Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Eight Years

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About This Report

This report is the sixth in a series of Technical Papers prepared by Benbrook Consulting Services on the development, costs and benefits, and environmental impacts of genetically engineered (GE) crops in the United States. The full series of Technical Papers has been posted on the website Ag BioTech InfoNet and are accessible at http:/www.biotech-info.net/highlights.html#technical_papers.

The following organizations and institutions have provided funding or in-kind services for the preparation of this report and the analytical work required to calculate the impacts of genetically engineered crops on pesticide use in the United States since 1996:

- Union of Concerned Scientists
- Leopold Center for Sustainable Agriculture, Iowa State University
- Center for Food Safety
- Consumer Policy Institute, Consumers Union
- Institute for Agriculture and Trade Policy
- Organic Farming Research Foundation

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INTRODUCTION

Today's genetically engineered (GE) crops are designed to simplify and expand the use of pesticide-based strategies for the management of common weed and insect pests. Proponents of biotechnology claim that today's GE varieties substantially reduce pesticide use, while U. S. Department of Agriculture (USDA) analysts and some independent researchers have reached different conclusions. Here, USDA data are relied on in calculating the overall impact of GE crops on the volume of pesticides applied in the production of corn, soybeans, and cotton.

Proponents of biotechnology claim that GE varieties substantially reduce pesticide use. While true in the first few years of widespread planting it is clearly not the case now, nor is it true on average over the first eight years of use.

Most studies done to date on the impacts of GE crop technology on pesticide use have focused on the first three years of adoption, 1996-1998, and no study has estimated impacts in 2002 and 2003. This is the first comprehensive estimate of the impacts of GE crops on pesticide use over the eight years of commercial use since 1996.

This report draws on official USDA statistics on the acreage planted to GE varieties from 1996 through 2003, coupled with USDA data on pesticide use on corn, soybeans, and cotton. These three crops account for nearly all acres planted to GE crops in the United States. The analysis encompasses impacts of the following technologies on pesticide use –

- Herbicide tolerant (HT) corn, soybeans and cotton;
- *Bacillus thuringiensis (Bt)* transgenic corn and cotton.

Herbicide tolerant (HT) crops allow farmers to spray broad-spectrum herbicides over the top of growing plants, controlling weeds while leaving crops unharmed. HT weed management systems are simple and flexible, the major reasons why farmers have so enthusiastically embraced them. Despite increased seed prices, HT systems have also become less expensive for farmers, largely because the price of herbicides containing glyphosate has fallen from around $12.00 per acre treated when HT crops were first introduced to less than $6.00 per acre today.

New HT technology, coupled with competitive responses from other herbicide manufacturers, has created an economic windfall for soybean farmers who are paying less for herbicides despite spraying substantially more. The unprecedented popularity of Roundup Ready soybeans triggered more than a 40 percent across-the-board reduction in soybean herbicide prices in the late 1990s.

The other major category of GE crops has been engineered to produce the natural bacterial toxin *Bacillus thuringiensis* (*Bt*) in plant cells to control certain Lepidopteron insect pests. *Bt* plant varieties manufacture their own insecticides throughout the plant and reduce the need for farmers to treat fields with synthetic chemical insecticides.

Unlike chemical insecticides that are sprayed typically in a liquid form over growing plants one to three times a season, *Bt* toxins are manufactured continuously inside and throughout the plant, exposing both target and non-target organisms feeding on the plant or plant roots to *Bt* toxins.

PRINCIPAL FINDINGS

All GE crop varieties commercialized to date have been designed to simplify and/or improve the efficacy of pesticide-based methods of pest management.

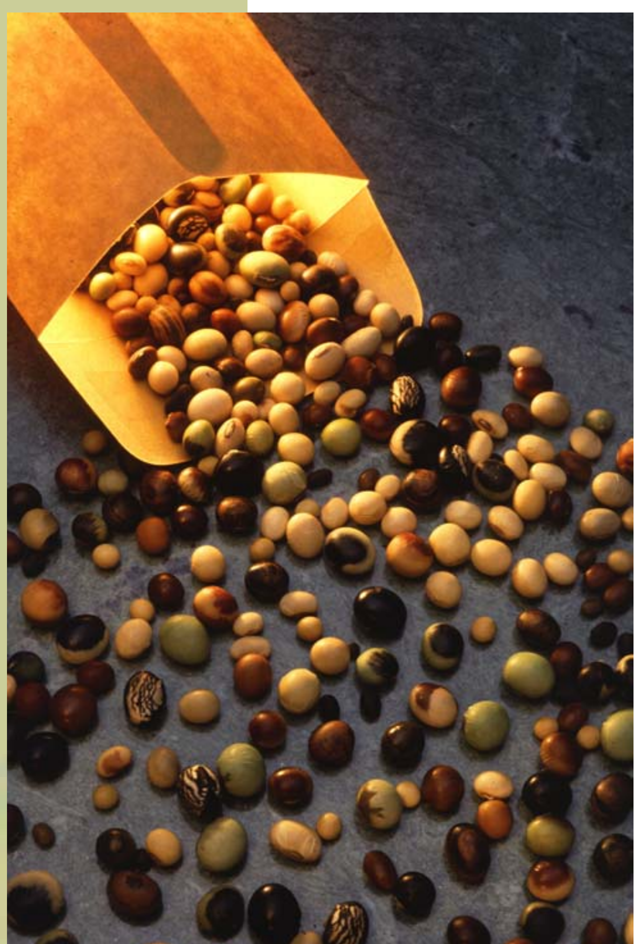
Crops engineered to tolerate applications of glyphosate account for the largest share of the acreage planted to HT crops and are often referred to as "Roundup Ready," or RR varieties. Some 400 million acres of HT crops have been planted since 1996, with soybeans accounting for about three-quarters (Table 6). HT soybeans account for about 54 percent of all GE acres planted since 1996. Some 150 million acres of *Bt* corn and cotton have been planted since 1996 (Table 7).

The dominance of HT soybeans in terms of total acres planted to GE varieties explains why recent increases in herbicide use on HT soybeans have so dramatically changed the overall impact of GE varieties on total pesticide use.

Crops engineered to tolerate applications of glyphosate account for the largest share of the acreage planted to HT crops and half of all acres planted to GE crops since 1996.

There is now clear evidence that the average pounds of herbicides applied per acre planted to herbicide tolerant (HT) varieties have increased compared to the first few years of adoption.

Contrary to the often-heard claim that GE technology has markedly reduced pesticide use, today's GE crops have modestly increased the overall volume of pesticides applied in the production of corn, soybeans, and cotton from 1996 through 2003 (Table 15, Charts 4 and 5). There is now clear evidence that the average pounds of herbicides applied per acre planted to herbicide tolerant (HT) varieties have increased compared to the first few years of adoption. This is no surprise, given that scientists have warned that heavy reliance on HT crops might lead to changes in weed communities and resistance, in turn triggering the need to apply additional herbicides and/or increase rates of application. These predictable ecological adaptations have now been documented in the case of HT crops and have eroded some measure of the initial efficacy of HT technologies.



Herbicide tolerant crops have increased pesticide use an estimated 70 million pounds over the last eight years, while *Bt* transgenic varieties have reduced pesticide use an estimated 19.6 million ponds. Total pesticide use has risen some 50.6 million pounds over the eight-year period studied.

The total pounds of pesticides applied to corn and cotton crops has fallen modestly in the case of GE corn and cotton technology, but the increase in the pounds of herbicides applied on HT soybeans has been far greater then the combined reductions in corn and cotton.

In the first three years of commercialization (1996-1998), GE corn, soybean, and cotton varieties reduced the total pounds of herbicides plus insecticides applied by an estimated 25.4 million pounds, but the volume of pesticides applied to the same GE varieties in the last three years (2001-2003) increased 73.1 million pounds (Chart 2). Many factors contributed to the increase in the average pounds of pesticides applied per acre of herbicide tolerant crops in recent years including changes in tillage and planting systems, shifts in herbicide formulations, falling prices for glyphosate, herbicide marketing strategies, and the growing popularity of low- and reduced rate herbicides.

Still, reliance on a single herbicide as the primary, if not sole method for managing weeds on fields planted to HT varieties, and the resulting, indeed inevitable ecological responses to such intense herbicide selection pressure, remains the primary factor that has led to the need to apply more herbicides per acre to achieve the same level of weed control.

Recent trends in overall pesticide use on GE varieties compared to conventional varieties are markedly negative from the perspective of reducing the volume of pesticides needed in managing pests. The pounds of herbicides required to achieve acceptable weed control is rising on most farms planting herbicide tolerant varieties, compared to the rates of application that were common in the 1996-1998 period. In addition, the pounds of herbicides and insecticides applied per acre on farms planting conventional varieties continue to trend downward as a result of incremental shifts toward newer pesticides applied at lower rates of application.

Of the five GE technologies studied, two are sustaining their positive impacts on the pounds of pesticides applied per acre – *Bt* corn and *Bt* cotton. There has been a decrease in the last few years in the reduction in insecticide pounds applied on cropland planted to *Bt* corn has fallen, despite an

The pounds of herbicides required to achieve acceptable weed control is rising on most farms planting herbicide tolerant varieties. Still, farmers are saving money from HT varieties because the price of herbicides has dropped so dramatically since 1996.

increase in the overall acres of *Bt* corn planted.

Estimates of the magnitude of the reductions in *Bt* crop insecticide use in this report do not take into account the pounds of *Bt* toxins produced within the cells of *Bt* transgenic plants. *Bt* endotoxins are not sprayed on plants, as the case with conventional pesticides, but still function as toxins within crop management systems.

In both the case of *Bt* corn and *Bt* cotton, extensive field monitoring has shown continued high levels of efficacy in controlling target pests. Equally important, there is still no evidence of resistance in field populations of insects targeted by *Bt* transgenic varieties.

While the reductions in insecticide use brought about by *Bt* corn and *Bt* cotton are significant, the reductions are modest compared to total corn plus cotton insecticide use. For example, in 2002 *Bt* corn and cotton reduced the pounds of insecticide applied by about 2.3 million pounds, or about 7 percent of total insecticide use on these two crops.

Plus, pest management challenges are constantly evolving. A new soybean insect pest, an aphid from China, has gained a foothold in several Midwestern states, forcing farmers to apply insecticides on millions of acres of soybeans, a crop that rarely suffers from serious insect damage.

Only one-tenth of one percent of soybean acres were sprayed with an insecticide in 2001, while 6.2 percent were sprayed in 2002. Insecticide use on soybeans rose 888,000 pounds in 2002. By way of contrast, *Bt* cotton reduced insecticide pounds applied by 959,980 pounds in the same year.

About two-thirds of the newly treated soybean acres were sprayed with two highly toxic organophosphate insecticides -- methyl parathion and chlorpyrifos. Plus, these applications were made during the growing season when potential environmental and human health risks are greatest.

