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FARM-LEVEL PRODUCTION EFFECTS RELATED TO THE ADOPTION OF GENETICALLY MODIFIED COTTON FOR PEST MANAGEMENT

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Herbicide-tolerant and Bt cotton varieties may offer farmers many benefits, including decreased pesticide use, increased yields, and greater planting flexibility. Farmer benefits appear to outweigh costs, translating into rapid adoption of these cotton varieties. USDA survey data was used to estimate the effect of GM cotton on crop yields, profits, and pesticide applications.

Key words: biotechnology; Bt cotton; herbicide-tolerant cotton; pest management; crop yields.

Herbicide-tolerant and insect-resistant cotton varieties have been developed using genetic engineering techniques. Although it has only been a few years since these varieties have been approved for commercial use, the rate of adoption has been rapid. By 1998, more than 40 percent of the cotton acres had been planted with genetically modified (GM) cotton (USDA/ERS, 1999a). For comparison, only 25 percent of cotton acres were devoted to GM cotton production in 1997. Adoption is expected to increase in 1999 as seed companies continue to offer new cotton varieties with these traits, including "stacked" varieties containing more than one trait.

Herbicide-tolerant cotton enables farmers to use herbicides that previously would have destroyed the crop along with the targeted weeds. Therefore, farmers are able to use a broader variety of herbicides that are more effective in weed control, such as postemergent herbicides. The most common herbicide-tolerant crops are Roundup Ready (RR) crops resistant to glyphosate, a herbicide effective on many species of grasses, broadleaf weeds, and sedges. Glyphosate tolerance has been incorporated into cotton, corn, soybeans, and canola. Another genetically modified herbicide-tolerant cotton is BXN cotton resistant to bromoxynil.

Bacillus thuringiensis (Bt) cotton contains a gene from the soil bacterium, *Bacillus thuringiensis*. The bacteria produce a protein that is toxic when ingested by certain lepidopteran insects. Crops containing the Bt gene are able to produce their own toxin, thereby providing protection throughout the entire plant. *Bacillus thuringiensis* has been engineered into cotton along with many other crops, including corn and potatoes. *Bacillus thuringiensis* cotton is effective primarily in controlling tobacco budworms and somewhat effective in controlling bollworms. These insect pests can cause considerable damage to cotton. In cotton, bollworms and budworms combined accounted for about

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$186 million in cotton losses and treatment expenses in 1998 (Williams, 1999). In 1998, about nine million cotton acres were infested with bollworms and budworms (Williams, 1999).

Farmer Benefits From GM Cotton Adoption

Herbicide-tolerant and insect-resistant cotton varieties may offer farmers many benefits, including decreased pest management costs, increased yields, and greater crop production flexibility. The expected benefits and performance of these crops will vary greatly by region, mostly depending on pest infestation levels, the development of popular regional varieties containing these genes to ensure yield advantages, and seed and technology costs. Some studies (Falck-Zepeda & Traxler, 1998; Marra, Carlson & Hubbell, 1998; and Culpepper & York, 1998) show that benefits appear to outweigh expected costs for many farmers, translating into rapid adoption of these cotton varieties.

Cotton production relies heavily on herbicides to control weeds, often requiring applications of two or more herbicides at planting and postemergence herbicides later in the season (Culpepper & York, 1998). In 1997, close to 28 million pounds of herbicides were applied to 97 percent of the 13 million acres devoted to upland cotton production in the 12 major cotton-producing states (USDA, 1998). As shown in table 1, trifluralin was the principle herbicide applied (5.5 million pounds), followed closely by MSMA (4.9 million pounds) and fluometuron (4.9 million pounds). Considerable amounts of insecticide are also used in United States (U.S.) cotton production. Seventy-seven percent of the acres devoted to upland cotton production were treated with 18 million pounds of insecticides in 1997 (table 2). Table 2 shows that malathion was the major insecticide used. Farmers applied more than 7 million pounds of malathion in 1997. Aldicarb had the second highest use (2.4 million pounds), followed by methyl parathion (2 million pounds), and acephate (0.9 million pounds).

