A	Acres	%
AL	220	22867	10
AR	320	90521	28
AZ	53	16147	31
CO	1200	365821	31
DE	160	62325	39
GA	335	12844	4
ID	230	3404	2
IL	11750	2988168	25
IN	5700	403666	7
IA	12700	4294896	34
KS	3100	1097766	35
KY	1210	166780	14
LA	420	82775	20
MD	490	166207	34
MI	2200	497119	23
MN	7500	2628682	35
MS	460	26842	6
MO	2950	863666	29
MT	70	11050	16
NE	8250	3900987	47
NJ	86	45435	53
NM	125	13767	11
NY	980	64865	7
NC	820	47151	6
ND	1800	698725	39
OH	3350	245280	7
OK	250	22541	9
PA	1400	279120	20
SD	4650	1856100	40
TN	680	170499	25
TX	1830	377620	21
VA	500	78127	16
VT	95	13796	1
WA	170	5234	3
WI	3600	729246	20
Total	**79,654**	**22,350,039**	**28.0**

[1]Source: National Agricultural Statistics Service. 2005 Acreage
[2]Includes YieldGard Corn Borer and Herculex I corn
[3]YieldGard Corn Borer and Herculex I acreage adoption information in the United States is based on Doane Marketing Research, Inc.'s 2004 estimates

Table 7.2. Adoption of Herculex I (Cry1F) corn in the US in 2004

State	Adoption	Adoption as a % of total planted acres	Adoption as a % of Bt acres[1]
	Acres	%	%
CO	40835	3.4	11.2
IL	56168	0.5	1.9
IN	14802	0.3	3.7
IA	363711	2.9	8.5
KS	90054	2.9	8.2
KY	1842	0.2	1.1
MI	2388	0.1	0.5
MN	250944	3.4	9.6
MO	101737	3.5	11.8
NE	356175	4.3	9.1
NY	4568	0.5	7.0
ND	29455	1.6	4.2
OH	13458	0.4	5.5
PA	4342	0.3	1.6
SD	50437	1.1	2.7
TX	35094	1.9	9.3
WI	41430	1.2	5.7
Total	**1,457,440**	**2.0**	**6.5**

[1]Includes YieldGard Corn Borer and Herculex I
Source: Doane Marketing Research, Inc

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
ID[3]	7.0	23.0	5	5
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
MT[3]	5.0	11.0	7	3
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
WA[3]	5.0	11.0	7	3
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

[3]Based on assumptions from neighboring corn producing states

Table 7.4. Aggregate impacts of Bt 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*
	A	Bu/A		000 Bu/Year		$/A		000$/Year		000 $/Year	000 $/Year	
AL	22867	0.0	8.0	0	183	0.00	19.60	0	448	206	-206	242
AR	90521	5.0	30.0	453	2716	12.25	73.50	1109	6653	815	294	5838
AZ	16147	7.0	23.0	113	371	17.15	56.35	277	910	145	132	765
CO	365821	7.0	23.0	2561	8414	17.15	56.35	6274	20614	3292	2982	17322
DE	62325	3.9	11.2	243	698	9.56	27.44	596	1710	561	35	1149
GA	12844	5.0	11.0	64	141	12.25	26.95	157	346	116	41	230
ID	3404	7.0	23.0	24	78	17.15	56.35	58	192	31	27	161
IL	2988168	4.0	10.0	11953	29882	9.80	24.50	29284	73210	26894	2390	46316
IN	403666	3.0	7.0	1211	2826	7.35	17.15	2967	6923	3633	-666	3290
IA	4294896	5.0	11.0	21474	47244	12.25	26.95	52612	115747	38654	13958	77093
KS	1097766	5.0	40.0	5489	43911	12.25	98.00	13448	107581	9880	3568	97701
KY	166780	2.2	18.9	367	3152	5.39	46.31	899	7723	1501	-602	6222
LA	82775	4.0	30.0	331	2483	9.80	73.50	811	6084	745	66	5339
MD	166207	8.0	26.0	1330	4321	19.60	63.70	3258	10587	1496	1762	9091
MI	497119	4.0	12.0	1988	5965	9.80	29.40	4872	14615	4474	398	10141
MN	2628682	4.5	13.0	11829	34173	11.03	31.85	28994	83724	23658	5336	60066
MS	26842	2.5	5.5	67	148	6.13	13.48	165	362	242	-77	120
MO	863666	5.0	30.0	4318	25910	12.25	73.50	10580	63479	7773	2807	55706
MT	11050	5.0	11.0	55	122	12.25	26.95	135	298	99	36	199
NE	3900987	5.0	11.0	19505	42911	12.25	26.95	47787	105132	35109	12678	70023
NJ	45435	5.0	9.0	227	409	12.25	22.05	557	1002	409	148	593
NM	13767	7.0	23.0	96	317	17.15	56.35	236	776	124	112	652
NY	64865	3.0	11.0	195	714	7.35	26.95	477	1748	584	-107	1164
NC	47151	5.0	11.0	236	519	12.25	26.95	578	1271	424	154	847
ND	698725	5.0	11.0	3494	7686	12.25	26.95	8559	18831	6289	2270	12542
OH	245280	2.0	12.0	491	2943	4.90	29.40	1202	7211	2208	-1006	5003
OK	22541	8.0	18.0	180	406	19.60	44.10	442	994	203	239	791
PA	279120	3.3	11.5	921	3210	8.09	28.18	2258	7864	2512	-254	5352
SD	1856100	5.0	15.0	9281	27842	12.25	36.75	22737	68212	16705	6032	51507
TN	170499	5.0	11.0	852	1875	12.25	26.95	2089	4595	1534	555	3061
TX	377620	8.0	40.0	3021	15105	19.60	98.00	7401	37007	3399	4002	33608
VA	78127	3.0	15.0	234	1172	7.35	36.75	574	2871	703	-129	2168
VT	13796	3.0	11.0	41	152	7.35	26.95	101	372	124	-23	248
WA	5234	5.0	11.0	26	58	12.25	26.95	64	141	47	17	94
WI	729246	4.0	12.0	2917	8751	9.80	29.40	7147	21440	6563	584	14877
Total	**22,350,039**			**105,587**	**326,808**			**258,705**	**800,673**	**201,152**	**57,553**	**599,521**

