Special Article

U.S. Farmers Are Rapidly Adopting Biotech Crops

In just the last few years, adoption of genetically modified crop varieties has increased dramatically among several mainstays of U.S. agriculture—corn, soybeans, and cotton. Farmers have voted resoundingly in favor of the new crops as acreage soared to about 50 million in the 3 short years since commercial introduction. Further gains in acreage are expected in the years ahead. Research is also underway on genetically modified wheat, but commercial introduction is several steps away.

The new crop varieties currently being grown feature resistance to pests and the ability to tolerate herbicides. Farmers' rapidfire adoption of these varieties has been propelled by potential cost savings, including reductions in input use, although adoption has been so rapid and the technology is so new that only limited assessment of the economic impact has been made. Likewise, environmental pros and cons are being raised by proponents and critics.

Input traits such as pest resistance and herbicide tolerance represent the "first wave" of the new agricultural biotechnology, offering advantages to farmers in the production phase without changing the final product. The second wave of genetic modification will focus on output traits such as improved nutritional features and processing characteristics. More of these crops will be available commercially in the next few years.

The first generation of genetically modified (GM) crops has the potential to increase farmers' net returns through savings in production costs, reductions in chemical use, increased flexibility in crops planted, and in some cases, yield advantages. As farmers perceive benefits of the technology to outweigh the costs, growers' adoption of insect-resistant and herbicide-tolerant crops is spreading at a rapid pace.

Development of genetically modified organisms (GMO's) is an advance over conventional breeding techniques, which crossed similar plants or animals to create new varieties. Modern biotechnology, which includes genetic modification, applies cellular and molecular biology to expand the range of traits found in plants, animals, and microorganisms. Bt corn, for example, is enhanced with a gene from a naturally occurring soil bacterium


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(*Bacillus thuringiensis*) to produce proteins that kill specific groups of insects.

Much of the research on genetically modified organisms began in the 1980's. It took a number of years before the altered crop varieties were ready for the market. In contrast, commercialization has been rapid, partly because the testing and approval process in the U.S. is relatively rapid, especially compared with Europe. In the U.S., the genetically modified crops on the market have been approved by USDA's Animal and Plant Health Inspection Service (APHIS), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA).

Genetically modified crops reflect very substantial investments, largely by private sector firms. These new varieties are proprietary, and farmers pay a premium for the seed. The technology is generally available through many seed companies. For some products, the premium paid by farmers covers a technology fee that goes to the company that developed the technology. These firms have begun devising arrangements that respect intellectual property rights, which are critical in providing incentives to invest and develop products. Many major companies that develop and patent the technology are merging, acquiring, or forming alliances with seed companies.

Currently available genetically modified crops should have little or no direct impact on prices received by farmers, assuming the varieties are accepted by consumers and by other countries. This is because the products are basically indistinguishable from con-

USDA does not make official estimates of acreage or production of genetically modified varieties—the data are included in the total estimates for the various crops. The numbers cited here were developed from industry sources, and are not official USDA data. Information on the cost and effectiveness of the various genetically modified crop varieties is drawn largely from private-sector sources and from universities. Use of brand names in the article is for identification of products, and does not constitute an endorsement of any product.

ventional crops. Output traits, on the other hand, will enhance the value of the crops for end-users, with more pronounced effects on pricing and marketing.

The adoption of genetically modified crops also has implications for trade because other countries, and notably the European Union (EU), have lagged the U.S. in approval of GMO's and in the development of regulations. Most trading partners have placed no restrictions on GMO imports from the U.S., but roadblocks have been encountered in the EU because of the slowness of the approval process as well as consumer concerns.

For a relatively small group of U.S. consumers and in some foreign markets, a niche market for non-GMO products may develop, similar to the present market for organic foods, that will involve identity-preserved production and marketing.

Major New Pest-Resistant & Herbicide-Tolerant Crops

Herbicide-Tolerant Oilseeds. Insertion of a single gene, derived from a common soil microorganism, makes soybeans immune to glyphosate, the active ingredient of Monsanto's Roundup herbicide. In 1996, the first year of commercial production, U.S. farmers harvested about 1 million acres of genetically modified, glyphosate-tolerant soybeans. By 1997, as seed became available in most producing regions, about 9 million acres were grown. U.S. farmers are expected to harvest more than 20 million acres this year, about 30 percent of total soybean acreage, and by the year 2000, more than half could be planted to varieties with this gene. Another soybean variety that is near U.S. commercialization is resistant to an alternative herbicide, glufosinate ammonium (Liberty), which differs from glyphosate in some features.

