

The Payoffs to Transgenic Field Crops: An Assessment of the Evidence

Michele C. Marra

Professor, Department of Agricultural and Resource Economics,
North Carolina State University

Philip G. Pardey

Professor, Department of Applied Economics, University of
Minnesota

Julian M. Alston

Professor, Department of Agricultural and Resource Economics,
University of California, Davis

The purpose of this study is to compile and characterize the farm-level evidence of the impacts of transgenic field crops available in the public domain and to determine if any general implications can be drawn from it. The studies show that, compared to their conventional counterparts, transgenic crops have consistently higher average profit and, for the most part, lower pesticide use.

Key words: biotechnology, economic benefits, farm-level impacts, field crops, transgenic.

Introduction

Farmers in the United States have adopted transgenic field crops with an intensity not seen for a new varietal technology since hybrid corn technology first appeared in farmers' fields more than sixty years ago. The share of US soybean acres planted to Roundup Ready® (RR) soybeans increased from 1.9% to 74.0% in just six years, between 1997 and 2002 (Doane's Market Research, various years; United States Department of Agriculture National Agricultural Statistics Service [USDA NASS], various years). In some US states, the share of 2002 soybean acres planted to RR soybeans is approaching 90%. Since its commercialization in 1997, the proportion of cotton acres planted to RR cotton in the US increased from 4% to 70% (Gianessi & Carpenter, 2001; USDA NASS, various years).

The rapid uptake of *Bacillus thuringiensis* (Bt) cotton and RR cotton and soybeans is a testament to their net benefits at the farm level. Yet vocal critics persist, their arguments based in part on their beliefs that neither farmers nor other members of society benefit from these technologies (see Benbrook, 2001; Duffy & Ernst, 1999; Hart, 1999).¹ Many of these critics cite early USDA estimates of differences in profit, pesticide use, and pesticide cost between transgenic and conventional technologies, from an annual survey known as the Agricultural Resource Management Survey (ARMS; USDA Economic Research Service [ERS], 1999). But, as discussed in Marra (2001), in the early years this survey evidence was biased against the transgenic crops. The problem has been solved in more recent versions of the ARMS

survey, but the early estimates are still being used to support critics' arguments. It seems reasonable, then, to look elsewhere for evidence of the farm-level impacts of these technologies.

The economic impacts of these technologies have been estimated thus far in a piecemeal fashion.² The purpose of this study is to collect and characterize the farm-level economic evidence for field crops available in the public domain, organize it, and determine if any general implications can be drawn from it. A sample of studies estimating the aggregate impacts is also included. In addition to the references cited in the body of the article, citation details for the studies reported in the tables are included in the list of references. However, we have omitted the USDA study by Fernandez-Cornejo and McBride (2002), along with several others, whose results were based on the earlier (in this case 1997) ARMS data.

Empirical Evidence of Farm-Level Impacts

We obtained estimates of several measures of farm-level impacts associated with commercially available transgenic field crops from a search of the relevant academic journals, Internet searches, and inquiries of researchers who work in this area. Some *ex ante* estimates were discovered, as well, for technologies not yet released for commercial adoption at the time of the studies. Estimates of differences in yield, revenue, pesticide cost, and pesticide use, and estimates of net returns to transgenic crops were taken directly or, in some cases,

1. These concerns include the pest and disease resistance consequences of transgenic technologies and their effects on biodiversity generally (Snow, 2002; Smyth, Khachatourians, & Phillips, 2002).

2. The exception is a set of 40 case studies done by researchers at the National Center for Food and Agricultural Policy. They provide a comprehensive cross-section (the 2001 crop year) of state-level and aggregate impacts of biotech crops in the US (Gianessi, Silvers, Sankula, & Carpenter, 2002).

imputed from the reported information. Sources examined fall into one of the following categories: field trials, farmer and consultant surveys, expert opinion and secondary data, and studies reporting *ex ante* estimates of economic impacts. The mean and range of the estimates are reported in Tables 1 through 3, by crop, state or country (hereinafter, both referred to as state), and event (or transformation type). Most of the impact measures to date have been for Bt and RR cotton, Bt corn, and RR soybeans.