Use of herbicide-tolerant and Bt cotton may reduce pesticide costs. The ability to use more effective postemergent herbicides can reduce herbicide application rates. Similarly, farmers using Bt cotton may be able to reduce insecticide costs by discontinuing the use of Bt foliar sprays and possibly decreasing applications of other insecticides, such as pyrethroids. The study by Culpepper and York (1998) found that the greatest advantage of planting herbicide-tolerant varieties was the reduced herbicide use. Herbicide treatment systems that included glyphosate on RR cotton required fewer herbicide treatments and less total herbicide to produce equivalent yields and net returns. Similarly, farmers growing Bt cotton were found to have fewer insecticide applications, especially for pyrethroid insecticides (Marra, Carlson, & Hubbell, 1998).

Developers of herbicide-tolerant and insect-resistant cotton expect these varieties to offer more effective options for controlling pests, resulting in higher crop yields. The study by Marra, Carlson, and Hubbell (1998) on Bt cotton seems to support this. Analysis from a survey of cotton producers in North and South Carolina, Georgia and Alabama showed that yields were significantly greater for farmers planting Bt in the lower southern states and for the entire sample. This was not true for the upper southern states, however. Alternatively, some of the studies on herbicide-tolerant cotton (Culpepper & York, 1998; Marra, Carlson, & Hubbell, 1998) found that the adoption of these varieties did not necessarily translate into yield gains.

The overall benefits of adopting GM cotton varieties with pest management traits will depend on technology costs. Seed costs are greater than traditional seed and farmers are also required to pay a separate technology fee. Given these greater costs, it will require a certain pest infestation level for farmers to obtain economic benefits from adopting herbicide-tolerant and insect-resistant crops. The expected benefit from adopting these varieties greatly depends on infestation levels and the associated reductions in crop losses and pesticide costs. For farmers in regions that have an increased probability of pest infestations, the willingness to pay for Bt seed will be higher. Falck-Zepeda and Traxler (1998) estimated the distribution of benefits from the adoption of Bt cotton. Some farmers faced a 300-percent seed price premium. The net surplus for farmers adopting Bt cotton ranged from -$13 per acre to $65 per acre. Marra, Carlson, and Hubbell (1998) found that the rate of return was less in the upper south than the lower south. The additional crop revenues and insecticide savings outweighed the higher seed and technology costs in the lower south.

The Adoption Of GM Cotton: Farm-level Survey Results

Estimates on cotton yields and pesticide use for farmers growing GM cotton are based on yearly data from the nationwide Agricultural Resource Management Study (ARMS) survey developed by the ERS and the National Agricultural Statistics Service (NASS) of USDA. The ARMS survey was designed to link resource use and agricultural production information to farm financial/economic conditions. In particular, the ARMS survey data links the adoption of genetically modified crops with yields, other management techniques, chemical use, and profits. The data were obtained using a three-phase process (screening, obtaining production practices and cost data, and obtaining financial information).

In the survey, farmers were asked their main reason for adopting herbicide-tolerant and Bt cotton varieties (table 3). The majority of farmers surveyed (ranging from 54 to 76 percent of adopters) indicated that the main reason they adopted GM cotton with pest management traits was to "increase yields through improved pest control." The second reason, stated by 19-42 percent of adopters, was "to decrease pesticide costs." Very few adopters indicated that the other reasons were the most important consideration for adoption. Thus, it appears that expected profitability positively influenced the adoption of GM cotton. Factors expected to increase profitability by increasing revenues per acre (price of the crop times yield) or reducing costs are generally expected to positively influence adoption. However, the physical environment of the farm (e.g., weather, soil type) may affect profitability directly through increased fertility, and indirectly through its influence on pests. For these reasons, separate regional analyses are often conducted.

