Adoption of Genetically Engineered Seed in U.S. Agriculture: Implications for Pesticide Use

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Development of new crop varieties through genetic engineering offers a broad spectrum of potential benefits, including characteristics that reduce costs of production, enhance yield, or enhance the nutritional or other characteristics of plants that make them more valuable to consumers (USDA, 1999). Among the first developments brought to the market were changes in the genetic makeup of common field crops that made them tolerant to glyphosate herbicide and incorporated *bacillus thuringensis* (Bt) genes. These changes appealed to producers because they promised to simplify pest management, reduce its costs, increase its effectiveness, and increase flexibility in field operations. Evidence of that appeal lies in the rapid adoption of these crops, from very little U.S. acreage in 1996 to 27-57 percent of major crop acreage in 1999 (ERS, 1999a). A complete benefit/risk framework must consider a range of factors, from changes in tillage and erosion to gene flow, non-target effects, and resistance issues, but changes in pesticide use are surely an important element in any assessment (Royal Society, 1998; Henry A. Wallace Center, 2000). A poll of farmers and consumers in August 1999 showed that 73 percent of consumers were willing to accept biotechnology as a means of reducing chemical pesticides used in food production, while 68 percent said that farm chemicals entering ground and surface water was a major problem (Farm Bureau/Philip Morris Gap Research). The simple question addressed in this paper is, "Does adopting genetically engineered crops for pest management reduce pesticide use?"

Difficulties in Measurement and Interpretation

As with all simple questions, answering this one is not easy. One could compare the amount of pesticide used before and after adoption by the same producers, but weather conditions and pest pressures differ year-to-year. Such longitudinal data do not exist, but we do have cross-sectional data on pesticide use by producers who do and do not adopt GMO technology for each year since 1996. Differences in characteristics that affect the adoption decision may influence pesticide use decisions as well, making simple comparisons suspect. The challenge in using simple comparisons of data across years, or between adopters and nonadopters in a given year, is to control for all the sources of variation in pesticide use that are not accounted for by technology adoption. The true comparison is the counterfactual: "What pesticides would have been used in the given year in the absence of GMO adoption?"

In the case of the herbicide tolerance characteristic (which facilitates the use of a particular herbicide), the simple question must be phrased more subtly. Rather than "more" or "less" pesticide, adoption of this technology changes the mix of pesticides used in the cropping system. In addition, Bt enhanced seed only targets some pests, requiring continued use of conventional pesticides to control those pests not affected by the toxin. Counting acre-treatments or pounds of active ingredients for different pesticide compounds when pesticide mixes are changing is like adding apples and oranges. Finally, we are at a very preliminary stage in assessing pesticide changes with biotechnology. Producers will continue to learn and improve their use of biotech/pesticide combinations, resistance and other problems may force changes in management regimes, and the biotechnologies themselves could change, altering pesticide use characteristics. Despite these difficulties, Economic Research Service data are useful in framing a preliminary answer to the basic question of whether adopting genetically engineered crops provides benefits to society by reducing pesticide use.

Previous Studies

There have been many field tests and enterprise studies that have analyzed the agronomic, environmental and budget effects of adopting genetically modified crops. However, few studies have investigated the actual pesticide use changes associated with using genetically modified crops (McBride and Brooks, 2000;Fernandez-Cornejo, et al., 1999; Giannessi and Carpenter, 1999; Culpepper and York, 1998; Marra et al., 1998; Falck-Zepeda and Traxler, 1998; Fernandez-Cornejo and Klotz-Ingram, 1998; Gibson et al., 1997; ReJesus et al., 1997; Stark, 1997). These studies have generally shown some reduction in pesticide use with herbicide tolerant varieties, and reductions in insecticide use with Bt varieties.