[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	Total net value		Insecticide use
		Volume		Value					
	Acres	Bu/A[1]	000 Bu/Yr	$/A[2]	000 $/Yr	000 $/Yr[3]	$/A	000 $/Yr	Lb/Yr[4]
AL	22867	6.40	146	15.68	359	320	1.68	39	8689
AR	90521	24.00	2173	58.80	5323	1267	44.80	4056	34398
AZ	16147	18.40	297	45.08	728	226	31.08	502	6136
CO	365821	18.40	6731	45.08	16491	5121	31.08	11370	139012
DE	62325	8.96	558	21.95	1368	873	7.95	495	23684
GA	12844	8.80	113	21.56	277	180	7.56	97	4881
ID	3404	18.40	63	45.08	153	48	31.08	105	1294
IL	2988168	8.00	23905	19.60	58568	41834	5.60	16734	1135504
IN	403666	5.60	2261	13.72	5538	5651	-0.28	-113	153393
IA	4294896	8.80	37795	21.56	92598	60129	7.56	32469	1632060
KS	1097766	32.00	35129	78.40	86065	15369	64.40	70696	417151
KY	166780	15.12	2522	37.04	6178	2335	23.04	3843	63376
LA	82775	24.00	1987	58.80	4867	1159	44.80	3708	31455
MD	166207	20.80	3457	50.96	8470	2327	36.96	6143	63159
MI	497119	9.60	4772	23.52	11692	6960	9.52	4732	188905
MN	2628682	10.40	27338	25.48	66979	36802	11.48	30177	998899
MS	26842	4.40	118	10.78	289	376	-3.22	-87	10200
MO	863666	24.00	20728	58.80	50784	12091	44.80	38693	328193
MT	11050	8.80	97	21.56	238	155	7.56	83	4199
NE	3900987	8.80	34329	21.56	84105	54614	7.56	29491	1482375
NJ	45435	7.20	327	17.64	801	636	3.64	165	17265
NM	13767	18.40	253	45.08	621	193	31.08	428	5231
NY	64865	8.80	571	21.56	1398	908	7.56	490	24649
NC	47151	8.80	415	21.56	1017	660	7.56	357	17917
ND	698725	8.80	6149	21.56	15065	9782	7.56	5283	265516
OH	245280	9.60	2355	23.52	5769	3434	9.52	2335	93206
OK	22541	14.40	325	35.28	795	316	21.28	479	8566
PA	279120	9.20	2568	22.54	6291	3908	8.54	2383	106066
SD	1856100	12.00	22273	29.40	54569	25985	15.40	28584	705318
TN	170499	8.80	1500	21.56	3676	2387	7.56	1289	64790
TX	377620	32.00	12084	78.40	29605	5287	64.40	24318	143496
VA	78127	12.00	938	29.40	2297	1094	15.40	1203	29688
VT	13796	8.80	121	21.56	297	193	7.56	104	5242
WA	5234	8.80	46	21.56	113	73	7.56	40	1989
WI	729246	9.60	7001	23.52	17152	10209	9.52	6943	277113
Total	**22,350,039**		**261,445**		**640,536**	**312,902**		**327,634**	**8,493,015**

[1]Calculated at 80% of the increase attributed to Bt 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 adoption: typical year

State	# Years out of 10		Production volume increase			Production value increase			Production cost			Net value	Insecticide use[4]
	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	37	0	0	89	0	206	-114	206	-206	0
AR	5	5	453	543	498	1109	1330	1220	815	-452	182	1038	17199
AZ	5	5	113	74	94	277	182	230	145	-81	32	198	3068
CO	5	5	2561	1683	2122	6274	4123	5199	3292	-1829	732	4467	69506
DE	5	5	243	140	192	596	342	469	561	-312	125	344	11842
GA	9	1	64	28	60	157	69	148	116	-64	98	50	488
ID	5	5	24	15	20	58	39	49	31	-17	7	42	647
IL	5	5	11953	5977	8965	29284	14642	21963	26894	-14940	5977	15986	567752
IN	6	4	1211	565	953	2967	1385	2334	3633	-2018	1373	961	61357
IA	5	5	21474	9449	15462	52612	23149	37881	38654	-21475	8590	29291	816030
KS	5	5	5489	8782	7136	13448	21516	17482	9880	-5489	2196	15286	208576
KY	5	5	367	630	499	899	1545	1222	1501	-834	334	888	31688
LA	7	3	331	496	381	811	1217	933	745	-414	397	536	9436
MD	6	4	1330	864	1144	3258	2117	2802	1496	-831	565	2237	25263
MI	3	7	1988	1193	1432	4872	2923	3508	4474	-2486	-398	3906	132234
MN	6	4	11829	6835	9831	28994	16745	24094	23658	-13144	8937	15157	399560
MS	5	5	67	30	49	165	73	119	242	-134	54	65	5100
MO	5	5	4318	5182	4750	10580	12695	11638	7773	-4318	1728	9910	164097
MT	7	3	55	25	46	135	60	113	99	-56	53	60	1260
NE	7	3	19505	8582	16228	47787	21027	39759	35109	-19505	18725	21034	444713
NJ	3	7	227	82	126	557	201	308	409	-227	-36	344	12086
NM	5	5	96	64	80	236	155	196	124	-69	28	168	2616
NY	5	5	195	143	169	477	350	414	584	-324	130	284	12324
NC	2	8	236	104	130	578	254	319	424	-236	-104	423	14334
ND	7	3	3494	1537	2907	8559	3766	7121	6289	-3493	3354	3767	79655
OH	8	2	491	588	510	1202	1442	1250	2208	-1226	1521	-271	18641
OK	5	5	180	81	131	442	199	321	203	-113	45	276	4283
PA	7	3	921	642	837	2258	1573	2053	2512	-1396	1340	713	31820
SD	5	5	9281	5569	7425	22737	13643	18190	16705	-9280	3713	14477	352659
TN	7	3	852	375	709	2089	919	1738	1534	-853	818	920	19437
TX	2	8	3021	3021	3021	7401	7402	7402	3399	-1888	-831	8233	114796
VA	9	1	234	234	234	574	574	574	703	-391	594	-20	2969
VT	5	5	41	31	36	101	75	88	124	-69	28	60	2621
WA	7	3	26	12	22	64	28	53	47	-26	25	28	597
WI	3	7	2917	1750	2100	7147	4288	5146	6563	-3646	-583	5729	193979
Total:			**105,587**	**65,363**	**88,299**	**258,705**	**160,137**	**216,336**	**201,152**	**-111,750**	**59,955**	**156,381**	**3,832,633**

