Genetically Engineered Crops and Pesticide Use in the United States: The First Nine Years

Charles M. Benbrook
BioTech InfoNet
Technical Paper Number 7
October 2004

TABLE OF CONTENTS

Charts, Figures and Tables

Acknowledgements

The analysis in this report relies heavily on the good work of the USDA's National Agricultural Statistics Service (NASS). While NASS pesticide use data are neither perfect nor complete, the annual NASS survey on pesticide use in major field crops is the best and only source of publicly accessible, national data on pesticide use. NASS data are consistent over time and across production regions, key attributes for an assessment over several years such as the one reported herein.

Thanks to Karen Lutz Benbrook for compiling NASS pesticide use data into a database that allows more in-depth analyses. She also did an excellent job in producing the report's final format and layout.

Several pest management specialists working at land grant universities provided guidance regarding recent developments in the field and the appropriate interpretation of USDA data. The entomologists and weed science specialists at several universities, in particular Iowa State University, the University of Illinois, Purdue University, University of Arizona, and the University of Wisconsin are conducting and reporting independent analyses of the impacts, performance, costs and benefits of today's genetically engineered crops. Thank you to them for their important and ongoing work.

Also thanks to the Union of Concerned Scientists for providing the funding that made it possible for this analytical work to be carried out. This report was prepared by Benbrook Consulting Services and is being provided free of charge via Ag BioTech InfoNet as a public service.

EXECUTIVE SUMMARY

Genetically Engineered Crops and Pesticide Use in the United States: The First Nine Years

Photo by Jack Dykinga
Courtesy of ARS, USDA

The major genetically engineered (GE) crop varieties commercialized since 1996 in the United States have been designed to help control a damaging class of insects and simplify herbicide-based weed management systems. Over the first nine years of commercial use, 670 million acres of crops expressing GE traits have been planted, or about 23 percent of the total 2,970 million acres of crops harvested across the country during this period.

Remarkably rapid and extensive adoption of GE varieties in three major crops -- corn, soybeans and cotton – has brought enormous commercial success to the biotechnology and seed industry and reflects the popularity of these technologies to row crop farmers. Still, adoption is limited to two traits in three crops that are, for the most part, either fed to animals or heavily processed. Staple crops consumed directly by people in the U.S. remain GE-free, with the exception of very limited experimental plantings.

Crops engineered to tolerate applications of herbicides, or so-called "herbicide-tolerant" crops (HT), account for the largest share of GE acres. About 487 million acres have been planted since 1996, or 73 percent of total GE crop acres. HT soybeans are the most widely planted GE crop technology and account for over half the total acres planted to GE varieties since 1996. The vast majority of HT crops are engineered to tolerate glyphosate (trade name "Roundup"), a herbicide introduced to the market in 1972, by Monsanto. Crops engineered to tolerate glyphosate are also called "Roundup Ready."

Corn and cotton have been genetically engineered to express the bacterial toxin *Bacillus thuringiensis*, or *Bt*. This transgenic trait allows plants to manufacture within their cells a crystalline protein that is toxic to most Lepidopteran insects. Some 183 million acres of *Bt* transgenic corn and cotton have been planted since 1996, representing 27 percent of total GE crop acreage.

Pesticide Reduction Claims are Unfounded

"Since 1990, suggested glyphosate rates have increased by 50% to 200% on certain weeds including ryegrass, horseweed, foxtail, barnyardgrass and waterhemp."

Farm Journal Spring 2004

The debate over the costs, risks, and benefits of agricultural biotechnology has been underway for about a decade, with no end in sight. Throughout this period, biotech proponents have claimed repeatedly that today's GE crop technologies are reducing pesticide use. A comprehensive accounting of the impacts of HT and *Bt* transgenic varieties on total pesticide use demonstrates unequivocally that in the first three years of commercial use, this claim was justified. But since 1999 it has not been.

GE corn, soybeans and cotton have led to a 122 million pound increase in pesticide use since 1996. While *Bt* crops have reduced insecticide use by about 15.6 million pounds over this period, HT crops have increased herbicide use 138 million pounds. *Bt* crops have reduced insecticide use on corn and cotton about 5 percent, while HT technology has increased herbicide use about 5 percent across the three major crops. But since so much more herbicide is used on corn, soybeans, and cotton, compared to the volume of insecticide applied to corn and cotton, overall pesticide use has risen about 4.1 percent on acres planted to GE varieties.

The increase in herbicide use on HT crop acres should come as no surprise. Weed scientists have warned for about a

"Weed shifts and herbicide resistance are a direct result of a lack of diversification in weed management systems."

Dr. Jeff Gunsolus, University of Minnesota

decade that heavy reliance on HT crops would trigger changes in weed communities and resistance, in turn forcing farmers to apply additional herbicides and/or increase herbicide rates of application. The ecological adaptations predicated by scientists have been occurring in the case of Roundup Ready crops for three or four years and appear to be accelerating. Farmers across the American Midwest look back fondly on the initial efficacy and simplicity of the Roundup Ready system and many miss the "good old days."

Reliance on a single herbicide, glyphosate, as the primary method for managing weeds on millions of acres planted to HT varieties remains the primary factor that has led to the need to apply more herbicides per acre to achieve the same level of weed control.

Average application rates of glyphosate in HT weed management systems have jumped sharply in the last few years as a result of the spread of glyphosate-tolerant or resistant marestail (also known as horseweed), shifts in the composition of weed communities, and substantial price reductions and volume-based marketing incentives from competing manufacturers of glyphosate-based herbicides.

Glyphosate-resistant marestail (right) and nonresistant marestail stand side by side in an Indiana field.

(Photo/Purdue University Department of Botany and Plant Pathology)

4. The First Nine Years - Executive Summary

While ecological changes are pushing herbicide use upward on HT crop acres, regulatory forces and industry innovation are edging average application rates downward on land planted to conventional varieties. S-metolachlor herbicide was registered in time for the 1997 crop season. It is a new and more biologically active version of metolachlor, an older, high-rate herbicide. S-metolachlor is applied at 65 percent of the rate of original metolachlor and has reduced herbicide use by 10 to 12 million pounds per year since 1998. The Environmental Protection Agency also placed new restrictions on the most widely used corn herbicide, atrazine, triggering substantial drops in per acre application rates in 2000 and again in 2002.

As a result, the difference in the total pounds of herbicides applied per acre planted to HT crops compared to non-HT conventional varieties has increased steadily since 2000. Three factors – the emergence and spread of weeds resistant or less sensitive to glyphosate, limited supplies of conventional crop seeds in a number of popular maturity groups, and aggressive herbicide price cutting by companies seeking a larger share of the market -- are working together to create the "perfect storm" that now threatens to undermine the efficacy of HT technology.

For the foreseeable future, HT crops will increase pesticide use more than *Bt* transgenic crops reduce it. Unlike the worrisome erosion in the efficacy of HT technology, *Bt* transgenic corn targeting the European corn borer, and *Bt* cotton continue to perform well. Resistance management plans appear to be working.

For all current and future pest management related GE technologies, when and how GE varieties are utilized will determine their cost, benefits and longevity. The unraveling of HT technology is just the latest reminder that too much of a good thing is the kiss of death in the world of pest management

INTRODUCTION

Photo by Scott Bauer
Courtesy of ARS, USDA

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 Lepidopteran insect pests. Proponents of biotechnology claim that today's GE varieties substantially reduce pesticide use, a claim not substantiated by U. S. Department of Agriculture (USDA) data and reports. Here, USDA data on the acreage planted to GE crops and pesticide use 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 during the period 1996-2004.

All USDA 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 are accessible via the Economic Research Service's "Key Topics" page on biotechnology (http://www.ers.usda.gov/Topics/view.asp?T=101000). Analyses by Leonard Gianessi sponsored by the biotechnology industry have projected positive impacts on pesticide use, most recently in crop year 2001, and can be accessed on the website of the National Center for Food and Agricultural Policy (http://www.ncfap.org/whatwedo/40casestudies.php). No study by USDA or private analysts has estimated nor reported the impacts in recent years. This is the first comprehensive estimate of the impacts of GE crops on pesticide use over the nine years of commercial use, since 1996.

This report draws on official USDA statistics on the acreage planted to GE varieties from 1996 through 2004, coupled with USDA data on the volume of pesticides applied to corn, soybeans, and cotton. These three crops account for nearly all acres planted to GE crops in the United States. The analysis addresses the impacts of the two major types of GE traits –

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

Herbicide-Tolerant Crops

Current Inventory of Glyphosate- Resistant Weeds
Conyza bonariensis *Hairy Fleabane* *South Africa—2001* *Spain—2004*
Conyza canadensis *Horseweed* *USA— 2000-2004*
Eleusine indica *Goosegrass* *Malaysia —1997*
Lolium multiflorum *Italian Ryegrass* *Chile- 2001-2002* *Brazil-2003*
Lolium rigidum *Rigid Ryegrass* *Australia- 1996—1997, 2000* *USA- 1998* *South Africa-2001*
Plantago lanceolata *Buckhorn Plantain* *South Africa-2003*

Figure 1. Glycine (G/9) Resistant Weeds by Species and Country. Weedscience.org (International Survey of Herbicide Resistant Weeds)

Herbicide-tolerant (HT) crops allow farmers to spray broad-spectrum herbicides over the top of growing plants, controlling most weeds while leaving crops largely unharmed. HT weed management systems are simple, flexible, and forgiving, and in most years and regions, they have been very effective, at least until recent years. Good performance coupled with ease of use explains why farmers have so enthusiastically embraced HT crops.

The economic impacts of HT crops have been complex and dynamic. In the first three years of adoption, most farmers attained adequate control of weeds with a single application of glyphosate herbicide. As Roundup Ready (RR) crops gained market share at the expense of other herbicides, the companies losing market share cut herbicide prices aggressively. By 2000, the average cost of soybean herbicides had been cut about 40 percent, saving farmers hundreds of millions per year. These savings, however, have nothing to do with the inherent efficiency of HT technology; competitive forces in a hotly contested marketplace were the cause.

In 2000 patent protection for glyphosate herbicide came to an end, allowing generic competitors to enter the market. Since 2001, the price of glyphosate as fallen steadily to about one-half to one-third the level in 1996 when HT crops were first introduced. In September 2004, Monsanto announced further price reductions for Roundup brand herbicides for crop year 2005, coupled with substantial enhancements in their incentive programs for farmers agreeing to buy Monsanto seed and apply only Monsanto-brand herbicides. This sort of bundling of inputs is an increasingly common tactic used in fiercely contested agricultural input markets and has attracted the attention of the antitrust division of the Department of Justice.

7. The First Nine Years - Introduction

While glyphosate prices have fallen, use rates have risen, as has the need for farmers to apply additional herbicides to deal with tough-to-control grass weeds and weed species that have attained either tolerance or resistance to glyphosate. So despite dramatic, across-the-board decreases in the price of herbicides in 2002-2004, farmers are spending about the same amount on weed control because they have to spray two to three different herbicides, have to spray more times, and they are still paying a significant premium for HT seed.

Until the widespread adoption of RR crops, weed scientists had confirmed only two cases of glyphosate-resistant weeds – rigid ryegrass in Australia, South Africa, and the U.S., and goosegrass in Malaysia. Six different weeds are now resistance in multiple countries and states, and there is a long list of weeds that have developed a degree of tolerance sufficient to require applications of other herbicides. The Weed Science Society of America maintains an up to date global registry of resistance weeds. (See the sidebar, p. 6 for the current list of glyphosate-resistant weeds)

△ Glyphosate-resistant ryegrass in (NSW) Australia. Photo by Andrew Storrie (Andrew.Storrie@agric.nsw.gov.au)

Bt Transgenic Technology

The other major category of GE crops has been engineered to produce one or more of several crystalline forms of the natural bacterial toxin *Bacillus thuringiensis* (*Bt*). Unlike chemical insecticides that are sprayed typically in a liquid form one to three times a season to control Lepidopteran insects, *Bt* toxins are manufactured continuously inside and throughout the plant, exposing both target and nontarget organisms feeding on the plant, or on plant roots, to *Bt* toxins. The technology is inherently prophylactic, since the plant manufactures the *Bt* toxins whether or not insect populations exceed economic thresholds (the level of pest infestation at which crop losses exceed the cost of control interventions).

