United States
Department
of Agriculture

Economic
Research
Service

Economic
Information
Bulletin
Number 11

April 2006

# The First Decade of Genetically Engineered Crops in the United States


Jorge Fernandez-Cornejo
Margriet Caswell


Electronic
Report

## Visit Our Website To Learn More!

Want to learn more about genetically engineered crops?
Visit our website at **www.ers.usda.gov.**

You can also find additional information about ERS publications, databases, and other products at our website.

## National Agricultural Library Cataloging Record:

Fernandez-Cornejo, Jorge

The first decade of genetically engineered crops in the United States.
(Economic information bulletin ; no. 11)

1. Transgenic plants—Seeds—United States—Marketing.

2. Diffusion of information—United States.

3. Agricultural biotechnology—Public opinion—Economic aspects.
I. Fernandez-Cornejo, Jorge. II. Caswell, Margiet F.

III. United States. Dept. of Agriculture. Economic Research Service.

SB123.57

Cover photos by Jack Dykinga (left) and Doug Wilson (right), courtesy of Agricultural Research Service, USDA.

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

USDA
United States Department of Agriculture

Economic Information Bulletin Number 11

April 2006

An Electronic Report from the Economic Research Service

www.ers.usda.gov

# The First Decade of Genetically Engineered Crops in the United States

**Jorge Fernandez-Cornejo and Margriet Caswell, with contributions from Lorraine Mitchell, Elise Golan, and Fred Kuchler**

## Abstract

Ten years after the first generation of genetically engineered (GE) varieties became commercially available, adoption of these varieties by U.S. farmers is widespread for major crops. Driven by farmers' expectations of higher yields, savings in management time, and lower pesticide costs, the adoption of corn, soybean, and cotton GE varieties has increased rapidly. Despite the benefits, however, environmental and consumer concerns may have limited acceptance of GE crops, particularly in Europe. This report focuses on GE crops and their adoption in the United States over the past 10 years. It examines the three major stakeholders of agricultural biotechnology and finds that (1) the pace of R&D activity by producers of GE seed (the seed firms and technology providers) has been rapid, (2) farmers have adopted some GE varieties widely and at a rapid rate and benefited from such adoption, and (3) the level of consumer concerns about foods that contain GE ingredients varies by country, with European consumers being most concerned.

**Keywords:** genetically engineered crops, agricultural biotechnology, seed industry, research and development, adoption, crop yields, pesticide use, corn, soybeans, cotton

## Acknowledgements

The authors wish to thank William Lin, Paul Heisey, Keith Wiebe, Marca Weinberg, Utpal Vasavada, and Mary Bohman of ERS for the helpful comments provided on earlier drafts of this report. We also thank Andrew Rude from the Foreign Agricultural Service, Neil E. Hoffman from the Animal and Plant Health Inspection Service, John W. Radin from the Agricultural Research Service, Daniel Jones from the Cooperative State Research, Education, and Extension Service, and Matthew C. Rousu from Susquehanna University. We also thank Lou King for editorial assistance and Anne Pearl for graphics and layout.

# Contents

**Summary** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .iii

**Introduction** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .1

**Rapid Change and Pace of R&D Activity Characterize the Seed Industry and Technology Providers** . . . . . . . . . . . . . . . . . . . . .2
From the Laboratory to the Field . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .3

**Adoption of GE Crops by U.S. Farmers Increases Steadily** . . . . . . . . . .8
U.S. Farmers Expect To Profit From Adopting GE Crops . . . . . . . . . . . .9
Adoption of GE Crops and Yields . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .9
Adoption and Net Returns, Household Income, and Pesticide Use . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .10

**Consumer Demands Affects R&D, Adoption, and Marketing of GE-Derived Products** . . . . . . . . . . . . . . . . . . . . . . . . . . . .15

**Adoption Offers Market Benefits to Many Stakeholders** . . . . . . . . . . .19

**Conclusion** . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .21

**References**. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .22

# Summary

Over the past decade, developments in modern biotechnology have expanded the scope of biological innovations by providing new tools for increasing crop yields and agricultural productivity. The role that biotechnology will play in agriculture in the United States and globally will depend on a number of factors and uncertainties. What seems certain, however, is that the ultimate contribution of agricultural biotechnology will depend on our ability to identify and measure its potential benefits and risks.

***What Is the Issue?***

Ten years after the first generation of genetically engineered (GE) varieties of major crops became commercially available, adoption of these varieties by U.S. farmers has become widespread. United States consumers eat many products derived from these crops—including some cornmeal, oils, sugars, and other food products—largely unaware of their GE content. Despite the rapid increase in the adoption of GE corn, soybean, and cotton varieties by U.S. farmers, questions remain regarding the impact of agricultural biotechnology. These issues range from the economic and environmental impacts to consumer acceptance.

***What Did the Study Find?***

This study examined the three major stakeholders in agricultural biotechnology: **seed suppliers and technology providers, farmers**, and **consumers**.

**Seed suppliers/technology providers.** Strengthening of intellectual property rights protection in the 1970s and 1980s increased returns to research and offered greater incentives for private companies to invest in seed development and crop biotechnology. Since 1987, seed producers have submitted nearly 11,600 applications to USDA's Animal and Plant Health Inspection Service for field testing of GE varieties. More than 10,700 (92 percent) have been approved. Approvals peaked in 2002 with 1,190. Most approved applications involved major crops, with nearly 5,000 for corn alone, followed by soybeans, potatoes, and cotton. More than 6,600 of the approved applications included GE varieties with herbicide tolerance or insect resistance. Significant numbers of applications were approved for varieties with improved product quality, viral resistance, and enhanced agronomic properties such as drought and fungal resistance.

**Farmers.** Adoption of GE soybeans, corn, and cotton by U.S. farmers has increased most years since these varieties became commercially available in 1996. By 2005, herbicide-tolerant soybeans accounted for 87 percent of total U.S. soybean acreage, while herbicide-tolerant cotton accounted for about 60 percent of total cotton acreage. Adoption of insect-resistant crops is concentrated in areas with high levels of pest infestation and varies across States. Insect-resistant cotton was planted on 52 percent of cotton acreage in 2005—ranging from 13 percent in California to 85 percent in Louisiana. Insect-resistant corn accounted for 35 percent of the total acreage in 2005, following the introduction of a new variety to control the corn rootworm.

The economic impact of GE crops on producers varies by crop and technology. Herbicide-tolerant cotton and corn were associated with increased returns, as were insect-resistant cotton and corn when pest infestations were more prevalent. Despite the rapid adoption of herbicide-tolerant soybeans, there was little impact on net farm returns in 1997 and 1998. However, the adoption of herbicide-tolerant soybeans is associated with increased off-farm household income, suggesting that farmers adopt this technology because the simplicity and flexibility of the technology permit them to save management time, allowing them to benefit from additional income from off-farm activities.

Genetically engineered crops also seem to have environmental benefits. Overall pesticide use is lower for adopters of GE crops, and the adoption of herbicide-tolerant soybeans may indirectly benefit the environment by encouraging the adoption of soil conservation practices.

**Consumers.** Most surveys and consumer studies indicate consumers have at least some concerns about foods containing GE ingredients, but these concerns have not had a large impact on the market for these foods in the United States. Despite the concerns of U.S. consumers, “GE-free” labels on foods are not widely used in the United States. Manufacturers have been active in creating a market for GE-free foods. Between 2000 and 2004, manufacturers introduced more than 3,500 products that had explicit non-GE labeling, most of them food products.

In the European Union and some other countries, however, consumer concerns have spurred a movement away from foods with GE ingredients. Despite the fact that some European consumers are willing to consume foods containing GE ingredients, very few of these foods are found on European grocery shelves.

### *How Was the Study Conducted?*

This report examined the three major stakeholders of agricultural biotechnology: GE seed suppliers and technology providers (biotech firms), farmers, and consumers. To examine biotech and seed firms, we used information from the literature as well as from the database of USDA approvals of field testing for new GE varieties.  To study seed users, we drew on ERS studies based on USDA farm surveys, and to review the consumer perspective, we summarized surveys of consumers’ attitudes from the literature.

# The First Decade of Genetically Engineered Crops in the United States

**Jorge Fernandez-Cornejo and Margriet Caswell, with contributions from Lorraine Mitchell, Elise Golan, and Fred Kuchler**

## Introduction

Over the past decade, developments in modern biotechnology have expanded the scope of biological innovations by providing new tools for increasing crop yields and agricultural productivity. Agricultural biotechnology is a collection of scientific techniques, including genetic engineering, that are used to create, improve, or modify plants, animals, and microorganisms. Genetic engineering (GE) techniques allow a precise alteration of a plant's traits (facilitating the development of characteristics not possible through traditional plant breeding), and permit targeting of a single plant trait (decreasing the number of unintended characteristics that may occur with traditional breeding).[1]

[1]In the United States, under guidelines issued by USDA's Animal and Plant Health Inspection Service (as published in the *Federal Register*, 7CFR340: 340.1), genetic engineering is defined as "the genetic modification of organisms by recombinant DNA techniques" (Fernandez-Cornejo and McBride, 2000). A full biotechnology glossary is in USDA (2005).

The commercial success of GE crop varieties typically requires that biotechnology-derived trait enhancements be incorporated into successful cultivars (cultivated varieties with useful agronomic properties), the development of which requires significant knowledge of traditional plant breeding and the availability of genetic material (germplasm). This complementarity has been related to various institutional arrangements between seed and technology suppliers.

GE crops are often classified into one of three generations (Panos). Crops with enhanced input traits, such as herbicide tolerance, insect resistance, and tolerance to environmental stresses (like drought), represent the first generation. GE crops benefit farmers and may also offer environmental benefits. Second-generation crops include those with added-value output traits, such as nutrient enhancement for animal feed. Consumers will benefit directly from these products when they are available on the market. The third generation includes crops that produce pharmaceuticals or improve processing of bio-based fuels, and products beyond traditional food and fiber. At present, adoption of GE crops is generally limited to those with first-generation traits, which were tested on a large scale (field testing) in the 1980s to ensure that the desired traits will perform under production conditions. Second- and third-generation GE crops are in various stages of research and development.

Ten years after the first generation of GE varieties became commercially available, they have been widely adopted by U.S. farmers, driven by expectations of higher yields, savings in management time, and lower pesticide costs. Despite these benefits, environmental and consumer concerns may have limited acceptance of agricultural biotechnology, particularly in Europe. In the United States, foods containing GE ingredients currently available in the U.S. market do not require labels, since the U.S. Food and Drug Administration has determined that these foods are "substantially equivalent" to their non-GE counterparts (Shoemaker et al., 2003; FDA, 1992). Thus, U.S. consumers have been eating foods that contain GE ingredients (corn meal, oils, sugars) for the past 10 years while remaining largely unaware of their GE content.

## Rapid Change and Pace of R&D Activity Characterize the Seed Industry and Technology Providers

The U.S. commercial seed market is the world's largest—with an estimated annual value of $5.7 billion per year in the late 1990s—followed by China at $3 billion and Japan at $2.5 billion (Fernandez-Cornejo, 2004). Moreover, the U.S. seed market is growing (in quantity and value), mainly because farmers have been increasing purchases of seed and reducing the planting of saved seed. Growth in the seed market has been particularly rapid for major field crops—corn, soybeans, cotton, and wheat—that together constituted two-thirds of the seed market value in 1997.

