# Farm-Level Effects of Adopting Genetically Engineered Crops

## Preliminary Evidence from the U.S. Experience

### Issue

Driven by farmers' expectations of lower production costs, higher yields, and reduced pesticide use, the rate at which U.S. farmers adopted genetically engineered (GE) crop varieties jumped dramatically between 1996 and 1998. Actual benefits in terms of these factors are mixed.

### Context

Between 1996 and 1998, the number of U.S. acres planted with GE cotton more than doubled. Bt and herbicide-tolerant corn acreage rose from 4.4 percent to nearly 40 percent of total corn acreage. Herbicide-tolerant soybean acreage grew from 7 percent to 44 percent of total soybean acreage. Adoption rates of these varieties suggest they are becoming significant in the total mix of major field crop varieties. About 98 million acres of GE crops were cultivated worldwide in 1999, a 43-percent increase over acreage in 1998 (James, 1999). U.S. acreage accounts for approximately 72 percent of the world total. These rapid rates of adoption lead us to ask: Why are farmers adopting these crops so rapidly and what are the benefits of adoption for farmers?

### Background

Most of the commercially available GE crops have been developed to carry herbicide-tolerant or insect-resistant genes. Crops carrying herbicide-tolerant genes were developed to survive certain herbicides that previously would have destroyed the crop along with the targeted weeds. Development of these crops has allowed farmers to use a broader variety of herbicides to control weeds.

The most common herbicide-tolerant crops are Roundup Ready (RR) crops that are resistant to glyphosate. Glyphosate tolerance has been incorporated into cotton, corn, soybeans, and canola. Other genetically modified 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). Some of these, such as IMI corn, have been marketed since the early 1990's.

Bt crops containing the gene from a soil bacterium, *Bacillus thuringiensis*, are the only insect-resistant crops commercially available. The bacteria produce a toxin that can rupture an insect's gut. Crops containing the Bt gene are able to produce their own toxin, thereby providing protection throughout the entire plant. Bt has been incorporated into many crops, such as corn and cotton, and is effective in controlling particular insect pests, depending on the crop. For example, Bt cotton is primarily effective in controlling tobacco budworms and somewhat effective in controlling bollworms. However, Bt corn protects against the European corn borer (ECB) and, to a lesser extent, the corn earworm, the southwestern corn borer, and the lesser cornstalk borer.

Lower pesticide application rates or more effective herbicides may increase savings in pest management costs. For Bt crops, farmers can discontinue use of Bt foliar sprays and possibly decrease applications of other insecticides, such as pyrethroids in cotton. Farmers planting Bt crops may depend less on variable weather conditions. They would not have to worry about the timing of pesticide applications because the Bt toxin remains active throughout the plant. Planting flexibility may also rise. For example, herbicide-tolerant crops may alleviate problems from the carryover of herbicides. Farmers may be able to practice strip-cropping (a practice where corn and soybeans are grown in alternating rows) or grow corn and soybeans in rotation. Also, farmers that use such production practices as no-till may benefit if adopting herbicide-tolerant crops allows them to use a more effective herbicide treatment system.

Herbicide-tolerant and insect-resistant crops may lower chemical pesticide use in agriculture. One estimate suggests that converting 30 percent of cotton acreage to cotton varieties tolerant to bromoxynil, which is effective at much lower rates than traditional herbicides, could reduce herbicide use by 10 million pounds.

Although lower pest management costs and higher revenues may be attributed to herbicide-tolerant and insect-resistant crops, seed costs for these varieties are greater than traditional seed. Not only is there a seed price premium, but farmers were also required to pay a technology fee. Despite paying more for these seeds, U.S. cotton farmers share in the overall economic benefits of Bt cotton seed with the companies that developed the seed (Falck-Zepeda and Traxler, 1998). They each receive about 49 percent of the total economic benefits. Consumers, however, do not benefit that much. Only about 2 percent of the surplus goes to consumers in the United States and the rest of the world combined. Regional benefits will vary because of differences in pest infestation, seed prices, and technology fees.

## Measuring the Effects of GE Crops

The following is a summary of principal findings of these farm economic studies, including estimates from USDA survey data on yields and pesticide use associated with adoption.

### *Field Tests*

Many field tests have been aimed at analyzing the agronomic effects of adopting GE crops (for example, Culpepper and York). Relatively fewer studies have investigated the actual yield, pesticide management, and profit effects from farm-level adoption (Marra, Carlson, and Hubbell; Fernandez-Cornejo and Klotz-Ingram; Fernandez-Cornejo, Klotz-Ingram, and Jans).