When an acre is planted to a *Bt* transgenic variety, several changes often occur in the range of pest and beneficial species residing in the field. Sometimes the absence of insecticide applications targeting Lepidopteran insects creates an ecological window allowing other secondary insects to increase to potentially damaging levels. In other cases, lessened use of the generally broad-spectrum chemistry used to control Lepidoptera insects allows a range of beneficial arthropods to flourish in crop fields, reducing other insect problems. Sometimes both phenomena occur simultaneously, with secondary pest problems typically emerging rather quickly, followed by a gradual reduction in insect pest pressure as beneficial insect populations are established and thrive.

As a result, it is complicated to carry out a full accounting of the net impact of *Bt* varieties on insect populations and insecticide uses. There is another important factor that should be taken into account in estimating the net impact of *Bt* transgenic technology on insecticide use. The *Bt* toxin that is produced continuously in *Bt*-transgenic plant tissues is an insecticide that is nearly identical to the *Bt* toxins that are the active ingredients in liquid *Bt* insecticide sprays. The volume of *Bt* toxin produced over a full season in a field of *Bt* transgenic plants should be calculated and then counted in estimating the impacts of *Bt* technology on insecticide use. Doing so is difficult and beyond the scope of this report, and indeed no such estimate has been disclosed or published. Accordingly, this report's estimates of the impact of *Bt* crops on average insecticide use per acre overstate the actual impact by an amount equal to the quantity of *Bt* toxin produced by the plants on an average acre planted to a *Bt* transgenic variety.

ACREAGE PLANTED TO GENETICALLY MODIFIED VARIETIES AND PESTICIDE USE, 1996-2004

Commercial plantings of genetically engineered crops in the United States began in 1996. Appendix Table 1 and Table 1 (below) provides an overview of the land planted to three major crops – corn, soybeans, and cotton. Genetically modified varieties of these three crops account for nearly all the acres of genetically modified agricultural crops produced in the United States since 1996. A small number of acres have been planted to genetically modified potatoes and herbicide-tolerant canola (rapeseed).

Appendix Table 1 presents the total acres planted to the three major crops from 1996 through 2004, as well as over the full nine-year period. Summary data on pesticide use on these crops are also provided including –

- Pounds of herbicides applied per acre and total pounds of active ingredients applied by crop;
- Insecticides applied per acre and totals by crop; and
- Total pounds of herbicides, insecticides, and herbicides plus insecticides applied across the three crops.

The pesticide use estimates in 2004 in Appendix Table 1 are projections from recent trends. The factors taken into account in making these estimates are discussed in "Impacts of GE Crop Technology on Pesticide Use" (pages 32 – 38), where pesticide use on each of the three crops is discussed and analyzed.

Table 1. Corn, Soybean and Cotton Acreage Planted, Average Pesticide Use per Acre, and Total Pounds Applied; 1996-2004 (SUMMARY)

	Corn	Soybeans	Upland Cotton	Total Three Crops
Total Acres Planted	716,241,000	653,725,000	127,878,000	1,497,844,000
Total Pounds Applied (Herbicide & Insecticide)	1,743,593,040	746,226,410	421,586,580	2,957,137,030
Average Pesticide Use Per Acre (Pounds)	2.43	1.14	3.30	1.97

10. The First Nine Years - Acreage Planted to GE Varieties and Pesticide Use

Today, low-dose chemistry accounts for the lion's share of acres treated with both herbicides and insecticides. Several products are applied at rates less than 0.1 pound per acre, and some at rates below 0.01 pound per acre.

In the nine years since the introduction of genetically modified varieties of corn, soybeans, and cotton, the intensity of herbicide and insecticide use per acre has declined modestly on average from 2.2 pounds of active ingredients per acre to about 1.9 pounds, or by about 14 percent. Most of the reduction has been brought about by the registration and adoption of pesticides applied at markedly lower rates per acre than the older products they have displaced. Herbicide use in these crops was still dominated in 1996 by products applied at rates of 1.0 pound to over 2.0 pounds per acre. Likewise, insecticides applied at relatively high rates, sometimes up to 1.0 pound per acre, still accounted for a significant share of the corn and cotton acres treated with insecticides.

Today, low-dose chemistry accounts for the lion's share of acres treated with both herbicides and insecticides. Several products are applied at rates less than 0.1 pound per acre, and some are sprayed at rates below 0.01 pound per acre. For example, the most widely used corn insecticide in 1996 was permethrin, an insecticide then applied at an average rate of 0.12 pound per acre. The dominant insecticide applied in 2003 was cyfluthrin, a product effective at just 0.006 pound per acre. In soybean production, 27 percent of national acres in 1996 were treated with the herbicide pendimethalin at an average rate of 0.97 pounds per acre, and trifluralin was applied on 20 percent of national acres at a rate of 0.88 pounds. From 1996 to 2002, the combined percent of soybean acres treated with these two high-dose herbicides dropped from 49 percent to 16 percent. In 2002, sixteen herbicides were applied at average rates below 0.1 pound per acre on conventional soybeans. The shift to lower-dose herbicides in corn production is summarized in Appendix Table 2.

Table 2. Shift to Low-Dose Corn Herbicides from 1996 and 2003: Number of Top Ten Nationally Applied Active Ingredients by Rate of Application

Rate of Application (pound of AI per Acre)	1996	2003
>2.0	1	0
1.5—1.99	3	1
1.0—1.49	2	2
0.5—0.99	0	2
0.1—0.49	3	2
<0.1	1	3

Source: U.S.D.A. National Agricultural Statistic Service (NASS), Agricultural Chemical Usage, Field Crop Summary, 1996 and 2003.

Acreage Planted to Genetically Modified Varieties

Accurate data is available from the U.S. Department of Agriculture's Economic Research Service (ERS) on the percent of crop acres planted to GE varieties by State and nationally. ERS acreage estimates are based on farm-level survey data collected by USDA's National Agricultural Statistics Service (NASS). Table 3 summarizes recently released ERS data on the percent of total national crop acres planted to herbicide-tolerant (HT) and *Bt* transgenic varieties of corn, soybeans, and cotton. All estimates of the acres planted to GE varieties in this report are derived from these USDA estimates of percent acres planted to GE technology, coupled with the total acres planted to each of the three major crops in Table 1. Three appendix tables (Appendix Tables 2, 3, and 4) present more detailed information by crop and by State on the percent of acres planted to GE varieties. Chart 1 shows the trends over time in the percent of acres planted to HT and *Bt* transgenic varieties.

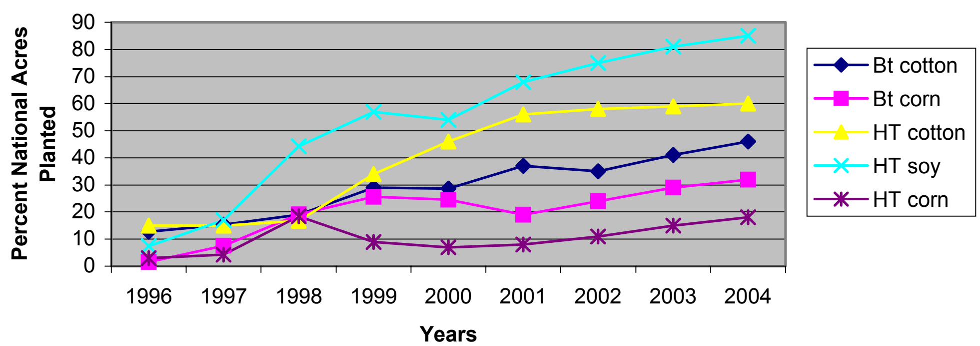
Table 3. Percent of National Acres Planted to All Herbicide-Tolerant (HT) and *Bt* Transgenic Crop Varieties, 1996—2004 [Combines percent acres planted to HT only and *Bt* only varieties with percent planted to stacked varieties]

	1996	1997	1998	1999	2000	2001	2002	2003	2004*
———All Herbicide-Tolerant Varieties———									
Corn	3%	4.3%	18.4%	9%	7%	8%	11%	15%	18%
Soybeans	7.4%	17%	44.2%	57%	54%	68%	75%	81%	85%
Cotton	15%	15%	16.8%	34%	46%	56%	58%	59%	60%
———All *Bt* Transgenic Varieties———									
Corn	1.4%	7.6%	19.1%	25.6%	24.5%	19%	24%	29%	32%
Soybeans	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cotton	12.7%	15.3%	19%	29%	28.7%	37%	35%	41%	46%

*Acres planted in 2004 are preliminary USDA projections

Herbicide-tolerant soybeans were planted on 85 percent of national crop acreage in 2004, up 4 percent from 2003. The rate of adoption of herbicide-tolerant corn is clearly increasing at a much slower pace than in the case of soybeans. Some 18 percent of national corn acres were planted to HT varieties in 2004, reflecting an average annual growth rate of under 2 percent of national corn acres per year since commercial introduction in 1996. In contrast, the rate of growth in adoption of HT soybeans has been about four-times greater.

Chart 1. Trends in the Percent of National Crop Acreage Planted to Herbicide-Tolerant and *Bt* Transgenic Crops, 1996-2004



Bt transgenic corn varieties were planted on an estimated 32 percent of total crop acres in 2004, up modestly from 2003. Since 1998, the percentage of corn acres planted to *Bt* corn has varied from 19 percent to 32 percent. Adoption went down in two years since 1998 and has risen in four years. *Bt* cotton was adopted on 12.7 percent of national acres in its first year of introduction and now is planted on about 46 percent of total acres.

Appendix Table 5 presents the national acres of corn, soybeans and cotton planted to herbicide-tolerant varieties for 1996-2004 and totals for the nine-year period. In 1996, the first year of commercial introduction, HT technology was used on 5.8 percent of the acres planted to the three major crops. The share planted to HT crops almost doubled in 1997, and then almost tripled in 1998. Growth has slowed since, *Over the first nine years of commercial use , HT soybeans have accounted for three-quarters of the total HT-acres planted, and 54 percent of total GE plantings (HT plus Bt transgenic acres).*

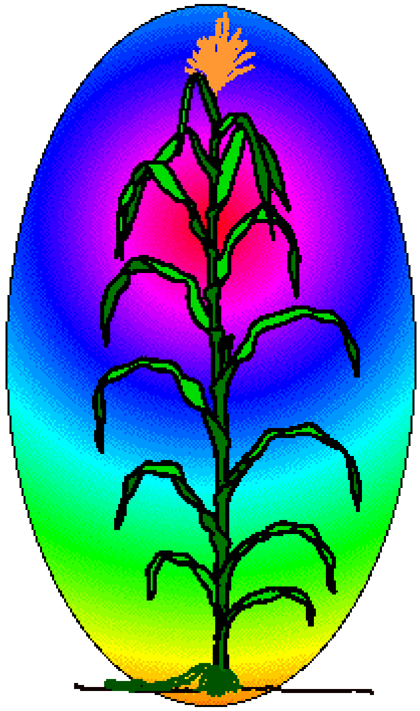
reaching 51 percent of the acreage planted to the three crops in 2004.

The dominance of herbicide-tolerant soybeans as a share of total acres planted to HT varieties since 1996 is evident in Appendix Table 5. Over the first nine years of commercial planting of HT varieties, HT soybeans have accounted for three-quarters of the total HT acres planted, and 54 percent of total GE plantings, including both HT and *Bt* transgenic acres. This is why the impact of HT soybeans on herbicide use plays such a major role in determining the overall impact of GE crop technology on total pesticides use since 1996.

National acres planted by crop to *Bt* transgenic varieties of corn and cotton is presented in Appendix Table 6 for the period 1996-2004. A total of 182.6 million acres have been planted since 1996, with corn accounting for about 80 percent and cotton, 20 percent. Corn acres planted to *Bt* varieties actually fell in 2000 and 2001, and cotton acres planted declined from 2001 to 2002. But over the full nine-year period, the percent of total national corn plus cotton acres planted to *Bt* varieties increased from 3.1 percent to 34.1 percent.

