Transgenic Technology for Crop Protection

The New "Super Seeds"

by Gerald Carlson, Michele Marra, and Bryan Hubbell

A new biotech revolution is sweeping through agriculture. With it comes enormous potential benefits, but also some potential problems, as a quick reading of the popular press readily shows:

> The new maize contains a gene from a widespread soil bacterium, *Bacillus thuringiensis* (Bt), which makes it resistant to the European corn borer, an insect pest which damages millions of hectares of the crop each year. It has been approved by regulators in a number of countries, including America, Canada and Japan, but in the European Union (EU), where environmental lobby groups have decried it as a "mutant," regulators have so far refused to allow it to be used. ...the EU will be faced with an awkward decision: either to ban all American maize imports (and start a trade war), or to permit the sale of a product which cannot be grown locally.
>
> (*The Economist,* 14–20 September 1996, p. 82).

> This year, for the first time, farmers have planted millions of commercial acres of genetically altered cotton, soybeans, corn and potatoes. The technology has worked surprisingly well, promising a new era of higher yields at lower cost. It is also triggering a stampede for Monsanto's so-called Roundup Ready soybeans and pest-resistant cotton, vindicating the company's years of investment in biotechnology.
>
> (*Wall Street Journal,* 24 October 1996, p. 1).

> Adoption of Roundup Ready soybeans has the potential to decrease herbicide use on soybeans by as much as one-third.
>
> (Monsanto press release, 24 September 1996, pp. 1–2)

> The bollworm dealt an unexpected blow to *Bacillus thuringiensis* cotton this season. Initial reports of bollworm infestations in the premium-priced cotton came from the Brazos Bottom area of Texas.... Did Monsanto promise more than it could deliver with Bollgard?
>
> (*Progressive Farmer Online,* 18 September 1996)

Here we summarize the latest information on the new super seeds, focusing on increased productivity, adoption potential, organization issues for the seed/agri-biotechnology/pesticide industry, and potential external effects of the new technologies. Finally, we offer some economic implications of this new biotechnology for agriculture.

Productivity effects

Bt corn

Overview. Bt corn is a plant which has *Bacillus thuringiensis* (Bt) toxins in many of its cells. This naturally occuring soil bacterium will control insect pests that feed on the plant. The new transgenic corn seed increases yield in regions where European corn borer (ECB) would reduce output. This insect is not well controlled by conventional insecticides because it is sporadic over time and space, and insects are shielded from sprays by boring into stalks. Experiments and field tests have shown that Bt corn plants will reduce ECB damage by about 95 percent, and this will translate into a 4–8 percent increase in yield (Koziel et al.), depending on ECB density.

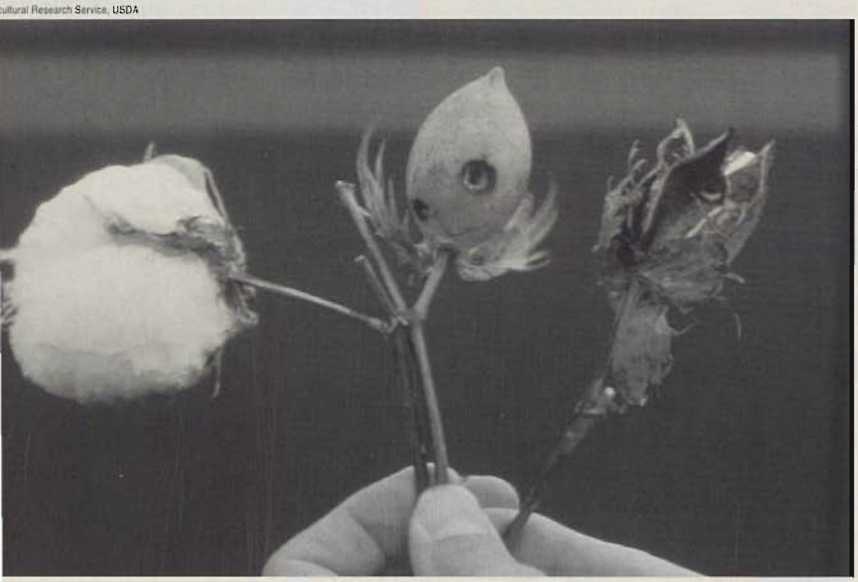
The 1996 experience. Mycogen and Ciba Seeds sold all seed permitted to be sold by the Environmental Protection Agency (EPA) (500,000 acres) at a cost premium of about $10 per acre, or a 30 percent increase in seed cost. ECB levels were lower than normal in many areas, so although Bt corn provided insurance in a year with relatively high corn price, protection values were probably lower than for the average year.