***Herbicide-Tolerant Crops.*** Weed control is critical in the production of many crops, especially cotton. Crops usually require several types and applications of herbicides to control weeds. However, glyphosate is one herbicide that is effective on many species of grasses, broadleaf weeds, and sedges. Some of the studies on herbicide-tolerant crops (Culpepper and York; Marra, Carlson, and Hubbell; Fernandez-Cornejo and Klotz-Ingram) found that adopting these varieties did not necessarily translate into yield gains. However, Fernandez-Cornejo, Klotz-Ingram, and Jans estimated a model using USDA survey data that indicates significant yield increases for farmers who adopted herbicide-tolerant cotton or soybeans. In addition, Roberts, Pendergrass, and Hayes concluded that herbicide treatments that included glyphosate on RR soybeans had the highest yields and net returns among weed management regimes.

Estimates on the effect of adoption on herbicide use were mixed. While herbicide-tolerant crops would be expected to increase glyphosate use, less total herbicide may be required to combat weeds since glyphosate is considered a more effective post-emergent herbicide. Herbicide treatments that included glyphosate were as effective, if not more effective, than traditional herbicide treatment systems on RR cotton and soybean varieties (Culpepper and York; Roberts, Pendergrass, and Hayes). Herbicide treatment systems with glyphosate on RR cotton required fewer herbicide treatments and less total herbicide to produce equivalent yields and net returns (Culpepper and York).

Two studies analyzed the effects of adopting herbicide-tolerant corn, soybeans, and cotton on yields, herbicide use, and profits (Fernandez-Cornejo and Klotz-Ingram; Fernandez-Cornejo, Klotz-Ingram, and Jans). The analyses in these studies used USDA field-level survey data on the use of herbicide-tolerant (mainly IMI) corn in 1996 and (mainly RR) soybeans and cotton in 1997.

According to the studies, adopting herbicide-tolerant corn did not increase yields. Herbicide-tolerant soybeans and cotton, however, did increase yields.

The findings on herbicide use varied greatly. The use of herbicide-tolerant corn was negatively and significantly related to acetamide herbicide applications. Although the use of glyphosate increased significantly with the adoption of herbicide-tolerant soybeans, the use of other herbicides (such as 2,4-D, acifluorfen, bentazon, clomazone, pendimethalin, and trifluralin) decreased. These studies found no change in herbicide use with the adoption of herbicide-tolerant cotton.

Adopting herbicide-tolerant cotton increased profits; adopting herbicide-tolerant corn and soybeans did not change farmer profits. A study by Marra, Carlson, and

Hubbell, however, determined that farmers had greater net returns from RR crop varieties. They estimated that the net gain from using RR soybeans was about $6 per acre. The lower herbicide costs alone were enough to outweigh the higher seed costs.

***Bt Crops.*** Insect pests can considerably damage crops. Bollworms and budworms combined are the number one pest for cotton. In 1995, these pests reduced cotton yields by about 4 percent (Williams, 1997). However, partly as a result of introducing Bt cotton in 1996, yield losses from these pests fell. Yield losses were about 2.4 percent in 1996 and 2.0 and 2.7 percent in 1997 and 1998 (Williams, 1997, 1998, 1999). In 1998, about 9 million cotton acres were infested with bollworms and budworms, accounting for about $186 million in cotton losses and treatment expenses. The European corn borer (ECB) is one of the major pests in corn production. Damages from ECB amount to about $1 billion per year. About 50 percent of 80 million U.S. corn acres are infested with ECB (James, 1999).

Many studies have found that Bt varieties have higher yields and lower insecticide costs than their conventional counterparts, which may translate into a significant increase in farmer profits, depending on adoption rates and the nature of demand for the commodity.

Marra, Carlson, and Hubbell conducted a Bt cotton survey to determine the effects of adoption on yields, net revenues, and pesticide use. Surveys were returned by 300 farmers in North and South Carolina, Georgia, and Alabama. Among them, yields were significantly greater for farmers planting Bt cotton in the lower southern States and for the entire sample. This was not true for the upper southern States. Marra, Carlson, and Hubbell found that farmers growing Bt cotton had fewer insecticide applications, especially for pyrethroids. The rate of return was less in the upper South than in the lower South. The additional crop revenues and insecticide savings outweighed the higher seed and technology costs in the lower South only. Marra, Carlson, and Hubbell determined that better control of ECB boosted yields 4-8 percent, depending on location and year. The study by Fernandez-Cornejo, Klotz-Ingram, and Jans supported the Bt cotton findings of Marra, Carlson, and Hubbell. They found that adopting Bt cotton decreased insecticide use (only for such insecticides as aldicarbs, chloropyrifos, oxamyls, and endosulfans).

