Farm-Level Effects on Crop Yields and Pest Control Costs

Benefits to producers from adopting biotech crops can be represented by a shift in supply, reflecting potential increases in crop yields and/or savings in pest control costs. U.S. and ROW consumers indirectly benefit from biotech adoption because increased crop supplies lower commodity prices. Because the technology-induced supply shift affects the surpluses of both producers and consumers, accurate information is needed about biotechnology's farm-level impacts.

This section details the impacts of biotechnology on crop yields and pest control costs. These estimated benefits are only a subset of the entire economic impact of biotechnology. Changes in pesticide use attributed to the adoption of biotechnology do not capture all the potential environmental and health impacts. Other benefits not covered include the ease of pest management associated with herbicide-tolerant crops and the insurance value against the potential infestation of targeted pests for Bt cotton (Fernandez-Cornejo and McBride, 2002).

Data Sources

Potential increases in crop yields and savings in pest control costs associated with the adoption of biotechnology are difficult to quantify. This section discusses two data sources that were used to measure the farm-level effects employed in this study.

Producer surveys are a primary data source for measuring differences in crop yields and pest control costs between adopters and nonadopters of a given biotech crop (e.g., Falck-Zepeda et al., 2000b). Survey data reflect actual producer costs associated with the use of each crop production technology. Moreover, survey data can be used to show frequency distributions of crop yields and pest control costs for adopters and nonadopters separately, as well as associated statistics, such as mean values and standard deviations.

The Agricultural Resource Management Survey (ARMS), a nationwide USDA producer survey, has been used by some researchers to quantify the farm-level impacts of biotechnology (Falck-Zepeda et al., 2000a). Farm financial and chemical use data are reported for all crops in the ARMS survey each year, while detailed enterprise production practices and cost data are collected for several commodities (including soybeans and cotton) on a rotating basis every 4 to 7 years (McBride).[6]

According to McBride, four characteristics of the ARMS data make it useful for assessing the farm-level impacts of biotech adoption. First, the ARMS has broad coverage, including all of the major producing States for a given commodity—generally more than 90 percent of the crop acreage. Second, ARMS uses a stratified random sample, where each farm represents a known number of similar farms in the population, based on sampling probabilities. Each farm is weighted by the number of farms it represents so that the ARMS sample can be expanded to reflect the targeted population. Third, ARMS enterprise cost-of-production data contain sufficient detail about specific inputs to isolate seed and pest control costs associated with commodity production. Finally, since enterprise cost-of-production data can be obtained for each responding farm, a distribution of costs can be developed.

An alternative to using producer survey data is to rely on State enterprise cost-of-production budgets estimated by State extension programs at land-grant universities. These budgets for biotech and conventional crop varieties are relatively inexpensive to obtain and can be easily modified for use in research applications (e.g., Duffy and Vontalge). One advantage of using these data is that factors other than the choice of crop variety can be controlled in order to isolate the cost difference between the two technologies (McBride). However, these data may not be representative of the entire farm population because input and output levels often reflect above-average management. In addition, State budgets are location specific, mainly for a State or a portion of a State, thus making it difficult to represent a broad population and/or geographic area. More important, enterprise budgets are typically not comparable across States because of inconsistencies in design and the inclusion of biotech crops. In fact, many States do not differentiate their enterprise budgets between biotech and conventional varieties.

[6] The 1997 ARMS data are used in this study because these are the latest available information on cotton and soybeans.

In this study, farm-level impacts resulting from biotech adoption are estimated from ARMS data—hereafter called "estimated ARMS effects"—using an econometric procedure that excludes the effects of other factors (Fernandez-Cornejo et al.; Fernandez-Cornejo and McBride). The econometric model accounts for the fact that farmers' adoption of biotechnology and pesticide use decisions may be simultaneous. In addition, the model corrects for self-selectivity to prevent biased results. Self-selection arises because farmers are not assigned randomly to one of the two groups (i.e., either adopters or nonadopters). Instead, they make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different, and these differences may manifest themselves in farm performance, which could confound the effect of biotech adoption.