Data and Methods

The analysis in this paper is based on data and models originally presented in Fernandez-Cornejo, et al. (1999) and McBride and Brooks (2000) and summarized in ERS (1999 a and b). The data for this paper were obtained from the 1996-98 Agricultural Resource Management Study (ARMS) surveys. The soybean survey covers 17-19 states, which account for about 90 percent of the U.S. soybean crop. The cotton data include cotton farms from 12 states, accounting for more than 90 percent of the U.S. upland cotton production. Data include information on adoption of genetically modified varieties and the applications and amounts applied of specific conventional pesticides. A map depicting the new U.S. agricultural regions is shown in figure 1 and more detailed descriptions are provided in ERS (1999c).

Three different analyses are presented to estimate changes in pesticide use: a regression analysis, a comparison of mean use by adopters and nonadopters within each year, and a comparison of changes in total pesticide use between 1997 and 1998. The results of two-stage multivariate regression modeling conducted by Fernandez-Cornejo, et al. (1999) to adjust for factors other than biotechnology adoption that account for differences in pesticide use are presented in table 1. The elasticities estimated in this analysis for 1996 and 1997 adoption, representing marginal changes in pesticide use for a small increase in the probability of adoption of genetic technologies, are applied to the acre-treatments and multiplied by the change in adoption between 1997 and 1998 (1996-97 for herbicide tolerant corn) to assess aggregate changes in these measures of pesticide use due to adoption. Changes in pounds of active ingredients used are estimated by assuming that the rate of application remains constant as the number of acre-treatments change. In table 2, unadjusted results of a simple comparison of mean pesticide use for adopters and nonadopters of genetically modified crops for 1997 and 1998 based on McBride and Brooks (2000) are applied to estimated acreages of crops adopting the technologies to estimate aggregate differences in acre-treatments and pounds of active ingredients (first four columns). Next, differences in total acre-treatments and pounds of active ingredients between 1997 and 1998 for all producers, adjusted for the difference in acreage in those years, are presented (next 2 columns). Finally, the results from the regression analysis are shown for comparison (last 2 columns).

Results

In the regression analysis (table 1), increases in glyphosate use on soybeans offset decreases in other herbicides and the rate of glyphosate application in pounds is higher than that of the herbicides replaced. Two-thirds of the decrease in treatments and all of the increase in pounds applied in the regression results are associated with herbicide tolerant soybeans. Smaller declines in acre-treatments are expected with Bt cotton, and larger decreases with herbicide tolerant corn, but differences between treatments with herbicide tolerant cotton are not statistically significant.

While the regression analysis included critical factors determining adoption, adoption rose rapidly between 1997 and 1998, so changes considered were not marginal. The estimates may be affected by structural changes not accounted for that occurred in 1997-98. For example, there may have been increased farmer awareness or access to information about biotech crops between 1997 and 1998.

In the first two columns of table 2, setting differences in surveyed rates that were not statistically significant (with less than 90 percent confidence) to zero, unadjusted pesticide applications for target pests at treatment rates used by adopters of genetically modified crops would have been 7.6 million acre-treatments (2.5 percent) fewer than at rates used by nonadopters in 1997, rising to nearly 17 million fewer acre-treatments (4.4 percent) than nonadopters would have used in 1998. In 1998, adoption of herbicide tolerant soybeans accounted for the greatest difference in unadjusted acre-treatments (54 percent), with most of the reduction occurring in the Heartland region. Seven percent of the difference in acre-treatments for target pests occurred with adoption of Bt cotton, with most of that reduction in the Southern Seaboard.

Again, setting statistically insignificant differences in rates to zero, 331,000 fewer pounds of active ingredients (less than 0.1 percent of total amounts applied) were used by adopters than if applications had occurred at nonadopters' rates in 1997 (second two columns). The difference narrowed to only 153,000 fewer pounds in 1998. In 1997, reductions in a.i. were due to Bt cotton and herbicide tolerant soybeans in the Southern Seaboard, while in 1998 herbicide tolerant cotton and Bt corn accounted for the decreases.

