Genetically Engineered Crops for Pest Management in U.S. Agriculture: Farm-Level Effects.
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Abstract

Adoption of genetically engineered crops with traits for pest management has risen dramatically since their commercial introduction in the mid-1990's. The farm-level impacts of such crops on pesticide use, yields, and net returns vary with the crop and technology examined. Adoption of herbicide-tolerant cotton led to significant increases in yields and net returns, but was not associated with significant changes in herbicide use. On the other hand, increases in adoption of herbicide-tolerant soybeans led to small but significant increases in yields, no changes in net returns, and significant decreases in herbicide use. Adoption of Bt cotton in the Southeast significantly increased yields and net returns and significantly reduced insecticide use.

Keywords: Biotechnology, genetic engineering, pest management, field crops, input traits.

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Summary

Use of crops genetically engineered with traits for pest management has risen dramatically in only a few years since their commercial introduction. By 1998, around 40 percent of the U.S. cotton acres, a third of the U.S. corn acres, and more than 40 percent of the U.S. soybean acres were planted to genetically engineered varieties as acreage increased from about 8 million acres in surveyed States in 1996 to more than 50 million acres in 1998.

Despite environmental and food safety concerns about the use of genetically engineered crops, farmers believe that the use of these crops will offer them many benefits, such as higher yields, lower pest management costs, and greater cropping practice flexibility. While benefits and performance of these crops vary greatly by region because of pest infestation levels and other factors, the rapid adoption rates are evidence that for many farmers expected benefits outweigh expected costs.

The farm-level impacts of adoption of genetically engineered crops on pesticide use, crop yields, and net returns vary with the crop and technology examined. The econometric analysis using 1997 data shows that adoption of herbicide-tolerant cotton led to significant increases in yields and net returns, but was not associated with significant changes in herbicide use. On the other hand, increases in adoption of herbicide-tolerant soybeans led to small but significant increases in yields, no changes in net returns, and significant decreases in herbicide use. Adoption of Bt cotton in the Southeast significantly increased yields and net returns and significantly reduced insecticide use.

This report presents and discusses USDA survey results on the adoption of genetically engineered cotton, soybeans, and corn by U.S. farmers. In addition, the report presents the results of an ongoing econometric study using USDA survey data on the farm-level effects of adopting genetically engineered soybeans and cotton on pesticide use, yields, and net returns.

Genetically Engineered Crops for Pest Management in U.S. Agriculture

Farm-Level Effects

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Introduction

Use of crops genetically engineered with traits for pest management has risen dramatically since their commercial introduction in the mid-1990's. Compared with traditional plant selection and breeding methods, genetic engineering reduces the time to identify desirable traits and allows a more precise alteration of a plant's traits. Seed developers are able to target a single plant trait without the unintended characteristics that may occur with traditional breeding methods. The most widely used pest management traits are herbicide tolerance and insect resistance. Crops having herbicide-tolerant traits permit farmers to use herbicides that offer more effective weed control. Insect-resistant crops containing a gene derived from the soil bacterium *Bacillus thuringiensis* (Bt) produce their own toxin to protect the entire plant from certain insects. (See box, "Agricultural Biotechnology," for definitions of terms.)

Seed companies and scientists claim that herbicide-tolerant and insect-resistant crops offer more effective options for controlling pests, reduce chemical pesticide use with consequent savings in pesticide costs, and increase crop yields. Some of the arguments put forth in support of these technologies are:

♦ Herbicide-tolerant genes allow crops to resist effective herbicides that previously would have destroyed the crop along with the targeted weeds. Although farmers using herbicide-tolerant crops continue to use chemical herbicides, these herbicides may be used at lower application rates, require a smaller number of applications, and may be more benign than herbicides required for crops without the herbicide-tolerant genes.

♦ Farmers using Bt crops can reduce insecticide costs by discontinuing or decreasing applications of chemical insecticides targeting certain insects susceptible to Bt such as European corn borer and the cotton bollworm. However, Bt crops may still require farmers to use insecticides to treat other pests. Farmers planting Bt crops benefit from decreased dependence on weather conditions affecting the timing and effectiveness of insecticide applications because the Bt toxin remains active in the plant throughout the crop year. These improvements reduce losses to pests, leading to higher yields.

Despite the promise of benefits, environmental and consumer concerns may temper acceptance of agricultural biotechnology in the United States and globally (see box, "Environmental and Other Concerns"). Moreover, although farmers may experience decreased pesticide costs and higher gross revenues from herbicide-tolerant and insect-resistant crops, there is a cost. Genetically engineered seed costs more than traditional seed, and, in addition, farmers are usually charged a fee to cover the development of the technology (technology fee). A threshold infestation level is thus required for farmers to obtain economic benefits from adopting herbicide-tolerant and insect-resistant crops. The expected benefits from adopting these varieties greatly depend on infestation levels, since the associated pesticide use and yield advantages of the new vari-

Agricultural Biotechnology: Basic Concepts and Definitions

"For thousands of years, genes have been manipulated empirically by plant and animal breeders who monitor their effects on specific characteristics or traits of the organism to improve productivity, quality, or performance. A basic understanding of how traits are transmitted was formed by Gregor Mendel in the 19th century. His experiments and concepts showed that traits were controlled by units of heredity called genes. Extensions of his work led to the formation of applied genetics and breeding programs. The physical and chemical nature of genes remained unknown until the 1950s when James Watson and Francis Crick discovered that genes consists of a chemical known as DNA (Deoxyribonucleic acid). DNA contains the information to control the synthesis of enzymes and other proteins that perform the basic metabolic processes of all cells. Each gene is a specific DNA sequence, and more than 100,000 different genes are found in a higher plant or animal species. This total set of genes for an organism (referred to as the nuclear genome) is organized into chromosomes within the cell nucleus. The process by which a multicellular organism develops from a single cell through an embryo stage into an adult is ultimately controlled in the genetic information of the cell and by interaction of genes and gene products with environmental factors" (Vodkin).

Agricultural biotechnology is a collection of scientific techniques, including genetic engineering, that are used to create, improve, or modify plants, animals, and microorganisms. Using conventional techniques, such as selective breeding, scientists have been working to improve plants and animals for human benefit for hundreds of years. Modern techniques now enable scientists to move genes (and therefore desirable traits) in ways they could not before—and with greater ease and precision (USDA, 1999).

Bt crops are genetically engineered to carry the gene from the soil bacterium *Bacillus thuringiensis*. The bacteria produce a protein that is toxic when ingested by certain Lepidopteran insects. Crops containing the Bt gene are able to produce this toxin, thereby providing protection throughout the entire plant.

Bt cotton is genetically engineered to control tobacco budworms, bollworms, and pink bollworms.

Bt corn is genetically engineered to provide protection against the European corn borer.

Cell is the smallest structural unit of living organisms that is able to grow and reproduce independently (ABA).

Genetic engineering, very broadly, is a technique used to alter or move genetic material (genes) of living cells. Narrower definitions are used by agencies that regulate genetically engineered organisms. In the United States, under guidelines issued by USDA's Animal and Plant Health Inspection Service, genetic engineering is defined as "the genetic modification of organisms by recombinant DNA techniques" (7CFR340: 340.1), while definitions used in Europe are somewhat broader.

Gene stacking involves combining traits (e.g. herbicide tolerance and insect resistance) in seed.