The need to apply more herbicides per acre planted to HT soybeans accounts for most of the increase in overall pounds of pesticides applied across the three crops. USDA data show a marked increase in the per acre rate of glyphosate applied to HT soybeans between 2001 and 2002 – about a 22 percent increase, from 0.85 pounds per acre to 1.04 pounds. Average glyphosate application rates per acre of HT soybeans no doubt continued rising in crop year 2003 as a result of –

- The spread of glyphosate-tolerant or glyphosate-resistant marestail (also known as horseweed);
- Shifts in the composition of weed communities toward species not as sensitive to glyphosate or better equipped to survive glyphosate applications;
- Early-stage resistance in a number of major weeds in the Midwest; and
- Substantial price reductions and volume-based marketing incentives from competing manufacturers of glyphosate-based herbicides.

The slipping efficacy and price competition of glyphosate is increasing the pounds of herbicides applied on HT varieties. Other factors have combined to reduce the average pounds of herbicides applied to conventional crop acreage. These include regulatory restrictions/phase-outs on high-dose herbicides; the registration of S-metolachlor in time for the 1997 crop season, a herbicide applied at 65 percent of the rate of original metolachlor; and, the adoption of dozens of new low-dose herbicides and herbicide mixtures by farmers planting conventional crop varieties.

As a result, the difference in total pounds of herbicides applied on an acre planted to HT varieties versus conventional acres has increased steadily since 2000 (Charts 4 and 5). Given the emergence and spread of weeds resistance or less sensitive to glyphosate, this difference is likely to widen further if HT technology continues to be relied on as heavily as it has been in recent years.

The efficacy of HT technology is now seriously threatened by weed shifts and resistance. Herbicide use and costs are bound to rise for the foreseeable future.

Changes in herbicide use now need to be monitored over full crop rotation cycles, not just in the years when a field is planted to an HT variety.

OVERVIEW

Commercial plantings of GE crops grew rapidly from 1996 through 1999.

Commercial plantings of genetically engineered crops in the United States began in 1996 and totaled just under six percent of the acreage producing corn, soybeans, and cotton. Herbicide tolerant (HT) soybeans accounted for over half the acreage planted in 1996. Adoption of HT and *Bt* transgenic varieties almost doubled in 1997, reaching 10.6 percent of the total acreage planted to corn, soybeans and cotton, and then almost tripled in 1998. Since 1999, the growth rate in acres planted to GE varieties has slowed.

Chart 1 plots trends in the percent of national corn, soybean and cotton acres planted to HT and *Bt* transgenic varieties.

Table 1 presents recently released Economic Research Service (ERS) data on the percent of corn acres planted to GE varieties by State and nationally for four years (2000-2003). Table 2 reports the same information for HT soybeans, and Table 3 covers HT and *Bt* cotton. (All tables appear in sequence at the end of the text).

Table 4 combines the percent of acreage planted to HT and *Bt* varieties with the percent of acres planted to "stacked" varieties that are both HT and *Bt* transgenic. For 2000-2003, this table draws on the adoption data in Tables 1-3. Adoption data for 1996-1999 were drawn from other USDA reports.

Table 5 presents the total acres planted to each crop and the three crops together by year and over the 1996-2003 period, as well as national insecticide and herbicide use data for these crops. Data in Table 5 include –

- Herbicide pounds applied per acre and total pounds applied by crop;
- Insecticide pounds applied per acre and totals by crop; and
- Total pounds applied across the three crops by type of pesticide and herbicide plus insecticide totals.

Table 6 presents the national acres of corn, soybeans and cotton planted to herbicide tolerant (HT) varieties for 1996-2003 and totals for the eight-year period.

Chart 1. Trends in the Acres Planted to HT and Bt Transgenic Varieties 1996-2003

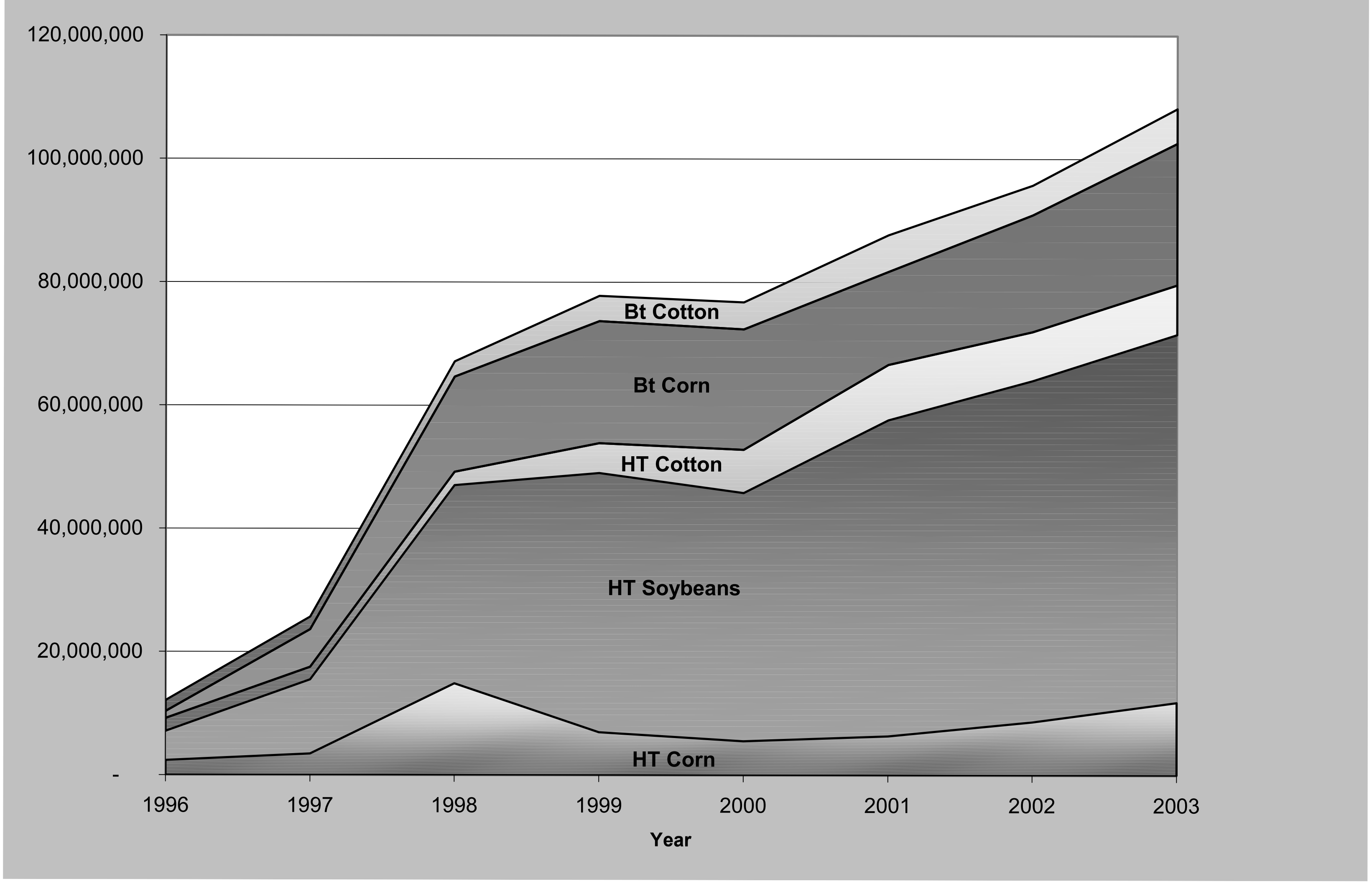


Table 7 covers *Bt* transgenic crops, and presents the national acres of corn and cotton planted to *Bt* varieties over the 1996-2003 period.

Average herbicide application rates on conventional and herbicide tolerant corn are presented in Table 8. The last line of this table estimates by year the difference in pounds of herbicides applied per acre of corn planted to HT varieties in contrast to an acre planted to conventional varieties. This difference is then multiplied by the acres planted to HT corn each year (from Table 6), producing an estimate of the impact of HT corn on the volume of herbicide use by year and over the eight-year period. The same basic approach is used in estimating the impact of other GE technologies on pesticide use.

Throughout this report, pesticide use estimates for 2003 are preliminary, since USDA will not release field crop pesticide use for 2003 until May 2004. Pesticide use estimates for 2003 are based on levels in 2002 and trends in recent years. (See the "Methodology and Data Sources" section for more details).

Table 9 presents average per acre insecticide use on *Bt* transgenic corn engineered to control the European corn borer and Southwestern corn borer, in contrast to conventional corn varieties. The differences in insecticide use on conventional versus *Bt* acres are overestimated because there is no way to accurately estimate, nor take into account, the pounds of *Bt* produced within the cells of transgenic corn plants. Given that *Bt* toxins are produced continuously in most *Bt*-transgenic corn plant tissues throughout the growth phase of the plant's life, the volume of *Bt* produced over a full season is significant compared to the rates of application of many of today's low-dose pesticides. Because the focus of this report is the impact of GE technology on the pounds of pesticides sprayed on acres planted to GE varieties, the pounds of *Bt* produced within the average 28,000 corn plants on an acre fall outside this analysis. It must be emphasized, however, that *Bt*-transgenic insect pest management technology is pesticide-based, despite the fact the pesticide is a natural endotoxin produced by the plant within its own cells.

Solid data on actual differences in pesticide use per acre are available for HT soybeans in 1998. A series of special tabulations of herbicide use data was carried out by the ERS, at the request of Benbrook Consulting Services. The ERS divided the sample points in the 1998 ARMS survey into four categories of soybean acres:

- Conventional varieties, no glyphosate applied;
- Conventional varieties, glyphosate applied (mostly on no-till acreage);
- Roundup Ready varieties; and
- Other HT varieties.

ERS reported both the percent of total soybean acreage by category, as well as the average number of herbicides and pounds of herbicides applied in each category. This information made possible an accurate weighted average calculation of total herbicide use per acre on conventional versus HT soybeans. The results are reported in Table 10.

Table 11 presents average herbicide use rates per acre on conventional versus HT soybeans over the eight-year period and shows clearly the upward trend in glyphosate and HT herbicide rates per acre since 2001.

Table 12 focuses on herbicide tolerant cotton and presents average per acre rates on conventional versus HT varieties.

Table 13 covers *Bt* transgenic cotton and presents estimates of the pounds of insecticides applied on *Bt* versus conventional acres of cotton in the 1996-2003 period. As the case with *Bt* corn, the average number of pounds of *Bt* endotoxin produced within the cells of plants on an acre of *Bt* cotton is not known and hence was not factored into the estimates of differences in pesticide use on *Bt*-transgenic versus conventional cotton acres. In addition, USDA did not collect cotton pesticide use data in 2002; data on pesticide use in 2002 and 2003 are estimates based on 2001 levels and recent trends.

Table 14 integrates all the estimates of pesticide use rates per acre on GE versus conventional varie-

Bt-transgenic insect pest management technology is pesticide based and delivered through the seed. This report does not take into account the pounds of Bt produced within Bt transgenic plants.

ties by crop and GE trait for 1996-2003, drawing on Tables 8-13.

Table 15 summarizes the overall impact by year, crop and trait of GE varieties on pesticide use. Totals are presented by crop for HT and *Bt* transgenic varieties, as well as across the three crops. Changes in the pounds of pesticides applied are expressed as a percent of total pesticide use on the crop and across the three crops.