Based on the total change in pesticide use between 1997 and 1998, about 9 million fewer pesticide acre-treatments were made (a 2.9 percent reduction), resulting in 7.9 million fewer pounds of active ingredients applied (3.4 percent) (columns 5 and 6). Most of the decrease was in herbicide tolerant soybeans in the Heartland region and herbicide tolerant cotton. Acre-treatments and pounds of active ingredient increased for herbicide tolerant corn in the Heartland region. Comparing year-to-year observed pesticide use on biotech crops cannot accurately attribute the proportion of total change in pesticide use to GMO adoption and other factors that may have also altered pesticide use. The regression analysis is necessary to account for those other factors.

Pesticide reductions related to increased adoption between 1997 and 1998, based on the regression analysis, are estimated to be 6.8 million acre-treatments (1.9 percent of total treatments), not counting estimates for Bt corn, which are not modeled (last 2 columns of table 2). These estimates are associated with the changes in adoption that occurred between 1997 and 1998 (except for herbicide tolerant corn, which is modeled for 1996-97). While such changes would normally be marginal over a single year, the spectacular growth in biotech crop use meant that adoption increased by 160 percent for herbicide tolerant soybeans, 150 percent for herbicide tolerant cotton, 12 percent for Bt cotton, and 43 percent for herbicide tolerant corn.

Assuming that the rates of application per acre treatment remain relatively constant, the expected changes in acre treatments imply changes in the pounds of active ingredients used. Reductions in other insecticides used on cotton, acetamide herbicides used on corn, and other synthetic herbicides used on soybeans would be expected. However, offsetting increases in the pounds of glyphosate used on soybeans would also be expected. On net, pounds of active ingredient used are estimated to decrease only 1.2 million pounds (0.4 percent).

Decreases in acre-treatments from all three methods on table 2 are very similar (-6.8 to -8.99 million acre-treatments). However, decreases in pounds of active ingredients estimated by the three methods vary considerably, from only 0.3 million pounds based on comparing adopters to nonadopters, to 1.2 million pounds from the regression analysis, and up to 7.9 million pounds from comparing 1997 and 1998. Most of the differences in amounts of pesticide used by adopters and nonadopters were not statistically significant at the 90 percent confidence level, resulting in little overall difference. Comparing 1997 to 1998 shows that total amounts of pesticide used were down, suggesting that decreases from adoption were matched by nonadopters for other reasons, such as lower crop prices, weather and pest threat levels which also influence pesticide use. The estimate from the regression analysis is likely a reasonable estimate of the portion of overall pesticide decrease due to biotechnology adoption.

Measuring pesticide use in pounds of active ingredient implicitly assumes that a pound of any two ingredients has equal impact on human health and the environment. However, we know that the more than 350 pesticide active ingredients in use over the last 40 years vary widely in toxicity per unit of weight and in their persistence in the environment. Scaling the pounds of pesticides applied by measures of these characteristics can provide an indication or index of pesticide impact or potential risk (ERS, 1996). With herbicide tolerant crops, the effect on pesticide use is to substitute glyphosate for previously used herbicides. For example, based on the regression results for soybeans reported in table 2, an estimated 13.4 million pounds of glyphosate are substituted for 9.9 million pounds of other synthetic herbicides, such as imazethapyr, pendimethalin, and trifluralin. A pound of glyphosate has a half-life in the environment of 47 days, compared with 60-90 days for the herbicides it replaces. For a chronic risk indicator based on the EPA reference dose for humans, the herbicides it replaces are 3.4 to 16.8 times more toxic than glyphosate. While the substitution enabled by genetic modifications conferring herbicide tolerance in soybeans results in 1.3 pounds of glyphosate replacing each pound of other synthetic herbicides, the replaced herbicides are 3.4-16.8 times more toxic and persist in the environment 1.6-1.9 times as long.