Herbicide-tolerant crops were developed to survive certain herbicides that previously would have destroyed the crop along with the targeted weeds. With herbicide-tolerant crops farmers can use potent postemergent herbicides, providing a more effective weed control than otherwise. The most common herbicide-tolerant crops (cotton, corn, soybeans, and canola) are Roundup Ready (RR) crops resistant to glyphosate, a herbicide effective on many species of grasses, broadleaf weeds, and sedges. Other genetically engineered herbicide-tolerant crops include Liberty Link (LL) corn resistant to glufosinate-ammonium, and BXN cotton resistant to bromoxynil. There are also traditionally bred herbicide-tolerant crops, such as corn resistant to imidazolinone (IMI) and sethoxydim (SR), and soybeans resistant to sulfonylurea (STS).

Plant breeding involves crossing plants to produce varieties with particular characteristics (traits) that are carried in the genes of the plants and passed on to future generations.

Transgenic plants result from the insertion of genetic material from another organism so that the plant will exhibit a desired trait. Recombinant DNA techniques (DNA formed by combining segments of DNA from different organisms) are usually used to develop transgenic plants.

eties vary with those levels. Therefore, farmers in regions that have a higher probability of pest infestations would expect greater benefits in the form of reduced pesticide applications and higher yields.

This report first establishes a context for interpreting the results by presenting information about pest management on major field crops in U.S. agriculture and then summarizes previously reported studies of the effects on pesticide use, crop yields, and producer returns from using genetically engineered crops for pest management. Next the report presents survey information obtained from USDA's Agricultural Resource Management Study (ARMS) about the extent of adoption of genetically engineered cotton, corn, and soybeans (by type of technology, crop, and region). The report then presents the results of an econometric analysis on the farm-level effects of adopting Bt cotton and herbicide-tolerant soybeans and cotton on pesticide use, crop yields, and net returns.

Environmental and Other Concerns

Although there are environmental benefits from using crops with herbicide-tolerant or insect-resistant traits, there are some concerns about extensive use of these crops. One concern is that herbicide-tolerant crops would foster farmers' reliance on herbicides. However, these crops may require lower application rates or fewer herbicide applications. And, in many cases, these crops allow farmers to use more benign herbicides instead of more harmful ones and allow farmers to use them as postemergent herbicides. For example, glyphosate is considered to be environmentally benign (Culpepper and York, 1998; Roberts et al., 1998). There could also be risks to nontarget insect species if Bt crops deplete populations of prey species, but this is also a problem with many traditional pest management systems.

Another concern is that extensive use of these crops could lead to the development of insect and weed resistance. Since genetically engineered crops interact with the environment, concerns have been raised about risks associated with their release. One potential risk is that herbicide-tolerant crops may pass their genes to weedy relatives, thereby making those weeds resistant to herbicides (Rissler and Mellon).

Another risk is that Bt crops would promote insect resistance to Bt. Resistant insects could make crops more vulnerable. This problem exists with chemical pesticides as well, but Bt genetically engineered into a plant will persist in the environment longer than foliar Bt, thus shortening the time for targeted insect pests to become resistant to foliar Bt. Some agricultural producers, such as organic growers, rely on Bt for insect control, and, if insects become resistant, these growers could lose the option of using these products. However, the Environmental Protection Agency (EPA) requires resistance management plans to control insect resistance to Bt to ensure that enough susceptible moths survive to mate with resistant ones (Cotton Insect Control Guide, 1997).

More recent concerns are related to popular press commentaries of a letter published in the May 20 issue of *Nature* (Losey et al., 1999) reporting results of laboratory tests showing that corn pollen of Bt corn killed the monarch butterfly larvae and recommending a comparison of "these risks with those of other pest-control tactics." However, several scientists noted that the popular press missed the subtleties of the research, and the lead author of the study recently declared that "it would be inappropriate to draw any conclusions about the risk to monarch populations in the field based solely on these initial results" (Wipf).

There are also concerns, especially in Europe, that foods with transplanted genes may cause allergic reactions. A gene from a nut inserted into another type of food, for example, might trigger allergic reactions in susceptible consumers (Panos). And some critics doubt that the body digests and assimilates biotechnology-derived foods in the same way as traditional foods. But the Food and Drug Administration (FDA) ensures that genetically engineered foods reaching the marketplace are "substantially equivalent" to current foods and pose no additional risk. The FDA would require a label for genetically engineered foods only if there were known risks, as with traditionally grown foods.

In addition, some believe genetic engineering interferes with "nature" and "creation." Scientists argue, however, that all plants are genetically modified ("that is what evolution means") either by natural selection from random mutations and recombinations, by domestic breeding, or more recently by "engineered mutation or recombination" (Panos).

Background

Pest Management on Major Field Crops

Corn is the largest herbicide user in U.S. agriculture, and 96 percent of the 62.2 million acres devoted to corn production in the 10 major corn-producing States were treated with more than 164 million pounds of herbicides in 1997 (USDA, 1998b). Atrazine was the top herbicide in 1997, as farmers applied more than 47 million pounds of this chemical (table 1). Metolachlor was second (nearly 44 million pounds applied), followed by acetochlor (28 million pounds) and cyanazine (16 million pounds).

Soybean production in the United States also uses a large amount of herbicides, and 97 percent of the 66.2 million acres devoted to soybean production in the 19 major soybean-producing States were treated with more than 78 million pounds of herbicides in 1997 (USDA, 1998). Pendimethalin was the top herbicide, as farmers applied more than 17 million pounds in 1997 (table 2). Glyphosate, use of which grew substantially over 1996 levels, was second (15 million pounds), followed by trifluralin (12 million pounds) and metolachlor (9 million pounds). Increased use of glyphosate has corresponded with the growth of herbicide-tolerant crop programs that use glyphosate as the primary herbicide.

Table 1—Major herbicides used on corn, 1997[1]

Herbicide active ingredient	Area applied	Appli-cations	Rate per crop year	Total applied
	Percent	*Number*	*Lbs./acre*	*Million lbs.*
Acetamides				78.86
Acetochlor	24	1.0	1.90	28.16
Alachlor	4	1.0	1.80	4.58
Metolachlor	35	1.0	2.00	43.77
Propachlor	<1	1.0	1.95	0.35
Triazines				64.63
Atrazine	69	1.1	1.09	47.16
Cyanazine	14	1.0	1.94	16.49
Simazine	1	1.0	1.36	0.98
Glyphosate	4	1.0	0.53	1.43
Other herbicides				21.13[2]
2, 4-D	9	1.0	0.37	2.09
Dicamba	29	1.0	0.32	5.80
Dimethenamid	6	1.0	1.21	4.73
EPTC	1	1.0	3.71	3.17
Pendimethalin	3	1.0	1.13	1.76
Bromoxynil	6	1.0	0.26	1.03
Bentazon	3	1.0	0.46	0.94
Paraquat	1	1.0	0.56	0.38
Nicosulfuron	10	1.0	0.03	0.16
Imazethapyr	1	1.0	0.02	0.01
Total				164.05

[1] 62.2 million acres were planted for the 19 States surveyed.
[2] Includes other herbicides not listed.
Source: USDA, 1998b.

Cotton production relies heavily upon herbicides to control weeds, often requiring applications of two or more herbicides at planting and postemergence herbicides later in the season (Culpepper and York, 1998). Close to 28 million pounds of herbicides were applied to 97 percent of the 13 million acres devoted to upland cotton production in the 12 major cotton-producing States in 1997 (USDA, 1998). Trifluralin was the top herbicide applied in 1997 (5.5 million pounds), followed closely by MSMA (4.9 million pounds) and fluometuron (4.9 million pounds) (see table 3).