Chart 2 contrasts the change in pesticide use in the first three years of commercialization (1996-1998) compared to the last three (2001-2003) and Chart 3 compares the total change in 1996-1998 to the change in 2001-2003. (Charts 2-5 appear in the "Principal Findings" section).

Chart 4 presents the changes in pesticide use by year for the five GE technologies studied in this report.

Chart 5 places into perspective the overall impact of the five GE technologies studied herein on pesticide use. It shows by year the percentage change in total pesticide use on corn, soybeans and cotton brought about by the adoption of HT and *Bt* crops.

Appendix Table 1 presents the data used to correct an error made by NASS in recoding the rate of metolachlor herbicide applied to corn in 1999-2002. In those years, NASS enumerators used the reduced rate of application of herbicides containing S-metolachlor for acres sprayed with original metolachlor. Use of the correct rate of application – 1.9 pounds per acre – increased the pounds of herbicide applied in 1999 by 10.8 million pounds, as shown in Appendix Table 1. As farmers progressively shifted from old metolachlor to S-metolachlor over the 1999-2003 period, the percent of acres treated with old metolachlor went down, as did the correction in the total pounds of herbicide pounds applied to

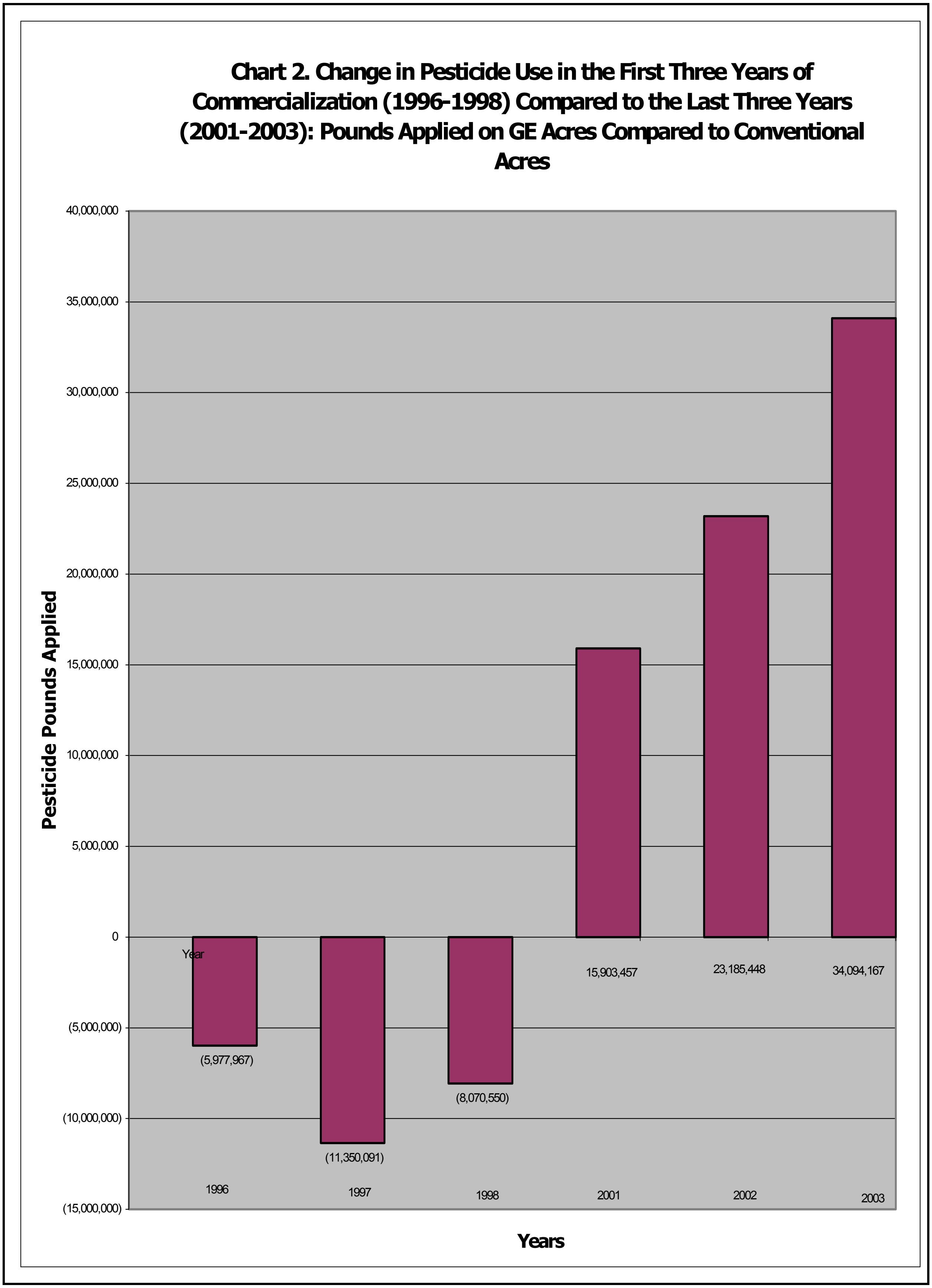


Chart 2. Change in Pesticide Use in the First Three Years of Commercialization (1996-1998) Compared to the Last Three Years (2001-2003): Pounds Applied on GE Acres Compared to Conventional Acres
Pesticide Pounds Applied
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
(5,000,000)
(10,000,000)
(15,000,000)
Year
(5,977,967)
(11,350,091)
(8,070,550)
15,903,457
23,185,448
34,094,167
1996
1997
1998
2001
2002
2003
Years

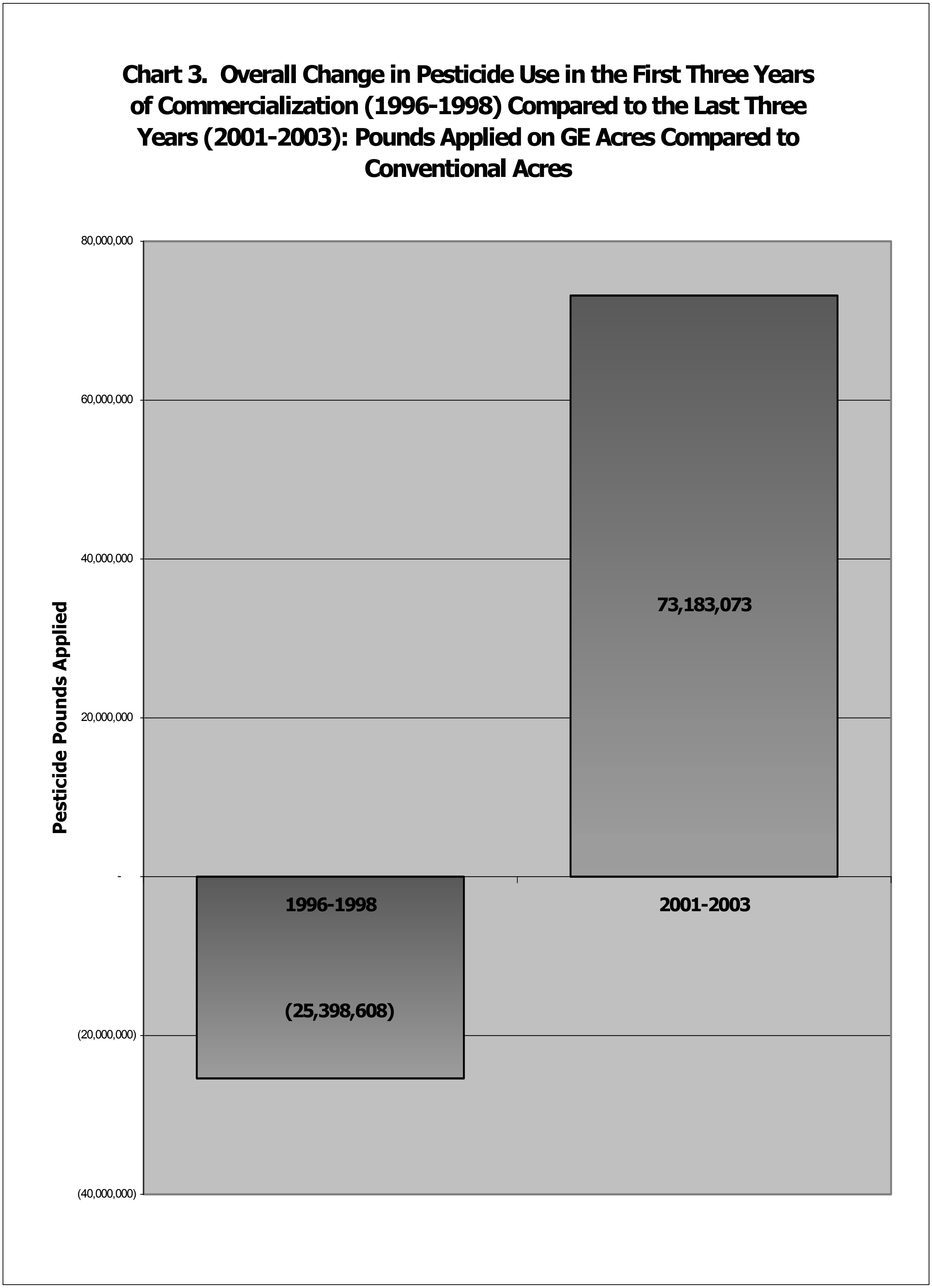


Chart 3. Overall Change in Pesticide Use in the First Three Years of Commercialization (1996-1998) Compared to the Last Three Years (2001-2003): Pounds Applied on GE Acres Compared to Conventional Acres
Pesticide Pounds Applied
80,000,000
60,000,000
40,000,000
20,000,000
-
(20,000,000)
(40,000,000)
1996-1998
(25,398,608)
2001-2003
73,183,073