In summary, adoption of genetically modified crops in the U.S. is associated with some statistically significant reductions in aggregated pesticide use, but isolating the effect of adoption on those reductions is difficult because of other factors contributing to changes in pesticide use. This results in a range of estimated reductions in acre-treatments from 6.8 to 9 million (-1.9 to -2.9 percent of total treatments), and decreases in active ingredients applied ranging from 0.3 to 7.9 million pounds (-0.4 to -3.4 percent of total pounds applied), with the regression estimate of 1.2 million fewer pounds a likely estimate of that due to adoption. Assessing changes in pesticide use associated with GMO adoption is confounded by the same difficulties as for pesticide use generally. The answer to the simple question, "Does adopting genetically engineered crops for pest management reduce pesticide use?" depends critically on what we mean by "more" or "less" pesticides.

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Table 1--Estimated change in pesticide use with increased adoption using regression estimates of adoption elasticities, 1997-98

	Acre-treatments 1997	Estimated change in acre-treatments 1/ 1997-98	Significance	Pounds of active ingredients 1997	Estimated change in pounds of active ingredients 2/ 1997-98
	Thousand acre-treatments			Thousand pounds	
Bt Cotton 3/	32,082	-215		18,280	-144
Organophosphate insecticides	18,864	0	ns	11,742	0
Pyrethroid insecticides	4,677	0	ns	229	0
Other insecticides	8,541	-215		6,309	-144
Herbicide tolerant Corn 4/	163,753	-2,454		176,827	-4,621
Acetamide herbicides	43,555	-2,454		81,510	-4,621
Triazine herbicides	65,403	0	ns	76,320	0
Other synthetic herbicides	51,985	0	ns	16,797	0
Glyphosate	2,810	0	ns	2,200	0
Herbicide tolerant Soybeans	123,529	-4,108		78,210	3,521
Acetamide herbicides	7,083	0	ns	13,410	0
Other synthetic herbicides	92,349	-20,686		49,880	-9,908
Glyphosate	24,097	16,579		14,920	13,429
Herbicide tolerant Cotton	37,361	0		27,610	0
Acetamide herbicides	721	0	ns	740	0
Triazine herbicides	6,052	0	ns	3,870	0
Other synthetic herbicides	28,204	0	ns	21,460	0
Glyphosate	2,384	0	ns	1,540	0
Total	356,725	-6,776		300,927	-1,244

1/ Statistically significant elasticities with respect to adoption estimated in Fernandez-Cornejo, et al. (1999) applied to pesticides used on crops in proportion to their use and based on the observed 1997-98 change in adoption.

2/ Per treatment pounds of active ingredients applied to estimated change in acre treatments.

3/ The elasticities for Bt cotton were estimated for the southeast region (Alabama, Georgia, North Carolina, and South Carolina) only.

4/ Based on 1996 data and applied to the 1996-97 change in adoption.

Table 2--Differences between estimates of change in pesticide use with increased adoption based on comparision of means and regression modeling, 1997-98

