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Adoption of Genetically Engineered Crops by U.S. Farmers Has Increased Steadily for Over 15 Years

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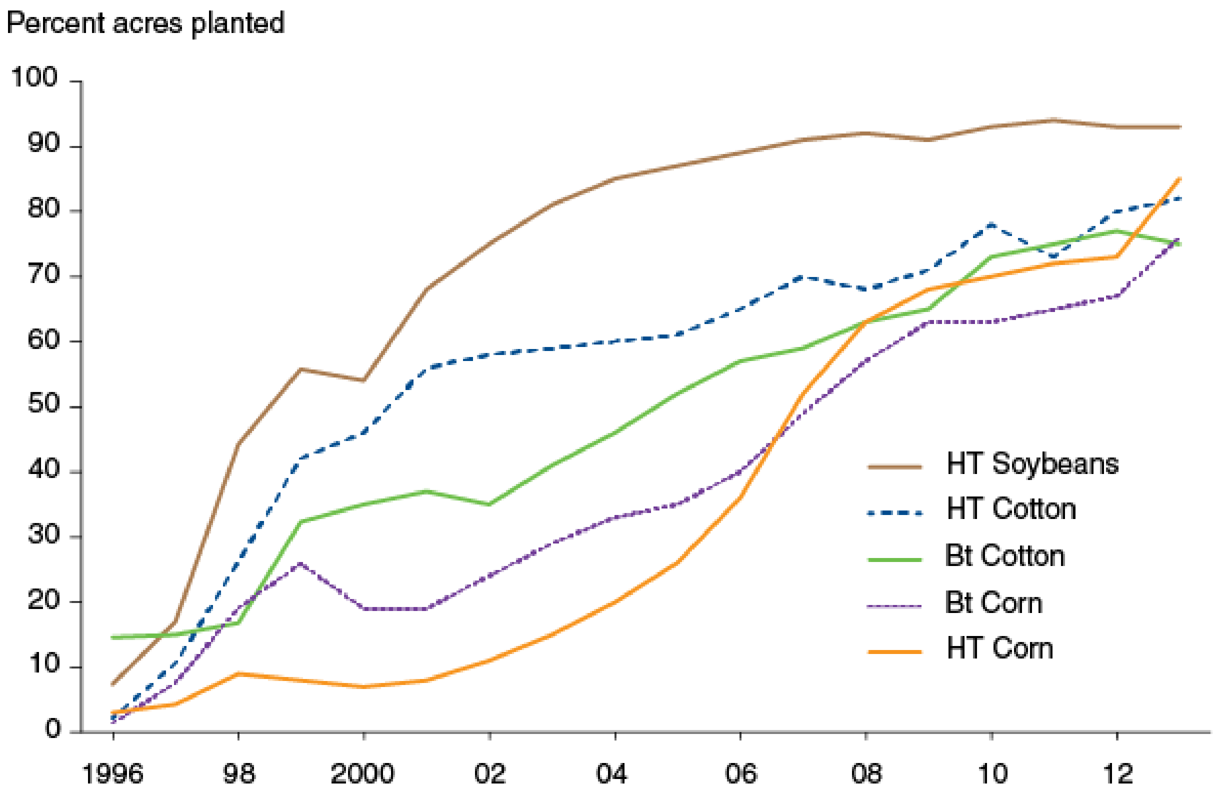
Genetically engineered (GE) crops with pest management traits first became commercially available for major crops in 1996. More than 15 years later, adoption of these crop varieties by U.S. farmers is widespread (170 million acres planted in 2013), and many products derived from these GE crops—including cornmeal, oils, and sugars—are commonly used in food products. While some GE seeds with traits that affect a crop's nutritional content and agronomic properties are already being commercialized and many more GE seeds are under development and testing, nearly all the GE seeds marketed to date to U.S. farmers are for pest management (pests here are defined to include insects, weeds, and some other organisms that interfere with the production of crops). Herbicide-tolerant (HT) seeds allow farmers to use certain effective herbicides to control weeds without damaging their crop. Other GE seeds leverage pesticidal proteins, naturally produced by the soil bacterium *Bacillus thuringiensis* (Bt), that are toxic to certain insects, protecting the plant over its entire life.