Prospects for 1997 and beyond. There are four genetically different Bt corn products being sold in 1997. EPA approval of sales by Monsanto, Northrup King, and DeKalb has quickly changed the availability of Bt incorporated into desirable corn hybrids. Seed supply may be sufficient for 6–8 million acres in 1997, but the price premium ($11 per acre) may prevent all available seed from being sold. Universal acceptance of the technology for a 30 percent seed price premium seems unlikely. The 1994 analysis by Ciba Seeds projected adoption on about 50–70 percent of all corn acreage with a seed cost premium of about 20 percent over the course of about five years of full seed supply.

Roundup-Ready soybeans

Overview. In contrast to Bt corn, the glyphosate-tolerant soybeans (Roundup Ready, RR) will not provide pest control without pesticides. This combination pesticide/seed provides a change in weed management from several applications of several active ingredients to a single application of one broad-spectrum herbicide. This technology will lower weed control expenditures, but will slightly increase seed costs. Farmers who use the new soybean seeds must, by agreement, not save and use their own seed and use certain herbicide practices.

...ultural Research Service, USDA



Mature cotton boll at left was protected by a gene for Bt; other bolls show damage from cotton pests.

The 1996 experience. The 1996 use of RR soybeans was slightly more extensive than Bt corn because seed was available for about one million acres. Monsanto, the patent holder, charged a technology fee of $5 per acre. There is considerable interest in this technology because it reduced average weed control costs from about $25–$30 for conventional herbicides to $18 per acre—$13 for Roundup and $5 for the technology fee (Fritsch and Kilman). The ability to spray soybeans with Roundup allows farmers to reduce preemergence herbicide applications, avoid some cultivations, and plant soybeans in narrower rows, thereby further crowding out weeds.

Prospects for 1997 and beyond. Seed companies rapidly expanded RR seed production during 1996. Seed for 8–10 million acres, about 20 percent of the soybean crop, was available in 1997 from seed companies working under licenses or agreements with the patent holder (Fritsch and Kilman). Acceptance of the soybeans in export markets has been approved, except in small parts of the European market. (However see the discussion below on possible export restrictions.) The higher cost associated with farmers not being able to save and use their own soybean seed and some additional costs related to the requirement that Roundup must be applied to RR soybeans may restrict adoption somewhat.

Tolerance for other herbicides, including a glyphosate substitute, glufosinate (Liberty), is being pursued rapidly in corn, soybeans, cotton, and other crops. A combination of Bt and herbicide tolerance in the same crop seed has been in process by Dekalb and other seed companies and is available in some cotton varieties this year (Monsanto). Achieving desired trait expression in commercial varieties now proceeds at a pace many times faster than development of the first transgenetic changes.

Bt cotton

Overview. The Bt insecticide, as that contained in the corn seed, is used to reduce insect damage from bollworm, pink bollworm, and budworm. This technology may sharply reduce conventional insecticide use. However, because the Bt toxin is highly effective, insect resistance may develop in a short period, rendering Bt less useful for some insect species of cotton and other crops. To prevent new resistance, the EPA has mandated that a resistance management program be put in place. For 1996, this took the form of either 3.85 percent of each field planted to non-Bt cotton and left untreated with insecticides, or 20 percent of the field planted with non-Bt cotton and use of insecticides other than foliar Bt, along with insect resistance monitoring.

The 1996 experience. Because of resistance development to conventional cotton insecticides in the 1990s, there was considerable interest in Bt cotton. In 1996, Bt cotton seed was planted on over 5,700 farms, or 1.8 million acres (Barton). Farmers paid the $32 per acre technology fee to the patent holder, Monsanto; a seed price premium of about $1.50 per acre; and the opportunity costs of providing the resistance management areas. There were no restrictions on cotton fiber or cottonseed sales. As the *Progressive Farmer* quote above indicates, there were problems with this technology in some regions, as high bollworm and budworm populations led to cotton boll losses. Other areas experienced lower insecticide use and good levels of insect control (Fritsch and Kilman). A survey of eighty-nine Bt cotton users showed an average yield increase of 7 percent compared with conventional cotton (Barton). In addition to the direct insecticide savings, Bt cotton decreased insecticide use which increased beneficial insect numbers, thereby reducing the costs of controlling other pest types (Smith).