[1]Low: Aggregate increase from Bt 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. Corn borer/cutworm/armyworm-resistant corn (Herculex I/IR-II)

Biotechnology-derived insect-resistant Herculex I corn entered its second growing season in 2004. Herculex I corn was planted on nearly 1.5 million acres in 2004, accounting for approximately 2% of the total planted acreage and 7% of the Bt acreage planted to combat corn borer (Table 8.1). In its introductory year of 2003, Herculex I was planted on 0.47 million acres. By 2004, planted acreage increased by 208%. Iowa, Nebraska, and Minnesota planted about 66% of the total Herculex I acres in the United States in 2004.

Herculex I expresses the Cry1F insecticidal protein, a different protein from the one expressed by the YieldGard Corn Borer corn (Cry1Ab). The Herculex I corn offers similar protection against corn borers (European and southwestern) and corn earworm and also expands protection to include black cutworm, western bean cutworm, and fall armyworm (Babcock and Bing 2001; McLeod 2003).

Unlike black cutworm, western bean cutworm has become an increasingly problematic pest in certain states of the United States since 2000 (Rice 2003; Rice et al. 2004). 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. It is a difficult pest to scout for due to its sporadic flight pattern and the time of year it hits. Considerable damage already occurs by the time feeding is detected on corn ears.

Herculex I provided a reliable choice to corn growers facing challenges from western bean cutworm in 2004, a year when it was more prevalent than years before. The adoption of Herculex I corn increased dramatically in states such as Minnesota and Nebraska in 2004 (compared with 2003) mainly due to increasing prominence and economic levels of infestation of western bean cutworm in these states in recent years (Table 8.1).

Table 8.2 displays data on the economic and agronomic impact of Herculex I corn due to protection against western bean cutworm and black cutworm. The economic advantage of Herculex I resulted from the ability of farmers to avoid labor-intensive scouting, insecticide use, and costs related to insecticide sprays. Impacts are estimated to be incremental to those provided due to corn borer control (Case study 7). Impacts of

Herculex I corn on cutworm (black and western bean) 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 none or negligible.

In order to assess the incremental value of Herculex I corn on cutworm control, several assumptions were made. It was assumed that Herculex I corn was planted on acreage that is not currently treated with insecticides for cutworm control. Therefore, it was also assumed that growers would achieve improved yields and reduced insecticide use and related costs.

Previous research 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). Historic yield losses due to western bean cutworm were as high as 40% in Nebraska (Pope and Rice 2003). Based on the above, it was assumed that Herculex I corn would improve corn yields by at least 5% due to improved cutworm, both black and western bean, control. A 5% yield increase is a conservative estimate.

It was also assumed that Cry1F protein is as effective as the currently available foliar insecticides for cutworm. Labeled insecticides for cutworm control in corn include bifenthrin, chlorpyrifos, esfenvalerate, lambda-cyhalothrrin, permethrin, methyl parathion, cyfluthrin, zeta-cypermethrin, and carbaryl. 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; Parker 2004). A \$10 per acre treatment cost was assumed. The insecticide use reduction is calculated assuming current application rates of 0.20 lb/acre, which is the average of application rates for recommended foliar insecticides used for cutworm control.

It was also assumed that adoption costs for Herculex I (for cutworm control alone) in 2004 to be \$1/acre. Clearly, if a grower switches from YieldGard Corn Borer corn to Herculex I corn for western bean cutworm and 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).

Growers produced an additional 636 million pounds of corn grain by planting Herculex I varieties in 2004. It is estimated that the value of improved crop production was worth $28 million approximately. Grower cost savings were $14 million due to lowered insecticide use of 0.28 million pounds. Net monetary gain due to Herculex I corn was $40 million in 2004.

Dow AgroSciences and Pioneer Hi-Bred International have developed the next generation traits in the Herculex insect protection family under the trade names Herculex RW and Herculex XTRA (Anonymous 2004). Herculex RW, which offers built-in protection against northern corn rootworm, western corn rootworm and Mexican corn rootworm, received full approval from U.S. regulatory agencies in October 2005. Approval for import to Japan is expected in the next few months. Corn growers will plant Herculex RW in 2006 crop season. Herculex XTRA is anticipated for commercial release in the 2006 crop growing season, pending regulatory approvals. Herculex XTRA will offer corn growers the broadest spectrum in pest protection on the market combining the insect protection of Herculex I (against major corn insect pests such as European corn borer, southwestern corn borer, black cutworm, western bean cutworm, fall armyworm, and corn earworm); rootworm protection of Herculex RW; and the ability to withstand the postemergence applications of non-selective herbicide glufosinate.