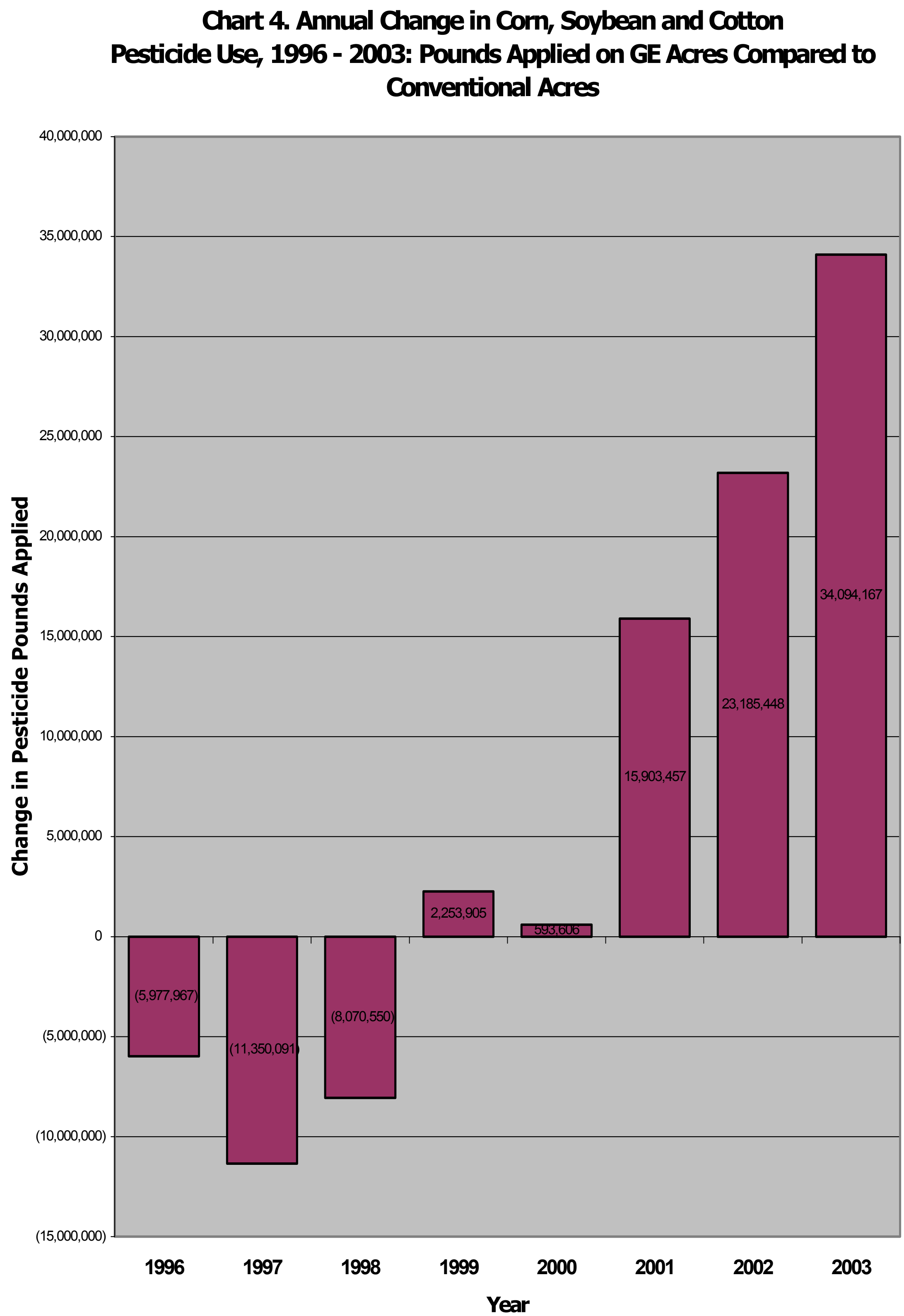
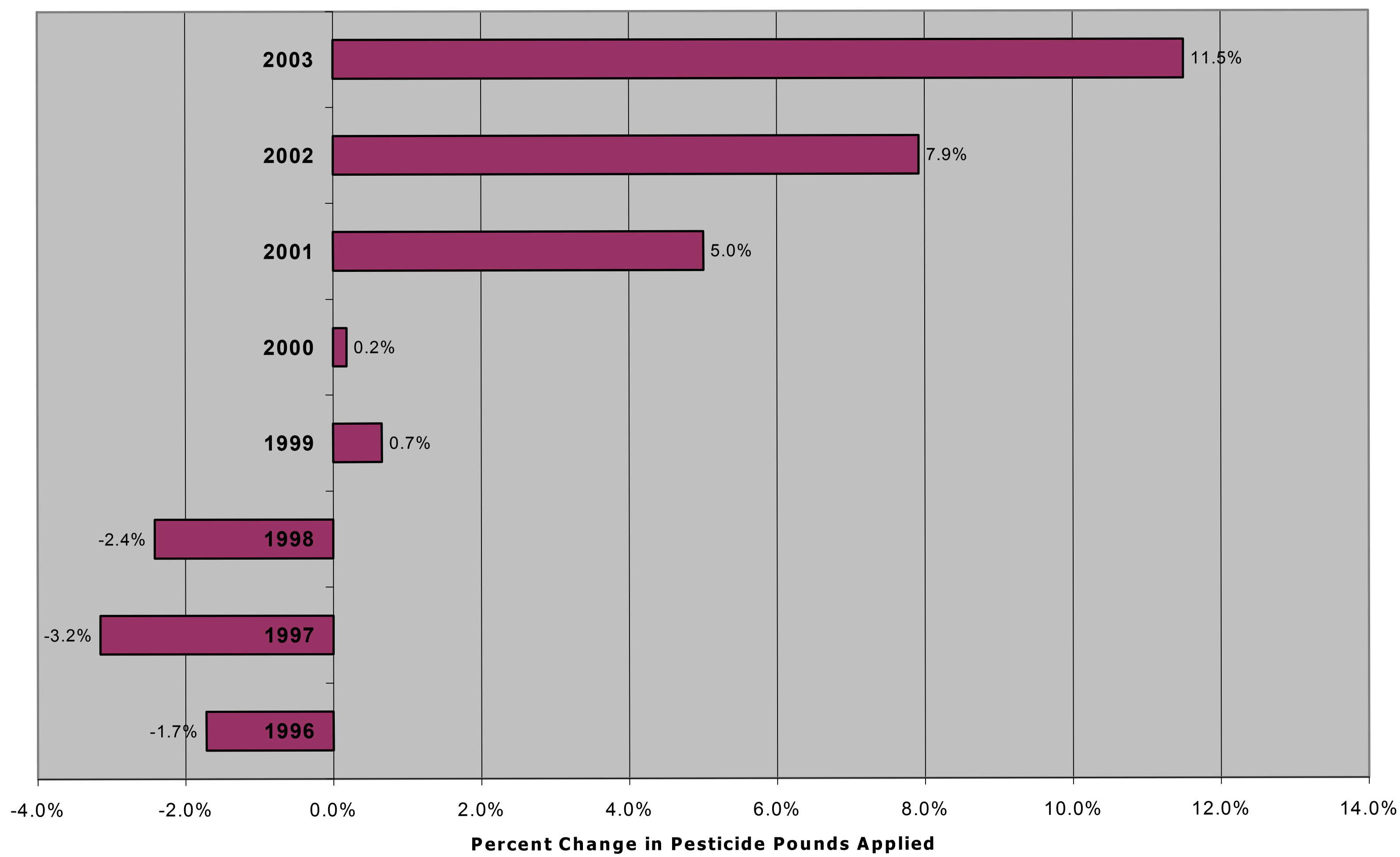


Chart 4. Annual Change in Corn, Soybean and Cotton Pesticide Use, 1996 - 2003: Pounds Applied on GE Acres Compared to Conventional Acres
Change in Pesticide Pounds Applied
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
(5,000,000)
(10,000,000)
(15,000,000)
(5,977,967)
(11,350,091)
(8,070,550)
2,253,905
593,606
15,903,457
23,185,448
34,094,167
1996
1997
1998
1999
2000
2001
2002
2003
Year

Chart 5. Overall Impact of GE Corn, Soybean, and Cotton: Percent Change in Total Pesticides Applied



OTHER ESTIMATES of the IMPACT of GE CROPS on PESTICIDE USE

The USDA's Economic Research Service (ERS) and the National Center for Food and Agricultural Policy (NCFAP) team led by Leonard Gianessi have produced national estimates of the impacts of contemporary GE crops on pesticide use. Table 16 presents a summary of published estimates across the three crops and by crop, for various years.

The ERS estimates focus on 1997 and 1998, and draw upon the Agricultural Resource Management Survey (ARMS). This is the one USDA survey that allows direct comparisons of pesticide use on acres planted to GE varieties, versus acres planted to conventional varieties.

This study relied on NASS pesticide use surveys because ARMS data are available for only two of the eight years that GE crops have been planted.

In studies released in 2000 and 2002, ERS estimated that the eight GE technologies covered in this report reduced pesticide use by 2,500,000 pounds in 1998. Based on the methodology and data used in this report, the reduction in pesticide use was actually greater in 1998 than the ERS estimate – some 8.1 million pounds. Estimated reductions in herbicide use on HT corn and cotton account for most of the difference.

This report and the ERS projections are in basic agreement on HT and *Bt* cotton. In the key case of HT soybeans, the ERS estimated that an additional 2,300,000 pounds of herbicide were applied on GE soybeans in 1998 in contrast to non-GE soybeans; this report estimates an increase of 2,304,103. ERS and this report also generally agree on the difference in pounds applied on HT soybeans in 1997, the last year there was a reduction in pounds applied.

Table 16 also reports estimates of the impacts of GE crops by the NCFAP team. These researchers have consistently projected major decreases in pesticide use on cropland producing GE varieties in a

...the USDA's Economic Research Service (ERS) estimated that an additional 2,300,000 pounds of herbicide were applied on GE soybeans in 1998 in contrast to non-GE soybeans.

NCFAP and this analysis are in general agreement on reductions in insecticide pounds applied in the case of Bt corn and Bt cotton in 2001. Estimates differ, however, in the case of HT corn, cotton, and especially soybeans.

series of reports dating back to 1998. In 2002, forty case studies were released that included estimates of the impacts of the eight GE varieties on pesticide use for the year 2001, as shown in Table 16. Since these NCFAP estimates are the most comprehensive released to date, they are used for purposes of comparison to this study's estimates.

NCFAP and this analysis are in general agreement on reductions in insecticide pounds applied in the case of *Bt* corn and *Bt* cotton in 2001. Estimates differ, however, in the case of HT corn, cotton, and especially soybeans. According to NCFAP, the average rate of herbicide application on cropland planted to HT soybeans in 2001 was 0.57 pounds less than the rate of application on conventional soybeans (Table 26.13 in Gianessi et al., 2002, cited in notes—Table 16). In addition, in Table 26.6 they report an average rate of herbicide application on HT acreage of 0.95. Accordingly, the rate on non-HT soybean acreage must be 1.52 pounds of herbicides per acre (0.95 plus 0.57 pounds per acre).

Given that the percent of acres planted in 2001 to HT and non-HT varieties is reported by NCFAP (69 percent GE; 31 percent non-GE), it is a simple exercise to calculate the average rate of herbicide application across HT and non-HT soybean varieties using the formula:

Average Herbicide Pounds Applied per Acre of Soybeans in 2001 =
[(Percent GE planted in 2001 x Rate GE acres in 2001) + Percent non-GE in 2001 x Rate Non-GE in 2001)]

Based on this calculation and the NCFAP estimates of herbicide use on GE and non-GE soybean acres in 2001, the average rate of herbicide application per acre would be 1.13 pounds. USDA survey data, on the other hand, shows that an average of 0.96 pounds of herbicide were applied on soybeans in 2001. Accordingly, the NCFAP estimates for 2001 are not consistent with USDA herbicide use data; for example, NCFAP estimates an average rate of glyphosate application of 0.95 pounds, USDA estimates the rate at 0.85. If the NCFAP estimate of 0.95 pounds of glyphosate per acre of HT soybeans were accurate, the rate would have to be 0.98 on non-GE acres for the average pounds applied to equal the USDA estimate of 0.96.