As shown in Table 1, the range of differences in yield between Bt and conventional cotton is quite large, mostly because of the wide range of pest incidence in the years since the commercial introduction of Bt cotton. For example, across the US Cotton Belt, a much higher incidence of the bollworm/budworm complex that Bt cotton is designed to control occurred in 1997 than in 1996. Even so, in 11 of the 13 states, yield averaged over years for Bt cotton exceeded that of conventional cotton. Where the data permit comparisons, Bt

cotton was more profitable than its conventional counterpart. The mean profit advantage ranges from about \$16 to almost \$173 per acre, including the costs of the technology fee.

Table 2 shows reduced pesticide use is also evident with Bt cotton—on average, a reduction of between 1.3 and 3.4 pesticide sprays per acre per season. The change in the number of pesticide sprays per season is a crude measure of both the environmental and the economic impact of transgenic crops. We were constrained by the data to use this measure as a common denominator so that the maximum number of studies could be included.

Pesticide cost savings are a more precise measure of the economic impact of changes in pesticide use, because the expenditure on pesticides is the dominant component of the total cost of chemical pest control. A reduction in average pesticide costs is reported for 11 of 13 states (Arizona and Mexico are the exceptions). The average cost savings range from \$1.20 per acre in Virginia to more than \$32 per acre in Alabama.

Table 1. Summary of farm-level yield and profit impact evidence for cotton.

State	Differences relative to conventional technology in:							
	Yield				Profit			
	Number of estimates (count)	Mean (pounds lint per acre)	Minimum	Maximum	Number of estimates (count)	Mean (dollars per acre)	Minimum	Maximum
Bt Cotton								
Alabama	4	143.5	38.0	231.5	2	77.6	38.7	116.5
Arizona	8	116.7	-331.5	917.0	10	57.5	-104.0	465.0
Georgia	3	75.2	38.0	104.0	3	92.0	38.7	169.2
Louisiana	2	-7.5	-37.0	22.0	2	16.5	-3.1	36.0
Mississippi	8	22.6	-73.0	92.0	6	34.5	-3.1	79.5
North Carolina	8	41.6	-35.7	182.5	8	20.5	-25.3	95.1
Oklahoma	4	168.0	123.0	203.0	4	53.8	25.5	85.5
South Carolina	2	90.5	62.0	119.0	4	51.8	17.1	80.1
Tennessee	2	-79.0	-243.0	85.0	2	67.5	60.7	74.3
Texas	3	116.6	81.0	177.5	1	46.0		
Virginia	1	62.0			1	41.7		
China	1	325.0			1	66.0		
Mexico	1	182.0			1	173.0		
RR Cotton								
Arkansas	1	-150.0			1	17.1		
North Carolina	5	120.0	65.8	196.5	5	108.0	67.2	152.3
South Carolina	3	74.7	0	159.0	3	95.1	72.3	112.0
Tennessee	9	-163.7	-762.0	-63.0	9	71.8	-621.0	104.0
Bt/RR Cotton								
Arkansas	2	292.8	-331.5	917.0	2	243.0	21.0	465.0

Note: Compiled by the authors.

Table 2. Summary of farm-level pesticide use and cost impact evidence for cotton.

State	Differences relative to conventional technology in:							
	Pesticide Use				Pesticide Cost			
	Number of estimates (count)	Mean (sprays per acre)	Minimum	Maximum	Number of estimates (count)	Mean (dollars per acre)	Minimum	Maximum
Bt Cotton								
Alabama	2	-1.3	0.3	-3.0	2	-32.4	3.1	-68.0
Arizona	3	-2.2	-1.8	-2.5	9	17.1	97.0	-24.6
Georgia	3	-2.7	-2.5	-3.0	3	-23.4	27.5	-68.0
Louisiana	2	-2.4	-2.2	-2.5	2	-20.0	-15.4	-24.6
Mississippi	4	-2.4	-1.3	-3.3	8	-5.1	13.8	-24.6
North Carolina	2	-2.4	-2.4	-2.5	2	-14.3	-1.2	-27.5
Oklahoma	4	-3.4	-2.3	-6.5				
South Carolina	2	-2.5	-2.5	-2.5	2	-16.2	-1.2	-31.1
Tennessee	1	-1.8			1	-5.6		
Texas								
Virginia	1	-2.5			1	-1.2		
China					1	-7.1		
Mexico					1	36.0		
RR Cotton								
Arkansas								
North Carolina					5	-24.2	-27.5	-14.5
South Carolina					3	-23.2	-27.5	-11.0
Tennessee					9	60.2	-23.0	145.8
BT/RR Cotton								
Arkansas					2	79.5	-269.0	159.0

Note: Compiled by the authors.