Table 8.1. Adoption of Herculex I (Cry1F) corn in the US in 2004

State	Planted corn acreage	Herculex I corn acreage[1]	Adoption as a % of total planted corn acres[2]	Adoption as a % of Bt acres[3]
	000A	Acres	%	%
CO	1200	40835	3.4	11.2
IL	11750	56168	0.5	1.9
IN	5700	14802	0.3	3.7
IA	12700	363711	2.9	8.5
KS	3100	90054	2.9	8.2
KY	1210	1842	0.2	1.1
MI	2200	2388	0.1	0.5
MN	7500	250944	3.4	9.6
MO	2950	101737	3.5	11.8
NE	8250	356175	4.3	9.1
NY	980	4568	0.5	7.0
ND	1800	29455	1.6	4.2
OH	3350	13458	0.4	5.5
PA	1400	4342	0.3	1.6
SD	4650	50437	1.1	2.7
TX	1830	35094	1.9	9.3
WI	3600	41430	1.2	5.7
Total	**74,170**	**1,457,440**	**2.0**	**6.5**

[1]Estimates from Doane Marketing Service, Inc.
[2]Calculated based on the National Agricultural Statistics Service: 2005 Acreage
[3]Includes YieldGard Corn Borer and Herculex I acres only

Table 8.2. Impacts of Herculex I (Cry1F) corn due to cutworm control in 2004 in selected states with economically damaging levels

State	Adoption[1]	Corn yield in 2004	Production gain on Herculex I acres[2]	Value of gained production[3]	Reduction in insecticide use[4]	Reduction in insecticide costs[5]	Adoption costs[6]	Net economic impact
	Acres	Lb/A	000lb	000$	Lb ai/A	000$	000$	000$
CO	40835	7560	15436	679	8167	408	41	1046
IL	56168	10080	28309	1246	11234	562	56	1752
IN	14802	9408	6963	306	2960	148	15	439
IA	363711	10136	184329	8110	72742	3637	364	11383
KS	90054	8400	37823	1664	18011	901	90	2475
MN	250944	8904	111720	4916	50189	2509	251	7174
MO	101737	9072	46148	2031	20347	1017	102	2946
NE	356175	9296	165550	7284	71235	3562	356	10490
OH	13458	8848	5954	262	2692	135	14	383
PA	4342	7840	1702	75	868	43	4	114
SD	50437	7280	18359	808	10087	504	50	1262
TX	35094	7784	13659	601	7019	351	35	917
Total	**1,377,757**	**8717**	**635,952**	**27,982**	**275,551**	**13,777**	**1,378**	**40,381**

[1]Includes select states with economically damaging levels of black cutworm and western bean cutworm
[2]A 5% yield increase is assumed on acres planted with Herculex I corn
[3]Yield increase times average corn selling price per pound (= 4.4 cents)
[4]Calculated at 0.2lb 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 cutworm control would be $1/acre

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9. Rootworm-resistant corn (YieldGard Rootworm/IR-III)

YieldGard Rootworm hybrids were planted on 1.3 million acres of corn acreage in 2004 (Table 9.1). This represented roughly 2% of the total corn acreage planted in the United States. Adoption was highest in Oklahoma (15%) followed by Delaware (7%). However, planted YieldGard Rootworm acreage was highest in Minnesota followed by Illinois, Iowa, and Nebraska. Planted acreage increased 290% in 2004 compared with 2003, a year when YieldGard Rootworm was first commercialized.

YieldGard Rootworm technology is currently available in hybrids suitable to various regions of the Corn Belt. Efforts are in progress at Monsanto to stack YieldGard Rootworm and YieldGard Corn Borer and market as YieldGard Plus hybrids. Once YieldGard Plus corn is available for planting, adoption of Bt corn will increase significantly. With the European Union's approval of YieldGard Rootworm corn (MON 863) on August 8, 2005 for import and use in animal feed (Haines 2005), it is expected that adoption will further increase in the United States in the next few years.

YieldGard Rootworm provided a revolutionary alternative in managing a difficult pest problem in corn. University trials and grower experiences indicated that YieldGard Rootworm corn sustained the lowest or no root injury compared to corn treated with conventional insecticides (Cullen et al., 2004; Hillyer 2005; Hoover et al., 2004; Rice and Oleson 2004). Moreover, Bt hybrids were more consistent in protecting corn roots compared to standard insecticides (Rice and Oleson 2004). Several researchers have also reported superior yields with YieldGard Rootworm compared to the isolines treated with insecticides (Eisley 2004; Lauer 2004; Rice 2004; Rice and Oleson 2004). Overall, corn growers realized significant agronomic and economic benefits from planting YieldGard Rootworm in 2004, similar to 2003.

The year 2004 was the second year of commercial planting of YieldGard Rootworm corn. Most of the field research with YieldGard Rootworm corn hybrids in 2003 and 2004 has focused on root injury. Information on yield response of YieldGard Rootworm corn hybrids was sparse and variable. However, limited information that is available indicates that Bt Rootworm hybrids yielded 1.5 to 4.5% higher relative to a soil insecticide treatment (Eisley 2004; Hoover 2004; Lauer 2004; Rice 2004). For analytical purposes, a 3% improvement in yield has been assumed due to YieldGard Rootworm corn hybrids in 2004, similar to 2003.

Table 9.2 displays information on changes in crop production and production value due to YieldGard Rootworm corn. Based on 3% gain in per acre yields due to YieldGard Rootworm hybrids, corn production in 2004 was improved by 364 million pounds. The value of this gained production was $16 million dollars.

Corn growers use both seed treatments (insecticides such as thiamethoxam and clothianidin at 1.25 mg ai/seed each) and soil insecticides (bifenthrin, carbofuran, chlorethoxyfos, chlorpyriphos, ethoprop, fipronil, phorate, tefluthrin , terbufos, 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 rootworm larvae are chlorpyriphos, terbufos, tebupirimphos + cyfluthrin, bifenthrin, fipronil, and tefluthrin.