It appears that the NCFAP team overestimated herbicide use on both GE and non-GE soybean acres, but overestimated use on non-GE acres by a wider margin. This led to the erroneous conclusion that HT soybeans were treated with an average of 0.57 fewer pounds of herbicides, hence reducing herbicide use by some 27.7 million pounds. Instead, this analysis estimates that the average acre of HT soybeans received 0.34 more pounds of herbicide in 2001, or an additional 17.6 million pounds. And consistent with both USDA herbicide use data and ERS estimates of the impact of HT soybeans on herbicide use, this analysis also finds that the difference between the pounds applied on HT soybean acres compared to non-HT acres is increasing over time.

METHODOLOGY and DATA SOURCES

The USDA does not routinely collect nor report data comparing in a given year the average number of pounds of herbicides applied per acre on cropland planted to HT crop varieties, compared to the average pounds of herbicides applied per acre on land planted to conventional crop varieties. Such data are needed to definitively settle whether GE crops have increased, decreased, or left the volume of pesticide use unchanged.

This report's estimates of the impacts of GE varieties on pesticide use are specific to a given crop, GE trait (HT or *Bt* transgenic), type of pesticide (herbicide or insecticide), and year. Overall impacts are simply the sum of annual impacts.

A simple three-step methodology produced the estimates in this report.

First, the number of acres producing HT and *Bt* transgenic crops each year is calculated using USDA data on the total acres planted to corn, soybeans, and cotton by year,

Data comparing the average number of pounds of herbicides applied per acre on cropland planted to HT varieties, compared to the average pounds of herbicides applied per acre on land planted to conventional varieties, are needed to definitively settle whether GE crops have increased, decreased, or left the volume of pesticide use unchanged.

coupled with USDA data on the percent of the acres of each crop planted to each GE technology. The data used in reaching these numbers appear in Tables 4, 5, 6, and 7. There is widespread agreement on these data.

Second, for each year and GE technology, the average pounds of pesticides applied per acre on conventional acres are calculated, along with the average rate on acres planted to the GE trait. When the rate applied to the GE portion of the crop is lower/higher than the rate applied to acres planted to non-GE varieties, pesticide use is reduced/increased. It is assumed that an acre not planted to the GE trait would receive the same level of pesticide use as acres planted to non-GE varieties. Hence, the difference between these two rates is an estimate of the impact of the GE trait on average per acre pesticide use.

Third, the difference in pesticide pounds applied per acre by crop and GE technology are combined with acres planted to each GE trait, to produce an estimate of the increase or decrease in pesticide pounds applied across all acres planted to a given GE trait in a given year between 1996 and 2003.

Estimating Average Application Rates by GE Technology

Slightly different methods were used to calculate the average pesticide application rates per acre in the case of herbicide tolerant and *Bt* transgenic varieties. In order to maximize the reliability of the estimates, as well as the trend data, the same basic data source for pesticide use rates and percent acres treated was used in making all the estimates. These data come from the annual National Agricultural Statistical Service (NASS) field crop pesticide use surveys.

By state and at the national level, this USDA-NASS survey reports by crop the percent of acres treated with a given pesticide, the average rate of application (for each distinct application), the average number of applications, the rate per crop year (average one-time rate multiplied by the number of applications), and the pounds applied. Electronic copies of annual NASS survey results covering 1991 through 2002 are accessible at http://usda.mannlib.cornell.edu/reports/nassr/other/pcu-bb/#field.

In the case of herbicide tolerant crops, the pounds of herbicides applied per HT acre in a given year were estimated by adding together the glyphosate rate of application in that year and an estimate of the average pounds of other herbicides applied. The pounds applied on non-GE acres were then calculated using the reported USDA average pounds applied across all acres; the percent of acres planted to HT and non-HT varieties, and the average pounds applied on HT acres, using the following formula –

Herbicide Pounds Applied per Acre Non-HT varieties of $Crop_x$ =

[USDA Ave Rate All acres $crop_x$ – (% acres HT varieties $crop_x$ x Rate GE varieties $crop_x$)] divided by (% acres non-HT varieties $crop_x$)

Herbicide Tolerant Corn

In the case of HT corn, the average rate of herbicide application was calculated as a weighted average between the average rates in two HT corn weed management programs – the "Roundup Reliant" program and the "Residual Herbicide Applied" program. Both programs are discussed in the Monsanto Roundup Ready corn technical guide. The rates of glyphosate applied in the programs are based on the actual average NASS reported rates per acre by year. Weed management experts were consulted in arriving at the 30 percent "Roundup Reliant" and 70 percent "Residual Applied" split in total HT acreage.

The difference in average herbicide pounds applied per acre shifts from a reduction of 0.8 pounds per acre in 1996 to an increase of 0.58 pounds per acre in 2003. This shift is

caused by three main factors –

- Increases in the rate of glyphosate applied per acre driven largely by shifts in weed communities, resistance, changes in tillage and planting systems, and significant reductions in the price of herbicides containing glyphosate as the active ingredient;
- Incremental increases in reliance of farmers

on herbicides other than glyphosate to assure season-long control of grasses in acres planted to HT corn; and
- The downward trend in the average rate of application of herbicides on non-HT acres.

HT corn technology reduced herbicide use per acre from 1996 through 2001, but increased use thereafter. The big change between 2001 and 2002 was brought about by the drop in the average pounds applied to non-HT acres from 2.24 pounds per acre to 1.85 pounds per acre. This came about because of the combination of regulatory restrictions on high-rate herbicides and the shift to low-dose herbicides. The rate of the most widely used corn herbicide atrazine fell from 1.18 in 2001 to 1.04 in 2002.

Note that the big drop in average pounds applied per acre in 2000 is reflected in the reduction in the glyphosate rates that year, as well as the pounds of other herbicides applied on HT acreage.

Herbicide Tolerant Soybeans

The annual pounds of glyphosate applied per acre of HT soybeans was estimated by adding to the USDA reported rate of application of glyphosate –

- An average of 0.15 pounds of other herbicides in 1996 and 1997;
- An average 0.22 pounds in 1998-2001; and
- An average 0.25 in 2002-2003.

The addition of 0.22 pounds in 1998 produced the correct weighted average rate across all acres planted to soybeans in 1998. The USDA average rate for all herbicides applied to soybeans was 1.08 pounds. Adding 0.22 pounds to the reported glyphosate rate of 0.9 produced a total average rate per acre of HT soybeans of 1.12 pounds. These estimates were then used in the weighted average formula to calculate the rate on non-HT acres (1.05 in 1998).

These estimates – 1.05 on non-HT acres and 1.12 on HT acres – produced the correct differential of 0.07 pounds per acre, established in the special tabulation done by ERS drawing on the 1998 ARMS data. This tabulation produced the ERS estimate of 2,300,000 more pounds of herbicide applied on HT soybeans noted in Table 16, or 0.07 pounds per acre.

The 22 percent jump in glyphosate pounds applied per acre from 2001 to 2002 was caused by the major price reductions offered to farmers, the need to control more difficult sets of weeds, and the emergence of resistance and/or lessened sensitivity in many weed species that were once fully controlled by one glyphosate application.

Herbicide Tolerant Cotton

The difference in herbicide application rates on HT cotton and conventional varieties changed incrementally much like in the case of HT corn and soybeans. It was assumed that the average acre of HT cotton was treated with 0.7 additional pounds of herbicides other than glyphosate from 1996 through 2000, and with 0.6 additional pounds in 2001-2003. This assumption reflects the increased use of low-dose herbicides on both conventional and HT cotton acres.

The reduction in average pounds applied on conventional acres accelerated in 2001, with a drop from 1.84 to 1.55.

The USDA did not collect cotton pesticide use statistics in 2002. As a result, it is not possible to confirm that the average rate of glyphosate applied on acres of HT cotton increased in 2002, as it clearly did in the case of soybeans. Accordingly, the estimates for differences in cotton herbicide use 2002 and 2003 are unchanged from 2001.

***Bt* Transgenic Corn**

Calculating the reduction in insecticide pounds applied for each acre planted to *Bt* corn is complicated by the fact that not all acres planted to *Bt*

The 22 percent jump in glyphosate pounds applied per acre from 2001 to 2002 was caused by the major price reductions offered to farmers, and the emergence of resistance and/or lessened sensitivity in many weed species that were once fully controlled by one glyphosate application.

varieties would have been treated with insecticides for the control of European corn borers (ECB) and/or Southwestern corn borers SWCB) if the farmers had instead decided not to plant *Bt* corn. This is evident in the data on percent of acres treated with an insecticide applied wholly or partially for control of the ECB/SWCB, compared to the percent of corn acres planted to *Bt* varieties. For example, in 2001, 24 percent of corn acres were planted to *Bt* varieties, yet historically well less than 10 percent of corn acres were treated with an insecticide for the management of these insects.

The method used to estimate the average pounds of insecticides applied on corn acres for management of EBC/SWCB is straightforward. USDA reports indicate that seven insecticides are applied for the management of the ECB/SWCB. Of these, two are generally applied largely or solely for control of the ECB/SWCB:

- Lambda-cyhalothrin; and
- Permethrin.

Five other insecticides are applied for control of multiple corn insect pests, including the ECB/SWCB:

- Chlorpyrifos;
- Bifenthrin;
- Esfenvalerate;
- Dimethoate; and
- Methyl parathion

Corn insecticide use data from the USDA was used to calculate the average pounds of these seven insecticides applied to corn acres by year, weighted in accord with each insecticide's share of the total pounds of these seven that were applied. The results (see the "Conventional Corn – weighted average rate per acre treated" line in Table 9) show a steady decline in the pounds applied per acre from 0.63 in 1995 to 0.36 in 2002 and 2003. The shift in acres treated toward low-dose synthetic pyrethroid insecticides accounts for the significant reduction between 2001 and 2002-2003.

Because of the efficacy of *Bt* corn, very few farmers planting *Bt* corn treated their fields with insecticides for control of the ECB/SWCB. Hence, projected insecticide applications on *Bt* corn acres are zero. In reality though, not all *Bt* corn acres would have been treated with insecticides, so the reduction in insecticide use as a result of *Bt* corn must be adjusted downward. This was done by first estimating the maximum percent of *Bt* corn acres that would have likely been treated with insecticides, based on the historic rate of ECB/SWCB insecticide treatment of 7.5 percent. In the first two years of *Bt* corn use, essentially all acres could have been previously treated with insecticides, but this percentage declines as the margin widens between the percent of acres planted to *Bt* varieties in contrast to 7.5 percent historically treated.

The estimate of the maximum percent of *Bt* corn acres that could have been treated with an insecticide needs to be adjusted a second time to reflect the degree of targeting of *Bt* varieties to acres previously treated with insecticides for ECB/SWCB control. It is assumed that farmers targeted *Bt* acres to acres previously sprayed for the ECB/SWCB with 60 percent efficiency. This estimate probably underestimates the efficiency of targeting in the southern and western edges of the Corn Belt where adoption of *Bt* corn was highest in step with ECB/SWCB pressure, and overestimates the percent in much of the northern and eastern Corn Belt, where far fewer corn acres were previously treated for ECB/SWCB control.

The estimated rate of application on acres planted to *Bt* varieties is then calculated by multiplying the percent of *Bt* acres that were not likely to have been treated with an insecticide by the average rate of application on acres that were treated. This adjustment reflects the fact that there can be no reduction from the planting of *Bt* corn on acres that were not previously treated with an insecticide. Hence, given the way this model estimates the difference in pesticide use between GE and non-GE varieties, for that portion of *Bt* corn acres planted where there was no actual reduction in insecticide use, we have to assume that those acres would have been treated at the same rate per acre as acres that were treated. This produces the correct estimate of the reduction in pounds applied as a result of planting *Bt* corn – zero.