Results of the econometric model are expressed in elasticity form. In terms of the impact on crop yields, the adoption of herbicide-tolerant soybeans has a small but positive and significant effect. U.S. herbicide-tolerant soybean yields in 1997 were estimated to have increased by less than 1 percent for a 10-percent increase in adoption (Fernandez-Cornejo and McBride). This yield effect is generally consistent with other studies (Gianessi and Carpenter, 2000; Carpenter and Gianessi, 1999b, 2000; Moschini et al.; Duffy and Vontalge). For Bt cotton in the Southeast and herbicide-tolerant cotton nationwide, yields in 1997 were estimated to have increased by 1 to 5 percent for a 10-percent increase in adoption (Fernandez-Cornejo and McBride).

The impact of biotech adoption on pesticide use, based on this econometric model, varies by commodity and across active ingredients. An increase in the adoption of herbicide-tolerant soybeans was estimated to have led to a statistically significant reduction in the use of herbicides other than acetamides and glyphosate, which fell 1.4 percent for a 10-percent increase in adoption in 1997 (Fernandez-Cornejo et al.). In contrast, the adoption caused a significant increase in glyphosate use, which rose 4.3 percent for a 10-percent increase in adoption. The change in acetamides was not statistically significant.

For each herbicide active ingredient, the rate of application and the share of area applied vary by region. Thus, the change in herbicide use by category (e.g., acetamides and other herbicides) differed across production regions. The net effect of an increase in biotech adoption on herbicide use depended on the extent to which the decrease in the use of other herbicides offset the increase in glyphosate use.

An increase in the adoption rate of Bt cotton did not lead to a significant change in the use of organophosphate and pyrethroid insecticides (Fernandez-Cornejo et al.). However, a 10-percent increase in adoption led to a 2.1-percent decrease in the use of other insecticides in the Southeast, which was statistically significant. Thus, the net effect of an increase in the adoption of Bt cotton in that region was a decrease in total insecticide use. The change in herbicide use nationwide associated with the adoption of herbicide-tolerant cotton was not statistically significant.

Other data sources for quantifying the farm-level impacts of biotech adoption are databases maintained by private firms. For example, in their study of 1997 Bt cotton, Falck-Zepeda et al. (2000a) used the comprehensive Enhanced Market Data II, or EMD (Plexus Marketing Group, Inc., and Timber Mill Research, Inc.). These data were derived from surveys in which cotton consultants provided agronomic and pest management information on matched pairs of Bt and non-Bt cotton fields in the same locations. To ensure similarity, the matched pairs of fields were carefully selected so that they represented equivalent agronomic practices and productivity. The EMD covers fields in Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and east Texas. Like the estimated ARMS effect in the Southern Seaboard, the EMD isolates the impacts of biotechnology on crop yields and pest control costs.

Estimated Impacts on Crop Yields

To truly calculate farm-level effects of biotech crops, one must discern the difference in crop yields (between adopters and nonadopters) that is attributable to the technology. This section discusses the impact on crop yields across the two data sources: (1) the estimated ARMS effects based on the econometric model for all three biotech crop varieties, and (2) the EMD database, which is applicable only to Bt cotton produced in the Southeast. The impact of adopting Bt cotton on crop yields, based on 1 year of data (1997), appears to vary significantly across the two data sources and production regions. In the Southern Seaboard, yields for Bt cotton adopters are estimated to have been higher than for nonadopters in both data sources, as shown in table 4 (see figure 6 for ERS crop

Table 4—Impact of adopting Bt cotton on crop yields by region and by data source, 1997

Production region	Data source: Estimated ARMS effect	Data source: EMD
	Percent	
Southern Seaboard	+21.0	+11.3
Fruitful Rim	n.a.	n.a.
Mississippi Portal	n.a.	+ 3.7
Eastern Uplands	n.a.	n.a.

n.a. = Not applicable. EMD = Enhanced Market Data II.

Sources: Estimated ARMS effects adapted from Fernandez-Cornejo et al. EMD obtained from Plexus Marketing Group, Inc., and Timber Mill Research, Inc.

production regions).[2] For example, according to the estimated ARMS effects, Bt cotton adopters' yields in the Southern Seaboard averaged about 847 pounds per acre, compared with 700 pounds for nonadopters, a 21-percent advantage.

The estimated ARMS effect indicates a 17-percent increase in yields for herbicide-tolerant cotton adopters nationwide. In some regions, herbicide-tolerant cotton yields may have been lower than for conventional varieties. In particular, farmers in the Mississippi Portal encountered serious and unexpected problems with their herbicide-tolerant cotton during the 1997 growing season (Virginia Cooperative Extension). Some growers found deformed bolls and bolls that dropped off the plants. About 20 percent of the region's herbicide-tolerant cotton was affected. However, the problems may have been caused by factors other than the herbicide-tolerant technology itself, such as soil type and weather conditions.