As in the case with HT varieties, the rapid growth in adoption of *Bt* transgenic varieties occurred in the first four years of commercial use. In crop year 2004, the first corn varieties engineered to express the Cry 3Bb *Bt* toxin for control of corn rootworms were introduced. Appendix Table 6 does not include the estimated two to four million acres planted to these new varieties.

AVERAGE PESTICIDE USE ON GE AND CONVENTIONAL CROP ACRES



Despite longstanding public debate over the impact of GE crop technology on pesticide use, the USDA does not routinely collect nor report data comparing the average pounds of pesticides applied per acre on cropland planted to GE varieties compared to conventional varieties. Accordingly, indirect methods must be used to estimate pesticide use on GE versus conventional crop acres.

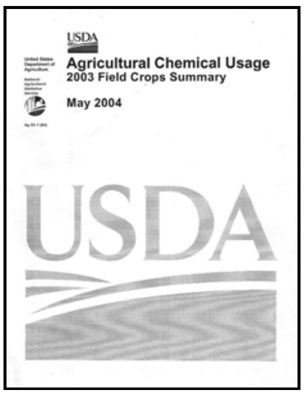
Calculations in this report of the impacts of GE varieties on average per acre pesticide use are based on publicly accessible National Agricultural Statistics Service (NASS) pesticide use data specific to a given crop, year, and pesticide. A three-step methodology is used.

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, and the percent of acres planted to various GE crops, as shown in Appendix Tables 1 through 6. Appendix Tables 2 through 4 present more detailed adoption data by State. There is widespread agreement on these estimates, although a survey carried out by the American Corn Growers Association in the early summer, 2004, suggests that the USDA estimate of adoption of *Bt* corn in 2004 may be marginally inflated.

Second, the average pounds of pesticides applied per acre on conventional (non-GE) acres are calculated for each year and GE technology, along with the average rate of application on acres planted to each GE trait. The rate applied to the GE portion of the crop is then compared to the rate applied to conventional acres, producing an estimate of the average difference in pesticide use between conventional and GE-planted acres. The differential is measured in pounds of herbicide or insecticide active ingredient per acre. This approach rests on the assumption that an acre not planted to the GE trait would receive the same volume of pesticide applications as acres planted to non-GE varieties.

In the third and last step, the difference in pesticide pounds applied per acre for each GE technology for a given year is multiplied by the acres planted to the GE crop that year, producing an estimate of the increase or decrease in pesticide use. These differences are then added across the nine-year period, producing estimates of the total impact of HT and *Bt* transgenic varieties on herbicide and insecticide use, both by crop and by trait.

Estimating Average Application Rates by GE Technology


USDA
Agricultural Chemical Usage
2003 Field Crops Summary
May 2004
USDA

Annual USDA-NASS pesticide use surveys are the only publicly accessible, consistent time-series data on the volume of pesticides applied on corn, soybeans, and cotton. Even for these three major field crops, USDA does not collect pesticide use data every year. No cotton data was collected in 2002 and remarkably, given the intense public debate over herbicide use in HT soybeans, no soybean pesticide use data was collected in 2003. In both cases, pesticide use estimates in this report for the missing years were based on extrapolation of trends in recent years.

By state and at the national level for a variety of crops, NASS surveys record and report 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 total pounds applied. Electronic copies of annual NASS survey results covering 1991 through 2003 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 crop acre in a given year were estimated by adding together the glyphosate rate of application in that year as reported by NASS, and an estimate of the average pounds of other herbicides applied. The basis for the estimates of other herbicide use on HT acres for each crop is discussed in the following sections.

The pounds applied on non-GE acres were then calculated using a simple mathematical formula:

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

[USDA average rate all acres $crop_x$ – (% acres HT varieties $crop_x$ x rate GE varieties $crop_x$)] divided by (% acres non-HT varieties $crop_x$)

This formula is based on the standard equation used to calculate a weighted average of two values – in this case, the average of the pounds of herbicides applied on HT acres and the pounds applied on conventional acres. These rates of application, weighted by their respective share of total acres planted, must equal the average pounds of herbicides applied on all crop acres.

In the above equation, the average pounds of herbicides applied on all acres of a given crop ("USDA average rate all acres $crop_x$") are calculated from NASS survey data. USDA data are also available to calculate the share of crop acres planted to HT versus conventional varieties (data are reported in Table 3, p. 11). NASS pesticide use data, coupled with information from herbicide manufacturers and universities, was used to estimate the average pounds of all herbicides applied on HT acres, leaving only one variable to calculate by solving the above equation. The impact of HT technology on herbicide use in a given year, by crop, is then calculated by subtracting the average rate applied to conventional acres from the average rate applied to HT acres. When this number is negative, HT technology reduced herbicide use; when it is positive, average herbicide use per acre increased.

Throughout this report, pesticide use estimates for 2004 are preliminary, since USDA will not release field crop pesticide use for 2004 until May 2005. Pesticide use

"There are increasing concerns that glyphosate-resistant common lambsquarter may occur in Wisconsin."

Glyphosate Stewardship Program

University of Wisconsin Extension

estimates for 2004 are based on levels in 2003 and trends in recent years. For corn and cotton, the estimates for 2004 are conservative, in that they reflect a smaller percentage increase from 2003 to 2004 than the increase evident in USDA data from 2002 to 2003.

The estimated increase in herbicide use on HT soybeans between 2003 and 2004 is also conservative. Three major factors drove up HT soybean herbicide use per acre in 2004 –

- Soybean producers had to contend with several tolerant and resistant weeds, some of which infested substantial acreage for the first time in 2004;
- Aggressive marketing by all major herbicide manufacturers of new combination products specifically formulated to augment weed control in RR soybeans. These new products contained two, and sometimes three, active ingredients; and
- Falling prices of herbicides containing glyphosate, and indeed most herbicides registered for use on soybeans, allowed farmers to increase applications without raising costs.

Herbicide-Tolerant Corn

Farmer adoption of herbicide-tolerant corn has progressed much more slowly than HT soybeans and cotton, in large part because growers have several other, comparably effective herbicide-based weed management alternatives. Farmers and university experts agree that managing weeds in corn in the mid-1990s was much simpler and more reliable – and less costly – than weed management in soybeans or cotton.

As shown in Table 4, the average rate of herbicide application on HT corn acres was calculated as a weighted average between the rates in the two major HT corn weed management programs – the "Roundup Reliant" program and the "Residual Herbicide Applied" program. These are the two basic program options discussed in the Monsanto Roundup Ready corn technical guide, and "Roundup Ready" HT technology accounts for virtually all HT corn acres.

18. The First Nine Years - Average Pesticide Use

Table 4. Herbicide Pounds Applied per Acre to Conventional and Herbicide-Tolerant (HT) Corn, 1996-2004 (see notes)									
	1996	1997	1998	1999	2000	2001	2002	2003	2004 *
NASS Ave Glyphosate Rate per Crop Year	0.68	0.52	0.64	0.71	0.65	0.73	0.70	0.83	0.90
NASS Ave Glyphosate Rate per Application	0.68	0.52	0.64	0.59	0.59	0.66	0.64	0.69	0.69
Percent Acres HT Crop Planted	3%	4.3%	18.4%	9%	7%	8%	11%	15%	18%
ROUNDUP RELIANT ROGRAM (30% HT ACREAGE)									
Glyphosate per RR Acre (Ave 2.0 applications)	1.36	1.04	1.28	1.18	1.18	1.32	1.28	1.38	1.38
Other Herbicide Applied on RR Acre	0.5	0.75	0.85	0.85	0.75	0.85	0.9	1.0	1.1
Total Herbicide Applied per RR Acre	1.86	1.79	2.13	2.03	1.93	2.17	2.18	2.38	2.48
RESIDUAL HERBICIDE APPLIED (70% HT ACREAGE)									
Glyphosate per RR Acre	0.68	0.52	0.64	0.59	0.59	0.66	0.64	0.69	0.69
Other Herbicide Applied	1.2	1.2	1.4	1.4	1.2	1.4	1.5	1.6	1.7
Total Herbicide Applied per RR Acre	1.88	1.72	2.04	1.99	1.79	2.06	2.14	2.29	2.39
WEIGHTED AVERAGE HERBICIDE USE PER RR CORN ACRE	1.87	1.74	2.07	2.0	1.83	2.09	2.15	2.32	2.42
NASS Average Rate	2.65	2.63	2.47	2.41	2.11	2.24	1.9	2.04	2.1
Conventional Acres Rate	2.67	2.67	2.56	2.45	2.13	2.25	1.87	1.99	2.03
Difference in Rate Between H and Conventional Varieties	-0.80	-0.93	-0.49	-0.45	-0.30	-0.16	0.28	0.33	0.39
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 applications rates in 2004 are estimates based on continuation of recent trends									

These program options are also discussed in the weed management field guides, bulletins, and reports issued by all Midwestern land grant university weed management departments.

The rates of glyphosate applied in these programs are based on the average NASS rates per acre reported for each year. Weed management experts were consulted in determining that about 30 percent of corn HT areas are planted using the "Roundup Reliant" program and about 70 percent adhere to the "Residual Applied" program.

The "Roundup Reliant" program utilizes an average of two applications of glyphosate, while the "Residual Herbicide Applied" program depends on a single application. For both programs, the one-time rate of application of glyphosate reported by NASS was used in calculating the pounds of glyphosate applied.

Differences in average herbicide use on HT and conventional corn acres are calculated in Table 4. The first line of data in the table reports the NASS average rate for glyphosate per crop year. These rates take into account both the average rate per single application and the average number of applications per acre. The second line shows the average one-time application rate of glyphosate.

Note the substantial jump in the glyphosate rate per crop year from 2002 to 2003, and from 2003 to 2004. NASS reported that the average rate increased from 0.7 to 0.83 pounds per acre from 2002 to 2003, an increase of 18.6 percent. Average glyphosate use per crop year in 2004 was estimated at 0.9 pounds per acre, a 7.8 percent increase over 2003 use rates. This increase is less than half the jump reported by NASS between 2002 and 2003, and as previously noted, is likely conservative. The upward trend in per acre herbicide use on HT corn acres is driven by the same dominant factors noted above that are also increasing HT soybean herbicide use.

The difference in herbicide use on HT versus conventional corn acres shifted from a reduction of 0.8 pounds per acre in 1996 to an increase of 0.39 pounds in 2004. This shift from a significant reduction to a moderate increase in herbicide use is caused by a combination of two factors –

- Increased average herbicide use on HT acres; and
- Reductions in the pounds of herbicides applied on conventional corn acres, as a result of regulatory restrictions on high-dose herbicides including atrazine, the replacement of metolachlor with the lower-rate herbicide S-metolachlor, and the registration of a growing number of low- and very-low-dose corn herbicides.

The big change between 2001 and 2002 was brought about by the drop in the average pounds applied to non-HT acres from 2.25 pounds per acre to 1.87 pounds per acre. This came about because of the combination of regulatory restrictions on high-rate herbicides and the shift to low-dose herbicides. NASS reported that the rate of the most widely used corn herbicide, atrazine, fell from 1.18 pound per acre in 2001 to 1.04 in 2002. The registration of S-metolachlor in 1997 allowed farmers to cut the rate of application of a widely used, staple corn herbicide about 0.6 pounds per acre, without any sacrifice of weed control. This reduced-rate herbicide has decreased corn herbicide use on conventional corn acres by 10 to 12 million pounds annually since 1999.

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 use on Roundup Ready (RR) corn acres is almost certainly going to increase further. Monsanto has recently reported another aggressive round of price cuts, coupled with enhanced promotional programs for farmers buying Monsanto seed and Monsanto brand herbicides. Throughout the late summer and fall 2004, most major farm magazines have been running a Monsanto advertising campaign that promotes the RR corn system, featuring its compatibility with common tillage and planting systems and capacity to reduce costs. The "Roundup Ready Corn 2" program is composed of three steps –

1. "Spray [with Harness Xtra] for early weed control" prior to planting;
2. "Plant RR Corn 2"; and
3. "Spray Roundup Herbicide" during the growing season.