Bt corn use resulted in only modest savings from reduced insecticide applications. Returns from increased corn yields, however, were greater than the seed premiums and technology fees, translating into net gains of about $3-$16 per acre (Marra, Carlson, and Hubbell).

For farmers to receive economic benefits from adopting herbicide-tolerant and insect-resistant crops, it takes a certain infestation level to break even. The expected benefits from adopting these varieties greatly depend on infestation levels and the associated yield advantages and pesticide application rates. Therefore, farmers in regions that have an increased probability of pest infestations would benefit from reduced pesticide applications and higher expected yields. Their willingness to pay for Bt seed should be higher, all else constant.

### USDA Survey Data—ARMS[1]

The effects of GE crops just discussed were obtained from limited regional studies or field trials. USDA's Economic Research Service (ERS) and the National Agricultural Statistical Service (NASS) annually conduct the Agricultural Resources Management Study (ARMS) survey to estimate agricultural inputs use and costs of production for major commodities and to support farm income and other financial indicators. The ARMS survey was used to estimate the extent of adoption of genetically modified crops and to compare yield and pesticide use with traditional crop varieties. The survey was not designed to statistically test the difference in the yield performance and input use between varieties, but it can provide insight into the effects of using GE crops.

A summary of the results from the ARMS survey on the adoption of GE cotton, corn, and soybeans follows. The tables include the extent of adoption in terms of the percentage of acres planted and production by type of technology, crop, and region for 1996, 1997, and 1998. These data were compared with estimates from industry sources and were found generally to agree, with a few exceptions.

### ARMS Survey Results—Adoption Rates

The survey suggests that adoption of GE soybeans, cotton, and corn has increased dramatically since introduction in the mid-1990's, encompassing 20-44 percent of acreage planted in 1998 (table 1). Acreage planted with GE crops increased from about 8 million acres in surveyed States in 1996 to more than 50 mil-

[1]Information is drawn from and additional detail can be found at the ERS website: <http://www.ers.usda.gov/data/arms/>

lion acres in 1998. 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. The Environmental Protection Agency (EPA) approved Bt corn in August 1995, and its use has grown from about 1 percent of planted corn acreage in 1996 to 19 percent in 1998.

Adoption rates for herbicide-tolerant crops have been particularly rapid. Herbicide-tolerant soybeans initially became available to farmers in limited quantities in 1996, but its 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. Herbicide-tolerant cotton expanded from 10 percent of surveyed acreage in 1997 to 26 percent in 1998.

**Table 1—Adoption of genetically engineered U.S. field crops, 1996-98**

| Field crop | Year of introduction | Estimated planted acreage 1996 | 1997 | 1998[1] |
|---|---|---|---|---|
| | | *Percent of planted acreage* | | |
| Cotton: | | | | |
| Bt | 1995 | 14.6 | 15.0 | 16.8 |
| Herbicide-resistant | 1996 | i.d. | 10.5 | 26.2 |
| Corn: | | | | |
| Bt | 1996 | 1.4 | 7.6 | 19.1 |
| Herbicide-resistant[2] | 1996 | 3.0 | 4.3 | 18.4 |
| Soybeans: | | | | |
| Herbicide-resistant | 1996 | 7.4 | 17.0 | 44.2 |

i.d. = Insufficient data for a reliable estimate.
[1]Includes stacked varieties (with Bt and herbicide-tolerant genes).
[2]Includes seeds obtained by traditional breeding but developed using biotechnology techniques that helped to identify the herbicide-tolerant genes.
Source: Calculated from USDA's ARMS data for 1996, 1997, and 1998.

***Reasons for Adoption.*** According to the 1997 ARMS survey, most farmers surveyed (54-76 percent of adopters) indicated that the main reason they adopted GE crops with pest management traits was to "increase yields through improved pest control" (table 2). The second reason (19-42 percent of adopters) was "to decrease pesticide costs." All other reasons combined ranged between 3 and 15 percent of adopters. These results confirm traditional theories of adoption, which show 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.

### *ARMS Survey Results—Effects of GE Crop Use on Yields, Pesticide Use, and Net Returns*

An essential factor in determining adoption of a new technology is that it must be more profitable relative to existing alternatives. As just discussed, farmers believe that the use of these crops will offer many benefits, such as increased yields, decreased pest management costs, and greater cropping practice flexibility. Benefits and performance of these crops are expected to vary greatly by region, pest infestation levels, seed and technology costs, irrigation, and other factors. Performance may improve after popular regional varieties containing these genes are developed. For many farmers, expected benefits appear to have outweighed expected costs, as evidenced by the rapid adoption rates.