Highlights:

- Farmers planted about 170 million acres of GE crops in 2013—principally corn, cotton, and soybeans—representing about half of the U.S. farmland used to grow crops.
- Pest management traits are the main feature engineered into GE crops grown, but over time, traits providing protection against additional pests and seeds combining several traits have been introduced and quickly adopted by farmers.
- Findings suggest that Bt seeds have increased yields and reduced insecticide use, and herbicide tolerant seeds have enabled farmers to substitute less toxic herbicides in place of more toxic alternatives and facilitated the adoption of conservation tillage.

U.S. farmers tend to adopt HT seeds more than seeds with insect resistance partly because weeds are a pervasive problem. HT adoption was particularly rapid in soybeans, with U.S. farmers planting HT soybeans on 93 percent of all soybean acreage in 2013. HT cotton occupied 82 percent of cotton acreage and HT corn 85 percent of corn acreage in 2013. Insect infestations tend to be more localized than weed infestations. Farmers planted Bt cotton (engineered to control insects such as tobacco budworm, bollworm, and pink bollworm) on 75 percent of cotton acreage in 2013. Bt corn—which controls the European corn borer, the corn rootworm, and the corn earworm—was planted on 76 percent of corn acres in 2013.

Adoption of genetically engineered crops in the U.S. grew steadily



Data for each crop category include varieties with both herbicide-tolerant (HT) and Bacillus thuringiensis (Bt) (stacked) traits.

Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, June Agricultural Survey.

While corn, cotton, and soybeans account for the vast majority of GE acreage in the U.S., other GE crops commercially grown include HT canola, HT sugar beets, HT alfalfa, virus-resistant papaya, and virus-resistant squash. Since being commercially introduced, the varieties of GE seeds commercially available with pest management traits have increased in complexity, incorporating resistance to a broader range of insects and tolerance to more herbicides, as well as combining (or "stacking") both HT and Bt traits. With these innovations, the price of GE seeds increased, both in nominal and real terms. The rapid adoption of GE varieties by farmers is consistent with the belief that GE seeds provide improved performance or other benefits that make their use worthwhile, but what do research findings suggest?

GE seeds and yield losses to pests

In the absence of pests, commercially available GE seeds do not increase maximum crop yields. However, by protecting a plant from certain pests, GE crops can prevent yield losses to pests, allowing the plant to approach its yield potential. Bt crops are particularly effective at mitigating yield losses.

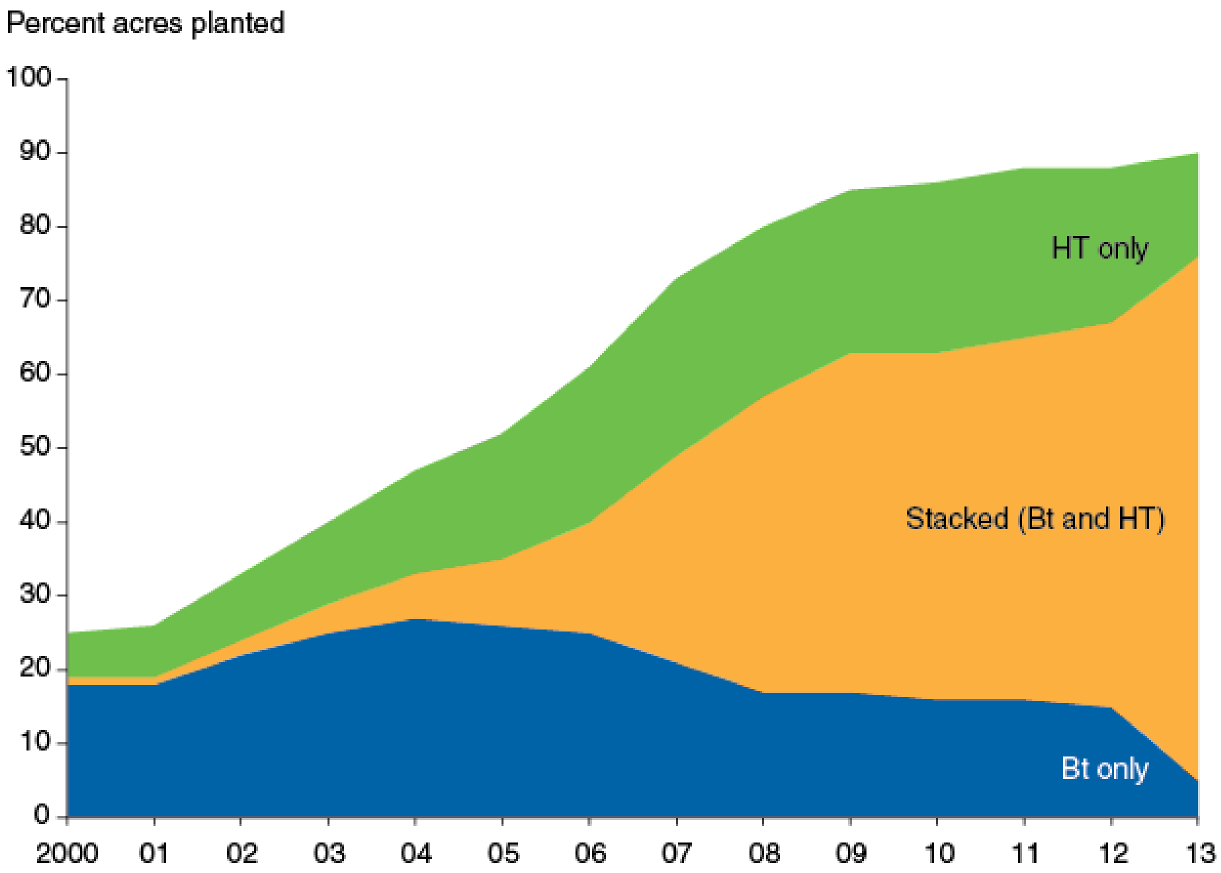
Average Bt corn yields have increased as new insect resistance traits have been incorporated into the seeds and seeds with multiple (stacked) traits have become available. In 1996, Bt corn was only resistant to one type of pest: the European corn borer. Since then, Bt corn resistance to corn rootworms (2003) and corn earworms (2010) has been introduced. Most experimental field tests and farm surveys show that Bt crops produce higher average yields than conventional crops. Data from USDA's Agricultural Resource Management Survey (ARMS) show that Bt corn yields were 17 bushels per acre higher than conventional corn yields in 2005 and about 26 bushels higher in 2010. Moreover, using an econometric model that controls for other factors, ERS researchers found that a 10-percent increase in the rate of Bt corn adoption was associated with a 1.7-percent increase in yields in 2005 and a 2.3-percent increase in yields in 2010. Researchers also found that a 10-percent increase in the adoption of Bt cotton in 1997 was associated with a 2.1-percent increase in yields.