A survey of corn entomologists indicated that on average growers applied 0.51lb ai/A of insecticides at a cost of $15/A in 2004 (Larson 2005; Parker 2005; Wildie 2005). Based on this assumption, it was calculated that growers that planted YieldGard Rootworm corn hybrids in 2004 have applied 0.67 million pounds fewer insecticides (Table 9.3).

Similar to 2003, YieldGard Rootworm corn growers spent $17 per acre in 2004 to gain access to YieldGard Rootworm corn hybrids (Bacon 2005; Schultz 2005). Therefore, adoption costs, based on 1.3 million acres of planted acreage of Bt corn, were $22.5 million. However, net economic gain, due to increase in crop production and decrease in insecticide use and spray applications, was $13.4 million.

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 such as wireworms, white grubs, flea beetles, and seed corn maggots, especially if their frequency of occurrence 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. Monsanto requires seed companies to treat YieldGard Rootworm corn seed with an insecticide for control of secondary pests. While imidacloprid was used as seed treatment for YieldGard Rootworm in 2003, thiamethoxam and clothianidin have been used since 2004. Thiamethoxam controls wireworms, white grubs, seed corn maggots and early flea beetles, while clothianidin controls all the above pests as well as black cutworm. The convenience of having soil insect protection in and on the seed without having to apply a soil insecticide at planting for secondary pest control is another reason for the increased adoption of YieldGard Rootworm corn hybrids in 2004.

The Herculex RW trait, developed jointly by Dow AgroSciences and Pioneer Hi-Bred International Inc., received full approval from U.S. regulatory agencies in October 2005 and will be available for commercial planting in 2006. Herculex RW provides built-in protection against northern corn rootworm, western corn rootworm and Mexican corn rootworm. Approval for import to Japan is expected in the next few months. A third choice for corn rootworm management, MIR-604 from Syngenta, is currently being evaluated by the regulatory agencies. When approved, the trait will be marketed as Agrisure RW.

Table 9.1. Adoption of YieldGard Rootworm corn in 2004

State	Planted acres[1]	YieldGard Rootworm corn acreage[2]	Adoption of YieldGard Rootworm corn
	000A	Acres	%
California	540	23660	4.4
Colorado	1200	3451	0.3
Delaware	160	11366	7.1
Idaho	230	3664	1.6
Illinois	11750	237231	2.0
Indiana	5700	101351	1.8
Iowa	12700	198713	1.6
Kansas	3100	70266	2.3
Maryland	490	2503	0.5
Michigan	2200	3102	0.1
Minnesota	7500	244688	3.3
Missouri	460	7102	1.5
Nebraska	8250	190242	2.3
New Mexico	125	1442	1.6
North Dakota	1800	33298	1.9
Ohio	3350	35196	1.1
Oklahoma	250	36406	14.6
Pennsylvania	1400	25191	1.8
South Dakota	4650	40048	0.9
Tennessee	680	6058	0.9
Texas	1830	25571	1.4
Wisconsin	3600	21647	0.6
Total	**71,965**	**1,322,196**	**1.8**

[1]National Agricultural Statistics Service. 2005 Acreage
[2]YieldGard Rootworm corn adoption information in the United States is based on Doane Marketing Research Inc.'s 2004 estimates

Table 9.2. Impacts of YieldGard Rootworm corn on crop yield and value in 2004

State	Corn yield in 2004	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	$/A	Acres	000Lb	000$
California	175	5.3	297	13.07	23660	7027	309
Colorado	135	4.1	230	10.12	3451	794	35
Delaware	152	4.6	258	11.35	11366	2932	129
Idaho	148	4.4	246	10.82	3664	901	40
Illinois	180	5.4	302	13.29	237231	71644	3152
Indiana	168	5.0	280	12.32	101351	28378	1249
Iowa	181	5.4	302	13.29	198713	60011	2640
Kansas	150	4.5	252	11.09	70266	17707	779
Maryland	153	4.6	258	11.35	2503	646	28
Michigan	134	4.0	224	9.86	3102	695	31
Minnesota	159	4.8	269	11.84	244688	65821	2896
Missouri	162	4.9	274	12.06	7102	1946	86
Nebraska	166	5.0	280	12.32	190242	53268	2344
New Mexico	180	5.4	302	13.29	1442	435	19
North Dakota	105	3.2	179	7.88	33298	5960	262
Ohio	158	4.7	263	11.57	35196	9257	407
Oklahoma	150	4.5	252	11.09	36406	9174	404
Pennsylvania	140	4.2	235	10.34	25191	5920	260
South Dakota	130	3.9	218	9.59	40048	8730	384
Tennessee	140	4.2	235	10.34	6058	1424	63
Texas	139	4.2	235	10.34	25571	6009	264
Wisconsin	136	4.1	230	10.12	21647	4979	219
Total/Average	**152**	**4.6**	**255**	**12.10**	**1,322,196**	**363,658**	**16,000**

[1]A 3% yield gain was assumed due to planting of YieldGard Rootworm corn
[2]Approximate selling price of corn in 2004 = $2.45/bushel or 4.4 cents/lb