For herbicide-tolerant soybeans, the estimated ARMS effect indicates only 3-percent higher yields for adopters nationwide, which is consistent with other studies' findings that the adoption of herbicide-tolerant soybeans has little or no overall impact on soybean yields (Gianessi and Carpenter, 2000; Moschini et al.). The negligible yield effect is consistent with the argument that the simplicity and flexibility in pest management programs are key drivers of the rapid adoption of herbicide-tolerant soybeans (Fernandez-Cornejo and McBride, 2002).

[7] No estimated ARMS effects are available for Bt cotton yields in other production regions.

Estimated Impacts on Pest Control Costs

Impacts of Bt and herbicide-tolerant technologies on cotton and soybean pest control costs include expenses associated with pesticide materials, application, scouting, and cultivation. Pest control costs for Bt cotton adopters were lower than for nonadopters in 1997. Regional differences in pest control cost savings were quite large, depending on the data source. For example, adopters' pest control costs averaged about 7 percent lower than for nonadopters in the Southern Seaboard, based on the estimated ARMS effects (table 5). These savings reached as high as 60 percent (based on the EMD) in the Southern Seaboard and 54 percent in the Mississippi Portal. While both data sources isolate the impact of biotechnology on insect-control costs, the divergent estimates are hard to reconcile. Computing the benefits from biotech adoption with the EMD is likely to result in much larger estimated benefits for U.S. farmers than with the estimated ARMS effects.

The estimated ARMS effect for pest control costs in the Southern Seaboard was calculated using elasticities that reflect the percentage change in pesticide use in response to a 1-percent increase in the adoption of biotech crops (Fernandez-Cornejo et al.). To illustrate, the first step is to estimate the expenses associated with pesticide active materials, ingredient by ingredient, used by nonadopters in a specific production region, such as the Southern Seaboard in the case of Bt cotton. Based on USDA's State-level chemical use data, the insecticide application rate per crop year and the percent of area applied with insecticides were tabulated by insecticide active ingredient at the regional level, as shown in table 6 (USDA, 1998a).

Insecticide active ingredients were grouped into three categories: organophosphates, pyrethroids, and other

Table 5—Impact of adopting Bt cotton on pest control costs by region and by data source, 1997

Production region	Adopters' differences in pest control costs from nonadopters: Estimated ARMS effect	Adopters' differences in pest control costs from nonadopters: EMD
	Percent	
Southern Seaboard	-7.08	-60.0
Fruitful Rim	n.a.	n.a.
Mississippi Portal	n.a.	-54.3
Eastern Uplands	n.a.	n.a.

n.a. = Not applicable. EMD = Enhanced Market Data II.

Figure 6

ERS crop production regions

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

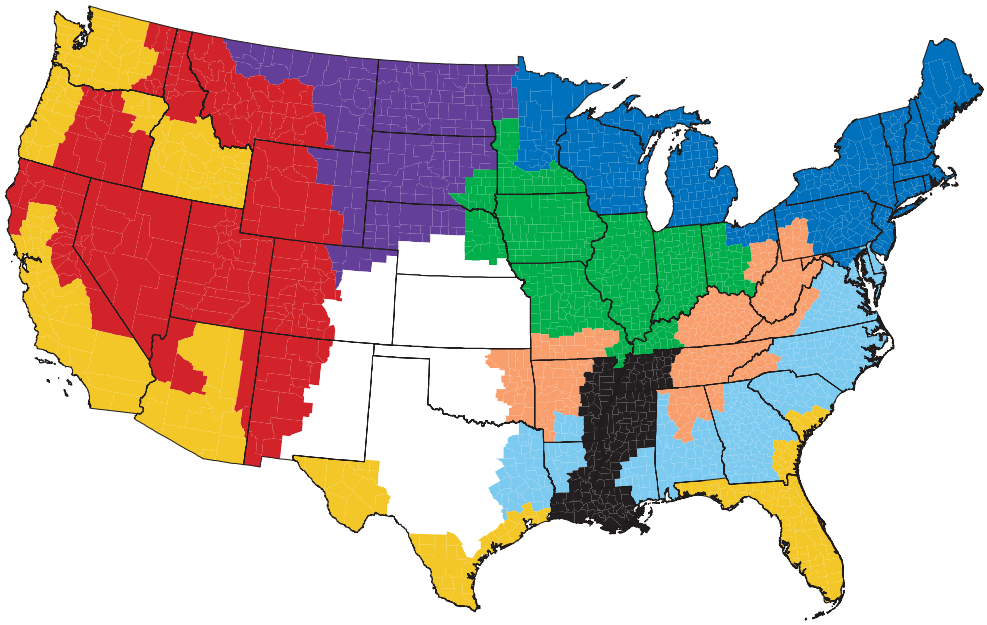
- Largest farms and smallest population.
- 5% of farms, 6% of value of production, 17% of cropland.
- Wheat, cattle, and sheep farms.