Harness Xtra is a Monsanto herbicide mixture developed specifically for RR corn that contains its proprietary herbicide acetochlor, as well as atrazine. This product targets early season and residual grass control and is applied at a recommended rate of 1.8 to 2.3 quarts per acre, depending on soil type. Rates as high as 2.7 quarts are recommended in the event of heavy weed infestation. Assuming an average application rate of 2 quarts per acre, just modestly above the minimum label rate, an application of Harness Xtra, followed during the season with a single application of glyphosate, results in the following rates of herbicide application per acre –

- Acetochlor – 2.15 pounds
- Atrazine – 0.85 pounds
- Glyphosate – 0.7 pound
- Total program – 3.7 pounds.

Some fields of RR Corn 2 will require two applications of glyphosate, leading to a total of 4.4 pounds of herbicide applied per acre. Even if one application of glyphosate proves effective, this newly recommended Monsanto program requires substantially more herbicide per acre than the projections for 2004 under the "Residual Herbicide Applied" section in Table 4, where the total herbicide volume applied is estimated at 2.39 pounds per acre.

Roundup Ready Corn 2 + Harness Xtra + Roundup = 3.7 to 4.4 pounds per acre of RR Corn

Herbicide-Tolerant Soybeans

Appendix Table 7 presents average herbicide application rates per acre on conventional versus HT soybeans over the nine-year period. As in the case of HT corn, HT soybeans reduced herbicide use moderately in the first two years on commercial use. By the fourth year of use, herbicide use started to rise. By the seventh year of use, the average increase in per acre herbicide use equaled the decrease in applications in the first year of use. The biggest jump occurred between 2000 and 2001, the year glyphosate went off patent and herbicide prices were dramatically cut in a struggle among the leading herbicide manufacturers to increase or hold market share.

USDA data shows a clear upward trend in glyphosate and HT herbicide rates per acre since 2001. The 22 percent jump in glyphosate pounds applied per acre from 2001 to 2002 was caused by price reductions, 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 a single glyphosate application.

The pounds of all herbicides applied per acre of HT soybeans by year were estimated in Table 6 by adding to the USDA reported rate of application of glyphosate –

- An average of 0.15 pounds of other herbicides in 1996 and 1997;
- 0.22 pounds of other herbicides in 1998-2001;
- 0.25 pounds in 2002-2003; and
- 0.3 pounds in 2004.

Marestail plant surviving after herbicide application to a RR soybean Field. (Note that the bottom of the plant was killed, but the plant was still able to regrow) From "Identifying Glyphosate-Resistant Marestail in the Field", July 21, 2003, Purdue Weed Science (www.btny.purdue.edu/weedscience/)

NASS did not collect soybean pesticide use data in 2003, so rates in 2003 and 2004 were projected from recent trends and weed management updates on land grant university websites. Crop year 2003 was an extremely challenging one for soybean weed management. Erratic weather in the spring delayed herbicide applications in some areas, allowing hard-to-control weeds to reach a size requiring higher rates of glyphosate application and/or treatment with additional herbicides. Untimely spring rains washed some applications of glyphosate off weeds before uptake, requiring re-treatment. Glyphosate-resistant marestail emerged as a serious problem in more than a dozen states. In 2004, the extent and severity of weed control failures linked to resistant or tolerant weeds required a significant increase in herbicide use in many regions and accounted for most of the increase in per acre herbicide use projected between 2003 and 2004.

Special Tabulation in 1998 Provides Solid Data Point

A series of special tabulations of herbicide use data on HT and conventional acres were carried out by the ERS at the request of Benbrook Consulting Services. The ERS divided the sample points in the 1998 Agricultural Resources Management Survey (ARMS) 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.

For 1998 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 was used to calculate total herbicide use per acre on conventional and HT soybeans in 1998, using a simple weighted average formula. The rates and percents of acres planted to conventional varieties treated and not treated with glyphosate were used to calculate the overall conventional-acres rate of 1.13 pounds per acre. (Conventional acres treated with glyphosate were planted using either no-tillage or conservation tillage systems in which the glyphosate is applied before soybean seeds germinate).

The same information was used to calculate the average rate of all herbicides applied on HT acres, which was 1.2 pounds per acre. These results are reported in Table 5 and show that the average acre of HT soybeans in 1998 was treated with 0.07 pounds more herbicide than conventional acres. This is the most accurate estimate of this difference that can be made drawing on available USDA data on actual herbicide use. The difference reflects total herbicide use per acre reported by farmers on fields planted to HT versus conventional varieties. This solid estimate of the difference was used to calibrate the estimates in Appendix

Table 7, which also reports a difference of 0.07 pounds per acre in 1998 between the pounds of herbicides applied on HT versus conventional acres.

The average rate for all herbicides applied to soybeans in 1998 was 1.08 pounds according to NASS data, as shown in the 1998 column in Appendix Table 7. On HT acres, an average of 0.9 pounds of glyphosate was applied, again according to NASS survey results. An estimated 0.22 pounds of other herbicides were applied on HT acres. Total herbicide use on HT acres was 1.12 pounds. This estimate, along with NASS-reported total herbicide use of 1.08 pounds, was then used to calculate the average rate on conventional acres using the weighted average formula. This calculated rate was 1.05 in 1998.

Table 5. Difference in Average Herbicide Application Rates per Acre on Herbicide-Tolerant (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 HT 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 HT Acres	1.20			
DIFFERENCE BETWEEN CONVENTIONAL AND HT VARIETIES	0.07			

Source: Percent area treated, number of applications and pounds applied per acre by type of seed are from special tabulations done by the Economic Research Service for Benbrook Consulting Services. Calculations of rates of application on conventional and HT soybeans by Benbrook Consulting Services.

The estimate of 1.05 pounds of all herbicides applied on non-HT acres and 1.12 on HT acres in Appendix Table 7 corresponds to the correct differential of 0.07 pounds per acre, as reported in the special ERS tabulation of actual use data in Table 5.

Herbicide-Tolerant Cotton

Weed management in cotton has always required more herbicide per acre than soybeans. This is because cotton fields are planted in somewhat wider rows and do not form as dense of a closed canopy of foliage as soybeans. More weeds germinate and grow in cotton fields compared to soybeans because more sunlight reaches the ground. In addition, the growing season for a cotton crop is longer, which gives weeds more time to get established and requires active management of weeds over a longer period of time. In the first few years of commercial use, many HT soybean farmers got through a season with very clean fields following just one application of glyphosate; cotton farmers planting HT varieties were never able to replicate this level of performance and always needed to apply additional herbicides, or multiple applications of glyphosate or bromoxynil, the other herbicide used in conjunction with HT cotton varieties.

Photo by William Molin
Courtesy of ARS, USDA

The difference in herbicide application rates on HT cotton and conventional varieties shifted incrementally over time much like in the case of HT corn and soybeans, as shown in Appendix Table 8. In the first two years of commercial use, each acre planted to HT cotton reduced herbicide use by about one-third pound. Efficacy slipped in years three and four such that there was essentially no difference in total herbicide use on HT and conventional acres.

By year five, weed shifts, tolerance, and resistance had pushed total herbicide use on HT acres to a level 0.23 pounds above total herbicide use on conventional acres. The upward trend has continued, reaching a differential of 1.01 pounds in 2003, a very difficult year for weed management in cotton country. Substantial weed control failures in 2003 in parts of the cotton belt, coupled with the rapid spread of glyphosate-resistant marestail, made weed management even more difficult in 2004, triggering an estimated 10 percent increase in the average pounds of herbicides applied her acre.

NASS reported a large jump in glyphosate use per acre of cotton between 2001 and 2003 – 1.12 pounds to 1.38 pounds per acre. (Recall that NASS did not collect cotton pesticide use data in 2002). Appendix Table 8 assumes that the total increase of 0.26 pounds was evenly divided between the two subsequent production seasons. The average acre of HT cotton was treated with 0.8 to 1.1 pounds of herbicides other than glyphosate from 1996 through 2004, with levels tracking general trends in total herbicide use.

The reduction in average pounds applied on conventional acres accelerated between 1999 and 2000, reflected the registration and wider use of low-dose herbicides. Heavier weed pressure accounts for much of the increase in pounds applied in 2004.

Bt Transgenic Corn

Calculating the impact of *Bt* corn on insecticide use is complicated by several factors. For decades, about 8 to 12 percent of the corn acres planted nationally have been treated for control of European corn borers (ECB) and/or Southwestern corn borers (SWCB) -- the insects targeted by *Bt* corn. In its third year of commercial use in 1998, *Bt* corn was planted on 19.1 percent of national corn acres – about twice the acreage ever sprayed to control the ECB or SWCB. Clearly, a significant portion of the acres planted to *Bt* corn varieties in 1998, and since, would not have been sprayed if the farmers had continued to plant conventional varieties. Accordingly, estimates have to be made of the portion of the acreage planted to *Bt* corn each year that would have likely been sprayed with insecticides for management of ECBs and/or SWCBs.

The third line of data from the bottom of Appendix Table 9 is labeled "Percent Acres Planted to *Bt* Previously Treated with Insecticide." It presents annual estimates of the share of *Bt* corn acres that would have been sprayed and starts out very high – an estimated 90 percent of the 1.1 million acres of *Bt* corn in 1996 would likely have been sprayed. As the acres planted to *Bt* corn increases, the percentage that was likely sprayed with insecticides declines. Over the period 1997 through 2004, the percent of *Bt* corn acres planted that would have been sprayed is estimated to vary between 26 and 33 percent. In 2004 about one-third of national corn acres were planted to *Bt* corn. An estimated 27 percent of these acres had previously been treated with insecticides for ECB and/or SWCB management. Accordingly, *Bt* corn reduced insecticide use on about 7 million acres.

The introduction of *Bt* corn varieties in the mid-1990s heightened research and grower focus on the damage caused by ECBs and SWCBs. As a result of better documentation of the losses caused by these insects, farmers have managed them more aggressively than prior to 1996. This is evident in Appendix Table 9, which reports that the combined number of acres planted to *Bt* corn, plus acres producing conventional corn that were sprayed with insecticides for ECB/SWCB control, rose appreciably above historical levels. In 2003, for example, 7 million acres were planted to *Bt* corn and 8.8 million acres were sprayed with insecticides for ECBs and SWCBs, for a total acreage under insect pest management of 15.8 million acres. This estimate of the acres treated for ECBs/SWCBs reflects about a 50 percent increase over historical levels. Some land grant entomologists are urging farmers to rethink their decision to automatically plant *Bt* corn for ECB/SWCB in those parts of the Corn belt where population levels have been low in recent years. Strong evidence suggests that corn growers are now over treating for ECBs/SWCBs in some major growing areas, resulting in unnecessary expenditures, needless impacts on nontarget species like Monarch butterflies, and increasing the risk of resistance.

The method used to estimate the average pounds of insecticides applied on corn acres for management of EBC/SWCB is straightforward. USDA data and university pest management specialists indicate that eight insecticides are applied for the management of the ECB/SWCB. Of these, three are generally applied largely or solely for control of the ECB/SWCB:

- Lambda-cyhalothrin;
- Cyfluthrin; and
- Permethrin.

Five other insecticides are applied for control of multiple corn insect pests, including the ECB/SWCB, corn rootworms, cutworms, armyworms, and aphids. These insecticides, and the share of their annual use that targets the ECB/SWCB, are:

- Chlorpyrifos (10 percent);
- Bifenthrin (50 percent);
- Esfenvalerate (75 percent);
- Dimethoate (75 percent); and
- Methyl-parathion (25 percent).