The average per-acre profit measures for each state unambiguously favor the RR cotton varieties over conventional varieties in the four states for which we have data. The average net benefit to growing RR cotton ranges from \$17 per acre in Arkansas to \$108 per acre in North Carolina. Yield and pesticide cost impact measures are quite variable, however, with the yield change ranging from 120 bushels per acre in North Carolina to -163.70 bushels per acre in Tennessee. On average, the studies showed pesticide cost savings of around \$24 per acre in North and South Carolina, while there was an average pesticide cost increase in the Tennessee studies. In the two studies available the stacked gene cotton (including both Bt and RR technologies) compared favorably with conventional cotton, with an average 292 pounds per acre yield increase and a \$243 per acre profit increase. However, pesticide costs showed an average increase of \$79.50 per acre.

Table 3 reports similar results for other transgene types. The most prevalent impact measure for Bt corn is

the yield difference. In most locations and years, however, the incidence of European corn borer is not severe enough to control profitably with pesticides. Therefore, the yield difference between the Bt and conventional varieties (multiplied by corn price) is sufficient to calculate the difference in profit, because there is no change in pesticide use. In the states where a range of yield differences could be reported, all show an unambiguous yield increase with Bt corn, although one estimate (Illinois 1998) is probably below the break-even yield increase that would cover the additional cost of the Bt corn seed. Studies estimating the impact of Bt corn across the Corn Belt report yield increases ranging from 5.3 to 14.9 bushels per acre. The mean yield increases are all in the profitable range, with results for some states (Illinois and Minnesota) indicating substantial profitability from adoption of Bt corn.

Studies from Illinois and North Carolina show average yield gains, reaching 6.8 bushels per acre for RR soybeans in North Carolina in 1997. However, most of

Table 3. Summary of farm-level impact evidence for other technologies and crops.

Transgene type	State	Differences relative to conventional technology in:							
		Yield				Profit			
		Number of estimates (count)	Mean (bushels per acre)	Minimum	Maximum	Number of estimates (count)	Mean (dollars per acre)	Minimum	Maximum
Bt Corn	Corn Belt	6	10.8	5.3	17.0	1	60.1		
	Illinois	4	16.3	1.5	30.0	1	23.4		
	Iowa	5	7.1	2.9	12.2				
	Kansas	3	7.8	3.7	12.0				
	Minnesota	1	18.2	18.2	18.2				
	Nebraska	2	7.4	4.2	10.5				
	South Dakota	2	10.3	7.7	12.9				
	United States	5	6.7	3.3	12.0	3	4.8	-1.8	18.0
RR Canola	Australia	2	24.49	7.62	41.36				
	Canada	3	-1.9	-2.7	-1.0	2	11.3	-1.9	24.5
RR Soybeans	Illinois	5	1.3	-0.3	1.8				
	Iowa	3	-3.4	-4.0	-2.8				
	Kansas	1	-3.0	-3.0	-3.0				
	Michigan	3	-2.2	-2.5	-1.7				
	Minnesota	3	-4.4	-4.6	-4.2				
	Nebraska	3	-4.4	-5.8	-2.1				
	North Carolina	4	2.7	-2.3	6.8	2	14.0	6.0	22.1
	Ohio	3	-2.3	-3.1	-1.7				
	South Dakota	3	-3.8	-5.0	-2.4				
	Wisconsin	3	-1.2	-2.0	0.1				
VR Potatoes	Mexico	6	23.7	6.7	43.0	6	288.8	69.6	559.4
IR Sweet Potatoes	Kenya	2	12.1	7.8	16.3	2	65.5	42.3	88.6
VR Sweet Potatoes	Kenya	2	16.6	14.7	18.5	2	88.7	76.2	101.1
BT Irish Potatoes	Illinois					3	15.5	-4.6	37.2
	United States					3	22.4	-1.8	51.0

Note: Compiled by the authors.

the available evidence for RR soybeans shows slightly lower yields—as much as a 5.7 bushels per acre deficit in Nebraska in 1997. The only profit estimates we could find thus far indicate a net return to using RR soybeans in North Carolina averaging \$14 per acre. These results indicate that yield trial differentials are insufficient to tell the whole profit story. Although definitive conclusions will require more research, the widespread adoption of this technology clearly indicates that the production costs are sufficiently lower to make RR soybeans profitable for the vast majority of growing conditions and farm types throughout the US.