On the other hand, evidence on the impact of HT seeds on soybean, corn, and cotton yields is mixed. Some researchers found no significant difference between the yields of adopters and non-adopters of HT; others found that HT adopters had higher yields, while still others found that adopters had lower yields.

An analysis of ARMS corn data indicates that stacked seeds (seeds with several GE traits) have higher yields than conventional seeds or seeds with only one GE trait. For example, 2010 ARMS data show that conventional corn seeds had an average yield of 134 bushels per acre. By contrast, seeds with two types of herbicide tolerance (glyphosate and glufosinate) and three types of insect resistance (corn borer, corn rootworm, and corn earworm) had an average yield of 171 bushels per acre.

Not surprisingly, adoption rates of stacked-seed varieties have increased quickly. Use of stacked corn seed grew from 1 percent of planted acres in 2000 to 71 percent in 2013. GE varieties incorporating three or four traits are now common.

Stacked traits for GE corn grew from 1 percent in 2000 to 71 percent in 2013



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, June Agricultural Survey.

Bt seeds, net returns, and household income

The market price of seed incorporates the costs associated with seed development, production, marketing, and distribution. The price of GE soybean and corn seeds grew by about 50 percent in real terms (adjusted for inflation) between 2001 and 2010. The price of GE cotton seed grew even faster. The increase in GE seed prices can be attributed in part to increasing price premiums over conventional seeds associated with the rising share of GE seeds with multiple (stacked) traits and /or more than one mode of action for particular target pests Another factor contributing to the increase in seed prices is the improvement in seed genetics (germplasm).

The profitability of GE seeds for individual farmers depends largely on the value of the yield losses mitigated and the pesticide and seed costs, which vary by crop and technology. Most studies show that adoption of Bt cotton and Bt corn is associated with increased net returns/variable profits. However, some studies of Bt corn show that profitability is strongly dependent on pest infestation levels (adoption of Bt cotton and Bt corn was associated with increased returns when the pest pressure was high).

The evidence on the impact of HT seeds on net returns is less consistent. Several researchers found that the adoption of herbicide-tolerant cotton had a positive impact on net returns. However, other researchers found no significant difference between the net returns of adopters and non-adopters of HT soybeans, and others found that HT soybean farmers are less profitable than their conventional counterparts. Overall, the empirical evidence on the impact of adopting herbicide-tolerant soybeans on net returns is inconclusive.