Table 9.3. Overall impacts of YieldGard Rootworm corn in 2004

State	YieldGard Rootworm 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	000Lb	000$	000$	000$	000$	lb ai/yr
California	23660	7027	309	402	355	262	12067
Colorado	3451	794	35	59	52	28	1760
Delaware	11366	2932	129	193	170	106	5797
Idaho	3664	901	40	62	55	33	1869
Illinois	237231	71644	3152	4033	3558	2677	120988
Indiana	101351	28378	1249	1723	1520	1046	51689
Iowa	198713	60011	2640	3378	2981	2243	101344
Kansas	70266	17707	779	1195	1054	638	35836
Maryland	2503	646	28	43	38	23	1277
Michigan	3102	695	31	53	47	25	1582
Minnesota	244688	65821	2896	4160	3670	2406	124791
Missouri	7102	1946	86	121	107	72	3622
Nebraska	190242	53268	2344	3234	2854	1964	97023
New Mexico	1442	435	19	25	22	16	735
North Dakota	33298	5960	262	566	499	195	16982
Ohio	35196	9257	407	598	528	337	17950
Oklahoma	36406	9174	404	619	546	331	18567
Pennsylvania	25191	5920	260	428	378	210	12847
South Dakota	40048	8730	384	681	601	304	20424
Tennessee	6058	1424	63	103	91	51	3090
Texas	25571	6009	264	435	384	213	13041
Wisconsin	21647	4979	219	368	325	176	11040
Total	**1,322,196**	**363,658**	**16,000**	**22,479**	**19,835**	**13,356**	**674,321**

[1]Calculations on crop yield and value were detailed in Table 9.2

[2]Adoption costs for YieldGard Rootworm corn in 2004 = $17/A

[3]Average cost of insecticides used for rootworm control in 2004 = $15/A

[4]Average insecticide use rate for rootworm control = 0.51 lb ai/A

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10. Bollgard cotton (IR-IV)

The 2004 adoption of Bollgard cotton was 51% in the United States (Table 10.1). Adoption varied from a low of 8% in California to a high of 94% in Tennessee. Adoption of Bollgard cotton was highest in Tennessee (94%) followed by Louisiana (90%), and Arkansas (88%). Adoption was lower in California (8%), Kansas (11%), and Texas (18%), due to lower incidence of Bollgard target pests (lepidopteran pests) (Whitworth 2005). Bollgard adoption is expected to increase in Texas due to a rise in the level of pink bollworm infestations in the 2004 growing season.

Bollworm and budworm pest complex was ranked as number one pest problem in US cotton in 2004, similar to years before. Of the total crop loss of 4.2% due to cotton insect pests in 2004, bollworm/budworm accounted for 29% (Williams 2005). Cotton production losses due to arthropod pests were lower in 2004 compared to years before the commercialization of Bt varieties (Williams 2005). Increased use of Bollgard cotton was credited to have lowered the impact and aggregate losses due to arthropod pests in 2004. Bollgard cotton provided growers with an improved and reliable method to control bollworms and budworms.

Mullins et al. (2005) assessed the agronomic and economic advantage of Bollgard cotton in comparison with conventional cotton, based on large-scale university field trials in various cotton producing states. Assessments included insect control costs, number of insecticide applications, lint yields (volume and value), end-of-season boll damage levels, gross income, and changes in net revenue. Analysis indicated that Bollgard cotton growers have reduced per acre insecticide sprays by 0.93 applications, insecticide costs by $14.76; improved per acre lint yields by 81 lb, and net returns by $40.87 compared with conventional cotton (Mullins et al. 2005). The above stated estimates served as the basis for the impact assessment of Bollgard cotton in this report. Per-acre estimates were used to calculate aggregate impact estimates for each state and are presented in Table 10.2.

Analysis indicated that Bollgard cotton was associated with significantly higher yields and lower pesticide use in all the cotton producing states in 2004 (Table 10.2). In aggregate, Bollgard cotton produced 562 million more pounds of cotton lint valued at $337 million. Crop production costs were reduced by $102 million mainly due to reduced spray applications and reduced insecticide use. Insecticide use in Bollgard cotton was reduced by 1.6 million pounds compared to conventional cotton. These calculated estimates represent 55% higher lint production in 2004 compared to 2003. Averaged across various cotton growing states, insecticide applications were reduced by at least one, which translated to time, labor, and energy savings for cotton growers. Overall, net grower benefits due to Bollgard planting in 2004 amounted to $284 million.

The introduction of Bollgard cotton reduced the number of insecticide applications targeted towards lepidopteran pests. However, some insecticide applications are still required to suppress bollworms. Despite its proven usefulness as an important pest management tool, the need for supplemental remedial insecticide applications to fully control pests has been a minor drawback for Bollgard cotton. Bollgard cotton is extremely effective against tobacco budworm and pink bollworm but 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 2004, 82% of US cotton crop was infested with bollworm/budworm complex of which 94% were bollworms (Williams 2005). Approximately 38% of the Bollgard cotton acreage was sprayed with insecticide applications to control bollworms in 2004 (Table 10.3; Williams 2005). A second generation Bt cotton (Bollgard II) with enhanced resistance to key cotton pest problems was developed by Monsanto and was planted on a limited acreage in 2003. Evidence indicates that the end-of-season boll damage was significantly lower (333%) in Bollgard II compared with Bollgard cotton (Mullins 2005). Experience from the 2003 growing season suggested that Bollgard II cotton eliminated the need for additional insecticide sprays for bollworm control. The impact of Bollgard II on pest management in 2004 is presented in the next case study (Case Study 11).