Cotton production also uses a large amount of insecticides, and 77 percent of the 13 million acres devoted to upland cotton production in the 12 major States were treated with 18 million pounds of insecticides in

Table 2—Major herbicides used on soybeans, 1997[1]

Herbicide active ingredient	Area applied	Appli-cations	Rate per crop year	Total applied
	Percent	*Number*	*Lbs./acre*	*Million lbs.*
Acetamides				13.41
Metolachlor	7	1.1	1.87	8.91
Alachlor	3	1.0	2.36	4.50
Glyphosate	28	1.0	0.81	14.92
Other herbicides				49.88[2]
Pendimethalin	25	1.1	0.95	17.53
Trifluralin	21	1.0	0.88	12.27
Bentazon	11	1.0	0.65	4.74
Clomazone	5	1.0	0.71	2.32
2, 4-D	8	1.0	0.39	2.11
Acifluorfen	12	1.0	0.21	1.69
Metribuzin	10	1.0	0.25	1.69
Imazethapyr	38	1.0	0.05	1.24
Sethoxydim	7	1.0	0.21	1.03
Total				78.21

[1] 66.2 million acres were planted for the 19 States surveyed.
[2] Includes other herbicides not listed.
Source: USDA, 1998b.

1997 (USDA, 1998). Malathion was the top insecticide, as farmers applied more than 7 million pounds of this chemical in 1997 (table 4). Aldicarb was second (2.4 million pounds), followed by methyl parathion (2 million pounds) and acephate (0.9 million pounds).

Previous Studies on the Farm Effects of Genetically Engineered Crops

Many field-test and enterprise studies have analyzed the agronomic, environmental, and budget effects of adopting genetically engineered crops (for example, Arnold et al., 1998; Culpepper and York, 1998; Delannay et al., 1995; Goldman et al., 1996; Keeling et al., 1996; ReJesus et al., 1997; Roberts et al., 1998; Vencill, 1996). However, only a few studies have investigated the actual yield, pesticide use, and economic effects of using farm-level adoption data (Fernandez-Cornejo and Klotz-Ingram, 1998; Gibson et al., 1997; Marra et al., 1998; Stark, 1997). Some of the findings of these studies are summarized below.

Herbicide-Tolerant Soybeans

♦ Prior to commercial release of the technology, yields from plots with a glyphosate-tolerant soybean line treated with glyphosate were compared with non-treated control plots at numerous sites in both northern and southern soybean-producing areas—17 locations in 1992, 23 locations in 1993, and 18 locations in 1994 (Delannay et al., 1995). No significant yield reductions resulted from the glyphosate applications at any of the locations. Results of the study indicated that the glyphosate-tolerant soybean line was tolerant to applications of glyphosate at rates as high as twice the level needed to control most weeds, with no negative impact on yields.

Table 3—Major herbicides used on cotton, 1997[1]

Herbicide active ingredient	Area applied	Applications	Rate per crop year	Total applied
	Percent	*Number*	*Lbs./acre*	*Mil. lbs.*
Triazines				3.87
Cyanazine	18	1.3	0.95	2.20
Prometryn	19	1.2	0.66	1.67
Other herbicides				22.20[2]
Trifluralin	55	1.1	0.76	5.46
MSMA	29	1.4	1.30	4.90
Fluometuron	44	1.3	0.84	4.85
Pendimethalin	28	1.1	0.69	2.49
Norflurazon	13	1.0	0.63	1.04
Diuron	12	1.1	0.55	0.88
Metolachlor	5	1.1	1.17	0.74
Glyphosate	14	1.3	0.81	1.54
Total				27.61

[1] 13.1 million acres were planted for the 12 States surveyed.
[2] Includes other herbicides not listed.
Source: USDA, 1998b.

♦ Data from field trials in west Tennessee were used in an economic analysis of glyphosate-tolerant soybeans (Roberts et al., 1998). Comparing per acre net returns from 14 trials, the returns from the glyphosate system were 13 percent higher than the returns from the second most profitable system. The higher returns from the glyphosate system resulted from both higher yields and lower herbicide costs.

♦ Research results from trials in Mississippi (Arnold et al., 1998) have also shown higher yields and net returns from glyphosate-tolerant soybeans versus conventional varieties.

♦ Using farm-level data, Marra et al. (1998) estimated that the net farm returns from using glyphosate-tolerant soybeans were about $6.00 per acre higher than

Table 4—Major insecticides used on cotton, 1997[1]

Insecticide active ingredient	Area applied	Applications	Rate per crop year	Total applied
	Percent	*Number*	*Lbs./acre*	*Mil. lbs*
Organophosphates				11.76
Malathion	11	5.9	4.97	7.25
Methyl parathion	13	2.7	1.22	2.00
Acephate	10	1.7	0.72	0.90
Phorate	7	1.0	0.73	0.67
Profenofos	4	1.6	0.98	0.56
Dicrotophos	8	1.7	0.35	0.38
Pyrethroids				0.41
Cypermethrin	8	1.7	0.14	0.14
Lambdacyhalothrin	18	1.9	0.05	0.13
Cyfluthrin	13	1.7	0.05	0.09
Zeta-cypermethrin	5	1.4	0.05	0.03
Tralomethrin	2	2.1	0.04	0.01
Fenpropathrin	1	1.1	0.19	0.01
Other insecticides				6.11[2]
Aldicarb	27	1.0	0.68	2.43
Chlorpyrifos	4	1.9	1.45	0.81
Oxamyl	15	1.6	0.33	0.65
Endosulfan	2	2.3	0.88	0.27
Dicofol	2	1.0	1.13	0.26
Total				18.28

[1] 13.1 million acres were planted for the 12 States surveyed.
[2] Includes other insecticides not listed.
Source: USDA, 1998b.

those of traditional varieties. The lower herbicide costs alone were enough to outweigh the higher seed costs and technology fee.

Herbicide-Tolerant Cotton

♦ Field tests from Arkansas and Missouri (Goldman et al., 1996), Georgia (Vencill, 1996), and Texas (Keeling et al., 1996) indicated little difference in cotton yields between weed control programs including glyphosate and those using standard cotton herbicides.

♦ An economic analysis of glyphosate-tolerant cotton using field tests in North Carolina concluded that glyphosate applied to glyphosate-tolerant cotton is a convenient and effective alternative to traditional herbicides (Culpepper and York, 1998). While yields and net returns of the glyphosate systems (including the technology fee) were similar to, but no greater than, those with the most effective traditional systems, fewer herbicide applications were required and less total herbicide was used with the glyphosate systems.

Herbicide-Tolerant Corn

♦ Using USDA field-level survey data on herbicide-tolerant corn adoption in 1996, Fernandez-Cornejo and Klotz-Ingram (1998) estimated the effects of herbicide-tolerant corn adoption on yields, profits (including the technology fees), and herbicide use. They concluded that lower herbicide use (especially for the acetamide herbicide family) was significantly related to the adoption of these corn varieties. Adoption of those corn varieties had a small effect on yields. The effect on profits was not statistically significant.

Bt Cotton

♦ Survey data from Georgia cotton growers indicated that Bt cotton produced an average yield of 104 pounds of lint per acre more than non-Bt varieties in similar production systems (Stark, 1997). Spray applications to control insect and plant growth were reduced by 2.5 applications per acre on Bt cotton. Despite the $32-per-acre technology fee, Bt cotton was found to have a sizeable economic advantage over the non-Bt varieties.