This technology is also being enthusiastically adopted by other world producers, including Argentina and Canada. In Brazil, the world's second-largest soybean producer, the government is likely to grant permission to raise herbicide-tolerant soybeans soon, and the outlook for adoption by farmers is very favorable (Monsanto predicts 20-30 percent use within 2 to 3 years after commercialization in Brazil). Imports of genetically modified soybeans for crushing are allowed into Brazil on condition that the resulting meal and oil be re-exported.

Why have farmers so enthusiastically adopted herbicide-tolerant soybean varieties? The higher cost of the seed is reportedly offset by a reduction in input costs. When planting Roundup Ready (glyphosate-tolerant) soybeans, for example, most farmers can limit herbicide treatment to a single application of Roundup shortly after the crop emerges from the soil, while the conventional herbicide program can involve multiple applications of several types of weed killers. Using glyphosate-tolerant soybeans, farmers can cut chemical costs by 10-40 percent, depending on the region and on the farmer's management practices.

Other oilseeds such as sunflowers, canola, and flax are also being genetically altered for herbicide tolerance. With no broad-spectrum weed control previously used for canola, yields of this crop have risen when the new varieties were planted. Canada preceded the U.S. in adopting herbicide-tolerant canola, planting 4 million acres by 1997. In 1998, nearly half of Canada's canola area (about 6.5 million acres) is expected to be seeded to herbicide-tolerant varieties. Glufosinate-tolerant canola was approved for U.S. producers in early 1998.

Bt and Herbicide-Tolerant Corn. Bt corn is designed to resist damage from the European corn borer (ECB), a major insect pest in the Corn Belt. Because the borer tunnels inside the stalk, the impact is not always readily apparent until damage has occurred. Bt corn, while resistant to specific groups of insects such as the corn borer, has not been shown to have a direct effect on beneficial insects.

Bt corn was first approved for sale in 1996, and use expanded greatly in 1997. Acreage has increased sharply in 1998, with the Bt trait incorporated into an increasing number of hybrids. Industry sources indicate Bt corn could be planted on 15-18 million acres in 1998 (about 20 percent of U.S. corn acreage), up from less than 5 million acres in 1997.

Because of the difficulty in predicting infestation and in properly timing treatment, the effectiveness of spraying had been mixed. Moreover, not all farmers who grow Bt corn treated their fields previously to control the corn borer. Given the indications of favorable yield, many farmers who had not previously sprayed for corn borer are apparently planting Bt corn to protect the crop against heavy infestations, and the higher yields can offset the added seed costs.

Results have generally been very positive in terms of protection from borer damage, compared with non-Bt corn in adjacent areas. However, yield performance was dependent on the particular hybrid. Where infestation was very heavy, yields of Bt corn varieties in some areas were dramatically higher than non-Bt corn.

The next major pest control feature would target the rootworm. This technology will be introduced in the next 2 or 3 years, and market prospects look promising. The industry is also working on disease resistance. Moreover, the industry expects further improvement in yield results as Bt becomes available with more elite germplasm.

Outside the U.S., some major corn producers, including Brazil and Argentina, are expected to grow Bt corn in the near future. European growers are also expressing strong interest in Bt corn, but political barriers in the EU could cloud the outlook.

Herbicide-tolerant corn is now on the market, including varieties that tolerate popular herbicides based on glyphosate (Roundup Ready corn), on glufosinate ammonium (Liberty Link corn), and on imidazolinone (IMI corn). Some herbicide-tolerant corn has also been developed through conventional breeding. For 1998, seed is available for more than 7 million acres of IMI corn, over 6 million acres of Liberty Link corn, and 900,000 acres of Roundup Ready corn.

Farmers' response to herbicide-tolerant corn is more complicated than for insect-resistant varieties such as Bt corn. Weed problems tend to be more varied, both by geography and by year. Usefulness and performance of herbicide-tolerant corn will vary by region and management practice. In areas where conventional tillage is more common, weed control may be less dependent on herbicide use, making adoption of herbicide-tolerant corn less likely.