Yields And Pesticide Use

Table 4 presents comparisons of mean yields for adopters and nonadopters of herbicide-tolerant and Bt cotton by region (USDA, 1999a and 1999b).[1] Percent differences between yields and pesticide use of adopters and nonadopters of GM cotton varieties were statistically compared using a difference of means test. However, caution must be exercised in interpreting these results. Differences between the mean estimates for yields and pesticide use from survey results cannot necessarily be attributed to the use of genetically engineered seed since they are influenced by several other factors not controlled for. These factors include: irrigation, weather, soils, nutrient and pest management practices, other cropping practices, operator characteristics, pest pressures, and others (USDA, 1999a). In general, yield differences between adopters and nonadopters of herbicide-tolerant cotton are not statistically significant, except in the Southern Seaboard region in 1997 where yields for adopters seem to be significantly less than yields for nonadopters. Alternatively, there are many cases (4 of 7 regions/year) where adopters of Bt cotton appear to have statistically significantly higher yields than nonadopters.

Results from the comparisons of mean pesticide acre-treatments by region for 1997 are presented in table 5 (USDA, 1999a and 1999b). These comparisons show that the adoption of herbicide-tolerant cotton varieties accompanied statistically significant reductions in herbicide treatments in the Southern Seaboard region, but this is not true for the Mississippi Portal region. The mean comparisons for Bt cotton show that in the Mississippi Portal and Southern Seaboard regions, the adoption of Bt cotton reduces treatments of insecticides normally used on the pests targeted by Bt. However, in the Mississippi Portal region, Bt cotton producers used more insecticides when targeting pests other than the Bt target pests. Insecticide treatments were not significantly affected by Bt cotton adoption in the Fruitful Rim.

<u>Econometric Results</u>

This section summarizes the results of an econometric model developed by Fernandez-Cornejo, Klotz-Ingram, and Jans (1999) to estimate the impacts from farmer adoption of GM cotton [2] on profits, yields, and pesticide use. The model was estimated using data from the 1997 ARMS survey for cotton. The data include farms from 12 cotton-producing states accounting for 96 percent of the U.S. upland cotton production. After excluding observations with missing values, 696 observations were available for analysis. To partially account for regional effects of Bt cotton adoption, selected southern states were analyzed separately. These states were Alabama, Georgia, and North and South Carolina.

The results of the farm-level impact model are presented in table 6. Table 6 shows the direction of the influence of adoption of herbicide-tolerant and Bt cotton on yields, variable profits,[3] and pesticide use.[4] The results indicate that the effect of herbicide-tolerant and Bt cotton adoption on yields and profits were significantly positive. However, herbicide use was not significantly affected by the adoption of herbicide-tolerant cotton when controlling for other factors. On the other hand, Bt cotton did significantly decrease the use of other synthetic insecticides, although the use of organophosphate insecticides were not significantly associated with the adoption of Bt cotton.

In Summary

Preliminary research based on the empirical model indicates that the adoption of GM cotton varieties may increase yields and may positively affect farmers' profits. However, the model seemed to show that GM cotton varieties may only affect pesticide use in some cases. The empirical analysis and the difference of means tests provide evidence that the benefits from and performance of GM cotton will depend greatly on regional and yearly differences, including input costs (pesticide and seed costs), infestation levels, and other production attributes.

End Notes

[1] The Mississippi Portal region includes (i) northern and western Mississippi; (ii) portions of southern and eastern Louisiana; (iii) east Arkansas; and (iv) western Tennessee. The Southern Seaboard region includes (i) parts of eastern Texas; (ii) northwestern Louisiana; (iii) mid-southern Arkansas; (iv) southeastern Mississippi; (v) most of Alabama, Georgia, South and North Carolina, Virginia and Delaware; and (vi) eastern Maryland. The Prairie Gateway region includes (i) most of Texas; (ii) eastern New Mexico; (iii) western Oklahoma; (iv) Kansas; (v) eastern Colorado; and (vi) southern Nebraska. The cotton producing regions of the Fruitful Rim includes (i) southwestern California; (ii) Arizona and Florida; (iii) coastal Texas; and (iv) coastal Georgia and South Carolina. (USDA/ERS, 1999b).