Bt Transgenic Cotton

Unlike *Bt* corn, virtually 100 percent of the acres planted to *Bt* cotton were previously sprayed for control of the target pests, the Budworm/Bollworm complex. Accordingly, the method used to estimate insecticide use on acres planted to *Bt* and conventional cotton varieties is simpler than in the case of *Bt* corn.

Fifteen insecticides are applied largely for the management of the Budworm/bollworm complex. Based on pounds applied across these 15 insecticides and acres of cotton planted, average insecticide application rates by year were calculated and used as the estimated rates on acres planted to non-*Bt* varieties. As in the case of *Bt* corn, the rates decline from 0.48 pounds per acre in 1996 to 0.3 in 2001-2003. The shift to synthetic pyrethroid insecticides accounts for most of this reduction over time.

While *Bt* cotton is highly effective in many areas, it does not eliminate insecticide applications targeting the Budworm/Bollworm complex. Accordingly, it was assumed that the average acre of *Bt* cotton was treated with 0.1 pound of insecticides. Accordingly, the reduction in insecticide pounds applied per acre planted to *Bt* cotton ranges from 0.38 pounds in 1996 to 0.2 pounds in 2001-2003.

Table 1. Genetically engineered (GE) corn varieties by State and United States, 2000-2003

	Insect-resistant (*Bt*) Only				Herbicide-tolerant Only			
	2000	2001	2002	2003	2000	2001	2002	2003
State	--Percent of all corn planted -------------------------							
Illinois	13	12	18	23	3	3	3	4
Indiana	7	6	7	8	4	6	6	7
Iowa	23	25	31	33	5	6	7	8
Kansas	25	26	25	25	7	11	15	17
Michigan	8	8	12	18	4	7	8	14
Minnesota	28	25	29	31	7	7	11	15
Missouri	20	23	27	32	6	8	6	9
Nebraska	24	24	34	36	8	8	9	11
Ohio	6	7	6	6	3	4	3	3
South Dakota	35	30	33	34	11	14	23	24
Wisconsin	13	11	15	21	4	6	9	9
Other States1/	10	11	14	17	6	8	12	17
U.S.	18	18	22	25	6	7	9	11
	Stacked gene varieties				**All GE varieties**			
	2000	**2001**	**2002**	**2003**	**2000**	**2001**	**2002**	**2003**
State								
Illinois	1	1	1	1	17	16	22	28
Indiana	*	*	*	1	11	12	13	16
Iowa	2	1	3	4	30	32	41	45
Kansas	1	1	2	5	33	38	43	47
Michigan	*	2	2	3	12	17	22	35
Minnesota	2	4	4	7	37	36	44	53
Missouri	2	1	2	1	28	32	34	42
Nebraska	2	2	4	5	34	34	46	52
Ohio	*	*	*	*	9	11	9	9
South Dakota	2	3	10	17	48	47	66	75
Wisconsin	1	1	2	2	18	18	26	32
Other States1/	1		2	2	17	20	27	36
U.S.	1	1	2	4	25	26	34	40

* Less than 1 percent.

1/ Includes all other States in which USDA collected corn data.

Table 2. Genetically engineered (GE) soybean varieties by State and United States, 2000-2003								
	Herbicide-tolerant Only				**All GE varieties**			
	2000	**2001**	**2002**	**2003**	**2000**	**2001**	**2002**	**2003**
State	**Percent of all soybeans planted**							
Arkansas	43	60	68	84	43	60	68	84
Illinois	44	64	71	77	44	64	71	77
Indiana	63	78	83	88	63	78	83	88
Iowa	59	73	75	84	59	73	75	84
Kansas	66	80	83	87	66	80	83	87
Michigan	50	59	72	73	50	59	72	73
Minnesota	46	63	71	79	46	63	71	79
Mississippi	48	63	80	89	48	63	80	89
Missouri	62	69	72	83	62	69	72	83
Nebraska	72	76	85	86	72	76	85	86
North Dakota	22	49	61	74	22	49	61	74
Ohio	48	64	73	74	48	64	73	74
South Dakota	68	80	89	91	68	80	89	84
Wisconsin	51	63	78	84	51	63	78	84
Other States1/	54	64	70	76	54	64	70	76
U.S.	54	68	75	81	54	68	75	81

1/ Includes all other States in which USDA collected soybean data.

Table 3. Genetically engineered (GE) upland cotton varieties by State and United States, 2000-2003

	Insect-resistant (*Bt*) Only				Herbicide-tolerant Only			
	2000	**2001**	**2002**	**2003**	**2000**	**2001**	**2002**	**2003**
State	**Percent of all upland cotton planted**							
Arkansas	33	21	27	24	23	29	37	25
California	3	11	6	9	17	27	26	27
Georgia	18	13	8	14	32	43	55	32
Louisiana	37	30	27	30	13	14	9	15
Mississippi	29	10	19	15	13	15	22	16
North Carolina	11	9	14	16	29	37	27	29
Texas	7	8	7	8	33	35	40	39
Other States1/	17	18	19	18	21	33	35	32
U.S.	15	13	13	14	26	32	36	32
	Stacked Gene Varieties				**All GE Varieties**			
	2000	**2001**	**2002**	**2003**	**2000**	**2001**	**2002**	**2003**
State								
Arkansas	14	28	26	46	70	78	90	95
California	4	2	1	3	24	40	33	39
Georgia	32	29	30	47	82	85	93	93
Louisiana	30	47	49	46	80	91	85	91
Mississippi	36	61	47	61	78	86	88	92
North Carolina	36	38	45	48	76	84	86	93
Texas	6	6	4	6	46	49	51	53
Other States1/	36	33	32	38	74	84	86	88
U.S.	20	24	22	27	61	69	71	73

1/ Includes all other States in which USDA collected upland cotton data.

Table 4. Percent of National Acres Planted to All Herbicide Tolerant and *Bt* Transgenic Crop Varieties, 1996 through 2003 [Combines percent acres planted to HT only and *Bt* only varieties with percent planted to stacked varieties]

	1996	1997	1998	1999	2000	2001	2002	2003*
	- All Herbicide Tolerant Varieties - - - - - - - -- - - - - - - - - - - - - -							
Corn	3%	4.3%	18.4%	9%	7%	8%	11%	15%
Soybeans	7.4%	17%	44.2%	57%	54%	68%	75%	81%
Cotton	15%	15%	16.8%	34%	46%	56%	58%	59%
	- All *Bt* Transgenic Varieties -							
Corn	1.4%	7.6%	19.1%	25.6%	24.5%	19%	24%	29%
Soybeans	0%	0%	0%	0%	0%	0%	0%	0%
Cotton	12.7%	15.3%	19.0%	29.0%	28.7%	37%	35%	41%

* Acres planted in 2003 are preliminary projections based on recent trends.

Table 5. Corn, Soybeans and Cotton Acreage Planted, Average per Acre Pesticide Use, and Total Pounds Applied, 1996 through 2003

	1996	1997	1998	1999	2000	2001	2002	2003*	Total 1996-2003
Corn									
Acres Planted	79,507,000	80,227,000	80,798,000	77,431,000	79,579,000	79,545,000	79,054,000	79,066,000	635,207,000
Herbicides per Acre	2.65	2.63	2.47	2.41	2.11	2.24	1.90	1.90	
Pounds Herbicides (H)	210,693,550	210,997,010	199,571,060	186,608,710	167,911,690	178,180,800	150,202,600	150,225,400	1,454,390,820
Insecticides per Acre	0.22	0.23	0.18	0.16	0.15	0.14	0.08	0.08	
Pounds Insecticides (I)	17,491,540	18,452,210	14,543,640	12,388,960	11,936,850	11,136,300	6,324,320	6,325,280	98,599,100
Total Pounds: H+I	228,185,090	229,449,220	214,114,700	198,997,670	179,848,540	189,317,100	156,526,920	156,550,680	1,552,989,920
Soybeans									
Acres Planted	64,205,000	70,850,000	72,720,000	73,780,000	74,496,000	75,416,000	73,758,000	73,653,000	578,878,000
Herbicides per Acre	1.17	1.18	1.08	1.04	1.05	0.96	1.20	1.25	
Pounds Herbicides (H)	75,119,850	83,603,000	78,537,600	76,731,200	78,220,800	72,399,360	88,509,600	92,066,250	645,187,660
Upland Cotton									
Acres Planted	14,100,000	13,558,000	13,064,000	14,241,000	15,347,000	16,054,000	13,714,000	13,748,000	113,826,000
Herbicides per Acre	1.88	2.09	1.88	1.88	1.84	1.65	1.65	1.65	
Pounds Herbicides (H)	26,508,000	28,336,220	24,560,320	26,773,080	28,238,480	26,489,100	22,628,100	22,684,200	206,217,500
Insecticides per Acre	1.25	1.39	1.28	2.96	2.82	1.83	1.83	1.83	
Pounds Insecticides (I)	17,625,000	18,845,620	16,721,920	42,153,360	43,278,540	29,378,820	25,096,620	25,158,840	218,258,720
Total Pounds: H+I	44,133,000	47,181,840	41,282,240	68,926,440	71,517,020	55,867,920	47,724,720	47,843,040	424,476,220
Total Three Crops									
Acres Planted	157,812,000	164,635,000	166,582,000	165,452,000	169,422,000	171,015,000	166,526,000	166,467,000	1,327,911,000
Pounds Herbicides (H)	312,321,400	322,936,230	302,668,980	290,112,990	274,370,970	277,069,260	261,340,300	264,975,850	2,305,795,980
Pounds Insecticides (I)	35,116,540	37,297,830	31,265,560	54,542,320	55,215,390	40,515,120	31,420,940	31,484,120	316,857,820
Total Pounds: H+I	347,437,940	360,234,060	333,934,540	344,655,310	329,586,360	317,584,380	292,761,240	296,459,970	2,622,653,800
Pounds H+I per Acre	2.20	2.19	2.00	2.08	1.95	1.86	1.76	1.78	1.98

* Pesticide use in 2003 are preliminary projections based on crop year 2000 to 2002 totals and recent trends. (See tables on individual HT crops).

Table 6. Herbicide Tolerant Varieties of Corn, Soybeans, and Cotton: Acres Planted, 1996-2003

	1996	1997	1998	1999	2000	2001	2002	2003*	Total 1996-2003
HT Corn	2,385,210	3,449,761	14,866,832	6,968,790	5,570,530	6,363,600	8,695,940	11,859,900	60,160,563
HT Soybeans	4,751,170	12,044,500	32,142,240	42,054,600	40,227,840	51,282,880	55,318,500	59,658,930	297,480,660
HT Cotton	2,058,600	2,033,700	2,194,752	4,841,940	7,059,620	8,990,240	7,954,120	8,111,320	43,244,292
All HT Crops	9,194,980	17,527,961	49,203,824	53,865,330	52,857,990	66,636,720	71,968,560	79,630,150	400,885,515
Percent of Total Acres Planted to Three Crops	**5.8%**	**10.6%**	**29.5%**	**32.6%**	**31.2%**	**39.0%**	**43.2%**	**47.8%**	**30.2%**

* Acres planted in 2003 are preliminary projections based on recent trends.