Bt and Herbicide-Tolerant Cotton. Adoption of genetically modified cotton is expanding rapidly, although the experiences of farmers vary and have not been without problems. Genetically modified cotton is available with insect-resistant and herbicide-tolerant traits, and some varieties combine the two traits. Adoption should continue to grow as farmers learn how to manage these varieties and as seed developers offer new varieties.

In 1996, a genetically engineered cotton, Bollgard, became available commercially. This Bt cotton was developed to control the tobacco budworm and bollworm and reduce the amount of insecticides needed.

Producer response to Bt cotton was mixed, with positive outweighing negative, according to a paper presented at the Beltwide Cotton Production Conference in January 1997. In a 1996 Monsanto survey of about four-fifths of the producers using Bollgard, about 80 percent of the surveyed producers were satisfied. Monsanto reported that U.S. growers using Bt varieties realized a modest yield increase over non-Bt cotton and that there was a decline in the use of insecticides. While overall insecticide use is expected to decline with Bt varieties, many factors affect the performance of any genetically modified crops: seed varieties, insect levels, weather, and other environmental conditions. For example, in 1996, some Texas producers using Bt cotton where insect infestation was unusually high claimed losses from cotton bollworm damage on 18,000 acres.

Producers are beginning to understand that use of Bt cotton does not eliminate all necessary pest management practices and that continued monitoring of insect activity is necessary. Given heavy insect infestations, some insecticide spraying may still be needed to achieve adequate control.

Roundup Ready cotton was introduced commercially in 1997, as well as limited quantities of varieties that combined genes containing both Roundup Ready and Bollgard Bt. Overall, results from Roundup Ready cotton appear favorable. However, some producers in the Mississippi Delta and in Texas reported some losses from bollworm damage with herbicide-tolerant cotton, which was attributed to possible interactions of many factors such as weather, management practices, and the particular crop variety used.

A subsequent article will focus on genetically modified crops that feature output traits such as nutritional attributes.

Calgene markets a genetically engineered product—BXN cottonseed—resistant to the herbicide Bromoxynil. Producers have reported favorable results. Calgene plans to introduce cotton varieties containing both the BXN and Bt gene in 1998.

Producers planted genetically modified cotton (mainly Bollgard) on about 13 percent of U.S. cotton acreage in 1996, or about 1.9 million acres. In 1997, about 25 percent of U.S. cotton acreage, approximately 3.4 million acres, was planted to genetically modified cotton. Industry expectations are for continued growth in GM cotton in 1998.

Future plans are to develop additional tolerances of insects, diseases, and nematodes, and to incorporate genes designed to improve yield, harvestability, and drought and salt tolerance of cotton. In addition, as for other crops, the next wave will add output traits—e.g., fiber qualities including natural colors that eliminate the need for chemical dyes.

Adoption of GM varieties by competitor nations is underway. Monsanto introduced genetically modified cotton to Australia in 1996. Bt cotton has also been sold in Mexico and China, and efforts are underway for sales in Argentina, South Africa, and Brazil.

An Early Assessment Of the New Technology

In addition to cost savings, an incentive to adopt any new technology is convenience. Pest-resistant crops can reduce management tasks by, for example, reducing pest scouting needs and eliminating insecticide use. Incentives for using herbicide-tolerant crops are also strong, as growers can simplify their herbicide use and often reduce the number of applications of the targeted chemicals. On the other hand, as new herbicide-tolerant crops proliferate, farmers will need to keep track of which herbicides can or cannot be applied to a particular crop.

Most of the new technology introduced so far is not aimed explicitly at increasing yields. However, some of the new corn products will effectively boost yields by cutting losses to pests or weeds, protecting the yield potential of the particular hybrid. Benefits will vary from year to year and over different locations, depending on environmental factors such as the level of pest infestation that may have otherwise lowered yields.

Because there is no solid estimate on yield loss at the national level due to pest damage, it is difficult to assess the impact on aggregate yields from adoption of Bt corn and cotton. But if adopted widely enough, and if yield advantages are sustained, it could bump the average U.S. yields above long-term trends.