Technology/Region	Difference in acre-treatment with adoption		Difference in pounds of active ingredients with adoption		Change in total pesticide use adjusted to 1997 acreage 1/		Estimated change based on regression modeling 2/	
	1997	1998	1997	1998	1997-98	1997-98	1997-98	1997-98
	Thousand acre treatments		Thousand pounds active ingredients		Thousand acre treatments	Thousand pounds active ingredients	Thousand acre treatments	Thousand pounds active ingredients
Bt Corn	-238	ns	ns	-54	-332	-772	na	na
Heartland, Bt target pests 3/	-238	ns	ns	ns	-332	-772		
Prairie Gateway, Bt target pests 3/	na	ns	na	-54	na	na		
Bt Cotton 3/	-1,386	-1,193	-64	ns	-73	-304	-215	-144
Mississippi Portal, Bt target pests 3/	-430	ns	ns	ns	-218	-69		
Southern Seaboard, Bt target pests 3/	-956	-1,193	-64	ns	147	-47		
Fruitful Rim, Bt target pests 3/	ns	ns	ns	ns	-2	-188		
Herbicide tolerant Corn 4/	ns	-3,515	ns	ns	1,877	2,413	-2,454	-4,621
Heartland	ns	-3,515	ns	ns	1,877	2,413		
Herbicide tolerant Soybeans	-5,536	-9,088	-267	ns	-9,858	-6,647	-4,108	3,521
Heartland	-3,567	-7,832	ns	ns	-7,183	-2,595		
Mississippi Portal	-1,316	ns	ns	ns	-675	-1,293		
Northern Crescent	ns	-1,256	ns	ns	48	-1,001		
Prairie Gateway	ns	ns	-267	ns	16	-1,197		
Southern Seaboard	-653	ns	ns	ns	-2,064	-560		
Herbicide tolerant Cotton	-467	-3,179	ns	-99	-604	-2,878	ns	ns
Mississippi Portal	ns	-752	ns	-418	-256	-1,325		
Southern Seaboard	-467	-1,499	ns	-1,020	-348	-1,553		
Prairie Gateway	na	-928	na	1,339	na	na		
Total change in studied regions	-7,627	-16,975	-331	-153	-8,990	-7,884	-6,776	-1,244

1/ Pesticide use on crops grown with biotech seed for 1997 and 1998 estimated using mean acre-treatments and pounds of active ingredients applied. The biotech category includes all acreage on which the specific seed technology was used. The all other category includes acreage planted to all other purchased and homegrown seed. Differences between the mean estimates cannot necessarily be attributed to the use of the seed technology since they are influenced by several other factors not controlled for, including irrigation, weather, soils, nutrient and other pest management practices, other cropping practices, operator management, etc. Actual changes between 1997 and 1998 are adjusted to 1997 acreage.

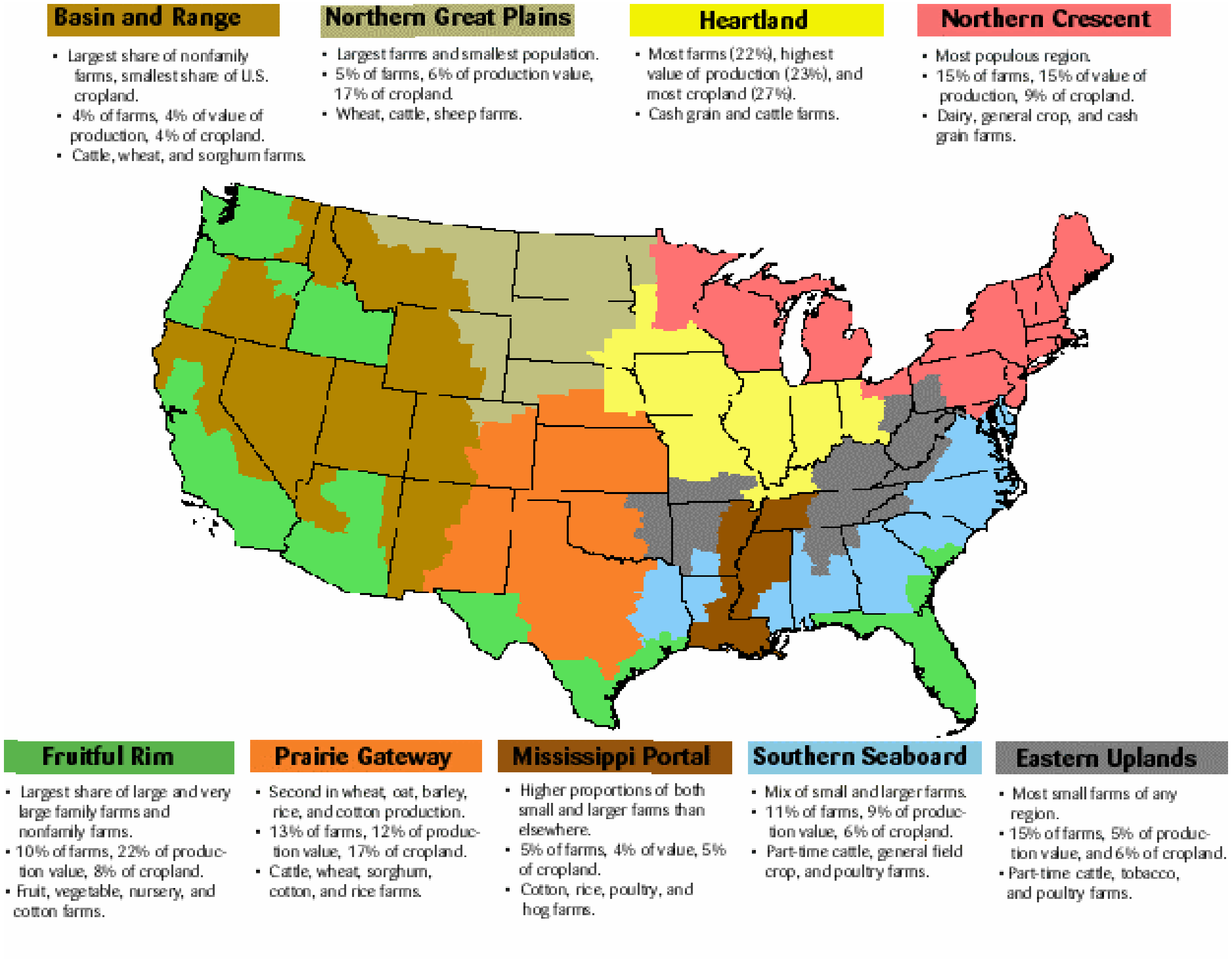
2/ 1997-98 percent change in adoption for herbicide tolerant soybeans (160%) and cotton (150%), bt cotton (12%) and for 1996-97 in bt corn (43%).