The U.S. seed industry began a transformation in the 1930s, with the introduction of commercially viable hybrid seeds. These hybrids were higher yielding than nonhybrid varieties but degenerative, so farmers had to purchase new seed every year to maintain the high yields. Further changes were motivated by the strengthening of intellectual property rights (IPR) protection, mainly during the 1970s and 1980s, which increased returns to research and offered a greater incentive for private companies to invest in seed development. The two principal forms of legal protection are plant variety protection (PVP) certificates issued by the Plant Variety Protection Office of USDA and patents issued by the U.S. Patent and Trademark Office. Both grant private crop breeders exclusive rights to multiply and market their newly developed varieties. However, patents provide more control since PVP certificates have a research exemption allowing others to use the new variety for research purposes. Agricultural biotechnology patents, mostly dealing with some aspect of plant breeding, have outpaced the general upward trend in patenting throughout the U.S. economy. During 1996-2000, 75 percent of over 4,200 new agricultural biotech patents went to private industry (King and Heisey).

Enhanced protection of intellectual property rights brought rapid increases in private research and development (R&D) investments and changes in market concentration in the U.S. seed industry. R&D expenditures on plant breeding for many major crops shifted from mainly public to mainly private. Private spending on crop variety R&D increased fourteenfold between 1960 and 1996 (adjusted for inflation), while public expenditures changed little (Fernandez-Cornejo, 2004).

As the amount of private capital devoted to R&D in the seed industry grew rapidly, the number of private firms engaged in plant breeding also grew, until peaking in the early 1990s. Subsequently, the seed industry consolidated, with fewer firms capable of sustaining the research investment needed to develop new seed varieties. Mergers and acquisitions created a seed industry structure dominated by large companies with primary investments in related sectors, such as pharmaceutical, petrochemical, and food (Fernandez-Cornejo, 2004).[2]

In the early 1980s, developments in biological sciences created an additional incentive for private firms to increase their investment in R&D and seed production. As the first products of crop biotechnology were tested on a large scale in the 1980s, the seed industry's structure underwent additional

[2]Some firms evolved in the 1990s toward developing "life sciences" complexes organized around the development of products such as agricultural chemicals, seeds, foods and food ingredients, and pharmaceuticals based on applications of related research in biotechnology and genetics. However, most of those life sciences companies have since divested their agricultural operations after "failing to realize adequate returns on their investments" (Shoemaker et al., 2003, p.32; Fernandez-Cornejo, 2004, p.42).

transformation. Companies sought to achieve economies of scale to offset the high costs of biotechnology R&D through an extensive process of mergers, acquisitions, and joint ventures. Chemical and seed businesses combined to take advantage of strong demand complementarities between products (Just and Hueth, 1993). For example, the herbicide glyphosate and soybean seeds tolerant to glyphosate are sold by the same firm. As a consequence of the merger activity, the seed industry became more concentrated. By 1997, the share of U.S. seed sales (including GE and conventional varieties) controlled by the four largest firms providing seed of each crop reached 92 percent for cotton, 69 percent for corn, and 47 percent for soybeans (table 1).

**Table 1**
**Estimated U.S. seed market shares for major field crops, 1997**

| Company | Corn | Soybean | Cotton |
|---|---|---|---|
| Pioneer Hi-Bred | 42.0 | 19.0 | |
| Monsanto[1] | 14.0 | 19.0 | 11.0 |
| Novartis | 9.0 | 5.0 | |
| Delta & Pine Land[2] | | | 73.0 |
| Dow Agrosciences/Mycogen | 4.0 | 4.0 | |
| California Planting Seed Distributors | | | 6.0 |
| All-Tex | | | 2.0 |
| Four largest total | 69.0 | 47.0 | 92.0 |

[1]Monsanto acquired DeKalb in 1997 and Asgrow in 1998.
[2]The merger proposed between Monsanto and Delta & Pine Land in 1998 was called off in December 1999.
Source: Fernandez-Cornejo, 2004.

## From the Laboratory to the Field

A critical part of new variety development is field-testing to ensure that the desired traits will perform under production conditions. The release of new GE varieties of organisms into the environment is regulated through field release permits and monitored by USDA's Animal and Plant Health Inspection Service (APHIS) (see box, "Regulatory Oversight"). The number of field releases of plant varieties for testing purposes provides a useful indicator of R&D efforts on crop biotechnology.

By early April 2005, nearly 11,600 applications had been received by APHIS since 1987 and more than 10,700 (92 percent) had been approved (Virginia Polytechnic Institute and State University, 2005). Approvals peaked in 2002 with 1,190 (fig. 1). Most applications approved for field testing involved major crops, particularly corn with nearly 5,000 applications approved, followed by soybeans, potatoes, cotton, tomatoes, and wheat (fig. 2). Applications approved between 1987 and early April 2005 included GE varieties with herbicide tolerance (3,587), insect resistance (3,141), improved product quality (flavor, appearance, or nutrition) (2,314), virus resistance (1,239), and agronomic properties like drought resistance (1,043) and fungal resistance (647) (fig. 3).

## Regulatory Oversight

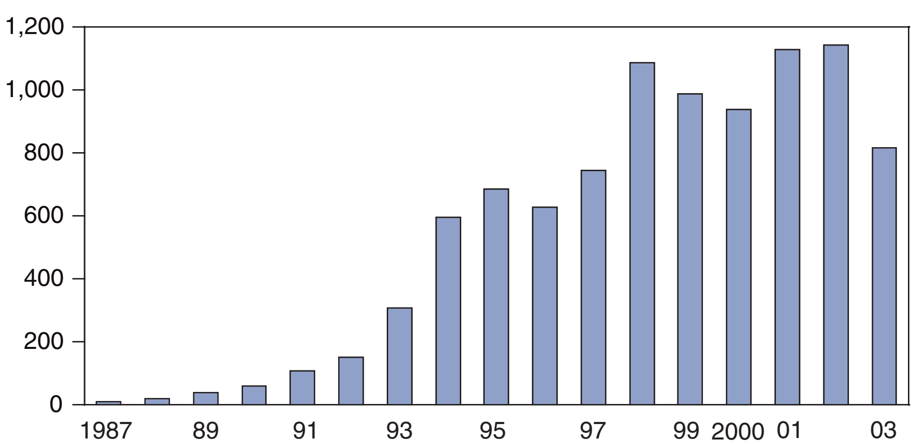
Before commercial introduction, genetically engineered crops must conform to standards set by State and Federal statutes (USDA, 2005). Under the Coordinated Framework for the Regulation of Biotechnology, Federal oversight is shared by the U.S. Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA), and the U.S. Food and Drug Administration (FDA).

USDA's Animal and Plant Health Inspection Service (APHIS) plays a central role in regulating field-testing of agricultural biotechnology products. Through either a notification or permit procedure, such products, which include genetically engineered plants, microorganisms, and invertebrates, are considered "regulated articles." APHIS determines whether to authorize the test, based on whether the release will pose a risk to agriculture or the environment. After years of field tests, an applicant may petition APHIS for a determination of nonregulated status in order to facilitate commercialization of the product. If, after extensive review, APHIS determines that the unconfined release does not pose a significant risk to agriculture or the environment, the organism is "deregulated." At this point, the organism is no longer considered a regulated article and can be moved and planted without APHIS authorization (USDA, 2004).

If a plant is engineered to produce a substance that "prevents, destroys, repels, or mitigates a pest," it is considered a pesticide and is subject to regulation by EPA (*Federal Register*, November 23, 1994). FDA regulates all food applications of crops, including those crops that are developed through the use of biotechnology, to ensure that foods derived from new plant varieties are safe to eat. A more complete description of the EPA and FDA regulations of GE products may be found in EPA (2003) and FDA (1992, 2005).

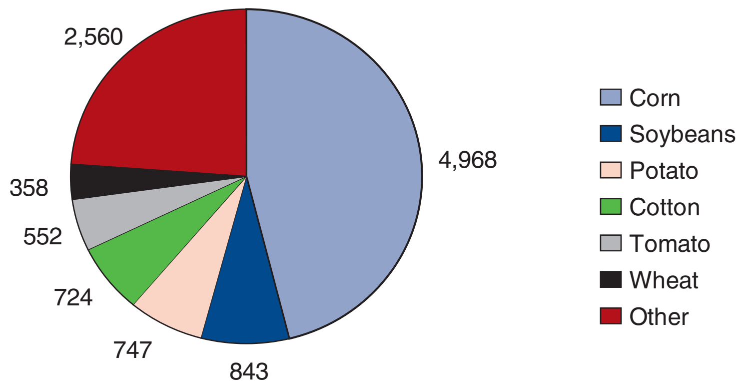
Though the current regulatory system is considered to be effective, USDA, EPA, and FDA continuously look forward and make necessary changes to address new trends and issues of the future. For example, USDA's APHIS has made updates in 1993 and 1997 and is currently considering the need for additional changes in the regulations (USDA, 2004). The National Academy of Sciences also issued a report that made recommendations suggesting that regulation "could be improved further" by making the process more "transparent and rigorous" by enhanced scientific peer review, solicitation of public input, and "more explicit presentation of data, methods, analyses, and interpretations" (NRC, 2003).

Figure 1
**Permits for release of GE varieties approved by APHIS**



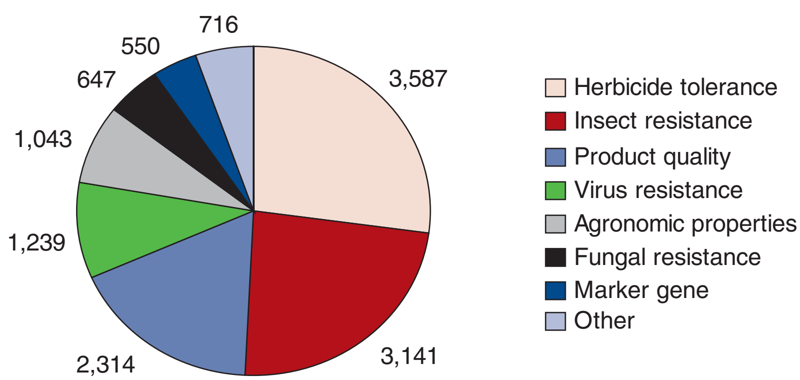

Source: Virginia Polytechnic Institute and State University, 2005.

Figure 2
**Total number of permits approved by APHIS, by crop**




Source: Virginia Polytechnic Institute and State University, 2005.

Figure 3
**Total number of permits approved by APHIS, by GE trait**




Source: Virginia Polytechnic Institute and State University, 2005.

APHIS approvals for field testing also provide an indication of products that are in development and that may come "through the pipeline" in the future (table 2). In addition to crops with improved pest management traits, approvals include crops with traits that provide viral/fungal resistance, favorable agronomic properties (resistance to cold, drought, salinity, more efficient use of nitrogen), enhanced product quality (delayed ripening, increased protein and oil content, modified starch content, nutraceuticals (added vitamins, iron, antioxidants such as beta-carotene), and pharmaceuticals. Additional information may be found in Runge and Ryan and in Pew Initiative on Food and Biotechnology (2001).