Prospects for 1997 and beyond. Like past insect control technologies, this one will require management and understanding. The cotton fruit are exposed for a long period to many potential insect types. The technology fee is high relative to that for soybeans and corn, but the potential insecticide reduction is also larger. The seed technology fees will partially support development of second-generation products which are introduced as pests become resistant, or improvements are made. Bt cotton was not widely adopted in some areas. North Carolina's cotton farmers used it on only 3% of cotton acreage in 1996. Consequently, discounts of $10 per acre on the technology fee were offered on the first 50 acres per farm at the beginning of the 1997 season (J.R. Bradley, professor of entomology, North Carolina State University, personal communication, April 1997).

Adoption issues

Who will adopt?

Following previous work on adoption, the early adopters should be farmers with high pesticide costs, those suffering from higher pest damage, and those who can better utilize other inputs which are complementary to the transgenic crops.

Usually, we think of early adopters of agricultural production technologies as those having more human capital, but this result may not hold in the case of transgenic crops. The transgenic crops seem to be easier to manage than the current crop/pest control methods. The pesticide spray decision is either irrelevant or simpler in the case of the Bt crops, and glyphosate-tolerant crops require only one spray and have a wider application window in most cases. So early adopters may include those with lower-than-average skills for managing variable pest populations. However, skilled managers can be expected to assess the profitability of the technology better in marginal cases, assimilate more information on local suitability of seeds, and process more complex information on multiple (transgenic and other) traits of seeds. Likewise, farmers with larger crop acreage will appreciate the lower management time requirements and may be among the early adopters.

Where will adoption occur?

It seems reasonable to expect areas with higher pest infestations and more severe resistance problems to be early targets for seed development and farmer adoption. For cotton, bollworm and budworm resistance to pyrethroid insecticides has been particularly acute in the Midsouth region. The Colorado potato beetle is resistant to many types of insecticides used in potato production in the eastern states. These were areas of widespread adoption in 1996.

European corn borer populations are sporadic over years and regions; however, they are more frequent pests in the western Corn Belt. There are usually two generations of this pest per season, and Bt corn seems effective against both generations. Crop value protected is highest in the high-yield, irrigated corn regions of the Plains states. Spatial availability of Bt corn seed is affected in 1997 since the EPA limited total sales in cotton-producing counties to help prevent resistance development for the corn ear-

Agricultural Research Service

Entomologist Hollis Flint compares an insect-ravaged cotton leaf from a control variety with one that has been genetically engineered with a protective gene from *Bacillus thuringiensis*.

worm. In addition, European restrictions on Bt corn imports, brought on by consumer safety concerns, may limit adoption in some regions.

Glyphosate is an effective broad-spectrum herbicide against both broadleafs and grasses. Roundup Ready soybeans should be adopted first in production zones where this weed combination requires a relatively high degree of control, such as in most areas of the South. Glyphosate and glufosinate can be used as burn-down herbicides in reduced-tillage systems. Farmers practicing no-till are likely adopters. Likewise, broad-spectrum herbicides with low cost may fit the weed spectrum on land coming out of CRP, and Roundup Ready crops may be widely adopted on these lands.

What crops and technologies are being tested?

The crops and genetic traits now being field tested provide an indirect picture of what to expect in the next three to five years. Figure 1 shows USDA Animal and Plant Health Inspection Service (APHIS) data on numbers of separate field trials of genetic products by transgene category. These trials are approved by APHIS and conducted by the private seed/pesticide companies or by university contractees. Herbicide tolerance, insect resistance, and product quality account for most of the growth in tests. However, the growing work on virus and fungus resistance is an important new trend. Even testing of pharmaceutical and industrial properties (such as plastic producing cotton) began to appear in 1994.