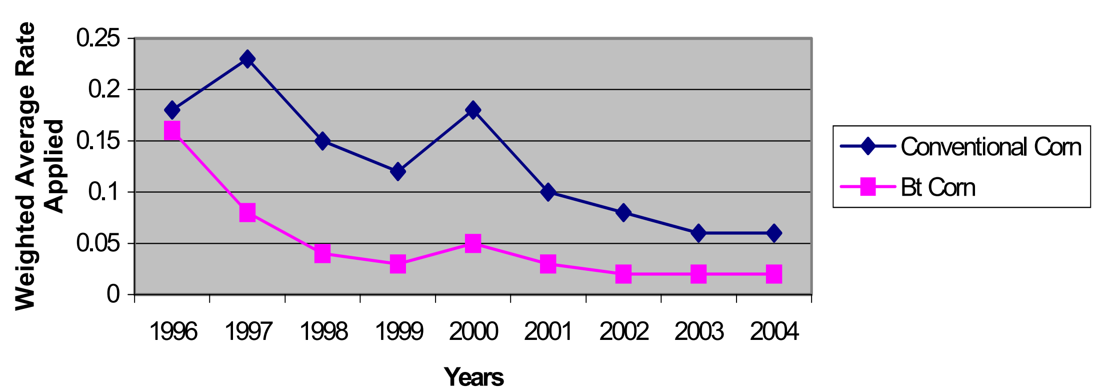
Adult Female ECB Moth
Photo courtesy of ARS, USDA

Corn insecticide use data from the USDA were used to calculate the average pounds per acre of these eight insecticides that were applied to corn acres by year. The estimates are weighted by each insecticide's share of the total pounds of the eight insecticides that were applied. The results are reported in the "Conventional Corn – Weighted Average Rate per Acre Treated" line in Appendix Table 9 and show a steady decline in the average pounds of insecticides applied per acre for control of the ECB/SWCB from 0.18 pounds in 1996 to 0.06 in 2003 and 2004. The shift in acres treated toward very low-dose synthetic pyrethroid insecticides, especially cyfluthrin, accounts for the significant reduction in rates applied between 2001 and 2003. Cyfluthin is applied at only 0.006 pounds per acre and has been the market leader since 2001.

Because *Bt* corn works so well in controlling ECBs/SWCBs, very few farmers planting *Bt* corn had to also treat their fields with insecticides for control of the ECB/SWCB. For this reason, projected ECB/SWCB insecticide applications on *Bt* corn acres are zero. The estimates of insecticide use on *Bt* corn acres does not include the amount of *Bt* toxin manufactured by the corn plants within their cells. It is generally correct to state that no insecticides are sprayed on virtually all acres of *Bt* corn, but inaccurate to claim that no insecticide was used on acres planted to *Bt* corn, given that the plants produced the *Bt* toxin internally.

The last step in estimating the reduction in insecticide use associated with the planting of *Bt* corn is carried out at the bottom of Appendix Table 9. The percent of acres planted to *Bt* corn that would previously have been treated with insecticide is multiplied by the average rate of application of insecticides applied to treat these insects. The amount of insecticide saved per acre of *Bt* corn in 1996 was 0.16 pounds of active ingredient. As more acres of *Bt* corn were planted, insecticide use was reduced on a smaller share of these *Bt* acres, leading to a lower average reduction in insecticide use across all acres planted to *Bt*. In recent years, the reduction has been only 0.02 pounds per acre, reflecting the fact that conventional corn acres treated for ECBs/ SWCBs were sprayed on average with just 0.06 pounds of insecticide and the estimate that insecticide use was reduced on about 30 percent of the acres planted to *Bt* corn (30 percent of 0.06 pounds is 0.02 pounds).

Chart 2. Trends in Insecticide Applications to Manage the European Corn Borer and Southwestern Corn Borer and the Reduction in Insecticide Use on *Bt* Corn Acres



Bt Transgenic Cotton

Unlike the case with *Bt* corn, nearly 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 the difference in insecticide use on acres planted to *Bt* and conventional cotton varieties is simpler than in the case of *Bt* corn.

Fourteen insecticides are applied largely for the management of the budworm/bollworm insect complex, as shown in Appendix Table 10. Based on the total pounds applied across these 14 insecticides and the acres of conventional cotton planted by year, average insecticide application rates on non-*Bt* cotton acres were calculated and appear in Appendix Table 10 in the row "Budworm/Bollworm Conventional Rate." As in the case with corn, the rates of insecticides applied on conventional acreage declines somewhat over the nine-year period, reflecting adoption of lower-rate products. Table 6 provides an overview of the shift toward lower-dose cotton insecticides and shows that one-half of the leading products in 2003 were applied at a rate less than 0.05 pound a.i. per acre, compared to one-quarter of the leading products in 1996.

Photo by David Nance
Courtesy of ARS, USDA

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. The estimated average 0.1 pound of insecticides applied per acre planted to *Bt* cotton also takes into account the pounds of *Bt* endotoxin produced within the cells of *Bt* cotton plants. Accordingly, the reduction in insecticide pounds applied per acre planted to *Bt* cotton ranges from 0.46 pounds in 1996 to 0.16 pounds in 2001.

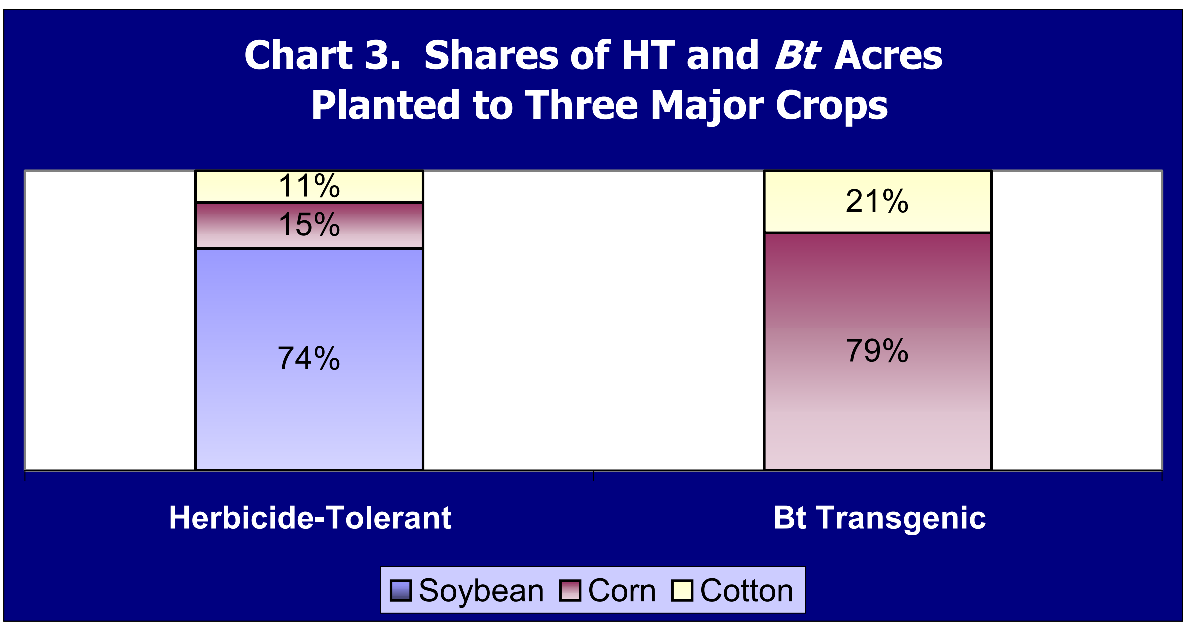
Table 6. Shift to Low-Dose Cotton Insecticides from 1996 and 2003: Number of Top Twelve Nationally Applied Active Ingredients by Rate of Application

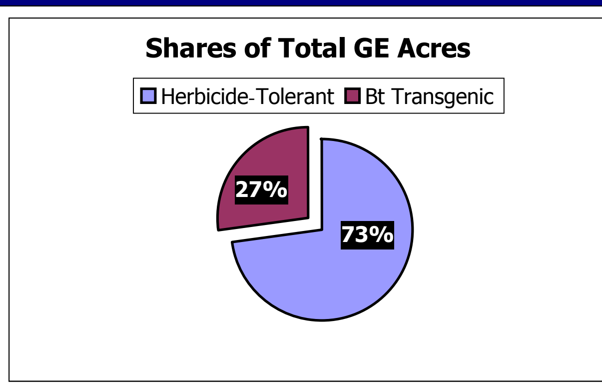
Rate of Application (pound of AI per Acre)	1996	2003
<0.01	0	1
0.01—0.049	4	5
0.05—0.099	1	1
0.1—0.24	2	0
0.25—0.49	3	2
0.50—0.74	1	2
0.75—1	1	1

Source: U.S.D.A. National Agricultural Statistic Service (NASS), Agricultural Chemical Usage, Field Crop Summary, 1996 and 2003.

IMPACTS OF GE CROP TECHNOLOGY ON PESTICIDE USE, 1996-2004

Three crops have accounted for nearly all acres of crops planted to genetically engineered (GE) varieties in the U.S. since 1996. About 487 million acres have been planted to herbicide-tolerant (HT) corn, soybeans and cotton, and another 183 million acres to *Bt* transgenic corn and cotton. Accordingly, HT crops have accounted for 73 percent of total GE crop plantings and *Bt* transgenic crops were grown on the other 27 percent. HT soybeans are by far the dominant GE crop, accounting for three-quarters of all acres planted to HT varieties and over half all GE crop acres since 1996. Chart 3 summarizes these findings.





Major Findings Across Three Significant Crops

Table 7 integrates all the estimates of average pesticide use rates per acre on GE-planted acres in contrast to acres planted to conventional varieties. For each crop and GE trait, the rates of pesticide use and the average differences per acre in pounds applied between GE and conventional acres are shown for 1996-2004.

The impact of GE crops on total pounds of pesticides applied across the three crops and for both HT and *Bt* traits are reported in Appendix Table 11. The numbers in Appendix Table 11 are calculated by multiplying the average difference in pesticide use per acre of crop planted to a GE trait by the acres planted to that GE trait each year. The last four rows of the table add together the impacts of GE technology on total herbicide, insecticide, and herbicide plus insecticide use across the three crops.

Chart 4. Changes in Pesticide Use in the First Three Years of Commercialization Compared to the Last Six Years

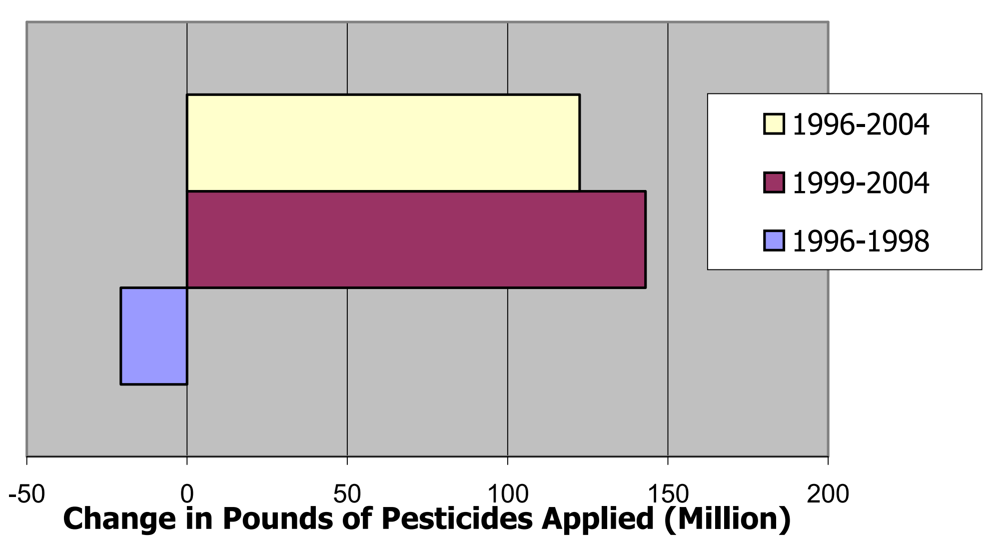


Table 7. Average Pesticide Pounds Applied per Acre Planted to Conventional, Herbicide-Tolerant (HT) and *Bt* Transgenic Varieties* and Estimated Differences per Acre, 1996—2004 [Includes acres planted to stacked varieties]