After extensively field-testing a GE variety, an applicant may petition APHIS to deregulate (grant nonregulated status) the variety. If, after extensive review, APHIS determines that the new variety poses no significant risk

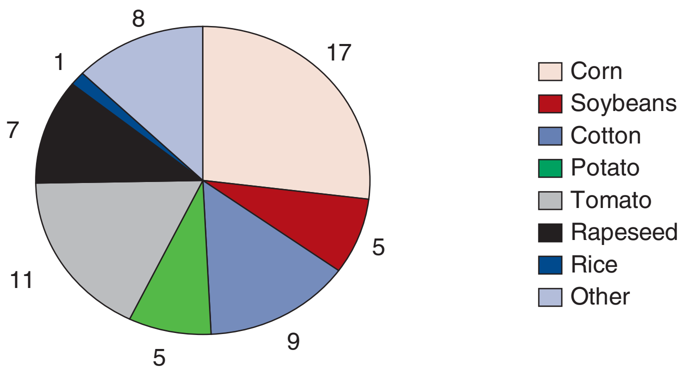
**Table 2**
**Biotech crops currently available and in development in the United States**

| Crop | Input traits | | | | Output traits | |
|---|---|---|---|---|---|---|
| | Herbicide tolerance | Insect resistance | Viral/fungal resistance | Agronomic properties[9] | Product quality[11] | Nutraceuticals; pharmaceuticals; industrial[13] |
| Corn | C | C[5] | D | D | D | D |
| Soybeans | C | D | | D | D | |
| Cotton | C | C[6] | | D | D | |
| Potatoes | | W[7] | D | D | D | D |
| Wheat | C[2] | | D | | | |
| Other field crops[1] | C[3] D[4] | D | D | D | D | D |
| Tomato, squash, melon | | | D | D | W[12] D | D |
| Other vegetables | D | | | | D | |
| Papaya | | | C[8] | | | |
| Fruit trees | | | D | | D | |
| Other trees | | | | D[10] | D | |
| Flowers | | | | | D | |

C = Currently available; D = In various stages of development and testing; W = Withdrawn from the market.
Sources: Virginia Polytechnic Institute and State University; USDA, APHIS; Colorado State University; Shoemaker et al.; Pew.
[1]Includes barley, canola, peanuts, tobacco, rice, alfalfa, etc.
[2]Monsanto discontinued breeding and field-level research on its GE Roundup Ready wheat in 2004.
[3]Canola.
[4]Barley, rice, sugar beets.
[5]Bt corn to control the corn borer commercially available since 1996; Bt corn for corn rootworm control commercially available since 2003.
[6]Bt cotton to control the tobacco budworm, the bollworm, and the pink bollworm, commercially available since 1996.
[7]Bt potatoes, containing built-in resistance to the Colorado potato beetle, were commercially introduced in 1996 and withdrawn in 1999.
[8]In the mid 1990s, researchers at Cornell University and at the University of Hawaii developed two virus-resistant varieties of GE papaya. First commercial plantings were made in 1998. The new varieties were proved successful in resisting a viral epidemic and were planted on more than 30 percent of Hawaii's papaya acreage in 1999.
[9]Resistance to cold, drought, frost, salinity; more efficient use of nitrogen; increased yield.
[10]Modified lignin content (for example, to reduce cost of paper making from trees).
[11]Includes delayed ripening; increased protein, carbohydrate, fatty acid, micronutrient, oil, and modified starch content; enhanced flavor and texture (fruits and vegetables); color (cotton, flowers); fiber properties (cotton); gluten content; natural decaffeination; and low phytase.
[12]Tomato genetically engineered to remain on the vine longer and ripen to full flavor after harvest; currently withdrawn from the market (Colorado State University, 2004).
[13]Includes increased vitamin, iron, beta-carotene content; antibodies, vaccines; specialty machine oils.

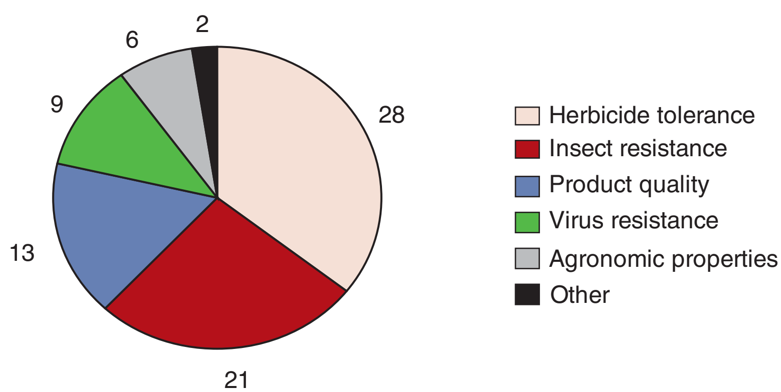
to agriculture or the environment, permission is granted (see box, "Regulatory Oversight"). As of April 2005, APHIS had received 103 petitions for deregulation and had granted 63 (fig. 4). Thirty-six percent of the released varieties have herbicide-tolerance traits, 27 percent have insect-resistance traits, and 17 percent have product-quality traits (fig. 5).

Figure 4
**Petitions for deregulation approved by APHIS, by crop**




Source: Virginia Polytechnic Institute and State University, 2005.

Figure 5
**Petitions for deregulation approved by APHIS, by GE trait**




Source: Virginia Polytechnic Institute and State University, 2005.

## Adoption of GE Crops by U.S. Farmers Increases Steadily

Farmers are more likely to adopt new practices and technologies if they expect to benefit from them. Benefits are usually thought of in monetary terms, but can also include ease of operation, time savings, lower exposure to chemicals, and other factors. Farmers choose technologies and practices they expect to yield the greatest benefit based on their own preferences, farm characteristics, demand for their product, and costs.

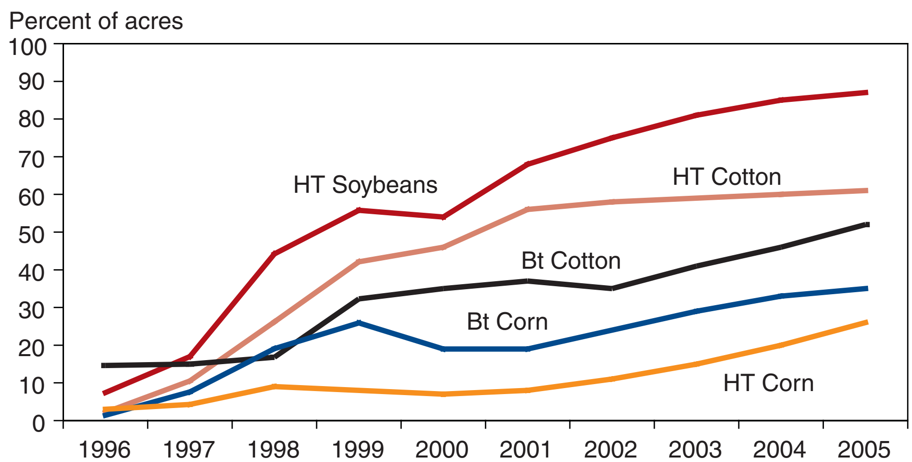
Farmers' expectations of higher yields, savings in management time, and lower pesticide costs have driven a rapid increase in the adoption of GE crop varieties in the United States and several other countries. An estimated 200 million acres of GE crops with herbicide tolerance and/or insect resistance traits were cultivated in 17 countries worldwide in 2004, a 20-percent increase over 2003. U.S. acreage accounts for 59 percent of this amount, followed by Argentina (20 percent), Canada and Brazil (6 percent each), and China (5 percent) (ISAAA, 2004).[3]

GE varieties of soybeans, corn, and cotton have been available commercially in the United States since 1996, and the rate of adoption by U.S. farmers has climbed in most years since then (fig. 6). For the most part, farmers have adopted herbicide-tolerant (HT) varieties—which help control weeds by enabling crops to survive certain herbicides that previously would have destroyed them along with the targeted weeds—at a faster pace than insect-resistant (Bt) varieties.

Weeds are such a pervasive pest for soybeans, corn, and cotton that over 90 percent of U.S. planted acreage for each crop has been treated with herbicides in recent years. The acreage share for HT soybeans has expanded more rapidly than that for HT varieties of cotton and corn, reaching 87 percent of U.S. soybean acreage in 2005.

Figure 6

**Adoption of genetically engineered crops grows steadily in the U.S.***




*Data for each crop category include varieties with both HT and Bt (stacked) traits.
Source: Fernandez-Cornejo (2005).

[3]Also, there has been an upward trend in the adoption of "stacked gene" varieties (with traits of herbicide tolerance and insect resistance) in the case of cotton and corn.

Insect-resistant crops contain a gene from the soil bacterium *Bacillus thuringiensis* (Bt) that produces a protein toxic to specific insects. Acreage shares for Bt cotton and corn are lower than those for HT soybeans and cotton, and adoption is more concentrated in areas with a high level of infestation of targeted pests (insect infestation varies much more widely across locations than does weed infestation). Farmers planted Bt cotton to control tobacco budworm, bollworm, and pink bollworm on 52 percent of U.S. cotton acreage in 2005. Bt corn, originally developed to control the European corn borer, was planted on 35 percent of corn acreage in 2005, up from 24 percent in 2002. The recent increase in acreage share may be largely due to the commercial introduction in 2003/04 of a new Bt corn variety that is resistant to the corn rootworm, a pest that may be even more destructive to corn yield than the European corn borer (Comis).

Other GE crops planted by U.S. farmers over the past 10 years include HT canola, virus-resistant papaya, and virus-resistant squash (table 2). In addition, Bt potato varieties were introduced in 1996 but withdrawn from the market after the 2001 season, and a tomato variety genetically engineered to remain on the vine longer and ripen to full flavor after harvest was introduced in 1994 but was withdrawn from the market after being available sporadically for several years.

## U.S. Farmers Expect To Profit From Adopting GE Crops

According to USDA's Agricultural and Resource Management Surveys (ARMS) conducted in 2001-03, most of the farmers adopting GE corn, cotton, and soybeans indicated that they did so mainly to increase yields through improved pest control (fig. 7). Other popular reasons for adopting GE crops were to save management time and make other practices easier and to decrease pesticide costs. These results confirm other studies showing that expected profitability increases through higher yields and/or lower costs (operator labor, pesticides) positively influence the adoption of agricultural innovations.