Aggregate Impacts

A few studies have attempted to estimate the aggregate economic impact of a particular transgenic field crop (or group of crops) and the distribution of the impact on the various sectors involved. Most of the studies present their results in terms of total welfare effects and the distribution of those effects under various scenarios, or assumptions, regarding parameters they see as important.

Falck-Zepeda, Traxler, and Nelson (2000) modeled the change in welfare effects from adoption of Bt cotton and Roundup Ready soybeans using a basic two-region

framework (US and rest of world [ROW]), based on the approach in Alston, Norton, and Pardey (1998), in which the farm-level benefit is allowed to vary among US states, creating several subregions. They used unpublished market survey data, as well as published agronomic and farmer survey data to estimate their supply shifts in the US and assumed that the ROW would experience either the same or half of the efficiency gains as the US. They found that, for the 1996 and 1997 crops, Bt cotton adoption generated large global benefits and significant benefits to US producers at the expense of producers in the ROW. For RR soybeans in 1997, they again found large global benefits and large benefits to US producers with relatively small losses to producers in the ROW. (See also Traxler & Falck-Zepeda, 1999.)

Moschini, Lapan, and Sobolevsky (1999) modeled the global welfare effects of RR soybeans. They developed a three-region world model that includes a monopolist technology seller as well as consumers and producers. They assumed that the technology resulted in a US\$20 per hectare increase in profit at the farm level, based on conditions in Iowa in 1997–98. They estimated benefits to consumers, producers, and in total for the US, South America, and the ROW, and the surplus accruing to the monopolist. They generally found large increases in total social welfare from the technology, but mostly losses to producers in all regions. They examined the sensitivity of their results to the supply shift assumptions and found that the magnitude of the shift for any region can have a large impact on the size and distribution of the welfare changes.

Qaim (1998) completed an *ex ante* study of virus-resistant white potatoes in Mexico and another of virus- and weevil-resistant sweet potatoes in Kenya (Qaim, 1999). The estimates of farm-level benefits used in both studies are based on a consensus of expert opinion. Qaim found that central and eastern Kenyan producers would benefit much less than western producers and that the expected benefits accruing to all groups are greater for the virus-resistance technology compared with the weevil-resistance technology. In the Mexican case study, producers were divided into small, medium, and large farmers, and the benefits were measured with and without the potential for trade. Qaim reported that trade reduced the benefits to this small-country producer and that some combinations of assumptions favored small farms, while others favored larger farms. In all cases, Qaim estimated a large net gain to all sectors and farm sizes—an average gain of US\$288 per acre.

Pray, Ma, Huang, and Qiao (2001) considered the impact of Bt cotton in China. They collected farm-level

data on the net benefits of the Bt varieties and, using the same basic modeling approach as Moschini, Lapan, and Sobolevsky (1999) and Falck-Zepeda, Traxler, and Nelson (2000), estimated the distribution of benefits among farmers, seed companies, and research institutes/companies. They found significant aggregate net benefits to farmers and much smaller benefits to the seed companies and research institutes/companies. Pray et al. (2001) also presented the only quantified farm-level nonpecuniary benefits we have found. They reported that only 4% of farmers planting the Bt varieties suffered any effects of pesticide poisoning, compared with 33% of those who did not plant Bt cotton.

Fulton and Keyowski (1999), in a theoretical modeling exercise, pointed to the importance of farmer heterogeneity in modeling the distribution of benefits when the transgenic and traditional markets are segregated. Burton, James, Lindner, and Pluske (2000), using the same methodology as most of the other aggregate studies, considered the effects of various identity preservation schemes on the total and distributional aspects of the benefits from adoption of genetically modified (GM) canola. Based on Fulton and Keyowski, they assumed that adoption of GM canola decreased marginal costs at the farm level by 8.5%. They divided the world into consumers and producers of GM and nonGM canola and estimated the distribution of total surplus accruing to each group under various assumptions about the form of technical change, the incidence of identity preservation costs, and the impact of a technology fee. They found that, under most scenarios, consumers of the nonGM canola would lose, while consumers of GM canola would gain. Estimates of producer benefits vary widely, depending on the assumptions listed above, but producers of conventional canola seem to fare better in this study in most cases than producers of GM canola.