♦ Producer survey data from Mississippi also showed returns above specified costs for Bt cotton to be higher than those of non-Bt cotton (Gibson et al., 1997). Total costs of production were not much different between Bt and non-Bt varieties, but higher yields for Bt cotton produced significantly higher net returns, despite the technology fee.

♦ Research using experimental plot data in South Carolina indicated no significant differences between Bt and non-Bt cotton yields, but did find an economic advantage for Bt cotton due to reduced pesticide costs (ReJesus et al., 1997). However, Bt cotton yields were more variable than yields of non-Bt varieties.

♦ In a 3-year study in Arkansas, Bt cotton produced higher yields and profits (despite the technology fees) in 1996 and 1998, but lower yields and profits in 1997 (Bryant, Robertson, and Lorenz III, 1998).

♦ Marra et al. (1998) in a survey of 300 farmers in North and South Carolina, Georgia, and Alabama, found that yields were significantly greater for Bt cotton in the lower southern States (Georgia and Alabama) and for the entire sample, but not for the upper southern States. They also found that farmers growing Bt cotton made fewer insecticide applications, especially of pyrethroid insecticides. The rate of return was less in the upper South than the lower South. The additional crop revenues and insecticide savings outweighed the higher seed and technology costs in the lower South.

Bt Corn

♦ Marra et al. (1998) determined that use of Bt corn resulted in better control of the European corn borer, boosting yields by 4 to 8 percent, depending on location and year. On the other hand, Bt corn use resulted in only modest savings from reduced insecticide applications. However, returns from increased corn yields were greater than the seed premiums and technology fees. This translated into net gains of about $3-$16 per acre.

In sum, several field test and enterprise studies have analyzed the effects of adopting genetically engineered crops, but few studies have investigated the yield, pesticide use, and profit effects from farm-level data. The main results for these studies are summarized in table 5.

Table 5—Summary of the effects of genetically engineered crops on yields, pesticide use, and returns, as reported in previous studies

Crop/ researchers	Data source	Yield	Effects on pesticide use	Returns
Herbicide-tolerant soybeans				
Delannay et al., 1995	Experiments	Same	na	na
Roberts at al., 1998	Experiments	Increase	Decrease	Increase
Arnold et al., 1998	Experiments	Increase	na	Increase
Marra et al., 1998	Survey	Increase	Decrease	Increase
Herbicide-tolerant cotton				
Vencill, 1996	Experiments	Same	na	na
Keeling et al., 1996	Experiments	Same	na	na
Goldman et al., 1998	Experiments	Same	na	na
Culpepper and York, 1998	Experiments	Same	Decrease	Same
Herbicide-tolerant corn				
Fernandez-Cornejo and Klotz-Ingram, 1998	Survey	Increase	Decrease	Same
Bt cotton				
Stark, 1997	Survey	Increase	Decrease	Increase
Gibson et al., 1997	Survey	Increase	na	Increase
ReJesus et al., 1997	Experiments	Same	na	Increase
Bryant et al., 1998[1]	Experiments	Increase	na	Increase
Marra et al., 1998[2]	Survey	Increase	Decrease	Increase
Bt corn				
Marra et al., 1998	Survey	Increase	Decrease	Increase

na = not available

[1] Results are for 1996 and 1998. Results were different in 1997 when pest pressure was low.

[2] Result is for the lower South (Alabama and Georgia).

Data and Methods

The rest of the report presents and discusses USDA survey results on the adoption of genetically engineered (GE) corn, cotton, and soybeans. In addition, the report presents the results of an econometric study of the farm-level effects of adopting GE cotton and soybeans on pesticide use, crop yields, and net returns. This section briefly describes the data sources and methodology used.

The ARMS Surveys

The data used in this analysis were obtained from the Agricultural Resource Management Study (ARMS) surveys developed by the Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS) of USDA and conducted each year from 1996 through 1998. The ARMS survey is designed to link data on the resources used in agricultural production to data on use of technologies (such as the use of genetically engineered crops), other management techniques, chemical use, yields, and farm financial/economic conditions for selected field crops. Each survey included three phases (screening, obtaining production practices and cost data, and obtaining financial information). The number of States covered by the surveys varies by crop and year but includes all major producing States, accounting for 90 percent or more of U.S. crop acreage (USDA, 1997, 1998b, 1999). The econometric analysis is conducted using data on soybean and cotton production collected in the 1997 ARMS survey.

Regions

This report uses the new set of farm-resource regions, recently constructed by ERS, depicting geographic specialization in production of U.S. farm commodities (USDA, ERSa, 1999). The nine farm-resource regions recognize both new capabilities and standards in the resolution of relevant data, and overcome some long-standing problems with the older USDA Farm Production Regions. In constructing the farm-resource regions, ERS analysts identified where areas with similar types of farms intersected with areas of similar physiographic, soil, and climatic traits, as reflected in USDA's Land Resource Regions. A U.S. map depicting the farm-resource regions is shown in figure 1 and a more detailed description is provided in USDA (1999b). Table 6 presents the regional share of acreage

Figure 1
Farm resource regions

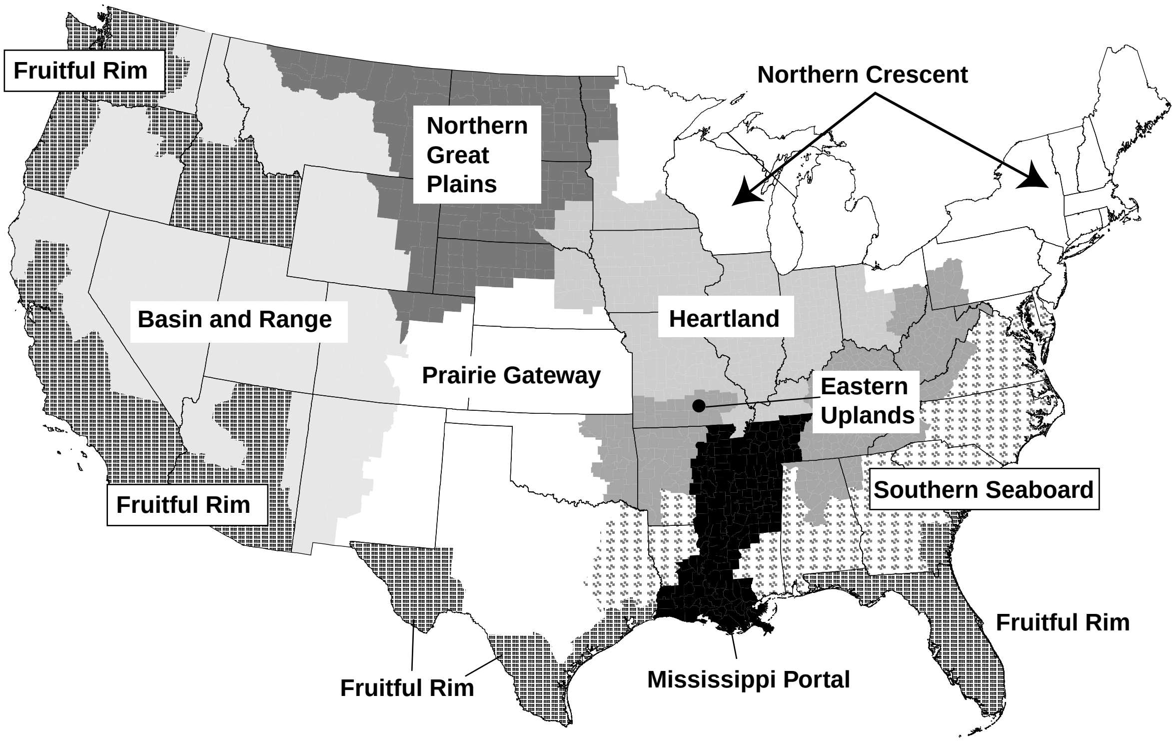

Table 6—Distribution of acreage and production among regions in corn, soybean, and cotton production, 1996-98