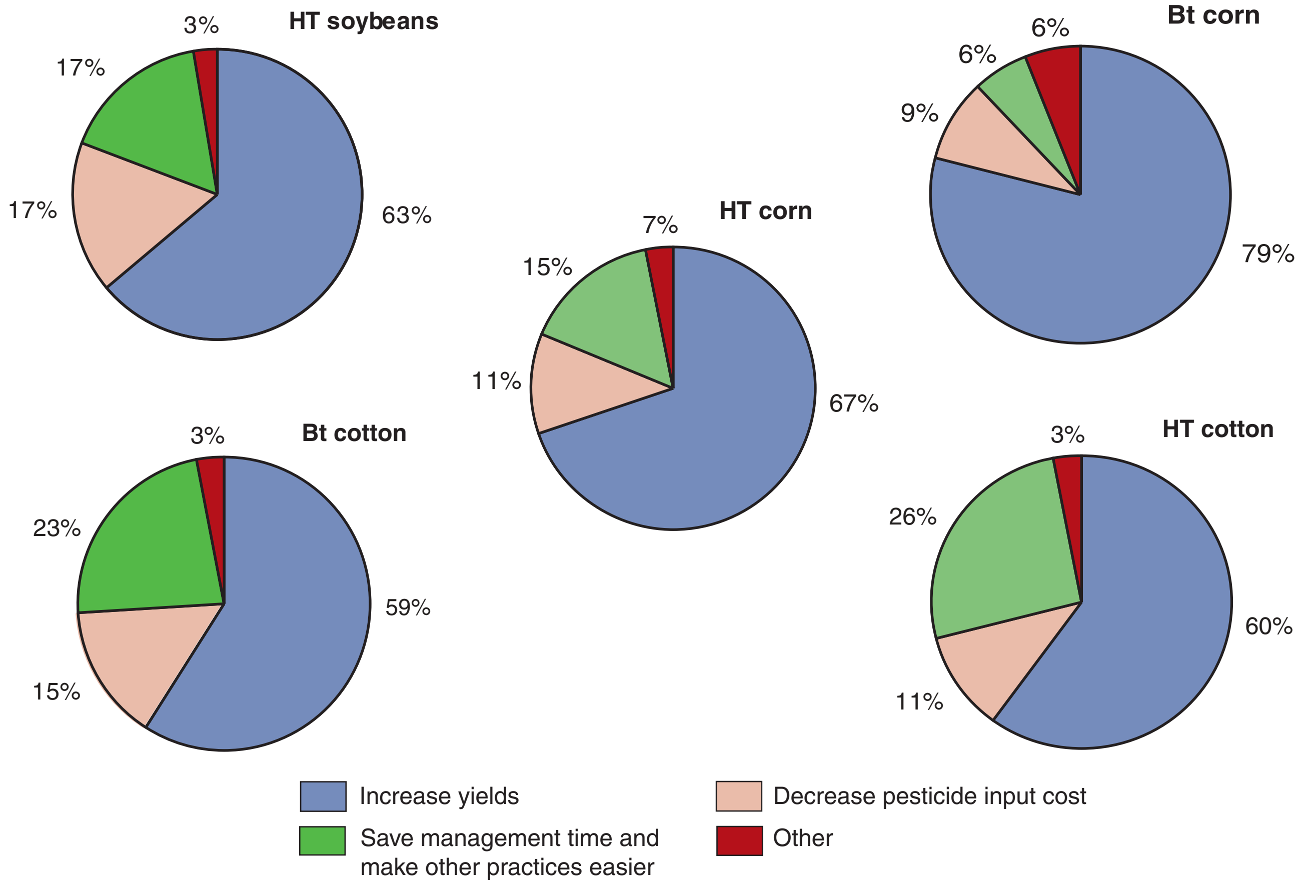
## Adoption of GE Crops and Yields

Currently available GE crops do not increase the yield potential of a hybrid variety. In fact, yield may even decrease if the varieties used to carry the herbicide-tolerant or insect-resistant genes are not the highest yielding cultivars.[4] However, by protecting the plant from certain pests, GE crops can prevent yield losses compared with non-GE hybrids, particularly when pest infestation is high. This effect is particularly important for Bt crops. For example, before the commercial introduction of Bt corn in 1996, the European corn borer was only partially controlled using chemical insecticides. Chemical use was not always profitable, and timely application was difficult. Many farmers accepted yield losses rather than incur the expense and uncertainty of chemical control. For those farmers, the use of Bt corn resulted in yield gains rather than pesticide savings. On the other hand, a recently introduced Bt corn trait selected for resistance against the corn rootworm, previously controlled using chemical insecticides, may provide substantial insecticide savings.[5]

[4]This yield decrease occurred mostly in early years. HT or Bt genes were introduced into high-yielding cultivars in later years.

[5]Entomologists estimate that the corn rootworm causes up to $1 billion in corn yield losses and insecticide expenditures annually in the U.S. (Comis).

Figure 7
**Farmers' reasons for adopting GE crops**




Source: Compiled by USDA's Economic Research Service using data from 2001, 2002, and 2003 Agricultural Resource Management Survey.

Many field tests and farm surveys have examined the yield and cost effects of using GE crops (table 3). The majority of the results show GE crops produce higher yields than conventional crops.

A 2002 ERS study found that increases in cotton yields in the Southeast were associated with the adoption of HT and Bt cotton in 1997—a 10-percent increase in HT cotton acreage led to a 1.7-percent increase in yield and a 10-percent increase of Bt cotton acreage led to a 2.1-percent increase in yield. Increases in soybean yields associated with the adoption of HT soybeans were statistically significant but small (Fernandez-Cornejo and McBride, 2002).[6]

A more recent ERS study using 2001 survey data found that, on average, actual corn yield was 12.5 bushels per acre higher for Bt corn than for conventional corn, an increase of 9 percent (Fernandez-Cornejo and Li, 2005).[7]

## Adoption and Net Returns, Household Income, and Pesticide Use

The impacts of GE crop adoption on U.S. farmers vary by crop and technology. Many studies have assessed the effects of the adoption of GE crops

[6]The study used an econometric model that takes into consideration that farmers' adoption of GE crops and pesticide use decisions may be simultaneous and that farmers are not assigned randomly to the two groups (adopters and non-adopters) but that they make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different. Differences may manifest themselves in farm performance and could be confounded with differences due to adoption. This self-selectivity may bias the results, unless corrected. To account for simultaneity and self-selectivity, the model uses a two-stage econometric model.

[7]In addition, results using an econometric model with the 2001 data showed a small but statistically significant yield increase associated with farmers who adopted Bt corn relative to those using conventional corn varieties. (Fernandez-Cornejo and Li, 2005).

on returns and pesticide use, and the results of these studies are summarized in table 3. ERS researchers found that:

***Planting HT cotton and HT corn was associated with increased producer net returns, but HT corn acreage was limited.***[8] The limited acreage on which HT corn has been adopted is likely to be acreage with the greatest comparative advantage for this technology. The positive financial association with adoption may also be due to low premiums for HT corn seed relative to conventional varieties in an attempt to expand market share (Fernandez-Cornejo and McBride, 2002).

[8]Net returns equal revenues minus variable costs, which include pesticide and seed costs. Seed costs paid by adopters of GE varieties include a technology fee paid by farmers to biotechnology developers and premiums to seed firms.

***Adoption of Bt cotton and corn was associated with increased returns when pest pressures were high.*** The adoption of Bt cotton had a positive association with producer net returns in 1997, but the association was negative for Bt corn in 1998. This suggests that Bt corn may have been used on some acreage where the (ex post) value of protection against the European corn borer was lower than the premium paid for the Bt seed. Because pest infestations vary from one region to another and from one year to another, the economic benefits of Bt corn are likely to be greatest where pest pressures are most severe. Farmers must decide to use Bt corn before they know what the European corn borer pest pressure will be that year, and damage caused by the European corn borer varies from year to year. Some farmers may have incorrectly forecast infestation levels, corn prices, and/or yield losses due to pest infestations, resulting in "overadoption." Also, producers may be willing to pay a premium for Bt corn because it reduces the risk of significant losses if higher-than-expected pest damage does occur (Fernandez-Cornejo and McBride, 2002).

***Despite the rapid adoption of HT soybeans by U.S. farmers, no significant association with net farm returns was evident in 1997 or 1998.*** The lack of increased profitability for some farmers who adopted HT soybeans suggests that factors other than those included in traditional farm returns calculations may be driving adoption for these farmers. In particular, weed control may become simpler and require less management time, which allows growers of HT soybeans to control a wide range of weeds and makes harvest easier and faster. One important alternative use of management time is off-farm employment by farm operators and their spouses (Fernandez-Cornejo and McBride, 2002).

***Adoption of HT soybeans is associated with increased household income.*** Recent ERS research showed that adoption of HT soybeans was associated with a significant increase in off-farm household income for U.S. soybean farmers. On-farm household income is not significantly associated with adoption but total farm household income is significantly higher for adopters, suggesting that most managerial time saved by adopters is used in off-farm work (Fernandez-Cornejo et al., 2005).

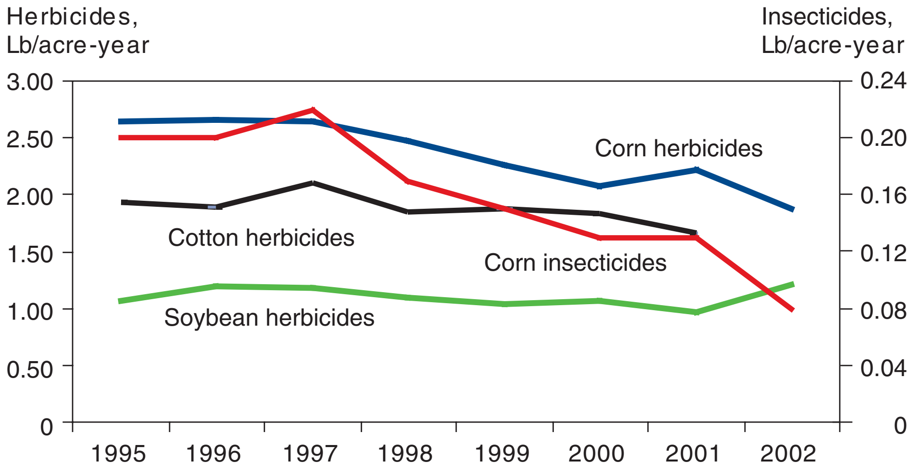
***Adoption of GE crops is associated with reduced pesticide use.*** Pesticide use rates (in terms of active ingredient) on corn and soybeans have declined since the introduction of GE corn and soybeans in 1996 (fig. 8). In addition, ERS research suggests that, controlling for other factors, pesticide use declined with adoption. There was an overall reduction in pesticide use associated with the increased adoption of GE crops (Bt and HT cotton, HT

**Table 3**
**Summary of primary studies on the effects of genetically engineered crops on yields, pesticide use, and returns**

| Crop/researchers/ date of publication | Data source | Effects on Yield | Effects on Pesticide use | Effects on Returns |
|---|---|---|---|---|
| **Herbicide-tolerant soybeans** | | | | |
| Delannay et al., 1995 | Experiments | Same | na | na |
| Roberts et al., 1998 | Experiments | Increase | Decrease | Increase |
| Arnold et al., 1998 | Experiments | Increase | na | Increase |
| Marra et al., 1998 | Survey | Increase | Decrease | Increase |
| Fernandez-Cornejo et al., 2002[1] | Survey | Small increase | Small increase | Same |
| McBride & El-Osta, 2002[2] | Survey | na | na | Same |
| Duffy, 2001 | Survey | Small decrease | na | Same |
| **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 |
| Fernandez-Cornejo et al., 2000[1] | Survey | Increase | Same | Increase |
| **Herbicide-tolerant corn** | | | | |
| Fernandez-Cornejo and Klotz-Ingram, 1998 | Survey | Increase | Decrease | Same |
| McBride & El-Osta, 2002[2] | Survey | na | na | Increase |
| **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., 1999[3] | Experiments | Increase | na | Increase |
| Marra et al., 1998 | Survey | Increase | Decrease | Increase |
| Fernandez-Cornejo et al., 2000[1] | Survey | Increase | Decrease | Increase |
| **Bt corn** | | | | |
| Rice and Pilcher, 1998 | Survey | Increase | Decrease | Depends on infestation |
| Marra et al., 1998 | Survey | Increase | Decrease | Increase |
| Benbrook, 2001 | Survey | Increase | na | Decrease |
| McBride & El-Osta, 2002[2] | Survey | na | na | Decrease |
| Duffy, 2001 | Survey | Increase | na | Same |
| Pilcher et al., 2002 | Survey | Increase | Decrease | na |
| Baute, Sears, and Schaafsma, 2002 | Experiments | Increase | na | Depends on infestation |
| Dillehay et al., 2004[4] | Experiments | Increase | na | na |
| Fernandez-Cornejo & Li, 2005[5] | Survey | Increase | Decrease | na |

na = not analyzed in the study.
[1]Results using 1997 data.
[2]Results using 1998 data.
[3]Results are for 1996 and 1998. Results were different in 1997 when pest pressure was low.
[4]Results using 2000-2002 data.
[5]Results using 2001 data.
[6]Net returns equal revenues minus variable costs.

Figure 8
**Pesticide use in major field crops**




Source: NASS surveys.

corn, and HT soybeans combined, using 1997/1998 data), resulting in a significant reduction in potential exposure to pesticides (Fernandez-Cornejo and McBride, 2002). Overall pesticide use on corn, soybeans, and cotton declined by about 2.5 million pounds, despite the slight increase in the amount of herbicides applied to soybeans. In addition, glyphosate used on HT crops is less than one-third as toxic to humans, and not as likely to persist in the environment as the herbicides it replaces (Fernandez-Cornejo and McBride, 2002).