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 value of production, 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 value of production, 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 of production, 5% of cropland.
- Cotton, rice, poultry, and hog farms.

Southern Seaboard

- Mix of small and larger farms.
- 11% of farms, 9% of value of production, 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 value of production, and 6% of cropland.
- Part-time cattle, tobacco, and poultry farms.

insecticides. Price data for insecticide active ingredients were obtained from USDA (1998c) and a database of 1996 prices developed by Gianessi and Marcelli, with some necessary conversions from the prices of final product to those of active-ingredient equivalents.

Multiplying the active ingredient prices by the individual weighting factors (application rate per crop year times the share of area applied) gives the per-acre expenses associated with each active ingredient for nonadopters. Adding up the per-acre expenses across active ingredients results in the total expense associated with insecticides—$20.48 per acre for nonadopters of Bt cotton in the Southern Seaboard. Including expenses for pesticide application, scouting, and cultivation (taken from the ARMS) increased the total insect control cost to $27.92 per acre for nonadopters in 1997.

Insecticide costs for adopters are estimated by accounting for potential savings in insecticide use, ingredient by ingredient. In the Southern Seaboard, the -0.21 elasticity for "other insecticides" means that adopters' use of those materials was 21 percent lower than for nonadopters. Expenses associated with the "other insecticides" were $1.86 per acre lower for adopters in 1997 (table 6). No change occurred in the use of organophosphates and pyrethroids. In total, expenses for all insecticides equaled

Table 6—Insecticide costs for Bt cotton adopters versus nonadopters: Southern Seaboard, 1997

Insecticide active ingredient	Rate per crop year	Area applied	Weight	Price	Cost for nonadopters	Cost for adopters
	lb. per acre	*Percent*	*lb. per acre*	*$ per lb.*	*$ per acre*	
Organophosphates						
Malathion	n.a.	n.a.	n.a.	4.820	n.a.	n.a.
Methyl parathion	n.a.	n.a.	n.a.	6.825	n.a.	n.a.
Acephate	0.290	6.451	0.019	17.067	0.319	0.319
Phorate	0.833	9.828	0.082	10.700	0.876	0.876
Profenofos	0.633	1.963	0.012	12.400	0.154	.154
Dicrotophos	0.038	4.010	0.002	11.075	0.017	0.017
Subtotal					**1.212**	**1.212**
Pyrethroids						
Cypermethrin	0.128	10.303	0.013	91.636	1.204	1.204
Lambdacyhalothrin	0.062	42.758	0.027	231.270	6.157	6.157
Cyfluthrin	0.066	16.467	0.011	239.500	2.599	2.599
Zeta-cypermethrin	0.029	3.925	0.001	186.667	0.216	0.216
Tralomethrin	0.025	3.434	0.001	275.280	0.232	0.232
Fenpropathrin	n.a.	n.a.	n.a.	78.030	n.a.	n.a.
Subtotal					**10.408**	**10.408**
Other insecticides						
Aldicarb	0.716	43.327	0.310	24.667	7.654	6.047
Chlorpyrifos	n.a.	n.a.	n.a.	12.68	n.a.	n.a.
Oxamyl	n.a.	n.a.	n.a.	386.25	n.a.	n.a.
Endosulfan	n.a.	n.a.	n.a.	13.03	n.a.	n.a.
Dicofol	n.a.	n.a.	n.a.	29.14	n.a.	n.a.
Methomyl	0.319	3.365	0.011	26.519	0.284	0.225
Disulfoton	0.277	3.487	0.010	9.538	0.092	0.073
Esfenvalerate	0.043	5.993	0.003	224.242	0.581	0.459
Thiodicarb	0.378	3.925	0.015	16.620	0.246	0.195
Subtotal					**8.858**	**6.997**
Total insecticide costs					**20.478**	**18.618**
Application costs					**3.185**	**2.653**
Scouting costs					**4.261**	**4.761**
Total per-acre insect control costs					**27.924**	**26.032**

n.a. = Not applicable

Sources: Gianessi and Marcelli; USDA 1998a, 1998c.