	1996		1997		1998	
	Acreage	Production	Acreage	Production	Acreage	Production
			Percent[1]			
Corn						
Heartland	65.6	73.1	74.4	75.6	65.4	69.9
Northern Crescent	15.6	9.2	14.0	12.6	13.5	11.6
Prairie Gateway	10.4	11.6	7.1	8.6	12.6	12.1
Northern Great Plains	3.9	2.6	4.1	2.9	5.0	4.6
Eastern Uplands	1.4	1.5	0.4	0.4	1.6	1.0
Southern Seaboard	2.0	1.6	ns	ns	1.2	0.5
Soybeans						
Heartland	77.8	79.8	69.8	74.4	69.8	76.0
Mississippi Portal	14.4	13.2	12.1	9.0	11.5	7.5
Northern Crescent	4.2	3.4	7.1	7.1	6.1	6.2
Prairie Gateway	1.3	1.7	5.6	5.2	5.5	5.0
Eastern Uplands	1.4	1.2	1.0	0.8	1.5	0.9
Northern Great Plains	id	id	1.8	1.6	3.3	2.7
Southern Seaboard	id	id	2.6	1.9	2.3	1.8
Cotton						
Prairie Gateway	41.8	26.6	38.2	25.9	42.1	24.1
Mississippi Portal	26.8	30.7	22.6	26.6	22.8	30.6
Fruitful Rim	18.9	27.0	14.3	21.8	13.5	20.0
Southern Seaboard	11.7	14.9	20.7	21.6	19.5	22.3
Eastern Uplands	id	id	id	id	2.1	3.0

ns = no surveyed States in region.
id = insufficient data for a statistically reliable estimate.
[1] Percent may not sum to 100 because of acreage and production in omitted regions.

and production for 1996-98 of each of the field crops studied.

Estimating Costs and Returns

The introduction of genetically engineered crops for pest management expanded the pest control options available to farmers. As a result, the relevant costs for comparing these crops with traditional crop varieties include not only the cost of seed, but also the full costs of pest control, such as pesticide materials, pesticide applications, pest scouting, and any alternative (e.g., mechanical) pest control costs. The 1997 ARMS survey data provided the information necessary to compute these costs for soybeans and cotton.

More specifically, the costs estimated from the ARMS survey include direct expenditures for purchased seed, seed technology fees, chemical materials, and custom charges for chemical applications, pest scouting services, and weed cultivation. The cost of homegrown seed was set using the previous year's State-average market price for soybeans and cottonseed (USDA, 1998) times the quantity of homegrown seed used. Chemical material costs for herbicides, insecticides, and other chemicals were estimated by valuing the quantity of each active ingredient applied at the State average price.[1] Pesticide application and cultivation costs were estimated as the sum of custom charges, an imputed labor cost, and machinery operating costs (fuel and repairs). Herbicide and insecticide application costs were estimated by allocating the total pesticide application cost according to the number of applications of each. Pest scouting included charges for weed- and insect-scouting services and an imputed cost for the hours of operator and other labor used to scout fields. Labor costs were imputed by valuing labor hour estimates from the ARMS data by State agricultural wage rates (USDA, 1997). Operating costs for the machinery used to apply pesticides and to cultivate weeds were estimated using ARMS data on individual field operations along with data and equations adapted from standards provided by the American Society of Agricultural Engineers (ASAE, 1996).

Gross returns were estimated as the value of production using the actual crop yield times a State-average

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[1] Average State prices were obtained from USDA (1998), Gianessi, and unpublished NASS data.

harvest-period price for each commodity (USDA, 1998). The value of production less total seed and weed control costs represents the relevant net returns (returns over variable costs) for comparing the herbicide-tolerant technology versus all other seed technologies. The value of production less seed and insect control costs are the net returns used to evaluate the Bt technology.

Modeling the Adoption Decision

The farm-level impact of the adoption of genetically engineered (GE) crops is assessed by statistically controlling for several factors that also affect crop yield, pesticide use, and net returns. That is, economic and environmental conditions, crop or management practices, and operator characteristics are held constant so that one can estimate the effect of adoption of the new crop varieties on pesticide use, yields, and variable net returns (see box, "Comparisons of Means and Econometric Models"). Those factors are controlled by using multiple regressions in a two-stage econometric model. The first stage of the model consists of the adoption decision model (for the adoption of GE crops as well as for other pest management practices that might affect pesticide use) and provides input for the second stage in order to control for self-selection. The second stage of the model is used to estimate the impact of GE crops on pesticide use, yields, and net returns.

The adoption decision model is estimated by a probit analysis. Using the 1997 ARMS data, we made separate estimations for (1) herbicide-tolerant soybeans, (2) herbicide-tolerant cotton, and (3) Bt cotton. The model considers a combination of producer characteristics and resource conditions to be associated with the probability of adopting genetically engineered crops. Variables examined in the adoption decision model include farm size, operator education and experience, target pest for insecticide use, seed price, debt-to-assets ratio, use of marketing or production contracts, irrigation, crop price, use of consultants, and pest pressure. The statistical significance and importance of these variables vary among crops and technologies.

The Adoption Impact Model

The impact of using herbicide-tolerant and insect-resistant crops on pesticide use, yields, and net returns is examined by conducting separate analyses for two herbicide-tolerant crops (soybeans and cotton) and an insect-resistant crop (Bt cotton) using the 1997 ARMS survey data. The adoption impact of the herbicide-tolerant technologies on soybeans and cotton is modeled using all surveyed States. For Bt cotton, the analysis is limited to only the Southeast region because States in the Southeast show much higher rates of adoption than other States (Falck-Zepeda and Traxler), and insecticide use in the Southeast was less affected by intense treatment of pests not targeted by Bt, such as the boll weevil in other producing regions, notably Mississippi.

In each case, the model statistically controls for pest infestation levels, other pest management practices, crop rotations, and tillage. Geographic location is included as a proxy for soil, climate, and agricultural practice differences that might influence impacts of adoption. In addition, the impact model includes correction factors (obtained from the adoption decision model) to control for self-selection of the technology due to differences in producer characteristics between adopters and nonadopters (Fernandez-Cornejo et al.). The adoption impact model is estimated separately for herbicide-tolerant soybeans, herbicide-tolerant cotton, and Bt cotton. For each case, we specify three herbicide (insecticide) demand functions, considering the main herbicide (insecticide) "families" together with the supply function and the variable profit function as a simultaneous system.[2]

The main results of such modeling can be interpreted as an elasticity—the change in a particular impact (pesticide use, yields, or net returns) relative to a small change in adoption of the technology from current levels. The results can be viewed in terms of aggregate impacts across the entire agricultural sector as more and more producers adopt the technology, or in terms of typical farmers as they use the technology on more and more of their land. As with most cases in economics, the elasticities estimated in the quantitative model should be used to examine only small changes (say, less than 10 percent) away from a given, e.g., current level of adoption.