Conclusion

It is worth emphasizing again that estimates of farm-level impact summarized in Tables 1 through 3 are for a relatively small number of locations and years. As more useful farm-level data become available for economic comparisons—both in the US and, more particularly, in the rest of the world—estimates of this type can be viewed with more confidence. However, preliminary conclusions can be drawn at this point in several cases. These apply only in the context of the US (although they might be expected to have parallels in other countries).

- Growing transgenic cotton (Bt, RR, or the stacked-gene type) is likely to result in reduced pesticide use

in most years in most states, and it is more likely than not to be a relatively profitable enterprise in most of the US Cotton Belt.

- Bt corn will provide a small but significant yield increase in most years across the Corn Belt, and in some years and some places the increase will be substantial, resulting in significant increases in profit.
- Although there is some evidence of a small yield discrepancy early on in the RR soybean varieties, in most years and locations savings in pesticide costs will more than offset the lost revenue. This yield discrepancy seems to be disappearing as the transgene is inserted into more varieties within the various soybean maturity categories.

The most consistent result from these studies is that transgenic field crops have been profitable. For every transgene type, crop, and state combination, the average profit is higher for the transgenic crop than for the conventional counterpart. There are still many intangible farm-level impacts, the value of which no one has attempted to measure thus far. One important aspect is the “convenience factor” for the RR crops. Farmers report that even if there is a slight yield discrepancy with RR soybeans, the reduced herbicide costs and the extra time available to attend to their higher-value crops are more than sufficient compensation. The impressive rates of adoption for many of these transgenic crops are strong evidence of their perceived value to farmers.

Only time will tell if the concerns of consumers and environmental groups will appreciably slow the pace of uptake of transgenic crops, but if these concerns can be addressed satisfactorily, then the adoption of many of the first-generation transgenic field crops represents a win-win situation for farmers. They can expect higher profits, reduced health problems resulting from using safer pesticides, and fewer negative environmental impacts compared with conventional production methods.

Policymakers and consumers will benefit from better estimates of the farm-level benefits, because information costs are part of the cost of regulation. Additional studies are warranted to estimate the potential pecuniary benefits more precisely using on-farm results based on farmer decisions. It is time also for an initial attempt to quantify the nonpecuniary benefits and to gain a better sense of the economics of the spatial and intertemporal (externality) effects of conventional versus transgenic technologies regarding their pest resistance and biodiversity consequences.

References

- Alston, J.M., Norton, G., and Pardey, P.G. (1998). *Science under scarcity: Principles and practice for agricultural research evaluation and priority setting*. Wallingford, UK: CAB International.
- Askew, S.D., Wilcut, J.W., Bailey, W.A., and Scott, G.H. (1999). Weed management in conventional and no-tillage cotton using BXN, Roundup Ready, and Staple OT regimes. *Proceedings of the Beltwide Cotton Conferences*, 743-744. Memphis, TN: National Cotton Council.
- Bacheler, J.S., Mott, D.W., and Morrison, D.E. (1998). Large-scale evaluation of Bollgard resistance to multiple pests in North Carolina under grower conditions. *Proceedings of the Beltwide Cotton Conferences*, 2, 961-64. Memphis, TN: National Cotton Council.
- Benbrook, C. (2001). Do GM crops mean less pesticide use? *Pesticide Outlook*, October 2001. Available on the World Wide Web: <http://www.mindfully.org/Pesticide/More-GMOs-Less-Pesticide.htm>.
- Benson, M.A., and Hendrix III, W.H. (1999). Economics of a tracer/karate Z conventional cotton program vs. Bt cotton. *Proceedings of the Beltwide Cotton Conferences*, 2, 1143-45. Memphis, TN: National Cotton Council.
- Bryant, K., Allen, C.T., Bourland, F.M., and Earnest, L.D. (1999). Cost and return comparisons of RR and Bollgard cotton varieties. *Proceedings of the Beltwide Cotton Conferences*, 1, 236-38. Memphis, TN: National Cotton Council.
- Bryant, K.J., Robertson, W.C., and Lorenz III, G. M. (1998). Economic evaluation of Bollgard Cotton in Arkansas: 1997. *Proceedings of the Beltwide Cotton Conferences*, 1, 388-89. Memphis, TN: National Cotton Council.
- Bryant, K.J., Robertson, W.C., and Lorenz III, G.M. (1999). Economic evaluation of Bollgard cotton in Arkansas. *Proceedings of the Beltwide Cotton Conferences*, 1, 349-50. Memphis, TN: National Cotton Council.
- Burton, M., James, S., Lindner, B., and Pluske, J. (2000, August 24-28). A way forward for Frankenstein foods. Paper presented at *The Economics of Agricultural Biotechnology*, Fourth Conference of the International Consortium on Agricultural Biotechnology Research, Ravello, Italy.
- Capps, C.D., Allen, C., Earnest, L., Tugwell, P., and Kharbouti, M. (1999). Performance of Bollgard cotton with and without insecticides. *Proceedings of the Beltwide Cotton Conferences*, 2, 1239-41. Memphis, TN: National Cotton Council.
- Carpenter, J., and Gianessi, L. (1999). Herbicide tolerant soybeans: Why growers are adopting Roundup Ready varieties. *AgBioForum*, 2(2), 65-72. Available on the World Wide Web: <http://www.agbioforum.org>.
- Carpenter, J., and Gianessi, L. (2001). *Agricultural biotechnology: Updated benefit estimates*. Washington, DC: National Center for Food and Agricultural Policy. Available on the World Wide Web: <http://www.ncfap.org>.