[2] A multiple regression analysis was used in an econometric model to statistically control for factors considered relevant and for which there are data. That is, differences in economic conditions and crop or management practices are held constant so that the effect of adoption can be observed. We control

for output and input prices, infestation levels, and self-selection of adopters. The analysis was conducted in two stages. First, we estimated the probability of adoption given farmer characteristics that may influence adoption. Then, we used the predicted probabilities of adoption to determine how increases in these probabilities affect yields, profits, and pesticide use.

3 Variable profits were defined as revenues minus the costs that are likely to vary with the adoption decision, including pesticide costs, seed costs, and the technology fee.

[4] The herbicide "families" considered were (i) triazines (atrazine, cyanazine, metribuzin, and prometryn), (ii) glyphosate, and (iii) other synthetic herbicides (such as 2,4-D, acifluorfen, bentazon, clomazone, pendimethalin, and trifluralin). The insecticide families included were (i) organophosphates (e.g., malathion, methyl parathion, acephate, and phorate); (ii) synthetic pyrethroids (e.g., cypermethrin and cyfluthrin); and (iii) other synthetic insecticides (such as aldicarb, chloropyrifos, oxamyl, and endosulfan).

Table 1. Major Herbicides Used On Cotton, 1997.

Herbicide Active Ingredient	Area Applied (percent)	Applications (number)	Rate Per Crop Year (lbs/acre)	Total Applied (million lbs)
Triazines				
Cyanazine	18	1.3	0.95	2.20
Prometryn	19	1.2	0.66	1.67
Other Herbicides				
Trifluralin	55	1.1	0.76	5.46
MSMA	29	1.4	1.30	4.90
Fluometuron	44	1.3	0.84	4.85
Pendimethalin	28	1.1	0.69	2.49
Norflurazon	13	1.0	0.63	1.04
Diuron	12	1.1	0.55	0.88
Metolachlor	5	1.1	1.17	0.74
Glyphosate	14	1.3	0.81	1.54

Note. Planted acres were 13.1 million for the states surveyed (Alabama, Arizona, Arkansas, California, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Texas). From Agriculture chemical usage: 1997 field crops summary by United States Department of Agriculture (USDA), National Agricultural Statistical Service (NASS), 1998, September. Washington, DC: USDA/NASS.

Table 2. Major Insecticides Used On Cotton, 1997.

Herbicide Active Ingredient	Area Applied (percent)	Applications (number)	Rate Per Crop Year (lbs/acre)	Total Applied (million lbs)
Organophosphates				
Malathion	11	5.9	4.97	7,246
Methyl parathion	13	2.7	1.22	1,996
Acephate	10	1.7	0.72	898
Phorate	7	1.0	0.73	667
Profenofos	4	1.6	0.98	558
Dicrotophos	8	1.7	0.35	377
Synthetic pyrethroid compounds				
Cypermethrin	8	1.7	0.14	137
Cyfluthrin	13	1.7	0.05	92
Other insecticides				
Aldicarb	27	1.0	0.68	2,428
Chlorpyrifos	4	1.9	1.45	805
Oxamyl	15	1.6	0.33	648
Endosulfan	2	2.3	0.88	267
Dicofol	2	1.0	1.13	255

Note. Planted acres were 13.1 million for the states surveyed (Alabama, Arizona, Arkansas, California, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, and Texas). From Agriculture chemical usage: 1997 field crops summary by United States Department of Agriculture (USDA), National Agricultural Statistical Service (NASS), 1998, September. Washington, DC: USDA/NASS.

Table 3. Main Stated Reason To Adopt Herbicide-Tolerant And Bt Cotton By U.S. Farmers, 1997.

Stated Reason To Adopt	Percent of Adopters[a]	
	Herbicide Tolerant Cotton	Bt Cotton
1. Increase yields through improved pest control.	76.3	54.4
2. Decrease pesticide input costs.	18.9	42.2
3. Increased planting flexibility (for example, easier to rotate crops, reduce carryover, use reduced tillage or notill systems, and so on).	1.8	2.2
4. Adopt more environmentally friendly practices.	0.9	0.0
5. For some other reason(s).	2.3	1.2

Note. [a] Percent of acreage among adopters.