The fact that adoption of HT crops has been continuously rising, even though several researchers found no significant differences between the net returns of adopters and non-adopters, suggests that adopters derive other benefits. In particular, weed control for HT soybeans may be simpler and more flexible (e.g., HT seed-based production programs allow growers to use one product to control a wide range of both broadleaf and grass weeds instead of using several herbicides to achieve adequate weed control), freeing up valuable management time for leisure, or to generate enterprise growth or off-farm income.

ERS research shows that HT adoption is associated with increased off-farm household income for U.S. soybean farmers, most likely because time savings associated with HT crops were used in off-farm employment. More recently, other researchers confirmed that GE crops led to household labor savings and that farmers adopting GE crops derived value from the convenience, flexibility, and increased worker safety associated with growing HT crops that enable them to use fewer toxic herbicides.

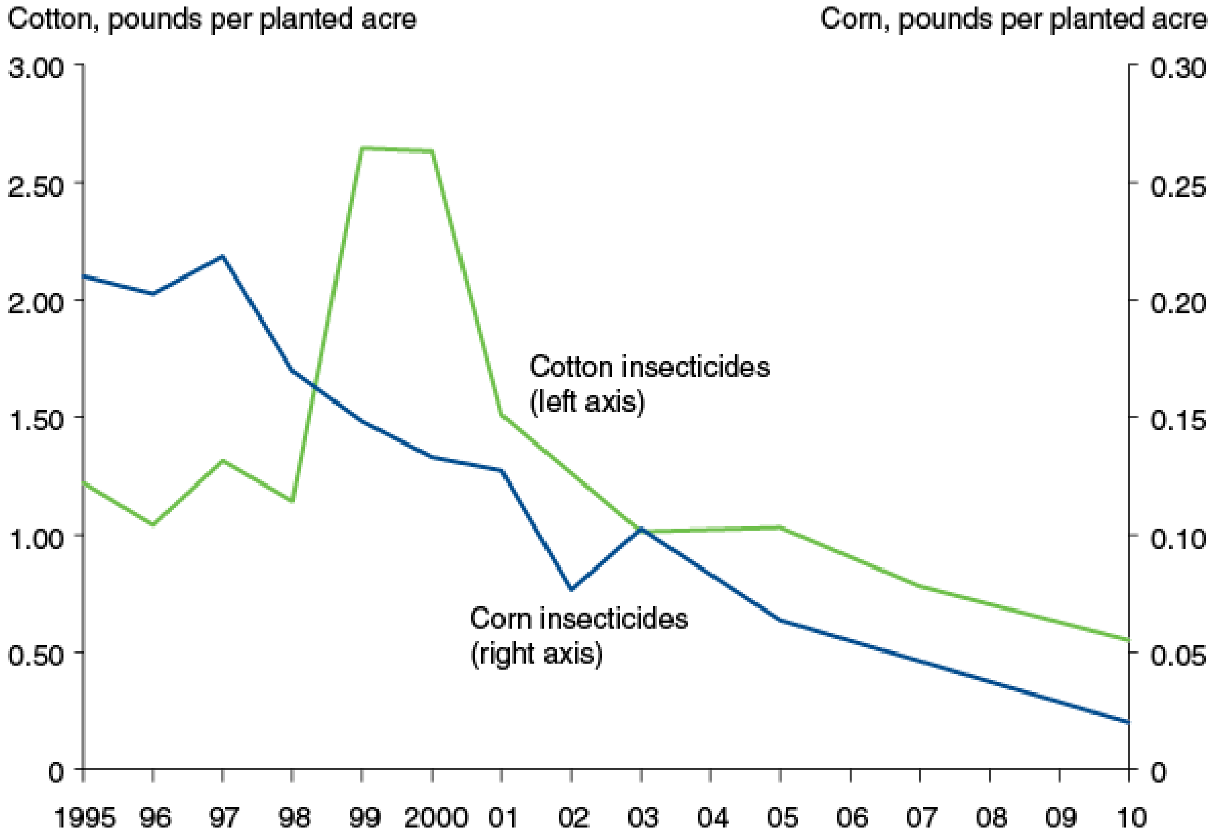
Adoption and pesticide use

Studies based on field tests and farm surveys have examined the extent to which GE crop adoption affects pesticide (insecticide and herbicide) use, and most results show a reduction in pesticide use. A 2010 National Research Council study concurred that GE crops lead to reduced pesticide use and /or to use of pesticides with lower toxicity compared to those used on conventional crops.