Table 10.1. Adoption of Bollgard cotton in the US in 2004

State	Planted acreage[1]	Bollgard cotton adoption	
	000 acres	% of total[2]	000 acres
Alabama	550	75	413
Arizona	220	75	165
Arkansas	950	88	836
California	560	8	45
Florida	105	79	83
Georgia	1330	81	1077
Kansas	120	11	13
Louisiana	500	90	450
Mississippi	1100	85	935
Missouri	400	73	292
New Mexico	60	69	41
North Carolina	720	79	569
Oklahoma	190	67	127
South Carolina	240	85	204
Tennessee	570	94	536
Texas	6000	18	1080
Virginia	85	84	71
US	**13,700**	**51**	**6,937**

[1]National Agricultural Statistics Service: 2004 Acreage
[2]Based on the 2004 Cotton Planting Data from the US Agricultural Marketing Service

Table 10.2. Aggregate impacts of Bollgard cotton in 2004[1]

State	Bollgard cotton adoption	Increase in cotton lint production	Increase in production value	Reduction in the number of insecticide sprays	Reduction in insecticide use	Reduction in insecticide and application costs	Adoption costs of Bollgard cotton[2]	Economic advantage due to Bollgard cotton
	000 acres	000 lb	000$	000	000lb	000$	000$	000$
AL	413	33453	20072	384	96	6096	9288	16879
AZ	165	13365	8019	153	38	2435	3711	6744
AR	836	67716	40630	778	194	12339	18802	34167
CA	45	3645	2187	42	10	664	1012	1839
FL	83	6723	4034	77	19	1225	1867	3392
GA	1077	87237	52342	1002	250	15897	24222	44017
KS	13	1053	632	12	3	192	292	531
LA	450	36450	21870	419	105	6642	10121	18392
MS	935	75735	45441	870	217	13801	21028	38213
MO	292	23652	14191	272	68	4310	6567	11934
NM	41	3321	1993	38	10	605	922	1676
NC	569	46089	27653	529	132	8398	12797	23255
OK	127	10287	6172	118	30	1875	2856	5190
SC	204	16524	9914	190	47	3011	4588	8337
TN	536	43416	26050	498	125	7911	12055	21906
TX	1080	87480	52488	1004	251	15941	24289	44140
VA	71	5751	3451	66	17	1048	1597	2902
Total	**6,937**	**561,897**	**337,139**	**6,452**	**1,612**	**102,390**	**156,014**	**283,514**

[1]Impacts were calculated based on Mullins et al., 2005. Accordingly, assessments, as compared to conventional non-Bt cotton, were as follows: reduction in total number of insecticide sprays in Bollgard cotton = 0.93; reduction in insecticide and application costs = $14.76/acre; gain in lint yields per acre = 81 lb; net economic advantage/acre = $40.87; cost of 1 lb of cotton lint in 2004 = $0.60; insecticide use in conventional cotton was estimated to be 0.25 lb ai/A/application

[2]Adoption costs for Bollgard cotton in 2004 were calculated to be $22.49/acre based on Mullins et al. (2005)

Table 10.3. Bollgard cotton acreage sprayed for bollworm control in 2004[1].

State	Bollgard acreage sprayed for bollworm control
AL	128,000
AZ	3,078
AR	488,000
CA	0
FL	400
GA	350,000
KS	0
LA	328,036
MS	530,100
MO	47,322
NM	600
NC	312,000[2]
OK	23,400
SC	120,000
TN	60,000
TX	190,725
VA	60,000
Total	**2,641,661**

[1]Williams 2005
[2]Bacheler 2006

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11. Bollgard II cotton (IR-V)

Bollgard II cotton was planted on around 200,000 acres in the 2004 crop growing season (Table 11.1). This represents 1.4% of the total planted cotton acreage and 2.7% of total Bt cotton acreage. Bollgard II cotton adoption increased by 6 times in 2004 compared with 2003. Overall, Bollgard II adoption is lower than Bollgard as the trait is not available in enough number of cotton varieties suitable for various geographic locations (Turnipseed 2005). In 2004, Bollgard II cotton was planted on all cotton producing states except California, Florida, and Virginia. Whereas percent acres planted to Bollgard II varieties was greatest in Missouri (6%) followed by Oklahoma (4%), number of planted acres were highest in Texas followed by Missouri (Table 11.1).

First available for planting since 2003, Bollgard II cotton is the second-generation of insect-resistant 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 the protection provided by the Bollgard). Bollgard II contains two Bt genes, Cry1Ac and Cry2Ab, as opposed to the single gene (Cry1Ac) in its predecessor, Bollgard. 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. The 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.

Multi-location large plot field trials were conducted across the cotton-belt in 2004 to assess the agronomic and yield performance of Bollgard II cotton in comparison with Bollgard and conventional cotton (Mullins et al. 2005). Research findings indicated that Bollgard II enhanced insecticidal activity against pests on which Bollgard was weakest. The enhanced control with 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 in 2004, similar to 2003.

Multi-location studies analyzed by Mullins et al. (2005) were the basis for the impact assessments of Bollgard II in this report. These studies have indicated that Bollgard II cotton averaged 0.47 fewer insecticide applications, 20 pounds more lint yields, and $10.76 more economic returns per acre compared to Bollgard cotton. In comparison to the conventional non-Bt cotton, the Bollgard II cotton averaged 1.12 fewer insecticide applications, $16.88 less insecticide costs, 128 pounds more lint yields, and $70.52 higher economic returns per acre in 2004. Impacts were analyzed based on the conclusions drawn from comparisons between Bollgard II and conventional (non-Bt) cotton. Estimates on insecticide use in Bollgard II cotton were made based on the National Center's 2002 report.

Bollgard II cotton provided similar agronomic advantages as its predecessor, Bollgard. These benefits included improved insect control as reflected by increased yields, reduction in input costs, reduced pesticide use, and number of spray applications (Table 11.2). However, yield improvement and pesticide use reduction, as noted above, is higher with Bollgard II compared to Bollgard (Mullins et al. 2005).

Based on the per acre impacts listed above, it is estimated that Bollgard II increased US cotton lint production by 24.9 million pounds, the value of which was $14.9 million in 2004. (Table 11.2). Cotton growers made 0.2 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 0.2 million pounds led to $3.3 million savings on insecticide costs. The economic advantage of Bollgard II cotton in 2004 was $70.5 and $10.8 per acre, respectively, compared with conventional and Bollgard cotton, respectively (Mullins et al. 2004). Net grower returns due to the planting of Bollgard II cotton in 2004 were $13.7 million.