$18.62 per acre for adopters, about 9 percent lower than for nonadopters. Including expenses for insecticide application and scouting brought the total pest control cost to $26.03 per acre for adopters, a savings of about 7 percent over nonadopters.

Herbicide-tolerant cotton shows no statistically significant impact on herbicide use nationwide, according to the estimated ARMS effect. However, adopters of this technology did realize gains through lower total weed control costs. Adopters in the Southern Seaboard, Mississippi Portal, and Prairie Gateway experienced a savings of 5-46 percent due to lower application, cultivation, and scouting expenses.

Similar to Bt cotton, weed control costs for herbicide-tolerant soybean adopters were lower than for nonadopters in 1997 (table 7). The savings realized by adopters ranged from about 1 percent to as much as 34 percent across production regions. This cost reduction is much smaller than in the study by Moschini et al. for 1999, which ranged from 49 percent to 66 percent (based on a reduction of $20 per hectare), depending on the number of additional glyphosate treatments applied.

Estimated ARMS effects for regional weed control costs are calculated in the same manner as for Bt cotton employing herbicide use elasticities (Fernandez-Cornejo et al.). A 1-percent increase in adoption leads

Table 7—Impact of adopting herbicide-tolerant soybeans on weed control costs, 1997

Production region	Estimated cost savings
	Percent
Heartland	-10.65
Northern Crescent	-12.21
Southern Seaboard	-3.91
Northern Great Plains	n.a.
Mississippi Portal	-4.45
Prairie Gateway	-0.89
Eastern Uplands	-33.92

n.a.= Not available.

Source: Estimated ARMS effects.

to a 0.43-percent increase in glyphosate use but a 0.14-percent decrease in the use of other synthetic herbicides. Expenses associated with the use of glyphosate were about $1.16 per acre higher for adopters in the Heartland (table 8). However, the decline in expenses associated with the use of other herbicides—$3.40 per acre—more than offset the increase in expenses for glyphosate. As a result, adopters' expenses for all herbicides totaled $25.64 per acre, versus $27.89 for nonadopters. Adopters of herbicide-tolerant soybeans in the Heartland are estimated to have realized a 10.7-percent ($3.50 per acre) savings in weed control costs when application, scouting, and cultivation expenses are considered along with herbicide costs.

Implications for Pesticide Use

Biotechnology led to reductions in pesticide use for Bt cotton in the Southern Seaboard, herbicide-tolerant cotton nationwide, and herbicide-tolerant soybeans in some major production regions. However, the reduction in pesticide use itself does not accurately measure total direct benefits to the environment and human health. Measuring herbicide use in pounds of active ingredients implies that, on a pound-for-pound basis, two ingredients have equal impacts. But in the case of herbicide-tolerant soybeans, other herbicides are replaced by glyphosate, which is less toxic and persistent than other herbicides (Heimlich et al.).

For Bt cotton, adoption clearly reduces insect control costs, but it also lowers the use of some insecticide active ingredients. While there is no compelling evidence showing that adopters' use of organophosphates and pyrethroids was lower, their use of "other insecticides" is estimated to be 21 percent lower than for nonadopters.

In contrast, the impact of adopting herbicide-tolerant soybeans on herbicide use is not as clear. While herbicide-tolerant soybeans lowered the use of "other herbicides" by 14 percent for adopters, adopters used 43 percent more glyphosate. Since average application rates vary across herbicide active ingredients, the net effect of substituting one herbicide for another may lead to an increase or a decrease in the total pounds of active ingredients used. Our analysis shows that the impact of adopting herbicide-tolerant soybeans on pesticide use was mixed—a net decline in the Heartland and Prairie Gateway but an increase in all other regions. Overall, the impact of herbicide-tolerant soybeans is a 3-percent increase in herbicide use (measured in pounds of active ingredients) nationwide in 1997.