More recently, using 2001 data, ERS found that insecticide use was 8 percent lower per planted acre for adopters of Bt corn than for nonadopters (Fernandez-Cornejo and Li, 2005).[9]

The ERS results generally agree with field-test and other farm surveys that have examined the effects of using GE crops (table 3). The majority of those results show that pesticide use for adopters of GE crops is lower than for users of conventional varieties.

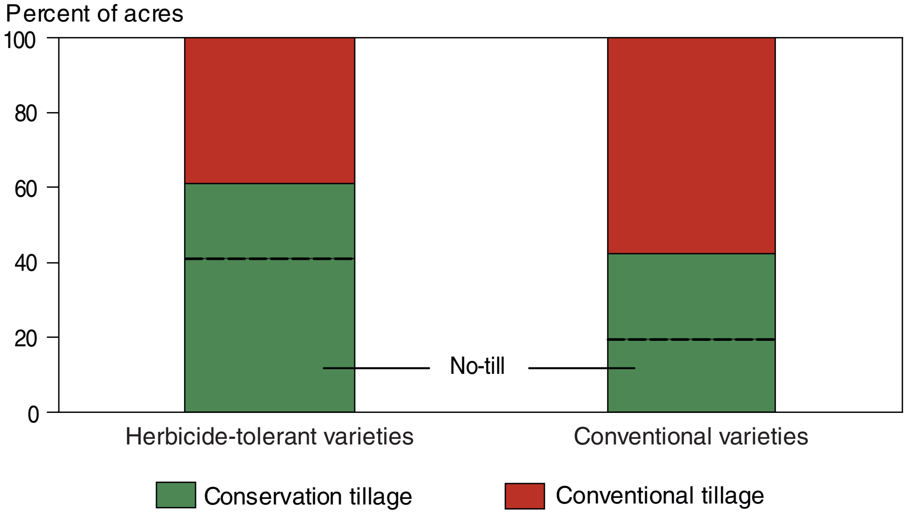
***Adoption of HT soybeans appears to be associated with conservation tillage.*** The environmental impact of conservation tillage is well documented.[10] The use of conservation tillage reduces soil erosion by wind and water, increases water retention, and reduces soil degradation and water and chemical runoff.

According to USDA survey data, about 60 percent of the area planted with HT soybeans was under conservation tillage in 1997, compared with only about 40 percent of the acres planted with conventional soybeans (fig. 9). Differences in the use of no-till between adopters and nonadopters of HT soybeans are even more pronounced: 40 percent of acres planted with HT soybeans were under no-till, twice the corresponding share of acreage planted with conventional soybeans. As a result, adoption of HT crops may indirectly benefit the environment by encouraging farmers to use soil conservation practices.

[9]In addition, using an econometric model with the 2001 data, the ERS study showed a moderate but statistically significant insecticide reduction associated with farmers who adopted Bt corn relative to those using conventional corn varieties (a 4.11-percent decrease in insecticide use was associated with a 10-percent increase in Bt corn adoption).

[10]Conservation tillage includes any tillage and planting system that leaves at least 30 percent of the soil surface covered with crop residue. It includes no-till, ridge-till, and mulch-till (Conservation Technology Information Center, 2004).

Figure 9
**Soybean area under conservation tillage* and no-till, 1997**




*Conservation tillage acres includes acres under no-till, ridge till, and mulch-till systems.
Source: Fernandez-Cornejo and McBride (2002).

## Consumer Demand Affects R&D, Adoption, and Marketing of GE-Derived Products

Investments in biotechnology-related research and development (R&D), the adoption of GE seeds, and the marketing of GE-derived products are all affected by consumer demand. While several surveys indicate that some U.S. consumers are concerned about GE food (table 4), these concerns have not had a large impact on the market for foods containing GE ingredients in the United States. In the European Union and a few other countries, consumer concern has resulted in substitution away from GE ingredients.

While opinion surveys give some indication of whether or not consumers are concerned about foods containing GE ingredients, they give little indication of the level of concern. Some researchers have attempted to quantify this concern through studies in which consumers are asked how much they would be willing to pay for foods made with GE ingredients, and for foods without GE ingredients. Researchers then use these data to measure whether or not there is a difference between these two hypothetical prices.

In most of these studies (table 5), consumers indicated that they were willing to pay more on average for GE-free foods or to avoid foods containing GE ingredients. However, in many of the studies, at least some consumers did not require a discount to buy foods containing GE ingredients, while some expressed that they would not be willing to buy foods containing GE ingredients at all.[11] Some respondents were willing to pay more for certain characteristics, such as improved nutrition and environmental benefits (Li et al., 2001; Lusk, 2003, Bocaletti and Moro, 2000).

While surveys and willingness-to-pay studies provide some insight into consumer opinion, they often do not reflect how consumers will behave in a real market situation when purchasing goods and services. Each food product has many characteristics, such as taste, color, and ripeness. The presence of a biotech-derived component is only one attribute. Empirically, it is difficult to determine what percentage of the price a consumer is paying for a specific characteristic. There are no published studies that indicate how many consumers have actually paid a premium to purchase non-GE goods, but there is some empirical evidence of the types of goods that are currently offered for sale to consumers. In the United States, many products contain GE ingredients, and the demands for these products apparently have been unaffected by negative opinions about biotechnology expressed in surveys. A few specialty brands are marketed as "GE free," but they represent a small percentage of supermarket sales.[12] In some other countries, however, strong consumer demand for non-GE products has limited the availability of GE items (see box, "Biotech Product Differentiation: A Tale of Two Markets").

[11]The amount that consumers indicate that they are willing to pay for a particular characteristic in a hypothetical situation is sometimes different from the amount that they actually pay when shopping (Lusk, 2003).

[12]In addition, organic foods are available. Use of any GE techniques bars a crop from being certified as organic. Although organic foods still have a small market share (1-2 percent ) of total U.S. food sales, their sales have been rising at a rate of 20 percent annually (Dimitri and Greene, 2002).

**Table 4**
**Surveys on consumer perceptions of foods containing GE ingredients**

| Country/ Population | Surveyed by | Details |
|---|---|---|
| United States | Pew Initiative/Mellman Group, 2003, 2004 | 27 percent favor introduction of GE foods; 47 percent oppose. However, 64 percent disagree with the statement, “genetically modified foods should not be allowed to be sold even if the Food and Drug Administration believes they are safe,” and 28 percent feel that those foods should not be allowed, even if the FDA feels they are safe. |
| United States | Gallup, 2001 | 52 percent support the application of biotechnology; 38 percent oppose the use of biotechnology in food production. |
| United States | Hallman, 2004 | 47 percent approved or leaned toward approval of the use of GE to make plant-based foods, 41 percent disapproved or leaned toward disapproval, and 12 percent were unsure. |
| United States | IFIC, 2005 | 50 percent said likely to buy and 45 percent said not likely to buy GE produce modified to taste better or fresher; 64 percent said likely to buy and 32 percent said not likely to buy GE produce modified to require fewer pesticide applications. |
| Beijing, China | Hu and Chen, 2004 | 67 percent were concerned about biotechnology. |
| Nanjing, China | Zhong et al., 2002 | 40 percent would buy GE foods; 17 percent would not; 34 percent don’t know. |
| Beijing, China, Shiajiazhuang, China | Ho and Vermeer, 2004 | 40 percent were willing or rather willing to consume foods containing GE-based ingredients, 51 percent were neutral, and 9 percent were rather unwilling or very unwilling to consume the foods. |
| Flemish speakers in Belgium | Verdurme and Viaene, 2003 | 15 percent opposed to GE foods; 34 percent perceived small risks and small benefits; 26 percent perceived moderate risks and moderate benefits; and 23 percent perceived large benefits. |
| United Kingdom | 2003 GE Public Debate Steering board | 86 percent preferred not to eat GE foods; 8 percent happy to eat GE foods. |

Source: Compiled by USDA’s Economic Research Service.

**Table 5**
**Willingness to pay for foods that do not contain GE ingredients**[1]

| Country | Food | Study | Willingness-to-pay premium |
|---|---|---|---|
| United States | Vegetable oil | Tegene et al., 2003 | In experimental auctions, consumers willing to pay 14 percent more for non-GE food. |
| United States | Potatoes | Loureiro and Hine, ` 2002 | Customers willing to pay 5 percent more for non-GE food. |
| United States | Golden rice | Lusk, 2003 | Customers willing to pay 93 cents for GE "golden rice" with added vitamin C, 65-75 cents for regular rice. |
| United Kingdom | All foods | Burton et al., 2001 | Customers indicated willingness to increase food budgets by 26-129 percent to avoid GE foods. |
| Italy | * | Bocaletti and Moro, 2000 | Consumers willing to pay a positive amount for GE attributes; 66 percent did not require a premium to consume GE foods. |
| United States, France, Germany, and United Kingdom | Beef fed with GE feed | Lusk et al., 2003 | U.S. consumers willing to pay $2.83 and $3.31 per lb. to avoid GE; European consumers $4.86 to $11.01. |
| United States, United Kingdom | Breakfast cereal | Moon and Balasubramanian, 2001 | Survey found 56 percent of UK consumers willing to pay a premium to avoid GE compared with 37 percent of U.S. consumers. |
| Norway, United States, Japan, Taiwan | Vegetable oil | Chern et al., 2002 | Norwegian students were willing to pay $1.51 (55-69 percent premium) per liter for non-GE vegetable oil, U.S. students were willing to pay $1.13 (50-62 percent premium), Japanese students were willing to pay $0.88 (33-40 percent premium), and Taiwanese students were willing to pay $0.45 cents (17-21 percent premium). |
| China | Rice | Li et al., 2002 | 80 percent of consumers did not require a premium to purchase GE rice and on average were willing to pay a 38-percent premium on GE rice and a 16-percent premium for GE soy oil. |
| Norway | Bread | Grimsrud, et al., 2004 | Consumers required discounts of 37-63 percent to buy GE bread; One-fourth willing to buy with no discount. |
| Australia | Beer | Burton and Pearse, 2002 | Younger consumers would pay $A 0.72 less and older consumers $A 0.40 less for beer made with GE barley. |
| Canada | * | West et al., 2002 | 83 percent of consumers ascribed a lower value to several GE foods. |
| France | * | Noussair et al., 2004 | 35 percent of consumers were unwilling to purchase GE foods, and 42 percent were willing to purchase them if they were less expensive. |
| United States | Oil, chips, and potatoes | Rousu et al., 2004 | Consumers reduced their demand by an average of 7-13 percent for each food product having 1 percent and 5 percent tolerance levels for GE material relative to GE-free food. |

[1]See also Lusk et al. (2005), who summarize a set of 25 studies including 57 GE valuation studies and report that, on average, consumers are willing to pay a positive premium for GE-free foods.

*This study did not focus on a specific food item.

Source: Compiled by USDA's Economic Research Service.

## Biotech Product Differentiation: A Tale of Two Markets

The introduction of genetically engineered (GE) crops has led food manufacturers to make a choice for each of their products: either pursue a non-GE strategy and market and produce a non-GE product or source inputs based on cost and quality, or market and produce an undifferentiated product.