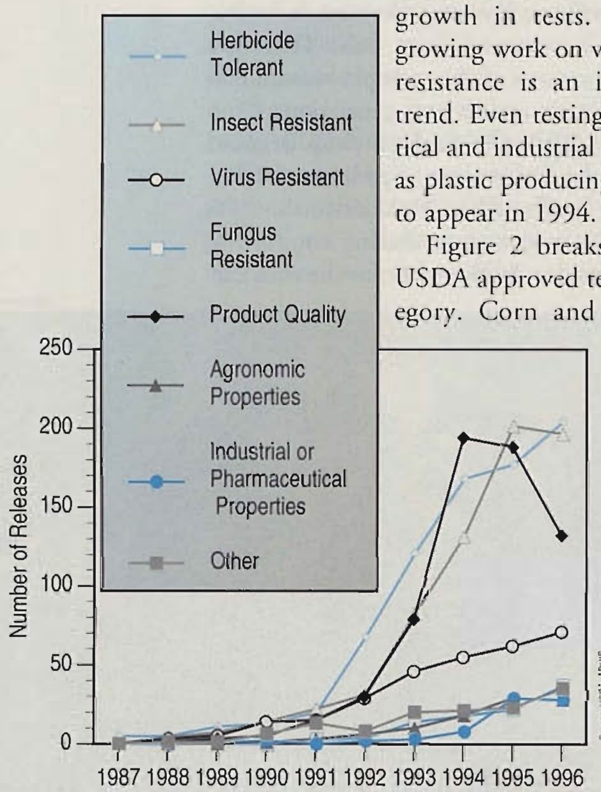


Figure 1. Trends in field releases by transgene category

Figure 2 breaks out the same USDA approved tests by crop category. Corn and vegetables account for most of the tests since 1993. Interestingly, the number of tests on cotton, corn, and soybeans declined in 1996. Almost half of all field tests for herbicide tolerance was conducted on corn during 1996 (USDA).

Table 1 shows a more direct picture of what may lie ahead in transgenic technology. Monsanto plans to increase its offerings of crops and genetic traits. These new products will use multiple genes for herbicide tolerance and insect control in the same plant, and second generation Bt proteins to combat insect resistance.

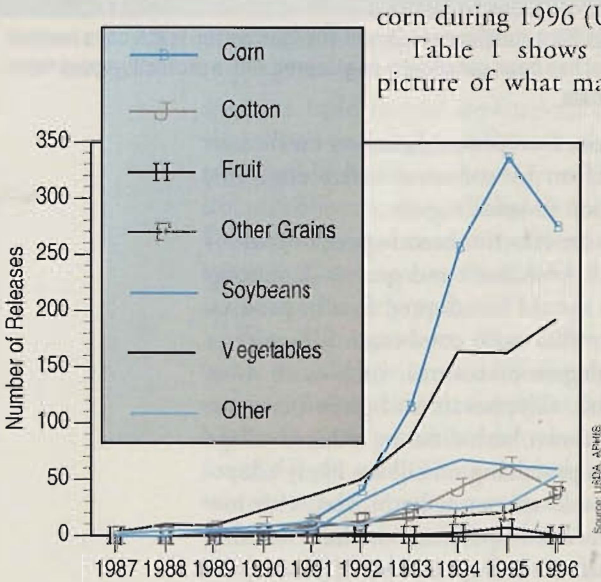


Figure 2. Trends in field releases by crop category

Aggregate supply and adoption

Roundup Ready soybeans may prove to have a comparative advantage over other crops such as corn. The pest control cost savings with little change in yield could make these beans more profitable than corn at prevailing output prices. Therefore, some regions may experience an acreage shift from corn to soybeans, particularly in the South where corn yields are much lower than in the Midwest.

The availability of transgenic seeds for other growing regions of the world will surely come. Monsanto, with Delta and Pine Land Seed, will sell Bt cotton seed in China in 1998, and Australia will slowly increase its Bt cotton over the next few years (Monsanto). U.S. farmers may have a few years of lead time in the biotech crops over their competitors and may see a short-run gain in crop export shares.

Organization of the seed/pesticide industry

Different industrial structures usually evolve when dramatic technological changes occur. Crop germplasm and pesticide supply need closer coordination with the transgenic crops than with conventional pesticides and crop varieties. Biotech firms will take organizational and marketing steps to improve scale economies, expand sales of the new technologies, and increase profits.

Pesticide and seed industry firms are making many different organizational and marketing changes. Some examples are listed in table 2, with few firms involved with the actions at the top of the list and more market-oriented strategies at the bottom. Acquisitions and mergers are self-explanatory, but the purchase of genetic resources may involve purchase of patents, research expertise, or access to gene libraries. In some cases seed companies make the purchases, and in others the pesticide firm has been the purchaser.

