# Data and Methods

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

## The ARMS Surveys

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

## Regions

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

Figure 1
**Farm resource regions**

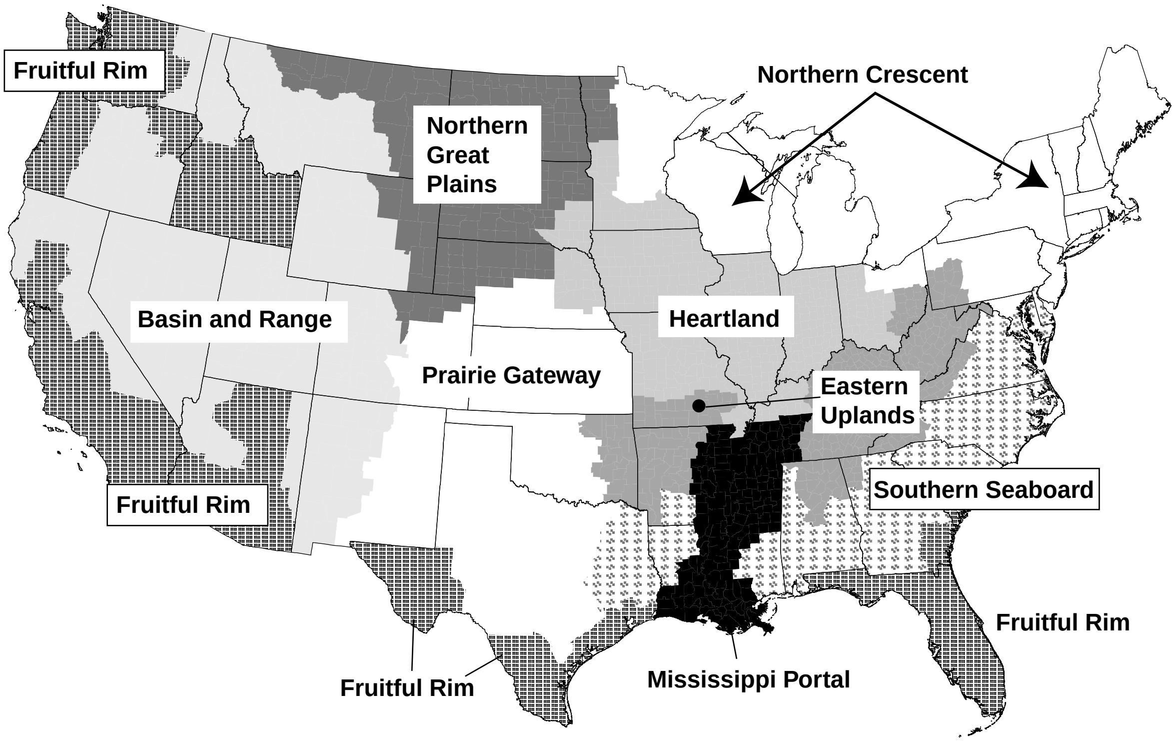

**Table 6—Distribution of acreage and production among regions in corn, soybean, and cotton production, 1996-98**

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

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

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

## Estimating Costs and Returns

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

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

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

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

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

## Modeling the Adoption Decision

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

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

## The Adoption Impact Model

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

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

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

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

## Comparisons of Means and Econometric Models

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

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

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

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

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

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

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