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[2] The herbicide "families" considered are: (i) acetamides (acetochlor, alachlor, metolachlor, and propachlor); (ii) glyphosate; (iii) triazines (e.g., atrazine, cyanazine, metribuzin, prometryn), and (iv) other synthetic herbicides (such as 2,4-D, acifluorfen, bentazon, clomazone, pendimethalin, and trifluralin). The insecticide families included are: organophosphates (e.g., malathion, methyl parathion, acephate, phorate); (ii) synthetic pyrethroids (e.g., cypermethrin, cyfluthrin); and (iii) other synthetic insecticides (such as aldicarb, chloropyrifos, oxamyl, and endosulfan). A normalized quadratic functional form was used for the profit function. For details, see Fernandez-Cornejo et al., 1999.

Comparisons of Means and Econometric Models

Comparison of means is sometimes used to analyze results from experiments in which factors other than the item of interest are "controlled" by making them as similar as possible. For example, means can be compared for yields or pesticide use of two groups of soybean plots that are equal in soil type, rainfall, sunlight, and all other respects, except that one group receives a "treatment" (e.g., genetically engineered crops), and the other group does not. As an alternative to controlled experiments, the subjects that receive treatment and those that don't can be selected randomly.

In "uncontrolled experiments," such as when comparing means obtained from farm survey data, caution must be exercised in interpreting the results. Conditions other than the "treatment" are not equal in farm surveys. Thus, differences between mean estimates for yields and pesticide use from survey results cannot necessarily be attributed to the use of genetic engineering technology since the results are influenced by many other factors not controlled for, including irrigation, weather, soils, nutrient and pest management practices, other cropping practices, operator characteristics, pest pressures, and others.

Moreover, farmers are not assigned randomly to the two groups (adopters and nonadopters), but make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different, and these differences may manifest themselves in farm performance and could be confounded with differences due purely to adoption. This situation, called self-selection, would bias the statistical results, unless it is corrected.

The ERS research program statistically controls for factors considered relevant and for which there are data by using multiple regressions in econometric models. That is, differences in economic conditions and crop or management practices are held constant so that the effect of adoption can be observed. For example, we control for output and input prices, infestation levels, farm size, and other management practices such as rotation and tillage. In addition, we correct for self-selection to prevent biasing the results.

The econometric model developed and used to examine the impact of adoption also takes into consideration that farmers' adoption and pesticide use decisions may be simultaneous, due to unmeasured variables correlated with both adoption and pesticide demand, such as the size of the pest population, pest resistance, farm location, and grower perceptions about pest control methods. Finally, the model ensures that the pesticide demand functions are consistent with farmers' optimization behavior, since the demand for pesticidal inputs is a derived demand (Fernandez-Cornejo et al.).

A two-stage model was developed to account for simultaneity and self-selectivity. The first stage consists of the adoption decision model—for the adoption of GE crops as well as for other pest management practices that might affect pesticide use. The adoption model is estimated by a probit analysis, common in economics. The adoption decision model (probit) allows the estimation of the predicted probabilities of adoption, used as instrumental variables in the second stage to account for simultaneity, as well as the correction factors (inverse Mills ratios) used in the second stage to account for self-selection.

The impact of using GE crops on yields, farm net returns, and pesticide use is examined in the second stage. The impact model includes three herbicide (insecticide) demand functions—considering three main herbicide (insecticide) "families," a supply function, and a variable profit function. The impact model is solved as a simultaneous system using a normalized quadratic restricted profit function, and includes the predicted probabilities of adoption and the inverse Mills ratio obtained from the adoption model (Fernandez-Cornejo et al.).

Adoption of Genetically Engineered Crops

Acreage planted in genetically engineered crops increased rapidly from 1996 to 1997, but even more sharply from 1997 to 1998 (figure 2). Table 7 includes a summary of the ARMS survey results on the extent of adoption of genetically engineered cotton, corn, and soybeans in terms of the percentage of planted acres and production, by type of technology, crop, and region in each year. In addition, table 8 shows the reasons given by farmers for adopting herbicide-tolerant soybeans and cotton as well as Bt cotton.

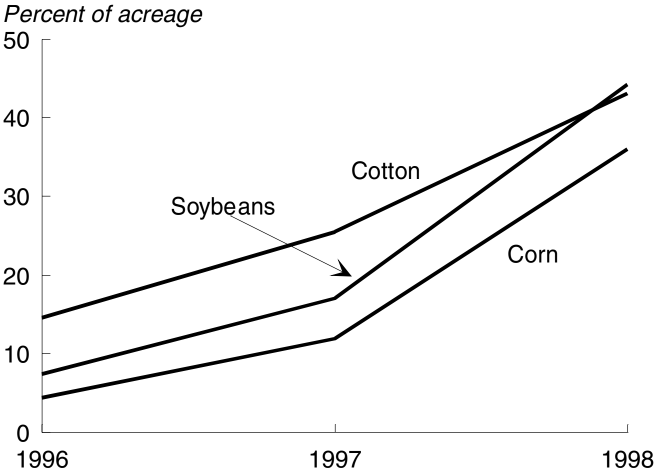
Adoption Rates

By 1998, around 40 percent of the U.S. cotton acres, a third of the U.S. corn acres, and more than 40 percent of the U.S. soybean acres were planted to genetically engineered varieties (fig. 2) as area increased from about 8 million acres in surveyed States in 1996 to more than 50 million acres in 1998.

Genetically engineered cotton containing the Bt gene protects cotton from the budworm, bollworm, and pink bollworm (see box, p. 2). Bt cotton became available to farmers in 1995 and its use expanded rapidly, reaching 15 percent of cotton acreage in 1996 and about 17 percent in 1998 (table 7). Similarly, Bt corn provides protection from the European corn borer. The Environmental Protection Agency (EPA) approved Bt corn in August 1995, and its use grew from about 1 percent of planted corn acreage in 1996 to 19 percent in 1998.

Figure 2

Adoption of genetically engineered crops, 1996-98: Herbicide-tolerant and Bt technologies



Adoption rates for herbicide-tolerant crops have been particularly rapid. Herbicide-tolerant soybeans became available to farmers for the first time in limited quantities in 1996, and usage expanded to about 17 percent of the soybean acreage in the major States surveyed in 1997 and to more than 40 percent of the soybean acreage in 1998 (table 7). Herbicide-tolerant cotton expanded from 10 percent of surveyed acreage in 1997 to 26 percent in 1998.

Comparison with Other Adoption Estimates

The adoption estimates obtained from the ARMS surveys and shown in table 7 (ERS estimates) broadly agree with industry estimates (Hayenga), with the following exceptions: for herbicide-tolerant soybeans in 1996 and 1998, the ERS estimates are between 4 and 9 percentage points higher than industry estimates; for herbicide-tolerant corn for 1998, the ERS estimates are about 10 percentage points higher than industry estimates; for herbicide-resistant cotton for 1998, the ERS estimates are about 11 percentage points below industry estimates.