	1996	1997	1998	1999	2000	2001	2002	2003	2004**
Conventional Corn									
Herbicides	2.67	2.67	2.56	2.45	2.13	2.25	1.87	1.99	2.03
Insecticides	0.18	0.23	0.15	0.12	0.18	0.10	0.08	0.06	0.06
GE Corn									
Herbicide-Tolerant	1.87	1.74	2.07	2.00	1.83	2.09	2.15	2.32	2.42
Bt Transgenic	0.16	0.08	0.04	0.03	0.05	0.03	0.02	0.02	0.02
Average Difference GE to Conventional									
Herbicide	(0.80)	(0.93)	(0.49)	(0.45)	(0.30)	(0.16)	0.28	0.33	0.39
Insecticide	(0.16)	(0.08)	(0.04)	(0.03)	(0.05)	(0.03)	(0.02)	(0.02)	(0.02)
Conventional Soybeans									
Herbicide	1.20	1.23	1.05	0.93	0.99	0.73	0.93	0.87	0.78
GE Soybeans									
Herbicide-Tolerant	0.84	0.94	1.12	1.12	1.10	1.07	1.29	1.34	1.45
Average Difference GE to Conventional									
Herbicide	(0.36)	(0.29)	0.07	0.19	0.11	0.34	0.36	0.47	0.67
Conventional Cotton									
Herbicide	1.93	2.16	1.96	2.03	1.86	1.35	1.46	1.42	1.67
Insecticide	0.56	0.53	0.47	0.52	0.41	0.26	0.27	0.35	0.42
GE Cotton									
Herbicide-Tolerant	1.58	1.84	1.97	1.99	2.09	1.92	2.15	2.43	2.60
Bt Transgenic	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Average Difference GE to Conventional									
Herbicide	(0.35)	(0.32)	0.01	(0.04)	0.23	0.57	0.69	1.01	0.94
Insecticide	(0.46)	(0.43)	(0.37)	(0.42)	(0.31)	(0.16)	(0.17)	(0.25)	(0.32)

*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 2004 are preliminary projections based on 2001-2003 data and recent trends.

Across all traits, GE crops reduced pesticide use 20.6 million pounds from 1996 through 1998, but from 1999 through 2004, pesticide use rose 143 million pounds, for a net increase of 122 million pounds over the full nine-year period. Chart 4 contrasts the change in pesticide use in the 1996-1998 compared to 1999-2004.

Herbicide-tolerant corn reduced the total pounds of herbicides applied from 1996 through 2001, but has led to increases each year since. Moreover, HT corn is requiring more and more herbicide each year compared to acres planted to conventional varieties, a negative trend driven by shifts in weed communities, resistance, and the sizable drop in the price of glyphosate herbicides. Over the nine-year period, HT corn reduced total herbicide use an estimated 6.3 million pounds, but in 2004, 5.6 million more pounds of herbicides were applied because of the planting of HT corn.

Bt corn reduced insecticide use each year, but only marginally given the very low rate of insecticides applied on conventional corn acres for control of the ECB/SWCB. Over the nine-year period Bt corn reduced insecticide use by about 4.5 million pounds. GE traits in corn have therefore reduced pesticide use by about 10.8 million pounds over the last nine years, less than a 1 percent reduction in total corn herbicide plus insecticide pounds applied.

Herbicide-tolerant soybeans reduced the total pounds of herbicides applied for the first two years of commercial use, but have triggered the need for increased use since. Over the nine-year period, 117 million pounds more herbicide has been applied because of the planting of HT soybeans. This large increase reflects the slipping efficacy of the Roundup Ready system, the emergence of tolerant and resistance weeds, and the falling price of soybean herbicides, and the progressively lower-rate herbicides used on conventional acres.

HT cotton reduced herbicide use in three of the first four years of commercial use but thereafter required steadily more herbicides to keep up with weed shifts and resistant/tolerant weeds. Over the nine-year period, HT cotton required 26.8 million pounds more herbicides than if HT acres had been planted to conventional varieties. *Bt* cotton, on the other hand, substantially reduced insecticide use over its nine years of commercial use, resulting in a decrease of 11 million pounds of insecticides. GE traits in cotton led to an increase of 15.7 million pounds in combined herbicide plus insecticide use from 1996-2004.

Across the three crops, HT varieties increased herbicide use by 138 million pounds over the nine-year period, or by about 5 percent. The two *Bt* transgenic crops reduced insecticide use by 15.6 million pounds, or by about 4.7 percent. All GE crops planted since 1996 have increased corn, soybean, and cotton pesticide use by 122.4 million pounds, or about 4 percent. Chart 5 places these findings into perspective. 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.

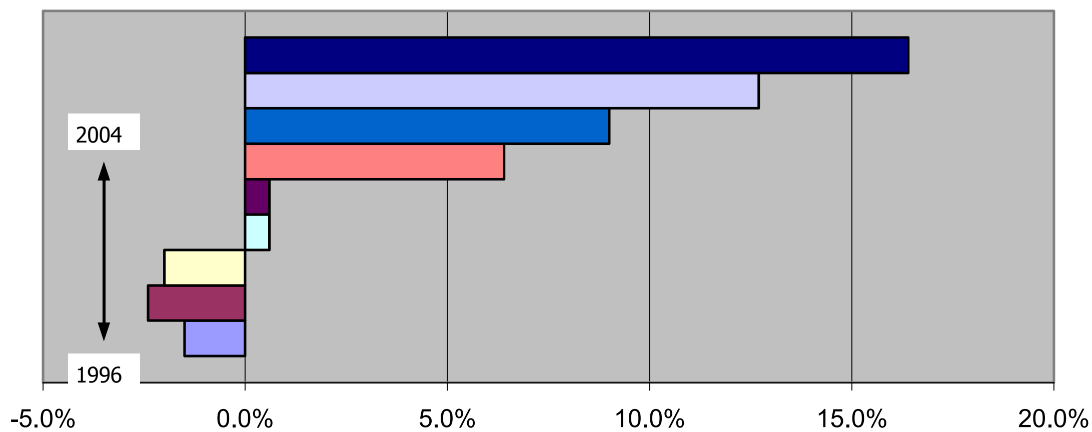


Chart 5. Annual Percent Change in Pesticide Use Brought About by Herbicide-Tolerant and *Bt* Transgenic Corn, Soybeans and Cotton

Conclusions and Future Prospects

While the discovery and adoption of GE crop technology has changed American agriculture in many ways, reducing overall pesticide use is not among them. *Bt* transgenic crops have reduced overall insecticide use, but HT crops have increased it by a far greater margin.

Moreover, the performance of HT crops appears to be slipping. The average acre planted to glyphosate-tolerant crops is requiring more and more help from other herbicides, a trend with serious environmental and economic implications.

Resistance to glyphosate has emerged as a serious concern across most of the intensively farmed regions of the U.S. The number of resistant weeds and their rate of spread is not surprising given the degree of selection pressure imposed on weed populations by farmers applying glyphosate herbicides multiple times per year, and sometimes year in and year out on the same field.

Resistant weeds typically emerge first on just a few isolated fields, but their pollen, genes, and seeds can travel widely and spread quickly, especially if glyphosate continues to be relied on as heavily has it has been in recent years. This is why both universities and some herbicide manufacturers are calling for more aggressive, prevention-oriented management of resistance to glyphosate. In the case of the weed marestail, the recent focus on resistance management has come too late.

No substantial change in the intensity of glyphosate use in the U.S. is expected in the foreseeable future, given the continued popularity of HT crops dependent on glyphosate, the limited supply of non-HT seed in some popular varieties, and the increasingly aggressive promotions offered to farmers relying exclusively on Roundup Ready technology. As a result, marestail will almost certainly be the first of several glyphosate-resistant weeds that emerge and spread, triggering the need for additional herbicide applications and eroding the cost advantage and popularity of HT technology.

The future of *Bt* transgenic crops is brighter, especially in the case of *Bt* cotton. Several university and USDA researchers are closely monitoring efficacy in *Bt* cotton, which appears to have changed little over the last nine years. The attention focused on resistance management, and the issuance of mandatory resistance management plans, has proven effective thus far in delaying the emergence of resistance. Indeed, some experts now think that the emphasis on resistance management in *Bt* cotton can be relaxed. History suggests that lessened diligence in cotton insect resistance management efforts would be premature, given that it has taken 10-15 years for cotton insects to develop resistance to each new type of insecticide applied to control them. This cycle began with the organochlorines in the 1960s and 1970s, and then repeated itself with the carbamates in the 1970s and 1980s and the synthetic pyrethroids in the 1980s and 1990s. Prudence dictates waiting until about 2010 before determining whether contemporary resistance management plans are indeed working and might possibly be simplified.

Bt corn for control of ECBs and SWCBs remains highly effective but is also almost certainly overused. Many farmers are planting these varieties as an insurance policy against potentially damaging insect populations. In 2004, Monsanto introduced its new Cry 3Bb *Bt* corn for rootworm management and by 2005, several corn varieties will express both the *Bt* toxin targeted toward the ECB/SWCB and the new toxin designed to manage corn rootworms.

There has been virtually no field research or regulatory review of the ecological and food safety implications when widely planted *Bt* corn varieties are simultaneously expressing dual *Bt* genes. Current USDA and EPA approvals are based on the assumption that the two *Bt* transgenes in corn plants will operate exactly as they do in varieties engineered to express a single *Bt* gene, and that the impacts of the dual transgenes will not in any way be additive or decrease the stability of gene expression. These are significant and questionable assumptions that if incorrect, could lead to major, unintended consequences. For this reason, these assumptions should be subjected to empirical study before widespread planting of dual-*Bt* varieties is authorized.

Appendix Table 1. Corn, Soybean and Cotton Acreage Planted, Average Pesticide Use per Acre, and Total Pounds Applied, 1996 - 2004.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total 1996-2004
Corn										
Acres Planted	79,507,000	80,227,000	80,798,000	77,431,000	79,579,000	79,545,000	79,054,000	79,100,000	81,000,000	716,241,000
Herbicides per Acre	2.65	2.63	2.47	2.41	2.11	2.24	1.90	2.04	2.10	
Pounds Herbicides (H)	210,693,550	210,997,010	199,571,060	186,608,710	167,911,690	178,180,800	150,202,600	161,364,000	170,100,000	1,635,629,420
Insecticides per Acre	0.22	0.23	0.18	0.16	0.15	0.14	0.08	0.10	0.10	
Pounds Insecticides (I)	17,491,540	18,452,210	14,543,640	12,388,960	11,936,850	11,136,300	6,324,320	7,751,800	7,938,000	107,963,620
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	169,115,800	178,038,000	1,743,593,040
Soybeans										
Acres Planted	64,205,000	70,850,000	72,720,000	73,780,000	74,496,000	75,416,000	73,758,000	73,700,000	74,800,000	653,725,000
Herbicides per Acre	1.17	1.18	1.08	1.04	1.05	0.96	1.20	1.25	1.35	
Pounds Herbicides (H)	75,119,850	83,603,000	78,537,600	76,731,200	78,220,800	72,399,360	88,509,600	92,125,000	100,980,000	746,226,410
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	13,900,000	13,900,000	127,878,000
Herbicides per Acre	1.88	2.09	1.88	1.88	1.84	1.65	1.84	1.99	2.20	
Pounds Herbicides (H)	26,508,000	28,336,220	24,560,320	26,773,080	28,238,480	26,489,100	25,233,760	27,661,000	30,580,000	244,379,960
Insecticides per Acre	1.25	1.39	1.28	2.96	2.82	1.83	1.83	1.06	1.09	
Pounds Insecticides (I)	17,625,000	18,845,620	16,721,920	42,153,360	43,278,540	29,378,820	25,096,620	14,686,740	15,151,000	222,937,620
Total Pounds: H+I	44,133,000	47,181,840	41,282,240	68,926,440	71,517,020	55,867,920	50,330,380	42,347,740	45,731,000	421,586,580
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	166,700,000	169,700,000	1,497,844,000
Pounds Herbicides (H)	312,321,400	322,936,230	302,668,980	290,112,990	274,370,970	277,069,260	263,945,960	281,150,000	301,660,000	2,626,235,790
Pounds Insecticides (I)	35,116,540	37,297,830	31,265,560	54,542,320	55,215,390	40,515,120	31,420,940	22,438,540	23,089,000	330,901,240
Total Pounds: H+I	347,437,940	360,234,060	333,934,540	344,655,310	329,586,360	317,584,380	295,366,900	303,588,540	324,749,000	2,957,137,030
Pounds H+I per Acre	2.20	2.19	2.00	2.08	1.95	1.86	1.77	1.82	1.91	1.97

* Pesticide use in 2004 are preliminary projections based on crop year 2003 totals and recent trends. (See tables on individual HT crops).