**Table 2—Top five reasons U.S. farmers gave for adopting herbicide-tolerant soybeans/cotton and Bt cotton, 1997**

| Reason | Share of acreage among adopters — Herbicide-tolerant: Soybeans | 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 | .9 | 0 |
| 5. Some other reason(s) | 6.8 | 2.3 | 1.2 |

The results of an econometric analysis from ongoing ERS research shows that the effects of GE crops on pesticide use, crop yields, and net returns vary with the crop and technology examined (table 3).[2] Controlling for other factors, such as climate, pest management strategies, crop rotation, and tillage, results indicate that increases in adoption of herbicide-tolerant cotton is associated with statistically significant increases in yields and net returns but not with changes in herbicide use. On the other hand, increases in adoption of herbicide-tolerant soybeans are associated with small, but statistically significant, increases in yields and significant decreases in herbicide use. Increases in adoption of Bt cotton in the Southeast were associated with significant increases in yields and net returns and decreases in insecticide use.

We generally can use our evaluations of new technologies to get some sense of the future expansion of the technology. Based on observed adoption rates of GE crops, one might expect a rapid diffusion of their use. However, based on the results just discussed, the advantages of current GE crops are clearly regionally dependent—that is, they are not uniformly beneficial, so we should not expect 100 percent adoption of these varieties. Furthermore, uncertainties with respect to foreign demand for these commodities and reductions in pest infestations make adoption patterns somewhat volatile.

[2]For a more thorough discussion of this analysis and results, see Fernandez-Cornejo and McBride.

## References


Culpepper, Alfred S., and A.C. York. "Weed Management in Glyphosate-Tolerant Cotton," *The Journal of Cotton Science*, Vol. 4, 1998, pp.174-185.

Falck-Zepeda, J. Benjamin, and G. Traxler. "Rent Creation and Distribution from Transgenic Cotton in the U.S." Auburn University, Alabama, Department of Agricultural Economics and Rural Sociology. Prepared for the symposium entitled, "Intellectual Property Rights and Agricultural Research Impacts," @ NC-208 and CIMMYT, El Batan, Mexico, Mar. 5-7, 1998.

Fernandez-Cornejo, J., and C. Klotz-Ingram. "Economic, environmental, and policy impacts of using genetically engineered crops for pest management." Selected paper presented at the Northeastern Agricultural and Resource Economics Association meetings, Ithaca, NY, June 22-23, 1998.


**Table 3—Effects of herbicide-tolerant and insect-resistant field crops on economic returns, crop yields, and pesticide use, 1997**

| | Effect with respect to change in the adoption of:[1] | | |
|---|---|---|---|
| | Herbicide-tolerant: | | Bt cotton |
| Item | Soybeans | Cotton | (Southeast) |
| 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.
[2]Small increases or decreases are less than 1 percent for a 10-percent change in adoption.
[3]Increases or decreases are more than 1 percent but less than 5 percent change for a 10-percent change in adoption.
[4]Percentage change in acre-treatments.
[5]Underlying coefficients are not statistically different from zero.

Fernandez-Cornejo, J., C. Klotz-Ingram, and S. Jans. "Farm-Level Effects of Adopting Genetically Engineered Crops in the U.S.A." Selected paper presented at the international conference entitled, "Transitions in Agbiotech: Economics of Strategy and Policy," NE-165, Washington, DC, June 24-25, 1999.

Fernandez-Cornejo, Jorge, and William D. McBride, with contributions from Cassandra Klotz-Ingram, Sharon Jans, and Nora Brooks. *Genetically Engineered Crops for Pest Management in U.S. Agriculture: Farm-Level Effects*. AER-786. U.S. Department of Agriculture, Economic Research Service, April 2000.

James, C. *Global Status of Transgenic Crops in 1999*. ISAAA Brief No. 12. International Service for the Acquisition of Agri-Biotech Applications, Ithaca, NY, 1999.

Marra, M., G. Carlson, and B. Hubbell. *Economic Impacts of the First Crop Biotechnologies*. Electronic publication, North Carolina State University, Department of Agricultural and Resource Economics, 1998, <http://www.ag-econ.ncsu.edu/faculty/marra/FirstCrop/sld001.htm>

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

Williams, M.R. *Cotton Insect Losses*. Mississippi State, MS, 1997, 1998, 1999, <http://www.msstate.edu/entomology/ctnloss/>