Reasons for Adoption

According to the 1997 ARMS survey, the majority of farmers surveyed (ranging from 54 to 76 percent of adopters) indicated that the main reason they adopted genetically engineered crops with pest management traits was to “increase yields through improved pest control.” The second reason, stated by 19-42 percent of adopters, was “to decrease pesticide costs.” All other reasons combined ranged between 3 and 15 percent of adopters (table 8). These results confirm other adoption studies pioneered by the economist Griliches who showed that expected profitability positively influences the adoption of agricultural innovations. Hence, factors expected to increase profitability by increasing revenues per acre or reducing costs are generally expected to positively influence adoption.[3] A main objective of

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[3] Other factors may also affect the adoption decision. For example, research results of the probit analysis for the case of herbicide-tolerant soybeans indicate that larger operations and more educated operators are more likely to use herbicide-tolerant soybean seed. Use of conventional tillage on

(please see next page for continuation of footnote 3)

Table 7—Extent of Bt and herbicide-resistant seed technologies used in corn, soybean, and cotton production, by region, 1996-98

Technology/region	1996		1997		1998[1]	
	Acreage	Production	Acreage	Production	Acreage	Production
Bt corn			*Percent*			
All surveyed States	1.4	1.5	7.6	7.8	19.1	20.7
Heartland	1.5	1.6	8.1	8.0	19.4	20.3
Northern Crescent	id	id	id	id	16.2	18.3
Prairie Gateway	id	id	id	id	19.2	23.7
Herbicide-resistant corn[2]						
All surveyed States	3.0	3.1	4.3	3.9	18.4	19.4
Heartland	2.8	2.8	4.8	4.3	19.7	20.6
Northern Crescent	id	id	id	id	9.5	11.6
Prairie Gateway	id	id	id	id	18.3	16.7
Herbicide-resistant soybeans[2]						
All surveyed States	7.4	7.2	17.0	17.5	44.2	44.8
Heartland	6.9	6.8	14.7	16.1	44.3	45.1
Mississippi Portal	9.8	10.1	30.8	29.2	46.6	45.5
Northern Crescent	id	id	15.2	14.8	27.5	28.0
Prairie Gateway	id	id	17.5	20.2	59.2	64.4
Southern Seaboard	id	id	17.3	19.1	72.0	76.3
Eastern Uplands	id	id	id	id	59.0	57.4
Bt cotton						
All surveyed States	14.6	19.0	15.0	18.3	16.8	23.5
Mississippi Portal	23.8	25.3	23.1	23.3	34.8	38.0
Southern Seaboard	id	id	21.5	24.7	18.2	18.2
Fruitful Rim	id	id	22.2	22.9	18.9	22.7
Herbicide-resistant cotton						
All surveyed States	id	id	10.5	11.1	26.2	29.3
Mississippi Portal	id	id	16.9	16.2	24.5	23.0
Southern Seaboard	id	id	16.1	14.5	28.1	31.7
Prairie Gateway	id	id	id	id	34.2	56.9

id=insufficient data for a statistically reliable estimate.

[1] 1998 estimates for corn and cotton include acreage and production with stacked varieties (with both Bt and herbicide-resistant genes).

[2] Includes seed obtained by traditional breeding but developed using biotechnology techniques that helped to identify the herbicide-resistant genes.

pest management in agriculture is to reduce crop yield losses. Thus, there is an incentive to adopt innovations that reduce yield loss. However, yields also depend on locational factors, such as soil fertility, rainfall, and temperature. The physical environment of the farm (e.g., weather, soil type) may affect profitability directly through increased fertility and indirectly through its influence on pests. For these reasons, empirical studies often control for location, using States or regions as proxies, or separate analyses are conducted for some regions.

(continuation of footnote 3)
soybean acreage is a factor that significantly reduces adoption since farmers use conventional tillage to help control weeds, while herbicides are used with conservation or no-till practices. Also, weed infestation levels are positively correlated with the adoption of herbicide-tolerant soybeans (USDA, ERS, 1999b).

Table 8—Main reason stated by U.S. farmers for adopting herbicide-tolerant soybeans/cotton and Bt cotton, 1997

Stated reason for adopting genetically engineered crops	Percent of acreage among adopters: Herbicide-tolerant soybeans	Herbicide-tolerant cotton	Bt cotton
		Percent	
1. Increase yields through improved pest control	65.2	76.3	54.4
2. Decrease pesticide input costs	19.6	18.9	42.2
3. Increased planting flexibility (for example, easier to rotate crops, reduce carryover, use reduced tillage or no-till systems, etc.)	6.4	1.8	2.2
4. Adopt more environmentally friendly practices	2.0	0.9	0.0
5. Some other reason(s)	6.8	2.3	1.2

Farm-Level Effects of Adoption

This section presents the estimated farm-level effects on pesticide use, crop yields, and net returns from the adoption of genetically engineered cotton and soybeans using the econometric adoption impact model and 1997 data described in the "Data and Methods" section. This model allows one to isolate the effect of adoption of genetically engineered crops once the effects of other factors are statistically controlled.

Pesticide Use

Results of the econometric analysis using 1997 data show that, controlling for other factors, the adoption of crops with traits for herbicide tolerance and insecticide resistance led, in most cases, to reduced pesticide use, although in some cases the effect was not statistically significant (table 9).

♦ An increase in the adoption of herbicide-tolerant soybeans is estimated to have led to a statistically significant reduction in the use of other herbicides (other than acetamides or glyphosate) and a significant increase in the use of glyphosate. The change in acetamides was not statistically significant. Acetamides constitute about 17 percent of all the herbicides used on soybeans, glyphosate 19 percent, and other herbicides represent nearly two-thirds of herbicides used on soybeans (table 2).

♦ While the percentage increase in glyphosate use for a given percentage increase in adoption was relatively high, the actual amount of the increase in glyphosate was smaller than the decrease in other herbicides. The net result was a decrease in total herbicide use.

♦ The change in herbicide use associated with the use of herbicide-tolerant cotton was not statistically significant.[4]

♦ While the changes in the use of organophosphate and pyrethroid insecticides associated with an increase in Bt cotton adoption were not statistically significant, adoption led to a significant decrease in use of other chemical insecticides.

Table 9— Econometric results on the impact of adopting herbicide-tolerant and insect-resistant field crops

	Effect with respect to an increase in the adoption of:		
	Herbicide-tolerant soybeans, 1997[1]	Herbicide-tolerant cotton, 1997[1]	Bt cotton, 1997 (Southeast)[1]
Change in yields	small increase[2]	increase[3]	increase[3]
Change in net returns	0[4]	increase[3]	increase[3]
Change in pesticide use:[4]			
Herbicides—			
Acetamide herbicides	0[5]		
Triazine herbicides		0[5]	
Other synthetic herbicides	decrease[3]	0[5]	
Glyphosate	increase[3]	0[5]	
Insecticides—			
Organophosphate insecticides			0[5]
Pyrethroid insecticides			0[5]
Other insecticides			decrease[3]

[1] Based on Fernandez-Cornejo, Klotz-Ingram, and Jans (1999).
[2] Small increases or decreases are less than 1-percent change for a 10-percent change in adoption.
[3] Increases or decreases are more than 1-percent change but less than 5-percent change for a 10-percent change in adoption.
[4] Percent change in acre-treatments.
[5] Underlying coefficients are not statistically different from zero.

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[4] The effect of the adoption of herbicide-tolerant crops on herbicide use differs by region. For example, mean herbicide use rates on herbicide-tolerant cotton were about 20 percent lower than on all other cotton in the Southern Seaboard, but not significantly different in the Mississippi Portal (USDA, ERSb, 1999).