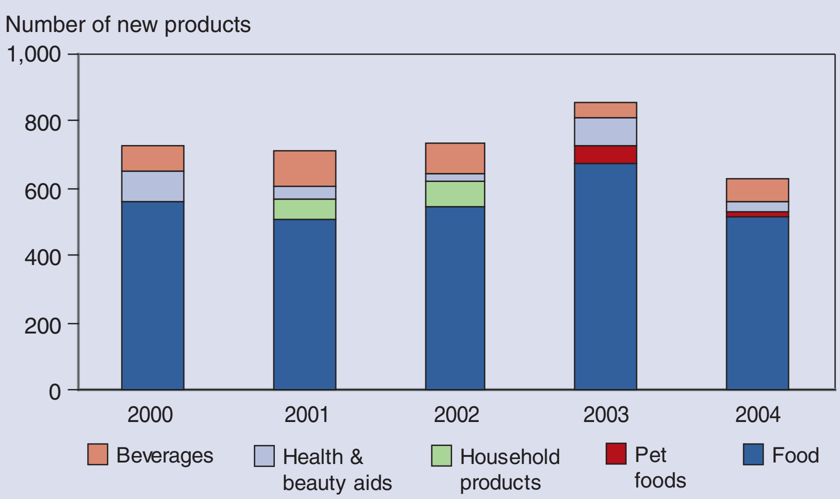
If all manufacturers were to pursue a non-GE strategy, farmers would eventually abandon GE technologies and consumer choice would be restricted to potentially higher cost non-GE products. If manufacturers were to pursue an undifferentiated strategy, then farmers' use of the technology would be determined by production costs and consumers would be faced with markets in which they could not differentiate between GE and non-GE foods. If manufacturers pursue both strategies, some farmers would continue to use the technology while others would grow conventional crops to supply non-GE markets. In this scenario, consumers would have a choice between GE and non-GE food, at least for some products.

In the United States, where unlabeled foods may contain GE ingredients, the data show that manufacturers have been active in creating a market for GE-free foods. From 2000 to 2004, manufacturers introduced over 3,500 products that had explicit non-GE labeling, mostly food products, with annual totals ranging from 854 in 2003 to 631 in 2004. This is in addition to organic foods (organic crops may not be grown using GE techniques) (Dimitri and Greene, 2002).

In the European Union and Japan, where unlabeled foods cannot contain GE ingredients, manufacturers have chosen a non-GE marketing strategy. Very few products labeled as containing GE ingredients are found on European or Japanese grocery store shelves.

The data also show that there have been limited attempts to market GE products in the United States. There were far fewer new GE products introduced than new non-GE products, and most of the GE products were introduced in the 1990s. GE products included tomatoes (advertised as better tasting with a longer shelf life), canola oil (advertised as heat stable), shrimp (advertised as gourmet-quality), beef (low-fat), dietary supplements, cigarettes (low-nicotine), and a drain cleaner.

**Annual non-GE new product introductions in the United States**




Source: Productscan Online.

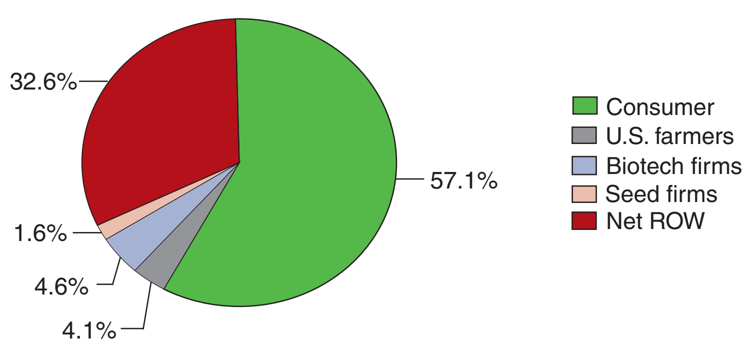
## Adoption Offers Market Benefits to Many Stakeholders

In addition to farmers, seed suppliers, technology providers, and consumers also benefit from the adoption of GE crops in the United States. Biotechnology developers and seed firms benefit by charging technology fees and seed premiums to adopters of GE varieties. U.S. and foreign consumers may benefit indirectly from GE crops through lower commodity prices that result from increased supplies.[13]

ERS estimated the total market benefit arising from the adoption of three GE crops in the United States—HT soybeans, Bt cotton, and HT cotton—in 1997 (Price et al., 2003).[14] Estimated benefits to farmers, seed producers, and consumers were around $210 million for Bt cotton, $230 million for HT cotton, and $310 million for HT soybeans. This estimate includes the change in total welfare in both the seed input and commodity output markets. The distribution of these benefits among consumers, farmers, technology providers (biotech firms), seed firms, and consumers and producers in the rest of the world (ROW) is shown in figures 10-12. The distribution of benefits varies by crop and technology because the economic incentives to farmers (crop prices and production costs), the payments to technology providers (biotech firms) and seed firms, and the effect of the technology on world crop prices are different for each crop and technology. For example, adoption of HT cotton benefits mainly consumers while Bt cotton benefits farmers and technology providers. Seed firms are by far the largest beneficiaries in the case of soybeans.

These results should be interpreted carefully, since the estimates are based on only a few years of data. Moreover, estimated benefits and their distribution depend particularly on the analytical framework, supply and demand elasticity assumptions,[15] crops considered, and year-specific factors (such as weather). In particular, the benefits attributable to HT soybeans and their distribution are very dependent on the soybean supply elasticity. Table 6 shows estimates of the benefits of Bt cotton and HT soybeans and their distribution obtained by other researchers.

Figure 10
**Stakeholders' shares of the estimated total world benefit from adopting herbicide-tolerant cotton, 1997**



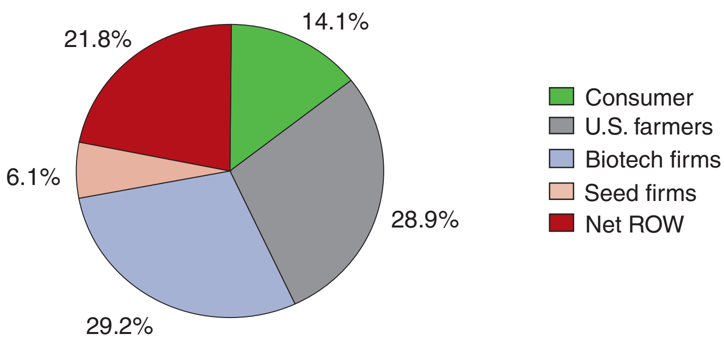

Source: Price et al., 2003.

[13]Consumers may also benefit directly when GE products of the second and third generation are commercialized.

[14]The study estimated the economic gains for various stakeholders associated with adoption by incorporating the potential yield enhancements and savings in pest control costs into models that derive each crop's supply shift resulting from biotechnology. Given domestic and export demands, counterfactual world prices and quantities demanded of the commodities—those that would have prevailed in the market if biotechnology had not been introduced—are determined from market equilibrium conditions. Producer and consumer surpluses in the U.S. and international markets and monopoly profits accruing to the biotech developers and seed firms are then calculated (Price et al., 2003).

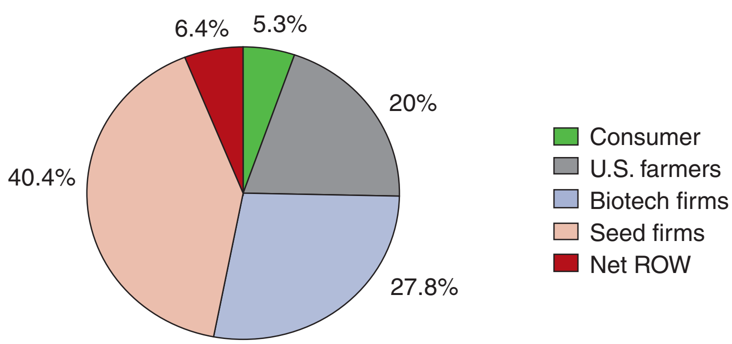
[15]Elasticity measures the responsiveness of one economic variable to a change in another (e.g., price and quantity demanded). It is unit free and always expressed in percentage terms.

Figure 11
**Stakeholders' shares of the estimated total world benefit from adopting Bt-cotton, 1997**




Source: Price et al., 2003.

Figure 12
**Stakeholders' shares of the estimated total world benefit from adopting herbicide-tolerant soybeans, 1997**




Source: Price et al., 2003.

**Table 6**
**Benefits of GE techniques and their distribution (from estimates in related studies)**

| Study | Year | Total benefits | Share of the total benefits | | | |
|---|---|---|---|---|---|---|
| | | | U.S. farmers | Innovators | U.S. consumers | Net ROW |
| | | *$ million* | *Percent* | | | |
| **Bt cotton** | | | | | | |
| Falck-Zepeda et al. (1999) | 1996 | 134 | 43 | 47 | 6 | |
| Falck-Zepeda et al. (2000b) | 1996 | 240 | 59 | 26 | 9 | 6 |
| Falck-Zepeda et al. (2000a) | 1997 | 190 | 43 | 44 | 7 | 6 |
| Falck-Zepeda et al. (1999) | 1998 | 213 | 46 | 43 | 7 | 4 |
| Frisvold et al. (2000) | 1996-98 | 131-164 | 5-6 | 46 | 33 | 18 |
| EPA (2000)[1] | 1996-99 | 16.2-45.9 | n.a. | n.a. | n.a. | n.a. |
| Price et al. (2003) | 1997 | 210 | 29 | 35 | 14 | 22 |
| **Herbicide-tolerant soybeans** | | | | | | |
| Falck-Zepeda et al. (2000a) | 1997-Low elasticity[2] | 1,100 | 77 | 10 | 4 | 9 |
| | 1997-High elasticity[3] | 437 | 29 | 18 | 17 | 28 |
| Moschini et al. (2000) | 1999 | 804 | 20 | 45 | 10 | 26 |
| Price et al. (2003) | 1997 | 310 | 20 | 68 | 5 | 6 |

n.a. = Not applicable.
ROW = Rest of the world.
[1]Limited to U.S. farmers.
[2]Assumes a U.S. soybean supply elasticity of 0.22.
[3]Assumes a U.S. soybean supply elasticity of 0.92.
Source: Price et al., 2003.

## Conclusion

The role that biotechnology plays in agriculture in the United States and globally depends on a number of factors and uncertainties. As the USDA Advisory Committee on Biotechnology and 21st Century Agriculture report indicates, "agricultural biotechnology sits at the crossroads of other debates on the future of American and world agriculture, on international trade relations, on biological diversity and the development of international instruments related to its preservation and exploitation, on the role of the multinational corporations, and on how best to build public confidence in rapidly evolving emerging technologies in general" (p.2.).  One thing seems certain, however: the ultimate contribution of agricultural biotechnology will depend on our ability to identify and measure its potential benefits and its risks as well as their distribution.

## References

Arnold, J.C., D.R. Shaw, and C.R. Medlin. "Roundup Ready™ Programs Versus Conventional Programs: Efficacy, Varietal Performance, and Economics." *Proceedings of the Southern Weed Science Society, Southern Weed Science Society*. 51(1998): 272-73.

Associated Press, Matt Moore. 2004. Covered by CBS news as "Europeans Balk At Biotech Beer" July 8, 2004. http://www.cbsnews.com/stories/2004/07/08/tech/main628305.shtml.

Baker, G., and T. Burnham. "Consumer Response to Genetically Modified Foods: Market Segment Analysis and Implications for Producers and Policy Makers," *Journal of Agricultural and Resource Economics,* 26(2) (December 2001): 387-403.

Baute, T.S., M.K. Sears, and A.W. Schaafsma. "Use of Transgenic *Bacillus thuringiensis* Berliner Corn Hybrids to Determine the Direct Economic Impact of the European Corn Borer (*Lepidoptera: Crambidae*) on Field Corn in Eastern Canada. *Journal of Economic Entomology.* 95(1)(2002): 57-64.