- Coble, H. (1997). Unpublished field trials [mimeo]. Raleigh, NC: North Carolina State University.
- Cooke, F.T., and Freeland, T.B. (1998). Some economic considerations for Bt cotton planting in the Yazoo-Mississippi Delta. *Proceedings of the Beltwide Cotton Conferences, 1*, 383–84. Memphis, TN: National Cotton Council.
- Culpepper, A.S., and York, A.C. (1998). Weed management in glyphosate-tolerant cotton. *Journal of Cotton Science, 1*, 174–185.
- Couvillion, W., Kari, F., Hudson, D., and Allen, A. (2000). *A preliminary economic assessment of Roundup Ready soybeans in Mississippi* (Mississippi State University Research Report 2000–005). Starkville, MS: Mississippi State University.
- Doane's Market Research. (Various years). Unpublished data.
- Duffy, M., and Ernst, M. (1999). *Does planting GM seed boost farmers' profits?* Ames: The Leopold Center, Iowa State University. Available on the World Wide Web: <http://www.ag-iastate.edu/centers/leopold/99-3gmoduffy.html>.
- Dunphy, J., and York, A. (2000). *Progress report to North Carolina Soybean Producers' Association Inc.* Raleigh. Available on the World Wide Web: <http://www.ncsoy.org/Research/1999/99-06/99-06.htm>.
- Dunphy, J., Heiniger, R., and York, A. (2000). *Progress report to North Carolina Soybean Producers' Association Inc.* Raleigh. Available on the World Wide Web: http://www.ncsoy.org/Research/_2000_Annual_Reports/2000_annual_reports.htm.
- European Commission. (2000). *Economic impacts of genetically modified crops on the agri-food sector.* Available on the World Wide Web: <http://europa.eu.int/comm/dgo61/publi/gmo/fullrep>.
- Falck-Zepeda, J., Traxler, G., and Nelson, R. (2000). Surplus distribution from the introduction of a biotechnology innovation. *American Journal of Agricultural Economics, 82*(5), 360–369.
- Fernandez-Cornejo, J., and McBride, W. (2002, May). *Adoption of bioengineered crops* (ERS Agricultural Economic Report No. 810). Washington, DC: USDA Economic Research Service.
- Fulton, M., and Keyowski, L. (1999). The producer benefits of herbicide-resistant canola. *AgBioForum, 2*(2), 85–93. Available on the World Wide Web: <http://www.agbioforum.org>.
- Gianessi, L., and Carpenter, J. (1999). *Agricultural biotechnology: Insect control benefits.* Washington, DC: National Center for Food and Agricultural Policy. Available on the World Wide Web: <http://www.ncfap.org>.
- Gianessi, L., and Carpenter, J. (2000). *Agricultural biotechnology: Benefits of transgenic soybeans.* Washington, DC: National Center for Food and Agricultural Policy. Available on the World Wide Web: <http://www.ncfap.org>.
- Gianessi, L., Silvers, C.S., Sankula, S., and Carpenter, J. (2002). *Plant biotechnology: Current and potential impact for improving pest management in U.S. agriculture.* Washington, DC: National Center for Food and Agricultural Policy. Available on the World Wide Web: <http://www.ncfap.org>.