Figure 3
Use of glyphosate herbicides

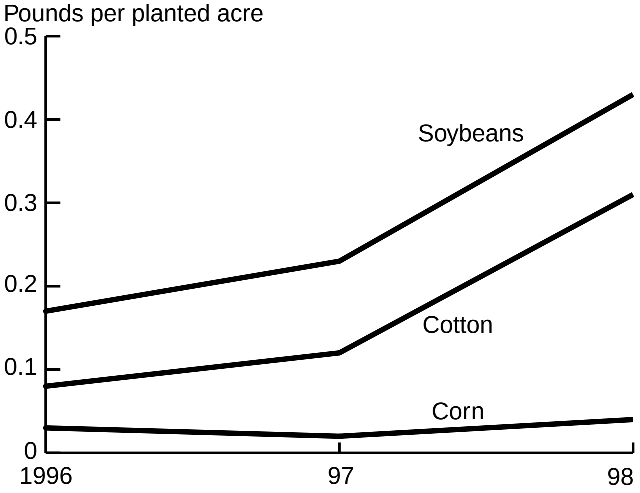
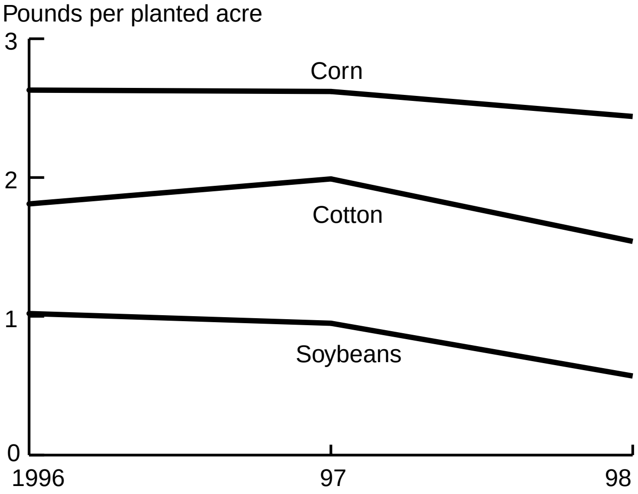


Figure 4
Use of all herbicides, other than glyphosate



The overall downward trend of herbicide application rates used for major U.S. crops during this period appears to confirm the herbicide-reducing effect of herbicide-tolerant crops. For soybeans, as adoption of herbicide-tolerant varieties increased from 7 to 45 percent between 1996 and 1998, the average annual rate of application of glyphosate increased from 0.17 pound per acre in 1996 to 0.43 pound per acre in 1998 (fig. 3) and all other herbicides combined dropped from about 1 pound per acre to 0.57 pound per year (fig. 4). As a result, the overall rate of herbicide use in soybeans declined by nearly 10 percent in that period.

Crop Yields

Results of the econometric research using the 1997 data show, controlling for other factors, a statistically significant relationship between increased yields and increased adoption of herbicide-tolerant and insecticide-resistant crops, although in one case the effect is small (table 9):

♦ Increases in the adoption of herbicide-tolerant cotton are estimated to have led to significant increases in yields.

♦ Increases in the adoption of Bt cotton are estimated to have led to significant increases in yields.

♦ Increases in the adoption of herbicide-tolerant soybeans are estimated to have led to significant (but relatively small) increases in yields. Yields increased less than 1 percent for a 10-percent increase in adoption.

Differences in the crop yields of genetically engineered and all other crops will vary by region and over time as technologies change. Comparisons of significant mean yield differences between genetically engineered and all other crops generally support the econometric findings, suggesting that yields of genetically engineered varieties have been greater than those of all other varieties, but the yields can vary substantially across years, regions, and the types of biotechnologies (USDA, ERS, 1999b).[5]

Net Returns

The econometric analysis using the 1997 data shows that, controlling for other factors, in most cases there is a statistically significant relationship between increased farm net returns and increases in the adoption of herbicide-tolerant and insecticide-resistant crops (table 9):

♦ Increases in the adoption of herbicide-tolerant cotton led to significant increases in net returns.

♦ Increases in the adoption of Bt cotton led to significant increases in net returns.

♦ Increases in the adoption of herbicide-tolerant soybeans did not lead to a statistically significant increase in net returns.

The substantial rate of adoption by farmers of the herbicide-tolerant and Bt cotton technologies supports the findings of higher farm net returns for the genetically engineered cotton compared with other cotton varieties. On the other hand, the failure to observe higher

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[5] Biotechnology companies can also influence the yield by their choice of the seed lines in which to insert the genetic material.

returns for herbicide-tolerant soybeans is surprising given their particularly rapid rate of adoption by farmers. However, this result may be explained by regional variation. While the results presented in table 9 are valid for the entire sample, a comparison of mean costs and returns for herbicide-tolerant and all other soybeans suggests that the net returns associated with herbicide-tolerant soybeans varies by region (table 10). Mean net returns from the herbicide-tolerant soybeans were significantly higher, about $40 per acre, in the Heartland where more than 70 percent of soybeans are produced. Mean net returns for herbicide-tolerant and all other soybeans were not significantly different in either of the southern regions.

Table 10—Costs of and returns from herbicide-tolerant seed technology used in soybean production compared with all other seed technologies, by region, 1997[1]

	Heartland		Mississippi Portal		Southern Seaboard	
Item	Biotech	All other	Biotech	All other	Biotech	All other
			Dollars per planted acre			
Value of production	330.80**	287.88	204.80	225.78	239.63	205.68
Seed and weed-control costs:						
Seed[2]	30.03**	17.70	26.78**	14.96	29.43**	15.74
Herbicide	19.20**	28.16	20.61**	28.15	12.54**	24.64
Herbicide application	2.88	3.34	3.57	3.91	2.20	2.83
Weed scouting	0.45	0.29	0.21**	0.60	1.12	0.69
Weed cultivation	0.31**	1.27	0.38*	1.35	0.28	1.04
Total seed & weed-control costs	52.87	50.75	51.54	48.96	45.56	44.94
Value of production less costs	277.93*	237.12	153.26	176.82	194.07	160.74

**significantly different from all other at the 5-percent level.

*significantly different from all other at the 10-percent level.

[1] Statistically compared using a difference of means test. The biotech category includes all acreage on which herbicide-tolerant soybeans were planted. The “all other” category includes acreage planted to all other purchased and homegrown seed. Differences between the mean estimates cannot necessarily be attributed to the use of the seed technology since they are influenced by several other factors not controlled for, including irrigation, weather, soils, nutrient and other pest management practices, other cropping practices, operator management, etc.

[2] Includes seed technology fee.

Concluding Comments

Despite environmental and food safety concerns about the use of genetically engineered crops, farmers believe that the use of these crops will offer them many benefits, such as higher yields, lower pest management costs, and greater cropping practice flexibility. While benefits and performance of these crops vary greatly by region because of pest infestation levels and other factors, the rapid adoption rates are evidence that, for many farmers, expected benefits outweigh expected costs.

The econometric analysis from ongoing research shows that the impacts of genetically engineered crops on pesticide use, crop yields, and net returns vary with the crop and technology examined. Controlling for other factors, increases in adoption of herbicide-tolerant cotton led to statistically significant increases in yields and net returns, but were not associated with significant changes in herbicide use. On the other hand, increases in adoption of herbicide-tolerant soybeans led to small but statistically significant increases in yields and significant decreases in herbicide use. Increases in adoption of Bt cotton in the Southeast led to significant increases in yields and net returns and decreases in insecticide use.

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