For soybeans, it is not clear whether herbicide-tolerant crops currently have a yield advantage over conventional varieties. While less weedy fields may enhance yields and reduce foreign material, other soybean varieties may be better tailored in certain locations to withstand pests, disease, or adverse weather conditions. As more varieties with these traits include the gene for herbicide resistance, U.S. yields may show improvement. In general, elite germplasm will still be the underlying driving force in crop productivity gains, regardless of the new technology applied.

To the extent that the new genetically modified crops, particularly the insect-resistant varieties, reduce the use of agricultural chemicals, they will appeal to farmers attempting to minimize the environmental impacts of their operations. The environmental benefits of herbicide-tolerant crops derive from the reduction in the number of chemical applications, reduction in energy use due to fewer passes across the fields, and reduction in the need for tillage.

Moreover, substitution of both glyphosate and glufosinate for other chemicals has potential environmental benefits. These two herbicides have less residual soil activity than some other herbicides. This means that runoff of chemicals into groundwater could be minimized. Herbicide-tolerant crops also accommodate no-till operations, which reduce erosion of topsoils.

Some critics are concerned that insects or weeds may develop resistance to the technology intended to suppress them. In the case of insect resistance, organic producers and gardeners, for example, are concerned about resistance to Bt, because it is an effective and environmentally friendly pesticide that they have used as a spray.

Companies selling Bt seed have a strong economic incentive to prevent the development of insect resistance, in order to preserve the value of Bt seed, and they acknowledge that development of resistant insect populations is a real threat to the long-term effectiveness of Bt crops. Producers using Bt seed sign agreements with the seed companies to follow certain production practices as part of an insect resistance management program.

For both cotton and corn, two-part pest management plans were developed by the Environmental Protection Agency (EPA). First, the developing company must ensure that the Bt strains carry enough toxin to kill most feeding insects so that they cannot mate. Second, the developing company must ensure that farmers plant nearby areas to a non-Bt variety to provide a refuge for survival of nonresistant insects. Such management plans will likely involve costs to growers.

Chemical and seed companies are also prepared to tap different strains and versions of Bt and to offer new generations of product, similar to the practice with some antibiotics in addressing resistance. The effectiveness of these measures will need to be evaluated over time.

Continued use of a particular herbicide raises fear of weed resistance. Another potential problem is weed shift, with species most susceptible to the herbicide declining over time, while less susceptible species build up. Further monitoring and research are needed over time to adequately address concerns about insect and weed resistance.

Trade & Genetically Modified Organisms

In late 1997 and in 1998, friction occurred over EU acceptance of U.S. corn exports because particular GM varieties from the 1997 crop had not yet been fully approved under the EU's approval process. This has effectively blocked imports of U.S. corn by Spain and Portugal, which typically purchase U.S. corn every year. Although the particular varieties were approved by an EU scientific advisory panel and an EU regulatory committee, other hurdles remain, including approval by France. As one of two member countries that sponsored the corn varieties, France must grant its consent before the corn varieties can be marketed in the EU. The United Kingdom, the second sponsoring country, previously granted its consent in June 1998.

Rapid introduction of new genetically modified varieties and a slow approval process in the EU suggests delays could occur again under the prevailing regulatory system. Moreover, the environmental impact as well as food safety is a concern in the EU. In addition, the EU passed a labeling requirement, which could provide disincentives to imports of foods processed from genetically modified crops, and could increase costs.

Looking Ahead

Early indications are that many of the new crop technologies are beneficial to U.S. farmers, although adoption is not without risk. Because the technology is so new, assessments of its effectiveness, cost and labor savings, yield advantages, and ecological impacts are limited. Sustained performance (such as weed control) over time, including performance of the new technologies under stress conditions like drought, is an unknown that could influence future adoption rates. Growing concentration among seed and chemical companies will present additional unknowns for farmers.

Meanwhile, many new features on the input side are expected to be introduced soon, such as resistance to more insect pests. In the future, "stacking" of multiple traits in a single variety will become more common, such as combining herbicide tolerance, disease resistance, and end-use or output properties. The breeding process becomes more complicated as the number of genes involved increases, so it is unlikely that one variety will ever be best for all situations. But stacking will likely broaden the appeal of genetically modified crops.

Given the considerable investment in research by the private sector, and the rapid adoption by farmers, the brisk pace of innovation in developing genetically modified crops is likely to continue. Economic and agronomic impacts will become more evident as the technology evolves.

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