Appendix Table 2. Genetically engineered (GE) Corn Varieties by State and United States, 2000-2004

	Insect-resistant (*Bt*) Only					Herbicide-Tolerant Only				
	2000	**2001**	**2002**	**2003**	**2004**	**2000**	**2001**	**2002**	**2003**	**2004**
State	…………………………Percent of all corn planted……………………									
Illinois	13	12	18	23	26	3	3	3	4	5
Indiana	7	6	7	8	11	4	6	6	7	8
Iowa	23	25	31	33	36	5	6	7	8	10
Kansas	25	26	25	25	25	7	11	15	17	24
Michigan	8	8	12	18	15	4	7	8	14	14
Minnesota	28	25	29	31	35	7	7	11	15	17
Missouri	20	23	27	32	32	6	8	6	9	13
Nebraska	24	24	34	36	41	8	8	9	11	13
Ohio	6	7	6	6	8	3	4	3	3	4
South Dakota	35	30	33	34	28	11	14	23	24	30
Wisconsin	13	11	15	21	22	4	6	9	9	14
Other States1/	10	11	14	17	19	6	8	12	17	21
U.S.	18	18	22	25	27	6	7	9	11	13

	Stacked gene varieties					All GE varieties				
	2000	**2001**	**2002**	**2003**	**2004**	**2000**	**2001**	**2002**	**2003**	**2004**
State	…………………………Percent of all corn planted……………………									
Illinois	1	1	1	1	2	17	16	22	28	33
Indiana	*	*	*	1	2	11	12	13	16	21
Iowa	2	1	3	4	8	30	32	41	45	54
Kansas	1	1	2	5	5	33	38	43	47	54
Michigan	*	2	2	3	4	12	17	22	35	33
Minnesota	2	4	4	7	11	37	36	44	53	63
Missouri	2	1	2	1	4	28	32	34	42	47
Nebraska	2	2	4	5	6	34	34	46	52	60
Ohio	*	*	*	*	1	9	11	9	9	13
South Dakota	2	3	10	17	21	48	47	66	75	79
Wisconsin	1	1	2	2	2	18	18	26	32	38
Other States1/	1		2	2	6	17	20	27	36	46
U.S.	1	1	2	4	5	25	26	34	40	45

* Less than 1 percent.

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

Data Source: NASS 'Acreage' Report, released June 2001, 2002, 2003, 2004 - http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0604.pdf

Appendix Table 3. Genetically engineered (GE) Soybean Varieties by State and United States, 2000-2004

	Herbicide-Tolerant Only					All GE Varieties				
	2000	2001	2002	2003	2004	2000	2001	2002	2003	2004
State	Percent of all soybeans planted									
Arkansas	43	60	68	84	92	43	60	68	84	92
Illinois	44	64	71	77	81	44	64	71	77	81
Indiana	63	78	83	88	87	63	78	83	88	87
Iowa	59	73	75	84	89	59	73	75	84	89
Kansas	66	80	83	87	87	66	80	83	87	87
Michigan	50	59	72	73	75	50	59	72	73	75
Minnesota	46	63	71	79	82	46	63	71	79	82
Mississippi	48	63	80	89	93	48	63	80	89	93
Missouri	62	69	72	83	87	62	69	72	83	87
Nebraska	72	76	85	86	92	72	76	85	86	92
North Dakota	22	49	61	74	82	22	49	61	74	82
Ohio	48	64	73	74	76	48	64	73	74	76
South Dakota	68	80	89	91	95	68	80	89	84	95
Wisconsin	51	63	78	84	82	51	63	78	84	82
Other States1/	54	64	70	76	82	54	64	70	76	82
U.S.	54	68	75	81	85	54	68	75	81	85

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

Data Source: NASS 'Acreage' Report, released June 2001, 2002, 2003, 2004 - http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0604.pdf

Appendix Table 4. Genetically engineered (GE) Upland Cotton Varieties by State and United States, 2000-2004

	Insect-resistant (*Bt*) Only					Herbicide-Tolerant Only				
	2000	2001	2002	2003	2004	2000	2001	2002	2003	2004
State	Percent of all upland cotton planted									
Arkansas	33	21	27	24	34	23	29	37	25	15
California	3	11	6	9	6	17	27	26	27	39
Georgia	18	13	8	14	13	32	43	55	32	23
Louisiana	37	30	27	30	26	13	14	9	15	7
Mississippi	29	10	19	15	16	13	15	22	16	23
North Carolina	11	9	14	16	18	29	37	27	29	27
Texas	7	8	7	8	10	33	35	40	39	40
Other States1/	17	18	19	18	22	21	33	35	32	24
U.S.	15	13	13	14	16	26	32	36	32	30
	Stacked Gene Varieties					**All GE Varieties**				
	2000	2001	2002	2003	2004	2000	2001	2002	2003	2004
State	Percent of all upland cotton planted									
Arkansas	14	28	26	46	45	70	78	90	95	94
California	4	2	1	3	7	24	40	33	39	52
Georgia	32	29	30	47	58	82	85	93	93	94
Louisiana	30	47	49	46	60	80	91	85	91	93
Mississippi	36	61	47	61	58	78	86	88	92	97
North Carolina	36	38	45	48	46	76	84	86	93	91
Texas	6	6	4	6	8	46	49	51	53	58
Other States1/	36	33	32	38	45	74	84	86	88	91
U.S.	20	24	22	27	30	61	69	71	73	76
cotton data.										

Data Source: NASS 'Acreage' Report, released June 2001, 2002, 2003, 2004 - http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg0604.pdf

Appendix Table 5. Herbicide Tolerant (HT) Varieties of Corn, Soybean and Cotton: Acres Planted, 1996 - 2004

	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total 1996-2004
HT Corn	2,385,210	3,449,761	14,866,832	6,968,790	5,570,530	6,363,600	8,695,940	11,865,000	14,580,000	74,745,663
HT Soybeans	4,751,170	12,044,500	32,142,240	42,054,600	40,227,840	51,282,880	55,318,500	59,697,000	63,580,000	361,098,730
HT Cotton	2,058,600	2,033,700	2,194,752	4,841,940	7,059,620	8,990,240	7,954,120	8,201,000	8,340,000	51,673,972
All HT Crops	9,194,980	17,527,961	49,203,824	53,865,330	52,857,990	66,636,720	71,968,560	79,763,000	86,500,000	487,518,365
Percent of Total Acres Planted to Three Crops	**5.8%**	**10.6%**	**29.5%**	**32.6%**	**31.2%**	**39.0%**	**43.2%**	**47.8%**	**51.0%**	**32.5%**

Appendix Table 6. *Bt* Transgenic Varieties of Corn and Cotton: Acres Planted, 1996 - 2004

	1996	1997	1998	1999	2000	2001	2002	2003	2004	Total 1996-2004
Bt Corn	1,113,098	6,097,252	15,432,418	19,800,000	19,500,000	15,113,550	18,972,960	22,939,000	25,920,000	144,888,278
Bt Cotton	1,796,390	2,078,890	2,486,493	4,123,252	4,409,348	5,939,980	4,799,900	5,699,000	6,394,000	37,727,253
Total	2,909,488	8,176,142	17,918,911	23,923,252	23,909,348	21,053,530	23,772,860	28,638,000	32,314,000	182,615,531
Percent of Total Acres Planted to Two Crops	**3.1%**	**8.7%**	**19.1%**	**26.1%**	**25.2%**	**22.0%**	**25.6%**	**30.8%**	**34.1%**	**21.6%**

Appendix Table 7. Herbicide Use in Conventional and Roundup Ready Herbicide Tolerant (HT) Soybeans, 1996 - 2004

	1996	1997	1998	1999	2000	2001	2002	2003	2004*
Acres Planted	64,205,000	70,850,000	72,720,000	73,780,000	74,496,000	75,416,000	73,758,000	73,700,000	74,800,000
HT Acres Planted	4,751,170	12,044,500	32,142,240	42,054,600	40,227,840	51,282,880	55,318,500	59,697,000	63,580,000
Percent Acres Treated									
HT Varieties	7.4%	17.0%	44.2%	57.0%	54.0%	68.0%	75.0%	81.0%	85.0%
RR Varieties	7.4%	14.5%	38.8%	51.6%	49.0%	63.0%	70.5%	76.5%	81.0%
Non-RR HT varieties	-	2.5%	5.4%	5.4%	5.0%	5.0%	4.5%	4.5%	4.0%
Glyphosate, all soybeans	25.0%	28.0%	46.0%	62.0%	62.0%	73.0%	78.0%	84.0%	88.0%
Glyphosate Notill, Non RR	17.6%	11.0%	1.8%	5.0%	8.0%	5.0%	3.0%	3.0%	3.0%
Rates per Acre									
NASS Average All Herbicides	1.17	1.18	1.08	1.04	1.05	0.96	1.20	1.25	1.35
Glyphosate on RR Acres	0.69	0.79	0.90	0.90	0.88	0.85	1.04	1.09	1.15
Other Herbicides on RR Acres	0.15	0.15	0.22	0.22	0.22	0.22	0.25	0.25	0.30
All Herbicides on RR Acres	0.84	0.94	1.12	1.12	1.10	1.07	1.29	1.34	1.45
Conventional Varieties	1.20	1.23	1.05	0.93	0.99	0.73	0.93	0.87	0.78
Difference in Pounds per Acre Between RR and Conventional Varieties	-0.36	-0.29	0.07	0.19	0.11	0.34	0.36	0.47	0.67

* Herbicide use rates in 2004 are preliminary projections based on 2002 data and recent trends.

Appendix Table 8. Herbicide Use in Conventional and Roundup Ready HerbicideTolerant (HT) Upland Cotton Varieties, 1996 - 2004									
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002***	**2003**	**2004***
Acres Planted	14,100,000	13,558,000	13,064,000	14,241,000	15,347,000	16,054,000	13,714,000	13,900,000	13,900,000
HT Acres Planted	2,058,600	2,033,700	2,194,752	4,841,940	7,059,620	8,990,240	7,954,120	8,201,000	8,340,000
Percent Acres Planted									
HT Varieties	14.6%	15.0%	16.8%	34.0%	46.0%	56.0%	58.0%	59.0%	60.0%
Glyphosate/RR	14.6%	14.0%	12.8%	27.0%	40.0%	55.0%	57.0%	58.0%	59.0%
Bromoxynil	NA	1%	4%	7%	6%	1%	1%	1%	1%
Rates per Acre									
NASS Average All Herbicides	1.88	2.09	1.88	1.88	1.84	1.65	1.84	1.99	2.20
Glyphosate on RR Acres	0.63	0.79	1.02	1.04	1.14	1.12	1.25	1.38	1.50
Other Herbicide on RR Acres	0.95	1.05	0.95	0.95	0.95	0.80	0.90	1.05	1.10
Total RR Acres	1.58	1.84	1.97	1.99	2.09	1.92	2.15	2.43	2.60
Conventional Varieties	1.93	2.16	1.96	2.03	1.86	1.35	1.46	1.42	1.67
Difference in Pounds per Acre Between HT Transgenic and Conventional Varieties	-0.35	-0.32	0.01	-0.04	0.23	0.57	0.69	1.01	0.94
* Herbicide rates in 2004 are preliminary estimates based on recent trends. There was no cotton pesticide use data collected by USDA in 2002.									