Boccaletti, S., and D. Moro. "Consumer Willingness-To-Pay For GM Food Products In Italy," *AgBioForum*, 3(4)(2000): 259-267.

Bryant, K.J., W.C. Robertson, and G.M. Lorenz III. "Economic Evaluation of Bollgard Cotton in Arkansas." In *Proceedings of the Beltwide Cotton Conferences*, National Cotton Council, Memphis, TN. 1(1998):388-89.

Burton, M., and D. Pearse. "Consumer Attitudes Towards Genetic Modification, Functional Foods, and Microorganisms: A Choice Modeling Experiment for Beer." *AgBioForum*, 5(2)(2002): 51-58.

Burton, M., D. Rigby, T. Young, and S. James. "Consumer Attitudes to Genetically Modified Organisms in Food in the UK." *European Review of Agricultural Economics*, 28 (4)(December 2001): 479-98.

Carter, C.A., and G.P. Gruère. "Mandatory Labeling of Genetically Modified Foods: Does it Really Provide Consumer Choice?" *AgBioForum*, 6(1 & 2): 68-70. 2003 (a).

Carter, C.A., and G.P. Gruère. "International Approaches to the Labeling of Genetically Modified Foods." *Choices*, June 2003 (b).

Chern, W.S., K. Rickertsen, N. Tsuboi, and Tsu-Tan Fu. "Consumer Acceptance and Willingness to Pay for Genetically Modified Vegetable Oil and Salmon: A Multiple-Country Assessment." *AgBioForum*, 5(3)(2002): 105-112.

Colorado State University, Department of Soil and Crop Sciences. "Discontinued Transgenic Products," in *Transgenic Crops: An Introduction and Resource Guide*. http://www.colostate.edu/programs/lifesciences/TransgenicCrops/defunct.html. March 2004.

Comis, D. “Safe Corn Pest Bait Expected to Slash U.S. Insecticide Use.” U.S. Department of Agriculture, Agricultural Research Service. http://www.ars.usda.gov/is/pr/1997/970116.htm?pf=1. 1997.

Conservation Technology Information Center (CTIC). National Crop Residue Management Survey. “Conservation Tillage Data.” http://www.ctic.purdue.edu/CTIC/CRM.html.

Culpepper, A.S., and A.C. York. “Weed Management in Glyphosate-Tolerant Cotton.” *The Journal of Cotton Science,* 4(1998):174-185.

Delannay, X., T.T. Bauman, D.H. Beighley, M.J. Buettner, H.D. Coble, M.S. DeFelice, C.W. Derting, T.J. Diedrick, J.L. Griffin, E.S. Hagood, F.G. Hancock, S.E. Hart, B.J. LaVallee, M.M. Loux, W.E. Lueschen, K.W. Matson, C.K. Moots, E. Murdock, A.D. Nickell, M.D.K. Owen, E.H. Paschall II, L.M. Prochaska, P.J. Raymond, D.B. Reynolds, W.K. Rhodes, F.W. Roeth, P.L. Sprankle, L.J. Tarochionc, C.N. Tinius, R.H. Walker, L.M. Wax, H.D. Weigelt, and S.R. Padgette. “Yield Evaluation of a Glyphosate-Tolerant Soybean Line After Treatment with Glyphosate.” *Crop Science*, 35(1995):1461-67.

Dillehay, B.L., G.W. Roth, D.D. Calvin, R.J. Karatochvil, G.A. Kuldau, and J. A. Hyde. “Performance of Bt Corn Hybrids, their Near Isolines, and Leading Corn Hybrids in Pennsylvania and Maryland.” *Agronomy Journal*, 96(204): 818-824.

Dimitri, C., and C. Greene. *Recent Growth Patterns in the U.S. Organic Foods Market.* U.S. Department of Agriculture, Economic Research Service. Agriculture Information Bulletin No. 777. Sept. 2002.

Duffy, M. “Who Benefits from Biotehnology?” Paper presented at the American Seed Trade Association meeting. Chicago, IL. December 5-7, 2001.

Falck-Zepeda, J.B., G. Traxler, and R.G. Nelson. “Rent Creation and Distribution from the First Three Years of Planting Bt Cotton.” ISAAA Briefs No. 14. International Service for the Acquisition of Agri-biotech Applications. Ithaca, NY. 1999.

Falck-Zepeda, J.B., G. Traxler, and R.G. Nelson. “Rent Creation and Distribution from Biotechnology Innovations: The Case of Bt Cotton and Herbicide-Tolerant Soybeans in 1997,” *Agribusiness*, 16(2000a): 21-32.

Falck-Zepeda, J.B., G. Traxler, and R.G. Nelson. “Surplus Distribution from the Introduction of a Biotechnology Introduction.” *American Journal of Agricultural Economics*, 82(2000b): 360-369.

Fernandez-Cornejo, J. *The Seed Industry in U.S. Agriculture: An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development.* U.S. Department of Agriculture, Economic Research Service, Agriculture Information Bulletin No. 786. Feb. 2004.

Fernandez-Cornejo, J. "Adoption of Genetically Engineered Crops in the U.S." Data product. U.S. Department of Agriculture, Economic Research Service. http://www.ers.usda.gov/Data/BiotechCrops/. July 2005.

Fernandez-Cornejo, J., and Jiayi Li. "The Impacts of Adopting Genetically Engineered Crops in the USA: The Case of Bt Corn." Paper presented at the American Agricultural Economics Association meetings. Providence, RI. 2005.

Fernandez-Cornejo, J., and W.D. McBride. *Genetically Engineered Crops for Pest Management in U.S. Agriculture*. U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 786. April 2000.

Fernandez-Cornejo, J., and W.D. McBride. *The Adoption of Bioengineered Crops*. U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 810. May 2002.

Fernandez-Cornejo, J., C. Hendricks, and A. Mishra. "Technology Adoption and Off-Farm Household Income: The Case of Herbicide-Tolerant Soybeans." *Journal of Agricultural and Applied Economics*, 37(2)(2005).

Fernandez-Cornejo, J., C. Klotz-Ingram, and S. Jans. "Farm-Level Effects of Adopting Genetically Engineered Crops in the U.S.A.," In *Transitions in Agrobiotech: Economics of Strategy and Policy*, pp. 57-72. W.L. Lesser, editor. Food Marketing Research Center, University of Connecticut and Department of Research Economics, University of Massachusetts. 2000.

Fernandez-Cornejo, J., C. Klotz-Ingram, and S. Jans. "Farm-Level Effects of Adopting Herbicide-Tolerant Soybeans in the U.S.A." *Journal of Agricultural and Applied Economics*, 34(1)(2002): 149-163.

Fernandez-Cornejo, J., M. Caswell, and C. Klotz-Ingram. "Seeds of Change: From Hybrids to Genetically Modified Foods." *Choices,* (Millennium issue, 4th quarter of 1999): 18-22.

Finke, M. S., and H. Kim. "Attitudes About Genetically Modified Foods Among Korean and American College Students." *AgBioForum*, 6(4)(2003): 191-197.

Frisvold, G., R. Tronstad, and J. Mortensen. "Effects of Bt Cotton Adoption: Regional Differences and Commodity Program Effects." Paper presented at the Western Agricultural Economics Association Meeting, Vancouver, British Columbia. June 30, 2000.

Gibson, J.W. IV, D. Laughlin, R.G. Lutrell, D. Parker, J. Reed, and A. Harris. "Comparison of Costs and Returns Associated with *Heliothis* Resistant Bt Cotton to Non-Resistant Varieties," *Proceedings of the Beltwide Cotton Conferences*. Cotton Weed Science Research Conference.1997. v.1, pp. 244-247.

Goldman, D.L., C. Guy, M. McCelland, and A. Kendig. "Weed Control Systems in Roundup Ready™ Cotton." In *Proceedings of the Beltwide Cotton Conferences*. Cotton Weed Science Research Conference. 1996. v.2. p. 1532.

Gracia, A., and L.M. Albisu. "Food Consumption in the European Union: Main Determinants and Country Differences." *Agribusiness,* 17(4)(Autumn, 2001): 469-488.

Graeber, J.V., E.D. Nafziger, and D.W. Mies. "Evaluation of Transgenic, Bt-Containing Corn Hybrids." *Journal of Production Agriculture,* (12)(4)(1999):659-663.

Greenpeace. EU Markets. http://www.greenpeace.org/raw/content/international/press/reports/european-markets-report-2005.pdf. February 3, 2005.

Grimsrud, K.M., J. McCluskey, M. Loureiro, and T. Wahl. "Consumer Attitudes to Genetically Modified Foods in Norway." *Journal of Agricultural Economics*, 55(1)(March 2004): 75-90.

Hallman, W., W. Hebden, C. Cuite, H. Aquino, and J. Lang. *Americans and GM Food: Knowledge, Opinion & Interest in 2004*. Food Policy Institute. http://www.foodpolicyinstitute.org/docs/reports/NationalStudy2004.pdf.

Harrison, R.W., S. Boccaletti, and L. House."Risk Perceptions of Urban Italian and United States Consumers for Genetically Modified Foods." *AgBioForum*, 7(4)(2004):195-201.

Ho, P., and E. B. Vermeer. "Food Safety Concerns and Biotechnology: Consumers' Attitudes to Genetically Modified Products in Urban China." *AgBioForum*, 7(4)(2004): 158-175.

House, L., J. Lusk, S. Jaeger, W. B. Traill, M. Moore, C. Valli, B. Morrow, and W.M.S. Yee. "Objective and Subjective Knowledge: Impacts on Consumer Demand for Genetically Modified Foods in the United States and the European Union." *AgBioForum*, 7(3)(2004): 113-123.

Hu, W.Y., and K. Chen. "Can Chinese Consumers Be Persuaded? The Case of Genetically Modified Vegetable Oil." *AgBioForum*, 7(3)(2004):24-132.

International Food Information Council (IFIC) Polls, 1999-2005. http://ific.org/publications/.

International Service for the Acquisition of Agri-biotech Applications (ISAAA). Preview: Global Status of Commercialized Biotech/GM Crops: ISAAA Briefs 32-2004. http://www.isaaa.org/kc/CBTNews/press_release/briefs32/ESummary/Executive%20Summary%20(English).pdf.

Just, R.E., and D.L. Hueth. "Multimarket Exploitation: The Case of Biotechnology and Chemicals." *American Journal of Agricultural Economics,* 75(4)(1993): 936-45.

Kaufman, P. "Consolidation in Food Retailing: Prospects for Consumers and Grocery Suppliers." *Agricultural Outlook*, August, 2000.

Keeling, W., P. Dotray, C. Jones, and S. Sunderland. "Roundup™ Ready Cotton: A Potential New Weed Management Tool for the Texas High

Plains." *Proceedings of the Beltwide Cotton Conferences*. Cotton Weed Science Research Conference. 1996. v.2. p. 1529.

King, J., and P. Heisey. "Ag Biotech Patents: Who is Doing What?" *Amber Waves*, November 2003. http://www.ers.usda.gov/Amberwaves/November03/DataFeature/.

Li, Q., K.R. Curtis, J.J. McCluskey, and T.I. Wahl. "Consumer Attitudes Toward Genetically Modified Foods in Beijing, China." *AgBioForum*, 5(4)(2002): 145-152.

List, J.A., and C. Gallet, "What Experimental Protocol Influence Disparities between Actual and Hypothetical Stated Values." *Environmental and Resource Economics,* 20(2001): 241-254.

Loureiro, M.L., and S. Hine. "Discovering Niche Markets: A Comparison of Consumer Willingness to Pay for Local (Colorado Grown), Organic, and GMO-Free Products." *Journal of Agricultural and Applied Economics*, 34(3)(December 2002): 477-487.