Using a strategy similar to Bollgard II, Dow Agrosciences developed 'WideStrike' cotton to simultaneously express two separate insecticidal Bt proteins, Cry1Ac and Cry1F. Similar to Bollgard II, the WideStrike cotton 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). WideStrike cotton received deregulatory status from USDA, full registration from EPA and completed pre-market consultations with FDA during 2004 (Agserv 2003; Richardson et al. 2003). Efforts are in progress to introduce WideStrike cotton varieties for commercial planting in the 2005 crop season (Richardson et al. 2003).

Another Bt cotton that is anticipated to be available for cotton growers in the near future is ‘VipCot’ developed by Syngenta. VipCot 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. Vip protein also protects the entire plant, including the flowering parts. 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. In August 2004, Syngenta entered into a cooperative agreement with Delta and Pine Land Company to develop and register VipCot (Negrotto and Martin 2005). VipCot may be commercially available in 1 to 2 years. The availability of WideStrike and VipCot 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.

Table 11.1. Adoption of Bollgard II cotton in the United States in 2004

State	Planted acreage[1]	Bollgard II adoption[2]	
	000A	%	Acres
Alabama	550	0.06	330
Arizona	220	0.27	594
Arkansas	950	0.17	1615
California	560	0	0
Florida	105	0	0
Georgia	1330	0.18	2394
Kansas	120	2.67	3204
Louisiana	500	1.29	6450
Mississippi	1100	0.61	6710
Missouri	400	6.19	24760
New Mexico	60	1.41	846
North Carolina	720	1.02	7344
Oklahoma	190	4.31	8189
South Carolina	240	1.14	2736
Tennessee	570	0.06	342
Texas	6000	2.15	129000
Virginia	85	0	0
Total	**13,700**	**1.42**	**194,514**

[1] National Agricultural Statistics Service: 2004 Acreage

[2] Based on the 2004 Cotton Planting Data from the US Agricultural Marketing Service

Table 11.2. Aggregate impacts of Bollgard II cotton in 2004[1]

State	Bollgard II cotton adoption	Increase in cotton lint production	Increase in production value	Reduction in the number of insecticide sprays	Reduction in insecticide use	Reduction in insecticide costs	Adoption costs of Bollgard II cotton[2]	Net economic advantage
	Acres	Lb	$	#	Lb	$	$	$
AL	330	42240	25344	370	249	5570	7590	23272
AZ	594	76032	45619	665	448	10027	13662	41889
AR	1615	206720	124032	1809	1217	27261	37145	113890
GA	2394	306432	183859	2681	1805	40411	55062	168825
KS	3204	410112	246067	3589	2415	54084	73692	225946
LA	6450	825600	495360	7224	4862	108876	148350	454854
MS	6710	858880	515328	7515	5058	113265	154330	473189
MO	24760	3169280	1901568	27731	18663	417949	569480	1746075
NM	846	108288	64973	948	638	14280	19458	59660
NC	7344	940032	564019	8225	5536	123967	168912	517899
OK	8189	1048192	628915	9172	6173	138230	188347	577488
SC	2736	350208	210125	3064	2062	46184	62928	192943
TN	342	43776	26266	383	258	5773	7866	24118
TX	129000	16512000	9907200	144480	97235	2177520	2967000	9097080
Total	**194,514**	**24,897,792**	**14,938,675**	**217,856**	**146,619**	**3,283,397**	**4,473,822**	**13,717,128**

[1]Impacts were calculated based on Mullins et al., 2005. Accordingly, assessments, as compared to conventional non-Bt cotton, were as follows: reduction in total number of insecticide sprays due to Bollgard II cotton = 1.12/acre; reduction in insecticide and spray costs = $16.88/acre; gain in lint yields per acre = 128 lb; net economic advantage/acre = $70.52; cost of 1 lb of cotton lint in 2004 = $0.6; average insecticide use in conventional cotton was estimated to be 0.25 and 0.423 lb ai/A for bollworm/budworm and armyworms/soybean loopers, respectively

[2]Adoption costs were calculated at $23.0/acre, based on Mullins et al., 2005

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Conclusion

American experience from almost a decade-long use of biotechnology-derived crops indicate that these crops have revolutionized crop production and provided best hope to growers by helping to meet one of the key goals of production agriculture: improving yields with the use of minimal inputs. Continuing improvements in productivity facilitated by biotechnology-derived crops will enable growers in the United States and worldwide to increase food security without having to bring more forestland into agricultural use.

American growers have increased planting of biotechnology-derived crops from 5 million acres in 1996 to 118 million acres in 2004. The fact that adoption of biotechnology-derived crops has continued to grow each year since their first introduction is a testimony to the ability of these products to deliver tangible positive impacts and to the optimistic future they hold.

Adoption increased at a phenomenal pace in the United States due to the positive impacts derived in the form of increased yields, improved insurance against pest problems, reduced pest management costs and pesticide use, and overall increase in grower returns. Biotechnology-derived crops becoming such a dominant feature of American landscape also indicates the confidence of American farmers in these crops. 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-resistant crops enhanced their adoption.

In spite of proven potential and documented positive impacts, opponents continue to argue about impacts of these crops on environmental safety and human health. Several researchers have concluded that biotechnology-derived crops are as safe as, if not safer, than their conventional counterparts. Other concerns such as pest-resistance and gene flow are not only akin to biotechnology-derived crops, but relate to conventional pest management practices as well.

Biotechnology-derived crops in production to date in the United States have modified crop protection characteristics only. The second generation of biotechnology-derived crops is already underway and includes traits that may solve production challenges such as cold tolerance, drought tolerance and increased nitrogen efficiency and output traits such as better flavor and appearance, greater shelf life, and improved nutritive value. With a pipeline that is packed with crops that may further improve yields and deliver health and safety benefits to consumers, public approval for these crops will continue to only increase in the near future.