3/ Target pests for Bt corn are European corn borers. Target pests for Bt cotton are the bollworm, pink bollworm, and the tobacco budworm. Regression results based on the southeast region (Alabama, Georgia, North Carolina and South Carolina) are applied to the increase in adoption on all cotton acreage.

4/ 1996 regression results applied to 1996-97 change in adoption. Includes seed obtained by traditional breeding but developed using biotechnology techniques that helped to identify the herbicide tolerant genes.

na= not analyzed ns= not statistically different from zero.

Figure 1


Basin and Range
• Largest share of nonfamily farms, smallest share of U.S. cropland.
• 4% of farms, 4% of value of production, 4% of cropland.
• Cattle, wheat, and sorghum farms.
Northern Great Plains
• Largest farms and smallest population.
• 5% of farms, 6% of production value, 17% of cropland.
• Wheat, cattle, sheep farms.
Heartland
• Most farms (22%), highest value of production (23%), and most cropland (27%).
• Cash grain and cattle farms.
Northern Crescent
• Most populous region.
• 15% of farms, 15% of value of production, 9% of cropland.
• Dairy, general crop, and cash grain farms.
Fruitful Rim
• Largest share of large and very large family farms and nonfamily farms.
• 10% of farms, 22% of production value, 8% of cropland.
• Fruit, vegetable, nursery, and cotton farms.
Prairie Gateway
• Second in wheat, oat, barley, rice, and cotton production.
• 13% of farms, 12% of production value, 17% of cropland.
• Cattle, wheat, sorghum, cotton, and rice farms.
Mississippi Portal
• Higher proportions of both small and larger farms than elsewhere.
• 5% of farms, 4% of value, 5% of cropland.
• Cotton, rice, poultry, and hog farms.
Southern Seaboard
• Mix of small and larger farms.
• 11% of farms, 9% of production value, 6% of cropland.
• Part-time cattle, general field crop, and poultry farms.
Eastern Uplands
• Most small farms of any region.
• 15% of farms, 5% of production value, and 6% of cropland.
• Part-time cattle, tobacco, and poultry farms.