Exclusive agreements restrict the spread of genetic resources more than nonexclusive licenses or agreements. However, the exclusive agreement can allow access to marketing and other resources as well as genetic ones. Access to local seed producers who tailor varieties to local growing conditions will remain important. The "low-cost seeds" strategy is novel for agriculture, but analogous to the strategy of software companies giving away products to developers so that a product can become widely used and seen as an industry standard. The technology fee charged to final users is relatively new in agricultural input industries but is used so farmers know the component prices of the genetic traits. The combining of technology fee and seed price represents the traditional pricing of genetic improvement. The tie-in sales strategy is only possible if a firm has some control over the two products—in this case the herbicide and the herbicide-tolerant crop seeds. Regional price discrimination promotes early adoption by charging a lower price where demand is more elastic and can be used effectively only with region-specific varieties.

The above actions tend to convert separate seed and pesticide industries into a combined industry (Seghal). Not all of the agreements and relationships are friendly. Conflicts arise as private firms attempt to rapidly enter these markets and keep others out. Currently, there are eight major lawsuits involving use of Bt. A recent edition of the *Information Systems for Biotechnology News Report* outlines the major issues and parties involved in these suits (Klein).

The primary role of the public sector in the deployment of the new seeds has been to oversee public safety. USDA's APHIS must approve initial field tests of new genes. The EPA under its pesticide authority must approve commercial use of "plant pesticides," and it has assumed the role of approving the commercial release of transgenic seeds. For example, the EPA has limited Bt corn sales and placed geographical restrictions on deployment of the Bt technologies to prevent resistance development. Reduction or delay of onset of negative external effects is the most credible rationale for these government interventions.

Table 1. Planned transgenic crop introductions by Monsanto Corporation

Expected Launch Year	Transgenic Crop
1997	Insect-protected tomatoes Insect- and Y-virus-protected potatoes RR cotton Bt corn RR and Bt cotton
1998	Insect- and virus-protected potatoes RR corn BXN herbicide-tolerant and Bt cotton
1999	RR oilseed rape Second generation Bt cotton Virus-protected tomatoes
2000	Insect-protected corn (corn rootworm) RR sugar beets
2001	Disease-controlled potatoes (fungal diseases)
2002	Boll weevil-protected cotton Disease-controlled strawberries
2003+	Higher-yielding corn Improved-quality potatoes Naturally colored cotton

Source: 1996 Monsanto Annual Report
Note: Commercialization depends on the successful completion of such factors as research, field trials, and regulatory approval.

Table 2. Organizational and marketing changes in the pesticide/seed industries related to transgenic crops

Strategies	Examples (Affected Transgenic Crops[a])
Organizational	
Acquisitions	Monsanto acquires Calgene, Asgrow, Agricetus (1, 2, 3)
Mergers	Ciba and Sandoz become Novartis (Ciba Seeds and Northrup King) (1)
Purchase genetic resources	Pioneer acquires gene libraries from Mycogen (1)
Marketing	
Exclusive sales agreement	Monsanto and Delta and Pine Land (2)
Nonexclusive licenses	Mycogen and Cargill and other seed companies (1)
Distributing seeds at low cost	Agro Evo and most corn seed companies (4)
Separate technology fee	Monsanto (1, 2, 3), DeKalb (1)
Combined seed and technology pricing	Novartis (1)
Tie-in sales	Monsanto and farmer licensees (3, 5)
Regional price discrimination	Monsanto (2)

[a] 1 = Bt corn, 2 = Bt cotton, 3 = Roundup Ready soybeans, 4 = Liberty Link corn, 5 = Roundup Ready and Bt cotton.

Potential externalities

Transgenic crops present two major types of negative external effects: (*a*) more rapid deployment of resistance in pests which damages both the target crop and surrounding crops, and (*b*) possible toxins in food produced from these genetically altered crops. Other safety concerns include development of herbicide tolerance in weedy relatives of the transgenic crops, spread of pesticide tolerance to bacteria or other human pests, and spread of allergens.

Observers often overlook the positive externalities associated with the new seeds and associated pest management. The new seeds will reduce resistance development to conventional pesticides thereby reducing the future dosages required to achieve acceptable control and the cost of replacing these now less effective chemicals. This affects pest control on both the transgenic crop and on other crops which these pests attack. The new seeds may also reduce negative external effects as amounts, movement, exposure, and toxicities of conventional pesticides are reduced. There is some evidence that Bt toxins will reduce crop problems, such as microtoxins on corn, in addition to the ECB. In some Bt cotton fields in 1996, beneficial insect populations increased because of farmers' reduced insecticide sprays (Smith, Wilkins). Transgenic crops may also reduce the run-off from foliar-applied relative to soil-applied herbicides. Transgenic crops may encourage the adoption of complementary, environmentally friendly techniques, such as conservation tillage, that reduce run-off problems. And finally, transgenic crops may enhance existing area-wide pest management strategies such as the boll weevil eradication program (Smith).