Table 7. *Bt* Transgenic Varieties of Corn and Cotton: Acres Planted, 1996-2003

	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**Total 1996-2003**
Bt Corn	1,113,098	6,097,252	15,432,418	19,800,000	19,500,000	15,113,550	18,972,960	22,929,140	118,958,418
Bt Cotton	1,796,390	2,078,890	2,486,493	4,123,252	4,409,348	5,939,980	4,799,900	5,636,680	31,270,933
Total	2,909,488	8,176,142	17,918,911	23,923,252	23,909,348	21,053,530	23,772,860	28,565,820	150,229,351
Percent of Total Acres Planted to Two Crops	**3.1%**	**8.7%**	**19.1%**	**26.1%**	**25.2%**	**22.0%**	**25.6%**	**30.8%**	**20.1%**

Table 8. Herbicide Pounds Applied per Acre to Conventional and Herbicide Tolerant Corn, 1996-2003 [See Notes]

Active Ingredient	1996	1997	1998	1999	2000	2001	2002	2003*
NASS Average Glyphosate Rate per Crop Year	0.68	0.52	0.64	0.71	0.65	0.73	0.70	0.75
Percent Acres HT Corn Planted	3%	4.3%	18.4%	9%	7%	8%	11%	15%
Roundup Reliant Program (30% HT Acreage)								
Glyphosate per RR Acre (Average 2.0 applications)	1.36	1.04	1.28	1.42	1.3	1.46	1.4	1.5
Other Herbicides Applied per RR Acre	0.5	0.75	0.85	0.85	0.75	0.85	1.0	1.0
Total Herbicide Applied per RR Acre	1.86	1.79	2.13	2.27	2.05	2.31	2.4	2.5
Residual Herbicide Applied (70% of HT Acreage)								
Glyphosate per RR Acre	0.68	0.52	0.64	0.71	0.65	0.73	0.7	0.75
Other Herbicide Applied	1.2	1.2	1.4	1.4	1.2	1.4	1.6	1.6
Total Herbicide Applied per RR Acre	1.88	1.72	2.04	2.11	1.85	2.13	2.3	2.35
Weighted Average Herbicide Use per RR Corn Acre	1.87	1.74	2.07	2.16	1.91	2.18	2.33	2.40
NASS Average Rate	2.65	2.63	2.47	2.41	2.11	2.24	1.90	1.90
Conventional Acres Rate	2.67	2.67	2.56	2.43	2.13	2.24	1.85	1.81
Difference in Rate Between HT and Conventional Varieties	-0.80	-0.93	-0.49	-0.28	-0.22	-0.06	0.48	0.58

Notes: Weighted average rate per acre planted to RR varieties assumes 30% of acres under "Roundup Reliant" program and 70% under "Residual Herbicide Applied" program.

* Herbicide application rates in 2003 are estimates based on continuation of recent trends.

Table 9. Pounds per Acre of Insecticides Applied to Control the European Corn Borer on Conventional and *Bt* Transgenic Varieties of Corn, 1996-2003 [See Notes]

	1996	1997	1998	1999	2000	2001	2002	2003*
Acres Planted	79,507,000	80,227,000	80,798,000	77,431,000	79,579,000	79,545,000	79,054,000	79,066,000
Bt Corn Acres Planted	1,113,098	6,097,252	15,432,418	19,800,000	19,500,000	15,113,550	18,972,960	22,929,140
% *Bt* Corn Acres Planted	1.4%	7.6%	19.1%	25.6%	24.5%	19.0%	24.0%	29.0%
Historic % Acres Treated for ECB/ SWCB	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
Percent Acres Treated								
lambda-cyhalotrin	2.0%	1.0%	2.0%	3.0%	2.0%	2.0%	2.0%	2.0%
permethrin	4.0%	5.0%	2.0%	3.0%	3.0%	3.0%	2.0%	2.0%
chlorpyrifos	8.0%	7.0%	6.0%	5.0%	6.0%	4.0%	3.0%	3.0%
bifenthrin	1.0%	0.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
esfenvalerate	1.0%	0.0%	0.0%	0.5%	0.6%	0.0%	0.0%	0.0%
dimethoate	0.4%	0.0%	1.0%	0.5%	0.3%	0.1%	0.6%	0.6%
methyl parathion	2.0%	4.0%	1.0%	1.0%	0.7%	1.0%	0.4%	0.4%
Total Percent Acres Treated	18.4%	17.0%	14.0%	15.0%	14.6%	12.1%	10.0%	10.0%
Percent Not Treated	81.6%	83.0%	86.0%	85.0%	85.4%	87.9%	90.0%	90.0%
Acres Treated								
lambda-cyhalotrin	1,590,140	802,270	1,615,960	2,322,930	1,591,580	1,590,900	1,581,080	1,581,320
permethrin	3,180,280	4,011,350	1,615,960	2,322,930	2,387,370	2,386,350	1,581,080	1,581,320
chlorpyrifos	6,360,560	5,615,890	4,847,880	3,871,550	4,774,740	3,181,800	2,371,620	2,371,980
bifenthrin	795,070	0	1,615,960	1,548,620	1,591,580	1,590,900	1,581,080	1,581,320
esfenvalerate	795,070	0	0	387,155	477,474	0	0	0
dimethoate	318,028	0	807,980	387,155	238,737	79,545	474,324	474,396
methyl parathion	1,590,140	3,209,080	807,980	774,310	557,053	795,450	316,216	316,264
Total Acres Treated	14,629,288	13,638,590	11,311,720	11,614,650	11,618,534	9,624,945	7,905,400	7,906,600
Weighted Share of Treated Acres								
lambda-cyhalotrin	0.11	0.06	0.14	0.20	0.14	0.17	0.20	0.20
permethrin	0.22	0.29	0.14	0.20	0.21	0.25	0.20	0.20
chlorpyrifos	0.43	0.41	0.43	0.33	0.41	0.33	0.30	0.30
bifenthrin	0.05	0.00	0.14	0.13	0.14	0.17	0.20	0.20
esfenvalerate	0.05	0.00	0.00	0.03	0.04	0.00	0.00	0.00
dimethoate	0.02	0.00	0.07	0.03	0.02	0.01	0.06	0.06
methyl parathion	0.11	0.24	0.07	0.07	0.05	0.08	0.04	0.04
Rates per Acre								
lambda-cyhalotrin	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
permethrin	0.12	0.10	0.10	0.09	0.09	0.10	0.10	0.10
chlorpyrifos	1.04	1.23	1.01	1.08	1.05	1.14	0.94	0.94
bifenthrin	0.05	0.00	0.07	0.07	0.07	0.05	0.06	0.06
esfenvalerate	0.03	0.00	0.00	0.05	0.13	0.02	0.00	0.00
dimethoate	0.46	0.00	0.52	0.46	0.48	0.51	0.42	0.42
methyl parathion	0.52	0.66	0.41	0.51	0.45	0.52	0.53	0.53

Table 9. (Cont.) Pounds per Ace of Insecticides Applied to Control the European Corn Borer on Conventional and *Bt* Transgenic Varieties of Corn, 1996-2003 [See Notes]

	1996	1997	1998	1999	2000	2001	2002	2003*
Conventional Corn								
Weighted Average Rate per Acre Treated	0.55	0.69	0.53	0.44	0.50	0.46	0.36	0.36
***Bt* Corn Acres**								
Maximum Possible % *Bt* Acres Previously Treated with Insecticide	100%	99%	39%	29%	31%	39%	31%	26%
Estimated % Acres Planted to *Bt* Previously Treated with Insecticide (Assumes 60% of Maximum value)	60%	59%	24%	18%	18%	24%	19%	16%
Estimated % *Bt* Acres Planted Not Previously Treated with Insecticides	40%	41%	76%	82%	82%	76%	81%	84%
Average Rate Applied on Acres Planted to *Bt* Varieties	0.22	0.28	0.40	0.36	0.41	0.35	0.30	0.31
Difference Between *Bt* Transgenic and Conventional Varieties**	-0.33	-0.41	-0.12	-0.08	-0.09	-0.11	-0.07	-0.06

* Pesticide use estimates for 2003 are preliminary projections based on 2002 data and recent trends.

** Differences in pounds of insecticides applied do not take into account the pounds of *Bt* produced within the cells of transgenic corn plants (see text for discussion).

Table 10. Difference in Actual Herbicide Application Rates per Acre on HT versus Conventional Soybeans, 1998				
	Percent Area Treated	**Acres Planted**	**Average Number of Herbicides Applied per Acre**	**Average Pounds of Herbicides Applied per Acre**
Conventional Varieties, No Glyphosate Applied	47.9%	34,803,176	2.7	1.08
Conventional Varieties, Glyphosate Applied	8.0%	5,789,284	3.2	1.45
Total Conventional Varieties		40,592,460		
RR Varieties	38.8%	28,197,596	1.4	1.22
Other Herbicide-Tolerant Varieties	5.4%	3,929,944	2.8	1.06
Total HT Varieties		32,127,540		
All Soybeans	100%	72,720,000		
Weighted Average Rate on Conventional Acres	**1.13**			
Weighted Average Rate on GE Acres	**1.20**			
Difference Between Conventional and GE Varieties	**0.07**			
Source: Special tabulations done by the Economic Research Service for Benbrook Consulting Services.				

Table 11. Pounds per Acre of Herbicides Applied to Conventional and Herbicide Tolerant Soybeans, 1996-2003

	1996	1997	1998	1999	2000	2001	2002	2003*
Acres Planted	64,205,000	70,850,000	72,720,000	73,780,000	74,496,000	75,416,000	73,758,000	73,653,000
HT Acres Planted	4,751,170	12,044,500	32,142,240	42,054,600	40,227,840	51,282,880	55,318,500	59,658,930
Percent Acres Treated								
HT Varieties	7.4%	17.0%	44.2%	57.0%	54.0%	68.0%	75.0%	81.0%
Glyphosate	25.0%	28.0%	46.0%	62.0%	62.0%	73.0%	78.0%	84.0%
Glyphosate Notill, Non RR	17.6%	11.0%	1.8%	5.0%	8.0%	5.0%	3.0%	3.0%
Rates per Acre								
NASS Average	1.17	1.18	1.08	1.04	1.05	0.96	1.20	1.25
Glyphosate	0.69	0.79	0.90	0.90	0.88	0.85	1.04	1.09
HT Varieties	0.84	0.94	1.12	1.12	1.10	1.07	1.29	1.34
Conventional Varieties	1.20	1.23	1.05	0.93	0.99	0.73	0.93	0.87
Difference in Pounds per Acre Between HT and Conventional Varieties	-0.36	-0.29	0.07	0.19	0.11	0.34	0.36	0.47

Notes: * Herbicide use rates in 2003 are preliminary projections based on 2002 data and recent trends.