- Gibson, J. W., Laughlin, D., Luttrell, R., Parker, D., Reed, J., and Harris, A. (1997). Comparison of costs and returns associated with Heliothis resistant Bt cotton to nonresistant varieties. *Proceedings of the Beltwide Cotton Conferences, 1*, 244–47. Memphis, TN: National Cotton Council.
- Harley, K. (1999). Unpublished farm level survey data. Raleigh, NC: North Carolina State University.
- Hart, K. (1999). Biotech crops do not improve yield or cut pesticide costs, USDA finds. *Pesticide and Toxic Chemical News, July 1*, 11–13.
- Jones, K., Kerby, T., Collins, H., Wofford, T., Bates, M., Presley, J., Burgess, J., Bueler, B., and Deaton, R. (1996). Performance of NuCOTN with Bollgard. *Proceedings of the Beltwide Cotton Conferences, 1*, 46–48. Memphis, TN: National Cotton Council.
- Karner, M., Goodson, J., and Hutson, A. (2000). *Bt cotton technology in Oklahoma: An overview* (OSU Current Report No. 7465). Stillwater, OK: Oklahoma State University.
- Layton, M.B., Stewart, S.D., Williams, M.R., and Long, J.S. (1999). Performance of Bt cotton in Mississippi, 1998. *Proceedings of the Beltwide Cotton Conferences, 2*, 942–45. Memphis, TN: National Cotton Council.
- Layton, M.B., Stewart, S.D., Williams, M.R., and Long, J.S. (1998). Performance of Bt cotton in Mississippi, 1997. *Proceedings of the Beltwide Cotton Conferences, 2*, 970–75. Memphis, TN: National Cotton Council.
- Magana-Magana, J.E., Garcia, J.G., Rodriguez, A.J.O., and Garcia, J.M.O. (1999). Comparative analysis of producing transgenic cotton varieties versus no transgenic variety in Delicias, Chihuahua, Mexico. *Proceedings of the Beltwide Cotton Conferences, 1*, 255–56. Memphis, TN: National Cotton Council.
- Marra, M.C. (2001). The farm level impacts of transgenic crops: A critical review of the evidence. In Philip Pardey (Ed.), *Agricultural Biotechnology: Markets and Policies in an International Setting* (chapter 8). Baltimore, MD: Johns Hopkins Press and International Food Policy Research Institute.
- Marra, M.C., Hubbell, B., and Carlson, G.A. (1997). Unpublished survey data. Raleigh, NC: North Carolina State University.
- May, L., Murdock, E.C., and Graham, R. (2000). Herbicide regime affects yield of Roundup Ready cotton cultivars [mimeo]. Clemson, SC: Clemson University.
- McVey, M., Pautsch, G., and Baumel, P. (1995). Estimated domestic producer and end user benefits from genetically modifying U.S. soybeans. *Journal of Production Agriculture, 8*(2), 209–14.
- Moschini, G., Lapan, H., and Sobolevsky, A. (1999). Trading technology as well as final products: Roundup Ready soybeans and welfare effects in the soybean complex. *The Shape of the Coming Agricultural Biotechnology Transformation: Strategic Investment and Policy Approaches from an Economic Perspective.* Proceedings of the Third Conference of the International Consortium on Agricultural Biotechnology Research, Rome, Italy.