Europe has the most pronounced commitment, presumably to protect consumers, against genetically altered crops. Consumer and farm interest groups and government leaders have discussed mandatory labeling and import bans. Limited exports of RR soybeans to the EU were approved in the summer of 1996, but Bt corn is facing stiff opposition. Environmental groups, including the Union of Concerned Scientists, Jeremy Rifkin, the Consumers Union, and Greenpeace, have been vocal in their criticism of transgenic crops.

Several approaches might be used to address food safety concerns, including import bans, mandatory labeling, voluntary labeling of unaltered products, deployment in limited quantities, information on relative toxicity, and product price discounts for genetically altered foods. In the United States, mandatory labels are required by the Food and Drug Administration only if the product contains a known allergen or has a composition significantly different than the standard crop (such as high-laurate canola).

Approaches for reducing externalities and transaction costs require more information on risks and benefits, and this seems to be a shortcoming at this time. Some of the approaches will have substantial costs; for example, mandatory labels necessitate separate marketing channels for biotech crops. Mandatory resistance management programs impose costs on farmers and seed/pesticide firms. Resistance management costs may exceed benefits if new transgenic versions of crops are forthcoming. On the other hand, the Consumers Union claims that Monsanto's resistance management plan (a high dose of Bt in the plant plus the refugia set-asides) failed against the cotton bollworm in 1996. They argue further that the EPA must act immediately to restrict plantings of Bt cotton to only the modest experimental plots required to continue research on resistance management (Benbrook and Hansen).

Summing up

These seed technologies, while not silver bullets in pest control, do expand the pest management arsenal through both substitute and complement relations to existing pest control approaches. The crop protection experience with the new traits will provide information about the technical and economic potential for other traits, for other crops, and for many regions of the world. The organizational structures being adopted in the seed/pesticide industries are helpful for rapid tailoring and marketing of these products to heterogeneous production areas. The external effects related to transgenic crops are both positive and negative and point to the potential demand for more consumer education and economic evaluation. Because these technologies are output expanding, and may lower costs of production for export crops, there may be lower food and fiber costs without decreasing U.S. farm income.

Gerald Carlson and Michele Marra are professor and associate professor, respectively, in the Department of Agricultural and Resource Economics at North Carolina State University. Bryan Hubbell is assistant professor in the Department of Agricultural and Applied Economics at the University of Georgia.

■ For more information

Barton, G. "Bollgard™ Cotton Update." Monsanto Corp., St. Louis MO, March 1997. Available online: http://www.monsanto.com/MonPub/InTheNews/Articles/97-03-20BollgardUpdate.html/

Benbrook, C., and M. Hansen. "Return to the Stone-Age of Pest Management." Remarks before EPA public meeting on behalf of the Consumers Union, March 1997. Available online: http://www.pmac.net/stoneage.htm/

Fritsch, P., and S. Kilman. "Seed Money: Huge Biotech Harvest Is a Boon for Farmers—and Monsanto." *Wall Street Journal.* New York: Dow Jones and Co., 24 October 1996.

Klein, J. "Litigating Bt Patents for Market Share." Information Systems for Biotechnology (ISB) News Report, April 1997. Available online: http://www.nbiap.vt.edu/news/1997/news.rpt

Koziel, M.G., et al. "Field Performance of Elite Transgenic Maize Plants Expressing an Insecticidal Protein Derived from Bacillus thuringiencis, 1993." *Bio/Technology* 4(1993):194–200.

Monsanto Corp. 1996 Annual Report, St. Louis, MO.

Seghal, S. "Patents Are Driving the Restructuring of the Seed Industry." *Seeds and Crop Digest,* November 1996.

Smith, R. "Alabama's Bollgard Gamble a Good Bet." *Southeast Farm Press,* Raleigh NC, 18 September 1996.

U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service (APHIS). Biotechnology Permit Database. Washington DC, various years. Available online: http://www.aphis.usda.gov/bbep/bp/

Wilkins, T. "Performance of Bt Cotton: Status Report." *Cotton Rev.* 41(1997). Available online: http://www.uckac.edu/danrscr/Vol.41.htm/