The decline in herbicide use (in terms of active ingredients applied) for herbicide-tolerant soybean adopters in 1997 was limited to selected regions, ranging from 1.6 percent in the Heartland to 3.3 percent in the Prairie Gateway. For example, the use of glyphosate increased from 0.19 pound per acre for nonadopters to 0.27 pound per acre for adopters in the Heartland (table 8). In contrast, the use of "other herbicides" decreased from 0.70 pound per acre for nonadopters to 0.60 pound per acre for adopters. The end result was a decline in the use of all herbicides from 0.997 pound for nonadopters to 0.981 pound for adopters (a 1.6-percent reduction), which was lower than the 10.7-percent decrease in weed control costs for adopters. The increases in herbicide use in other regions were as follows: 8.4 percent, Northern Crescent; 11.7 percent, Mississippi Portal; and 10.9 percent, Southern Seaboard.

Table 8—Impact of herbicide-tolerant soybeans on herbicide use and weed control costs: Heartland, 1997

Herbicide active ingredient	Rate per crop year	Area applied	Weight	Price	Cost for nonadopters	Costs for adopters	Herbicide use: Nonadopters	Herbicide use: Adopters
	lb. per acre	*Percent*	*lb. per acre*	*$ per lb.*	*$ per acre*		*lb. per acre*	
Acetamides								
Metolachlor	1.999	4.346	0.087	8.688	0.755	0.755	0.087	0.087
Alachlor	0.877	2.333	0.020	6.325	0.129	0.129	0.020	0.020
Subtotal					**0.884**	**0.884**	**0.107**	**0.107**
Glyphosate	0.710	26.807	0.190	14.175	**2.699**	**3.860**	**0.190**	**0.272**
Other herbicides								
Pendamethalin	1.074	29.479	0.317	8.909	2.820	2.425	0.317	0.272
Trifluralin	0.739	19.591	0.145	7.850	1.137	0.978	0.145	0.125
Bentaton	0.613	9.532	0.058	19.075	1.115	0.959	0.058	0.050
Clomazone	0.566	4.199	0.024	19.900	0.473	0.407	0.024	0.020
2, 4-D	0.372	9.567	0.036	3.725	0.133	0.114	0.036	0.031
Acifluorfen	0.140	8.338	0.012	28.920	0.338	0.291	0.012	0.010
Metribuzin	0.204	10.083	0.021	36.933	0.759	0.652	0.021	0.018
Imazethapyr	0.052	42.563	0.022	315.900	7.005	6.024	0.022	0.019
Sethodydim	0.154	8.009	0.012	67.333	0.833	0.716	0.012	0.011
Chlorimuron-thyl	0.030	13.868	0.004	1142.770	4.770	4.102	0.004	0.004
Clethodim	0.078	4.362	0.003	108.990	0.371	0.319	0.003	0.003
Dimethenamid	n.a.	n.a.	n.a.	14.23	n.a.	n.a.	n.a.	n.a.
Fenoxaprop	0.123	6.893	0.009	165.400	1.407	1.210	0.009	0.007
Fluazifop-P-butyl	0.048	7.774	0.004	64.830	0.242	0.208	0.004	0.003
Flumetsulam	0.055	1.915	0.001	n.a.	n.a.	n.a.	0.001	0.001
Flumiclorac Pentyl	0.020	1.292	0.000	215.830	0.055	0.047	0.000	0.000
Fomesafen	0.169	6.442	0.011	36.340	0.397	0.341	0.011	0.009
Imazamox	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Imazaquin	0.079	12.671	0.010	150.000	1.494	1.285	0.010	0.009
Lactofen	0.082	4.597	0.004	58.710	0.221	0.190	0.004	0.003
Linuron	0.053	0.089	0.000	24.000	0.001	0.001	0.000	0.000
Quizalofop-ethyl	0.035	2.533	0.001	143.190	0.128	0.110	0.001	0.001
Sulfentrazone	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Thifensulfuron	0.003	9.645	0.000	2084.320	0.503	0.432	0.000	0.000
Paraquat	0.273	1.912	0.005	14.470	0.075	0.065	0.005	0.004
Subtotal other herbicides					**24.276**	**20.877**	**0.698**	**0.600**
Adjusted subtotal (account for missing other herbicides)					**24.302**	**20.900**	**0.699**	**0.601**
Total herbicide use							**0.997**	**0.981**
Total herbicide material costs					**27.885**	**25.644**		
Application costs					**3.338**	**2.875**		
Scouting costs					**0.291**	**0.447**		
Cultivation costs					**1.267**	**0.314**		
Total weed control costs					**32.782**	**29.280**		

n.a. = Not applicable.

Sources: Gianessi and Marcelli; USDA 1998a, 1998c.