Table 4. Yields From GM Cotton Compared To All Other Cotton Seed Technologies By Region, 1996-1998

Technology / Region	Percent Difference[a]		
	1996	**1997**	**1998[b]**
Herbicide Tolerant Cotton			
Mississippi Portal	id	0[c]	0[c]
Southern Seaboard	id	-11.9*	0[c]
Prairie Gateway	id	id	id
Bt Cotton			
Mississippi Portal	8.6*	0[c]	15.0**
Southern Seaboard	id	19.6**	0[c]
Fruitful Rim	id	0[c]	26.1**

<u>Note.</u> Caution must be exercised in interpreting these results. Differences between the mean estimates for yields and pesticide use from survey results cannot necessarily be attributed to the use of genetically engineered seed since they are influenced by several other factors not controlled for, including: irrigation, weather, soils, nutrient and pest management practices, other cropping practices, operator characteristics, pest pressures, and others.

[a] Percent difference between the yield of Bt or herbicide-tolerant cotton and all other seed technologies. Differences were statistically compared using a difference of means test. All other seed technologies include acreage planted to all other purchased and homegrown seed. [b] 1998 estimates include acreage and production associated with stacked varieties (Bt plus herbicide-tolerant genes). [c] Not significantly different from all other. id = insufficient data for a statistically reliable estimate. **significantly different from all other at the 5 percent level. *significantly different from all other at the 10 percent level.

Table 5. Pesticide Acre-Treatments From GM Cotton Compared To All Other Cotton Seed Technologies By Region, 1997.

Technology / Region	Herbicide acre-treatments[b]	
	GM Cotton	**All Other**
Herbicide-tolerant Cotton		
Mississippi Portal	4.31	5.63
Southern Seaboard	3.69**	4.76
Bt Cotton Techology / Region	**Insecticide acre-treatments[b]**	
	GM Cotton	**All Other**
Mississippi Portal		
Bt target pests [c]	0.54**	1.27
All other pests	8.19**	4.43
Southern Seaboard		
Bt target pests [c]	0.31**	1.95
All other pests	2.19	1.37
Fruitful Rim		
Bt target pests [c]	0.63	0.60
All other pests	3.19	4.14

Note. Caution must be exercised in interpreting these results. Differences between the mean estimates for yields and pesticide use from survey results can not necessarily be attributed to the use of genetically engineered seed since they are influenced by several other factors not controlled for, including: irrigation, weather, soils, nutrient and pest management practices, other cropping practices, operator characteristics, pest pressures, and others.

[a] Statistically compared using a difference of means test. The "GM cotton" 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. [b] An acre-treatment is the number of different active ingredients applied per acre times the number of repeat applications. A single treatment containing two ingredients is counted as two acre-treatments as is two treatments containing a single ingredient. [c] Target pests for Bt cotton are the tobacco budworm, bollworm, and pink bollworm.
**significantly different from all other at the 5 percent level.

Table 6. Production And Pesticide Use Impacts From GM Cotton Adoption In 1997.

	Direction Of Impact With Respect To The Probability Of Adoption	
	Herbicide-tolerant cotton	**Bt cotton (selected states)**
Change in yields	(+)	(+)
Change in variable profits	(+)	(+)
Change in herbicides		
Triazine herbicides	0[a]	
Other synthetic herbicides	0[a]	
Other synthetic herbicides	0[a]	
Change in Insecticides		
Organophosphate insecticides		0[a]
Pyrethroid insecticides		0[a]
Other insecticides		(-)

Note. [a] Insignificant underlying coefficients. From "Farm-level effects of adopting genetically engineered crops in the U.S." by J. Fernandez-Cornejo, C. Klotz-Ingram, and S. Jans, 1999, June. Paper presented at the NE-165 meeting entitled Transitions in Agbiotech: Economics of Strategy and Policy; Washington, DC.

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