Lusk, J.L. "Effects of Cheap Talk on Willingness to Pay for Golden Rice." *American Journal of Agricultural Economics*, 85 (4)(November 2003): 840-856.

Lusk, J.L., J. Roosen, and J. Fox. "Demand for Beef with Growth Hormones and Fed Genetic Corn." *American Journal of Agricultural Economics*, 85 (1)(February 2003): 16-29.

Lusk, J.L., M. Jamal, L. Kurlander, M. Roucan, and L. Taulman. "A Meta Analysis of Genetically Modified Food Valuation Studies." *Journal of Agricultural and Resource Economics*, 30(April 2005):28-44.

Marks, L.A., N. Kalaitzandonakes, and S.S. Vickner. "Consumer purchasing behavior toward GM foods in the Netherlands," in *Consumer Acceptance of Biotech Foods*. R. Evenson and V. Santaniello (editors). Wallingford, UK: CABI Publishers, p. 23-29, 2004.

Marra, M., G. Carlson, and B. Hubbell. "Economic Impacts of the First Crop Biotechnologies." Available at http://www.ag.econ.ncsu.edu/faculty/marra/firstcrop/imp001.gif. 1998.

McBride, W.D., and H. El-Osta. "Impacts of the Adoption of Genetically Engineered Crops on Farm Financial Performance." *Journal of Agricultural and Applied Economics*, Vol. 34, No. 1(April 2002):175-191.

McBride, W., S. Short, and H. El-Osta. "Production and Financial Impacts of the Adoption of Bovine Somatropin on U.S. Dairy Farms." Paper presented at the 2002 American Agricultural Economics Association meetings, Long Beach, CA, July 28-31, 2002.

Moon, W.K., and S.K. Balasubramanian. "Public Perceptions And Willingness-To-Pay A Premium For Non-GM Foods in the US and UK." *AgBioForum*, 4(3&4)(2001): 221-231.

Moon, W.K., and S.K. Balasubramanian. "Is There a Market for Genetically Modified Foods in Europe? Contingent Valuation of GM and Non-GM Breakfast Cereals in the United Kingdom." *AgBioForum*, 6(3)(2003): 128-133.

Moschini, G., H. Lapan, and A. Sobolevsky. "Roundup Ready$^{TM}$ Soybeans and Welfare Effects in the Soybean Complex." *Agribusiness,* 16(2000): 33-55.

National Research Council. *Animal Biotechnology: Science Based Concerns*. Board on Agriculture and Natural Resources, Board on Life Sciences, Washington, DC: The National Academies Press. http://www.nap.edu/openbook/0309084393/html/R1.html#pagetop. 2002 (a).

National Research Council. *Environmental Effects of Transgenic Plants: The Scope and Adequacy of Regulation*. Board on Agriculture and Natural Resources, Committee on Environmental Impacts Associated with Commercialization of Transgenic Plants. Washington, DC: The National Academies Press. http://www.nap.edu/books/0309082633/html/. 2002 (b).

Noussair, C., S. Robin, and B. Ruffieux. "Do Consumers Really Refuse To Buy Genetically Modified Food?" *The Economic Journal*, 114(492)(2004): 102-120.

North Carolina Farm Bureau Federation. "Gallup Conducts Poll on Biotech Food." Aug. 6-12, 2001.

Office of Science and Technology Policy, Executive Office of the President. *Coordinated Framework for Regulation of Biotechnology*. Federal Register, 51 FR 23302, http://usbiotechreg.nbii.gov/Coordinated_Framework_1986_Federal_Register.html. 1986.

Onyango, B., R.M. Nayga, Jr., and B. Schilling . "Role of Product Benefits and Potential Risks in Consumer Acceptance of Genetically Modified Foods." *AgBioForum*, 7(4)(2004): 202-211.

Panos. "Greed or Need? Genetically Modified Crops." Panos Media Briefing No. 30. October 1998. http://www.oneworld.org/panos/.

Pew Initiative on Food and Biotechnology. *Harvest on the Horizon: Future Uses of Agricultural Biotechnology*. http://pewagbiotech.org/research/harvest/harvest.pdf. Sept. 2001.

Pew Initiative on Food and Biotechnology. "Public Sentiment About Genetically Modified Food: September 2003 Update." http://pewagbiotech.org/research/2003update/. 2003.

Pew Initiative on Food and Biotechnology. "Overview of Findings 2004 Focus Groups & Poll." http://pewagbiotech.org/research/2004update/overview.pdf. 2004.

Pilcher, C.D., M.E. Rice, R.A. Higgins, K.L. Steffey, R.L. Hellmich, J. Witkowski, D. Calvin, K.R. Ostlie, and M. Gray. "Biotechnology and the European Corn Borer: Measuring Historical Farmer Perceptions and Adoption of Transgenic Bt Corn as a Pest Management Strategy." *Journal of Economic Entomology,* 95(5)(2002): 878-892.

Price, G.K., W. Lin, J.B. Falck-Zepeda, and J. Fernandez-Cornejo. *The Size and Distribution of Market Benefits from Adopting Agricultural Biotechnology.* U.S. Department of Agriculture, Economic Research Service, Technical Bulletin No. 1906. Nov. 2003.

ReJesus, R.M., J.K. Greene, M.D. Hamming, and C.E. Curtis. "Economic Analysis of Insect Management Strategies for Transgenic Bt Cotton Production in South Carolina." *Proceedings of the Beltwide Cotton Conferences*. Cotton Economics and Marketing Conference. v.1. p. 247-251. 1997.

Rice, M.E., and C.D. Pilcher. "Potential Benefits and Limitations of Transgenic Bt Corn for Management of the European Corn Borer (*Lepidoptera: Crambidae*)." *American Entomologist*, 44(1998): 75-78.

Roberts, R.K., R. Pendergrass, and R.M. Hayes, "Farm-Level Economic Analysis of Roundup Ready™ Soybeans." Paper presented at the Southern Agricultural Economics Association Meeting, Little Rock, AR, Feb. 1-4, 1998.

Rousu, M., W.E. Huffman, J.F. Shogren, and A. Tegene. "Are United States Consumers Tolerant of Genetically Modified Foods?" *Review of Agricultural Economics*, 26(February 2004): 19-31.

Runge, C. Ford, and B. Ryan. *The Global Diffusion of Plant Biotechnology: International Adoption and Research in 2004*. University of Minnesota. http://www.apec.umn.edu/faculty/frunge/globalbiotech04.pdf. Dec. 8, 2004.

Shoemaker, R., J. Harwood, K. Day-Rubenstein, T. Dunahay, P. Heisey, L. Hoffman, C. Klotz-Ingram, W. Lin, L. Mitchell, W. McBride, and J. Fernandez-Cornejo. *Economic Issues in Agricultural Biotechnology*. U.S. Department of Agriculture, Economic Research Service, Agriculture Information Bulletin No. 762. Feb. 2001.

Shoemaker, R., D. Johnson, and E. Golan. "Consumers and the Future of Biotech Foods in the United States." *Amber Waves*, November 2003. http://www.ers.usda.gov/Amberwaves/November03/Features/futureofbiotech.htm.

Steering Board of the Public Debate on GM. *GM Nation? The Findings of the Public Debate*. http://www.gmnation.org.uk/docs/gmnation_finalreport.pdf. 2003.

Tegene, A., W. Huffman, M. Rousu, and J. Shogren. *The Effects of Information on Consumer Demand for Biotech Foods: Evidence from Experimental Auctions.* U.S. Department of Agriculture, Economic Research Service, Technical Bulletin No. 1903. April 2003.

Traill, W.B., S.R. Jaeger, W.M.S. Yee, C. Valli, L. O. House, J.L. Lusk, M. Moore, and J.L. Morrow, Jr. "Categories of GM Risk-Benefit Perceptions and Their Antecedents." *AgBioForum*, 7(4)(2004): 176-186.

Tripp, R. “Regulatory Issues: Varietal Registration and Seed Quality Control.” In Morris, M.L (editor), *Maize Seed Industries in Developing Countries*. Boulder, CO: CIMMYT (International Maize and Wheat Improvement Center). 1998. pp. 159-173.

United Nations Conference on Trade and Development (UNCTAD). *International Trade in GMOs and GM Products: A National and Multilateral Legal Framework*. Policy Issues in International Trade and Commodities Study Series No. 29. United Nations, New York, NY, and Geneva, Switzerland. 2005.

University of California, Davis Vegetable Research and Information Center, Pest-Resistance Management. “Insecticidal Bt-Potatoes.” http://ucce.ucdavis.edu/files/filelibrary/5283/2196.pdf. Feb. 1998.

USDA Advisory Committee on Biotechnology and 21st Century Agriculture (AC21). *AC21 Consensus Report—Preparing for the Future*. Washington, DC. http://www.usda.gov/agencies/biotech/ac21/reports/scenarios-4-5-05final.pdf. 2005.

U.S. Department of Agriculture. “Agricultural Biotechnology: Frequently Asked Questions. What Is Biotechnology?” http://www.usda.gov/agencies/biotech/faq/html.

U.S. Department of Agriculture. “Glossary of Agricultural Biotechnology Terms.” http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1OB?contentidonly=true&navid=AGRICULTURE &contentid=BiotechnologyGlosary.xml. October 2005.

U.S. Department of Agriculture, Animal and Plant Health Inspection Service. “*Changes in Regulation of the Products of Biotechnology by APHIS’ Biotechnology Regulatory Services*.” http://www.aphis.usda.gov/brs/eis/index.html. January 2004.

U.S. Department of Agriculture, Biotechnology, Animal and Plant Health Inspection Service, Regulatory Services. “United States Regulatory Oversight in Biotechnology Responsible Agencies – Overview.” http://www.aphis.usda.gov/brs/usregs.html. April 5, 2005.

U.S. Environmental Protection Agency. “*Bacillus thuringiensis* Plant-Pesticides.” Biopesticides Registration Action Document: Preliminary Risks and Assessments Sections. 2000.

U.S. Environmental Protection Agency. *EPA’s Regulation of Biotechnology for Use in Pest Management.* http://www.epa.gov/pesticides/biopesticides/reg_of_biotech/eparegofbiotech.htm. June 2003.

U.S. Food and Drug Administration. *Statement of Policy: Foods Derived from New Plant Varieties*, 57 FR 22984. http://vm.cfsan.fda.gov/~lrd/fr92529b.html. May 1992.

U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition. *Biotechnology*. http://www.cfsan.fda.gov/~lrd/biotechm.html. May 2005.

Vencill, W.K. "Weed Management Systems utilizing Herbicide-resistant Cotton." *Proceedings of the Beltwide Cotton Conferences*. Cotton Weed Science Research Conference. 1996. v.2. p. 1532-33.

Verdurme, A., and J. Viaene. "Consumer Beliefs and Attitude towards Genetically Modified Food: Basis for Segmentation and Implications for Communication." *Agribusiness,* 19(1)(Winter 2003): 91-113.

Virginia Polytechnic Institute and State University. "Information Systems for Biotechnology, Field Test Releases in the U.S." http://www.isb.vt.edu/cfdocs/fieldtests1.cfm. April 5, 2005.

West, G.E., C. Gendron, B. Larue, and R. Lambert. "Consumers' Valuation of Functional Properties of Foods: Results from a Canada-Wide Survey." *Canadian Journal of Agricultural Economics*, 50(4)(December 2002): 541-58.

Zhong, F., M.A. Marchant, Y. Ding, and K. Lu. "GM Foods: A Nanjing Case Study of Chinese Consumers' Awareness and Potential Attitudes." *AgBioForum*, 5(4)(2003):136-144.