Appendix Table 9. Insecticide Use to Control the European Corn Borer (ECB) and Southwestern Corn Borer (SWCB) on Conventional and *Bt* Transgenic Varieties of Corn, 2996 - 2004 [See Notes]

	1996	1997	1998	1999	2000	2001	2002	2003	2004*
Acres Planted	79,507,000	80,227,000	80,798,000	77,431,000	79,579,000	79,545,000	79,054,000	79,100,000	81,000,000
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	25,920,000
% *Bt* Corn Acres Planted	1.4%	7.6%	19.1%	25.6%	24.5%	19.0%	24.0%	29.0%	32.0%
Percent Acres Treated for ECB/SWCB									
lambda-cyhalotrin	2.0%	1.0%	2.0%	3.0%	2.0%	2.0%	2.0%	1.0%	1.0%
permethrin	4.0%	5.0%	2.0%	3.0%	3.0%	3.0%	2.0%	1.0%	1.0%
cyfluthrin	1.0%	1.0%	3.0%	2.0%	2.0%	4.0%	4.0%	7.0%	7.0%
chlorpyrifos (10% of total)	0.8%	0.7%	0.6%	0.5%	0.6%	0.4%	0.3%	0.4%	0.4%
bifenthrin (50% of total)	0.5%	0%	1.0%	1.0%	1.0%	1.0%	1.0%	1.5%	1.5%
esfenvalerate (75% of total)	0.8%	0.0%	0.0%	0.4%	0.5%	0.0%	0.0%	0.0%	0.0%
dimethoate (75% of total)	0.3%	0.0%	0.8%	0.4%	0.2%	0.2%	0.5%	0.2%	0.2%
methyl parathion (25% of total)	0.5%	1.0%	0.3%	0.3%	1.8%	0.3%	0.1%	0.1%	0.1%
Total Percent Acres Treated	9.9%	8.7%	9.6%	10.5%	11.0%	10.9%	9.9%	11.2%	11.2%
Percent Not Treated	90.2%	91.3%	90.4%	89.5%	89.0%	89.1%	90.2%	88.8%	88.8%
Acres Treated									
lambda-cyhalotrin	1,590,140	802,270	1,615,960	2,322,930	1,591,580	1,590,900	1,581,080	791,000	810,000
permethrin	3,180,280	4,011,350	1,615,960	2,322,930	2,387,370	2,386,350	1,581,080	791,000	810,000
cyfluthrin	795,070	802,270	2,423,940	1,548,620	1,591,580	3,181,800	3,162,160	5,537,000	5,670,000
chlorpyrifos	636,056	561,589	484,788	387,155	477,474	318,180	237,162	316,400	324,000
bifenthrin	397,535	0	807,980	774,310	795,790	795,450	790,540	1,186,500	1,215,000
esfenvalerate	596,303	0	0	290,366	358,106	0	0	0	0
dimethoate	238,521	0	605,985	290,366	179,053	178,976	355,743	177,975	182,250
methyl parathion	397,535	802,270	201,995	193,578	1,392,633	198,863	79,054	39,550	40,500
Total Acres Treated	7,831,440	6,979,749	7,756,608	8,130,255	8,773,585	8,650,519	7,786,819	8,839,425	9,051,750
Weighted Share of Treated Acres									
lambda-cyhalotrin	0.20	0.11	0.21	0.29	0.18	0.18	0.20	0.09	0.09
permethrin	0.41	0.57	0.21	0.29	0.27	0.28	0.20	0.09	0.09
cyfluthrin	0.10	0.11	0.31	0.19	0.18	0.37	0.41	0.63	0.63
chlorpyrifos	0.08	0.08	0.06	0.05	0.05	0.04	0.03	0.04	0.04
bifenthrin	0.05	0.00	0.10	0.10	0.09	0.09	0.10	0.13	0.13
esfenvalerate	0.08	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00
dimethoate	0.03	0.00	0.08	0.04	0.02	0.02	0.05	0.02	0.02
methyl parathion	0.05	0.11	0.03	0.02	0.16	0.02	0.01	0.00	0.00
Rates per Acre									
lambda-cyhalotrin	0.02	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	0.10
cyfluthrin***	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
chlorpyrifos	1.04	1.23	1.01	1.08	1.05	1.14	0.94	0.94	0.94
bifenthrin	0.05	0.00	0.07	0.07	0.07	0.05	0.06	0.06	0.06
esfenvalerate	0.03	0.00	0.00	0.05	0.13	0.02	0.00	0.00	0.00
dimethoate	0.46	0.00	0.52	0.46	0.48	0.51	0.42	0.42	0.42
methyl parathion	0.52	0.66	0.41	0.51	0.45	0.52	0.53	0.53	0.53
Conventional Corn									
Weighted Average Rate per Acre Treated	0.18	0.23	0.15	0.12	0.18	0.10	0.08	0.06	0.06
***Bt* Corn Acres**									
Estimated Acres Planted to *Bt* Previously Treated with Insecticide	1,000,000	2,000,000	4,400,000	5,000,000	5,000,000	4,000,000	5,500,000	7,000,000	7,100,000
Percent Acres Planted to *Bt* Previously Treated with Insecticide	90%	33%	29%	25%	26%	26%	29%	31%	27%
Weighted Average Rate Applied on Acres Planted to *Bt* Varieties	0.16	0.08	0.04	0.03	0.05	0.03	0.02	0.02	0.02
Reduction in Insecticide Use per Acre of *Bt* Corn	-0.16	-0.08	-0.04	-0.03	-0.05	-0.03	-0.02	-0.02	-0.02

* Pesticide use estimates for 2004 are preliminary projections based on 2003 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).

*** NASS reported the rate of application of cyfluthrin at 0.01 pounds per acre for 1996-2002, and 0.006 in 2003. The higher rate in the earlier years reflects a rounding up of the rate, which has been set at 0.006 for the whole period.

Appendix Table 10. Pounds per Acre of Insecticides Applied to Control the Budworm/Bollworm Complex of Insects on Conventional and *Bt* Transgenic Varieties of Cotton, 1996 - 2004

	1996	1997	1998	1999	2000	2001	2002*	2003	2004*
Acres Planted	14,100,000	13,558,000	13,064,000	14,241,000	15,347,000	16,054,000	13,714,000	13,900,000	13,900,000
NASS Acres Planted	11,900,000	13,100,000	12,000,000	13,300,000	14,400,000	12,700,000	12,750,000	12,800,000	12,800,000
Bt Cotton 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	6,394,000.0
% *Bt* Cotton Acres Planted	12.7%	15.3%	19.0%	29.0%	28.7%	37.0%	35.0%	41.0%	46.0%
Insecticide Use Budworm/Bollworm Complex									
Aldicarb	1,596,000	2,428,000	1,680,000	2,440,000	2,483,000	1,520,000	1,763,000	2,006,000	
Azinphos-methyl	315,000	293,000	95,000	211,000	143,000	-	-	-	
Bt	7,854	4,192	2,040	1,330	2,304	1,016	860	704	
Carbofuran	207,000	113,000	163,000	159,000	172,000	116,000	68,500	21,000	
Cyfluthrin	82,000	92,000	98,000	49,000	122,000	61,000	63,000	65,000	
Cypermethrin	132,000	137,000	123,000	45,000	79,000	31,000	57,000	83,000	
Emamectin benoate	-	-	-	-	2,000	-	-	-	
Fenpropathrin	-	13,000	6,000	3,000	14,000	-	5,500	11,000	
Indoxacarb	-	-	-	-	45,000	-	16,500	33,000	
Parathion-methyl	2,560,000	1,996,000	1,745,000	1,466,000	815,000	23,400	85,200	147,000	
Profenofos	413,000	558,000	383,000	357,000	124,000	-	72,500	145,000	
Tebufenizide	-	-	-	-	31,000	-	3,500	7,000	
Thiodicarb	349,000	226,000	209,000	42,000	11,000	27,000	13,500	-	
Tralomethrin	15,000	11,000	4,000	9,000	6,000	4,000	5,000	6,000	
Subtotal	**5,676,854**	**5,871,192**	**4,508,040**	**4,782,330**	**4,049,304**	**1,783,416**	**2,154,060**	**2,524,704**	**2,700,000**
Budworm/Bollworm Average Pounds Applied per NASS Conventional Acres Planted	0.56	0.53	0.47	0.52	0.41	0.26	0.27	0.35	0.42
Other Insecticides									
Total Pounds	**9,238,000**	**12,325,000**	**10,670,000**	**34,525,032**	**36,567,000**	**21,430,000**	**16,215,000**	**11,000,000**	**11,000,000**
Other Insecticides Average Pounds Applied per Acre	0.78	0.94	0.89	2.60	2.54	1.69	1.00	0.86	0.86
Budworm/Bollworm Conventional Rate	0.56	0.53	0.47	0.52	0.41	0.26	0.27	0.35	0.42
Budworm/Bollworm *Bt* Rate	0.1	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**	-0.46	-0.43	-0.37	-0.42	-0.31	-0.16	-0.17	-0.25	-0.32

* Insecticide rates for 2004 are estimated projections based on recent trends. There was no cotton pesticide use data collected by USDA in 2002. Insecticide rates for 2004 are preliminary projections based on data collected in 2003

** 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).

Appendix Table 11. Differences in the Pounds of Pesticides Applied to Conventional Versus GE Corn, Soybean and Cotton Varieties, 1996 - 2004 [Includes acres planted to stacked varieties]

	1996	1997	1998	1999	2000	2001	2002	2003*	2004	Totals 1996-2004
Corn										
Herbicides	-1,908,168	-3,204,637	-7,342,320	-3,124,468	-1,665,169	-1,016,793	2,462,221	3,866,594	5,636,415	-6,296,325
Insecticides	-183,096	-469,195	-645,563	-599,405	-890,703	-401,195	-460,102	-443,054	-449,190	-4,541,503
Herbicides plus Insecticides (H+I)	-2,091,264	-3,673,832	-7,987,883	-3,723,873	-2,555,872	-1,417,988	2,002,120	3,423,540	5,187,224	-10,837,829
H+I as % of Total Pesticides Applied	-0.9%	-1.6%	-3.7%	-1.9%	-1.4%	-0.7%	1.3%	2.0%	2.9%	-0.6%
Soybeans										
Herbicides (H)	-1,693,182	-3,482,747	2,304,103	7,824,112	4,372,591	17,628,490	19,914,660	28,277,526	42,386,667	117,532,221
H as % of Total Pesticides Applied	-2.3%	-4.2%	2.9%	10.2%	5.6%	24.3%	22.5%	30.7%	42.0%	15.8%
Cotton										
Herbicides	-723,162	-642,171	29,545	-214,953	1,628,942	5,124,437	5,463,723	8,315,014	7,797,900	26,779,275
Insecticides	-829,688	-899,582	-929,592	-1,736,448	-1,346,215	-973,077	-820,531	-1,438,706	-2,055,542	-11,029,381
Herbicides plus Insecticides (H+I)	-1,552,849	-1,541,753	-900,048	-1,951,401	282,727	4,151,360	4,643,192	6,876,308	5,742,358	15,749,894
H+I as % of Total Pesticides Applied	-3.5%	-3.3%	-2.2%	-2.8%	0.4%	7.4%	9.2%	16.2%	12.6%	3.7%
Three Crops										
Herbicides	-4,324,511	-7,329,555	-5,008,672	4,484,690	4,336,364	21,736,134	27,840,604	40,459,134	55,820,981	138,015,170
Insecticides	-1,012,784	-1,368,778	-1,575,155	-2,335,853	-2,236,918	-1,374,272	-1,280,633	-1,881,760	-2,504,732	-15,570,884
Herbicides plus Insecticides (H+I)	-5,337,295	-8,698,332	-6,583,827	2,148,837	2,099,446	20,361,862	26,559,972	38,577,374	53,316,249	122,444,286
H+I as % of Total Pesticides Applied	-1.5%	-2.4%	-2.0%	0.6%	0.6%	6.4%	9.0%	12.7%	16.4%	4.1%

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