Table 12. Pounds per Acre of Herbicides Applied to Cotton on Conventional and Herbicide Tolerant Varieties, 1996-2003

	1996	1997	1998	1999	2000	2001	2002*	2003*
Acres Planted	14,100,000	13,558,000	13,064,000	14,241,000	15,347,000	16,054,000	13,714,000	13,748,000
HT Acres Planted	2,058,600	2,033,700	2,194,752	4,841,940	7,059,620	8,990,240	7,954,120	8,111,320
Percent Acres Planted								
HT Varieties	14.6%	15.0%	16.8%	34.0%	46.0%	56.0%	58.0%	59.0%
Glyphosate/RR	14.6%	14.0%	12.8%	27.0%	40.0%	55.0%	57.0%	58.0%
Bromoxynil	NA	1%	4%	7%	6%	1%	1%	1%
Rates per Acre								
NASS Average	1.88	2.09	1.88	1.88	1.84	1.65	1.65	1.65
Glyphosate	0.63	0.79	1.02	1.04	1.14	1.12	1.12	1.12
Conventional Varieties	1.97	2.20	1.91	1.95	1.84	1.55	1.55	1.55
HT Varieties	1.33	1.49	1.72	1.74	1.84	1.72	1.72	1.72
Difference in Pounds per Acre Between HT Transgenic and Conventional Varieties	-0.64	-0.71	-0.19	-0.21	0.00	0.17	0.17	0.17

* Herbicide rates for 2002 and 2003 are preliminary estimates based on 2000-2001 data. There was no cotton pesticide use data collected by USDA in 2002.

Table 13. Pounds per Acre of Insecticides Applied to Control the Budworm/ Bollworm Complex of Insects on Conventional and *Bt* Transgenic Varieties of Cotton, 1996-2003

	1996	1997	1998	1999	2000	2001	2002*	2003*
Acres Planted	14,100,000	13,558,000	13,064,000	14,241,000	15,347,000	16,054,000	13,714,000	13,748,000
Bt Acres Planted	1,796,390	2,078,890	2,486,493	4,123,252	4,409,348	5,939,980	4,799,900	5,636,680
Percent Acres Planted to Bt Varieties	12.7%	15.3%	19.0%	29.0%	28.7%	37.0%	35.0%	41.0%
Budworm/ Bollworm Average Pounds Applied	0.48	0.45	0.38	0.36	0.28	0.30	0.30	0.30
Total Pounds per Acre	1.25	1.39	1.26	2.96	2.82	1.83	1.5	1.5
Budworm/ Bollworm Conventional Rate	0.48	0.45	0.38	0.36	0.28	0.30	0.30	0.30
Budworm/ Bollworm *Bt* Rate	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Difference in Pounds per Acre Between *Bt* Transgenic and Conventional Varieties**	-0.38	-0.35	-0.28	-0.26	-0.18	-0.20	-0.20	-0.20

* Insecticide rates for 2002 and 2003 are preliminary projections based on 2000-2001 data. There was no cotton pesticide use data collected by USDA in 2002.

** Differences in pounds of insecticides applied do not take into account the pounds of *Bt* produced within the cells of transgenic cotton plants (see text for discussion).

Table 14. Average Pesticide Pounds Applied per Acre Planted to Conventional, Herbicide Tolerant, and *Bt* Transgenic Varieties* and Estimated Differences per Acre, 1996 through 2003 [Includes acres planted to stacked varieties]

	1996	1997	1998	1999	2000	2001	2002	2003**
Coventional Corn								
Herbicide	2.67	2.67	2.56	2.43	2.13	2.24	1.85	1.81
Insecticide	0.55	0.69	0.53	0.44	0.50	0.46	0.36	0.36
GE Corn								
Herbicide Tolerant	1.87	1.74	2.07	2.16	1.91	2.18	2.33	2.40
Bt Transgenic	0.22	0.28	0.40	0.36	0.41	0.35	0.30	0.31
Average Difference GE to Conventional								
Herbicide	-0.80	-0.93	-0.49	-0.28	-0.22	-0.06	0.48	0.58
Insecticide	-0.33	-0.41	-0.12	-0.08	-0.09	-0.11	-0.07	-0.06
Conventional Soybeans								
Herbicide	1.20	1.23	1.05	0.93	0.99	0.73	0.93	0.87
GE Soybeans								
Herbicide Tolerant	0.84	0.94	1.12	1.12	1.10	1.07	1.29	1.34
Average Difference GE to Conventional								
Herbicide	-0.36	-0.29	0.07	0.19	0.11	0.34	0.36	0.47
Conventional Cotton								
Herbicide	1.97	2.20	1.91	1.95	1.84	1.55	1.55	1.55
Insecticide	0.48	0.45	0.38	0.36	0.28	0.30	0.30	0.30
GE Cotton								
Herbicide Tolerant	1.33	1.49	1.72	1.74	1.84	1.72	1.72	1.72
Bt Transgenic	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Average Difference GE to Conventional								
Herbicide	-0.64	-0.71	-0.19	-0.21	0.00	0.17	0.17	0.17
Insecticide	-0.38	-0.35	-0.28	-0.26	-0.18	-0.20	-0.20	-0.20

* Differences in pounds of insecticides applied do not take into account the pounds of *Bt* produced within the cells of transgenic corn and cotton plants (see text for discussion).

**Pesticide use rates in 2003 are preliminary projections based on 2000-2002 data and recent trends.

Table 15. Differences in the Pounds of Pesticides Applied to Conventional Versus GE Corn, Soybean, and Cotton Varieties, 1996 through 2003 [Includes acres planted to stacked varieties]

	1996	1997	1998	1999	2000	2001	2002	2003*	Totals 1996-2003
Corn									
Herbicides	-1,908,168	-3,204,637	-7,342,320	-1,929,819	-1,197,963	-387,350	4,201,409	6,906,648	-4,862,200
Insecticides	-368,193	-2,499,543	-1,914,047	-1,541,264	-1,787,339	-1,648,061	-1,296,327	-1,296,524	-12,351,299
Herbicides plus Insecticides (H+I)	-2,276,361	-5,704,180	-9,256,367	-3,471,083	-2,985,302	-2,035,410	2,905,082	5,610,123	-17,213,499
H+I as % of Total Pesticides Applied	-1.0%	-2.5%	-4.3%	-1.7%	-1.7%	-1.1%	1.9%	3.6%	-1.1%
Soybeans									
Herbicides (H)	-1,693,182	-3,482,747	2,304,103	7,824,112	4,372,591	17,628,490	19,914,660	28,259,493	75,127,521
H as % of Total Pesticides Applied	-2.3%	-4.2%	2.9%	10.2%	5.6%	24.3%	22.5%	30.7%	11.6%
Cotton									
Herbicides	-1,325,796	-1,435,553	-422,068	-1,027,078	0	1,498,373	1,325,687	1,351,887	-34,548
Insecticides	-682,628	-727,612	-696,218	-1,072,046	-793,683	-1,187,996	-959,980	-1,127,336	-7,247,498
Herbicides plus Insecticides (H+I)	-2,008,424	-2,163,164	-1,118,286	-2,099,124	-793,683	310,377	365,707	224,551	-7,282,046
H+I as % of Total Pesticides Applied	-4.6%	-4.6%	-2.7%	-3.0%	-1.1%	0.6%	0.8%	0.5%	-1.7%
Three Crops									
Herbicides	-4,927,146	-8,122,937	-5,460,285	4,867,215	3,174,628	18,739,514	25,441,756	36,518,027	70,230,772
Insecticides	-1,050,822	-3,227,154	-2,610,265	-2,613,310	-2,581,022	-2,836,057	-2,256,307	-2,423,860	-19,598,797
Herbicides plus Insecticides (H+I)	-5,977,967	-11,350,091	-8,070,550	2,253,905	593,606	15,903,457	23,185,448	34,094,167	50,631,976
H+I as % of Total Pesticides Applied	-1.7%	-3.2%	-2.4%	0.7%	0.2%	5.0%	7.9%	11.5%	1.9%

* Estimates for 2003 are preliminary projections based on data for 2001-2002 and recent trends.

Table 16. Estimates of the Impacts of Genetically Engineered Crops on the Pounds of Pesticides Applied in the United States, Selected Years ("HT" stands for herbicide tolerant)

	1997	1998	2001	Source
Economic Research Service				
Corn, soybeans, cotton:				
Total Pounds	-331,000	-153,000		[4]
Total Pounds		-2,500,000		[1]
HT Cotton		No change*		[2]
RR Soybeans Only		2,300,000		[2]
HT Soybeans	Decrease			[5]
HT Cotton	No change**			[5]
Bt Cotton	No change**			
Gianessi et al				
Eight current cultivars			-46,000,000	[3]
HT Soybeans: Pounds per Acre			-0.57	[3]
HT Soybeans: Pounds Applied			-27,703,001	[3]
HT Corn: Pounds Applied			-5,805,000	[3]
HT Cotton: Pounds Applied			-6,169,000	[3]
Bt Corn: Pounds Applied			-2,603,456	[3]
Bt Cotton: Pounds Applied			-1,870,100	[3]

* "No change" means that ERS found no statistically significant change in pesticide use.

** ERS reported no change in organophosphate or pyrethroid insecticide use, or in overall pesticide use, and a decrease in "Other insecticides."

Sources:

[1] "Agricultural Outlook," Sept 2002, pages 24-27, based on Economic Research Service analysis.

[2] "Adoption of Bioengineered Crops," Ferandez-Cornejo, J., and W.D. McBride, USDA Economic Research Service, May 2002.

[3] "Plant Biotechnology: Current and Potential Impact for Improving Pest Management in U.S. Agriculture," Gianessi, L. P., Silvers, C.S., Sankula, S. and J.E. Carpenter, National Center for Food and Agriucltural Policy, June 2002.

[4] "Genetically Engineered Crops: Has Adoption Reduced Pesticide Use?" USDA Economic Research Service, Agricultural Outlook, August 2000, pages 13-17.

[5] "Genetically Engineered Crops for Pest Management in U.S. Agriculture," Fernandez-Cornejo, J., and W.D. McBride, USDA Economic Research Service, April 2000.

Appendix Table 1. Correction in NASS Corn Herbicide Use Data for Error in Rate of Application of Metolachlor

	1998	1999	2000	2001	2002	2003*
	Pounds Applied per Acre Treated					
NASS Metolachlor Rate	1.86	1.42	1.65	1.64	1.52	1.52
Actual Metolachlor Rate	1.86	1.9	1.9	1.9	1.9	1.9
Difference in Rate	0	0.48	0.25	0.26	0.38	0.38
Corn Acres Planted	80,798,000	77,431,000	79,579,000	79,545,000	79,054,000	79,066,000
% Acres Treated with Metolachlor	32%	29%	12%	6%	8%	8%
Metolachlor Acres Treated	25,855,360	22,454,990	9,549,480	4,772,700	6,324,320	6,325,280
Change in Metolachlor Pounds	-	10,778,395	2,387,370	1,240,902	2,403,242	2,403,606

* The conversion from old Metolachlor to s-Metolachlor was completed in 2002, so Metolachlor use projected in 2003 would be from old inventory or stocks held on farms. Herbicide rates for 2003 are preliminary estimates based on 2000-2002 data.