- Mullins, J.W., and Mills, J.M. (1999). Economics of Bollgard versus non-Bollgard cotton in 1998. *Proceedings of the Beltwide Cotton Conferences*, 2, 958–61. Memphis, TN: National Cotton Council.
- Pioneer Hi-Bred International, Inc. (2000). Products and info: Canola. Available on the World Wide Web: <http://www.pioneer.com/australia/canola/44c71results>.
- Pray, C.E., Ma, D., Huang, J., and Qiao, F. (2001). Impact of Bt cotton in China. *World Development*, 29(5), 1-34.
- Qaim, M. (1998). *Transgenic virus resistant potatoes in Mexico: Potential social implications of North-South biotechnology transfer* (brief no. 7). Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications.
- Qaim, M. (1999). *The effects of genetically modified orphan commodities: Projections for sweet potato production in Kenya* (brief no. 13). Ithaca, NY: International Service for the Acquisition of Agri-Biotech Applications; Bonn, Germany: *Zentrum für Entwicklungsforschung* (ZEF) [Centre for Development Research].
- ReJesus, R.M., Greene, J.K., Hammig, M.D., and Curtis, C. (1997). Economic analysis of insect management strategies for transgenic Bt cotton production in South Carolina. *Proceedings of the Beltwide Cotton Conferences*, 1, 247–51. Memphis, TN: National Cotton Council.
- Rice, M., and Pilcher, C.D. (1998). Potential benefits and limitations of transgenic Bt corn for management of the European corn borer (Lepidoptera crambidae). *American Entomologist*, 44(1), 75–78.
- Slinsky, S.P., Edens, E.R., Larson, J.A., and Hayes, R.M. (1998). Evaluation of cost and returns for Roundup Ready cotton. *Proceedings of the Beltwide Cotton Conferences*, 1, 340–43. Memphis, TN: National Cotton Council.
- Sloderbeck, P., Buschman, L., Dumler, T., and Higgins, R. (1999). Bt corn and Non-Bt corn refuges: How do the economics pencil out? [mimeo]. Manhattan, KS: Kansas State University.
- Smyth, S., Khachatourians, G.G., and Phillips, P. (2002). Liabilities and economics of transgenic crops. *Nature Biotechnology*, 20(June), 537-541.
- Snow, A.A. (2002). Transgenic crops—why gene flow matters. *Nature Biotechnology*, 20(June), 542.
- Speed, T.R., and Ferreira, K.L. (1998). Performance of PM 2326RR and PM 2200RR on the Texas High Plains: A two-year summary. *Proceedings of the Beltwide Cotton Conferences*, 1, 565–66. Memphis, TN: National Cotton Council.
- Stark Jr., C.R. (1997). Economics of transgenic cotton: Some indications based on Georgia producers. *Proceedings of the Beltwide Cotton Conferences*, 1, 251–53. Memphis, TN: National Cotton Council.
- Traxler, G., and Falck-Zepeda, J. (1999). The distribution of benefits from the introduction of transgenic cotton varieties. *AgBioForum*, 2(2), 94-98. Available on the World Wide Web: <http://www.agbioforum.org>.
- United States Department of Agriculture Economic Research Service. (1999). *Genetically engineered crops for pest management*. Available on the World Wide Web: <http://www.econ.ag.gov/whatsnew/issues/biotech/index.htm>.
- United States Department of Agriculture National Agricultural Statistics Service. (Various years). *Crop Production*. Washington, DC: USDA NASS.
- Wier, A.T., Mullins, J.W., and Mills, J.M. (1998). Bollgard cotton: Update and economic comparisons including new varieties. *Proceedings of the Beltwide Cotton Conferences*, 2, 1039–40. Memphis, TN: National Cotton Council.
- Wilcut, J., Askew, S., Brecke, B., Bridges, D., Brown, S., Chandler, J., Hayes, R., Kendig, J., Miller, D., Nichols, R., and Snipes, C. (1999). A beltwide evaluation of weed management in transgenic and non-transgenic cotton. *Proceedings of the Beltwide Cotton Conferences*, 1, 746–47. Memphis, TN: National Cotton Council.
- Wolfenbarger, L., and Phifer, P. (2000). The ecological risks and benefits of genetically engineered plants. *Science*, 290(5499), 2088–93.
- York, A., and Culpepper, A. (1999). Economics of weed management systems in BXN, Roundup Ready, and conventional cotton. *Proceedings of the Beltwide Cotton Conferences*, 1, 744–45. Memphis, TN: National Cotton Council.

About the Authors

Marra is a Professor in the Department of Agricultural and Resource Economics at North Carolina State University, Pardey is a Professor in the Department of Applied Economics (formerly at the International Food Policy Research Institute when this paper was mainly written), University of Minnesota, and Alston is a Professor in the Department of Agricultural and Resource Economics at the University of California, Davis, and a member of the Giannini Foundation of Agricultural Economics. The authors thank Alice Kassens, Bailey Norwood, and Patricia Zambrano for their very able research assistance and the Swedish International Development Agency (Sida), the International Food Policy Research Institute, and the NSF Center for Integrated Pest Management for providing the funds to carry out this research.