Generally, Bt adoption is associated with lower levels of insecticide use. Pounds of insecticide (per planted acre) applied to corn and cotton crops have decreased steadily over the last 10 years (except for cotton in 1999-2001, when application levels were distorted during the boll weevil eradication program).

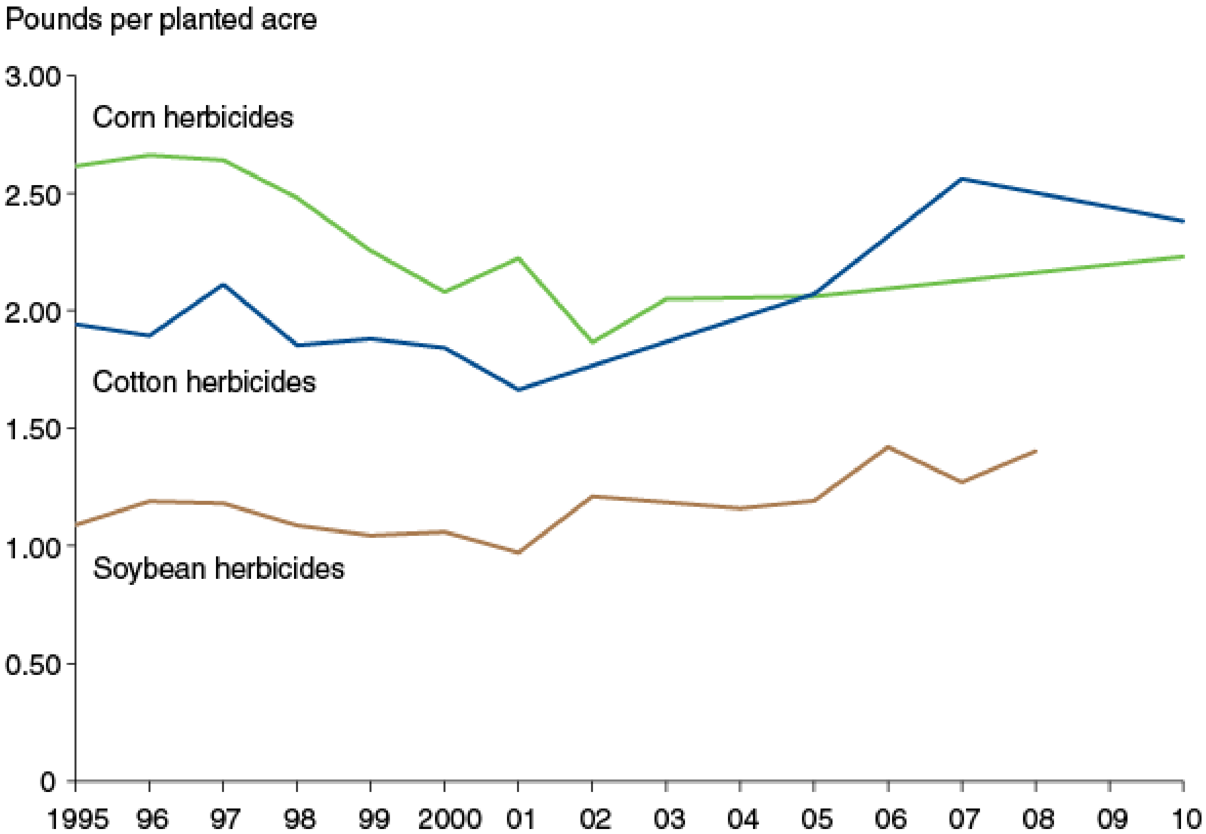
Insecticide use trends suggest that insect infestation levels on corn and cotton farms were lower in 2010 than in earlier years and are consistent with the fact that European corn borer populations have steadily declined over the last decade. In addition, several researchers have shown that areawide suppression of certain insects such as the European corn borer and the pink bollworm are associated with Bt corn and Bt cotton use, respectively. This suggests that Bt seeds have benefited not only adopters but non-adopters as well.

Insecticide use in corn and cotton declined in most years following GE crop adoption



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Agricultural Chemical Usage Reports and Quick Stats.

Herbicide use initially declined with GE crops but increased in later years



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, Agricultural Chemical Usage Reports.

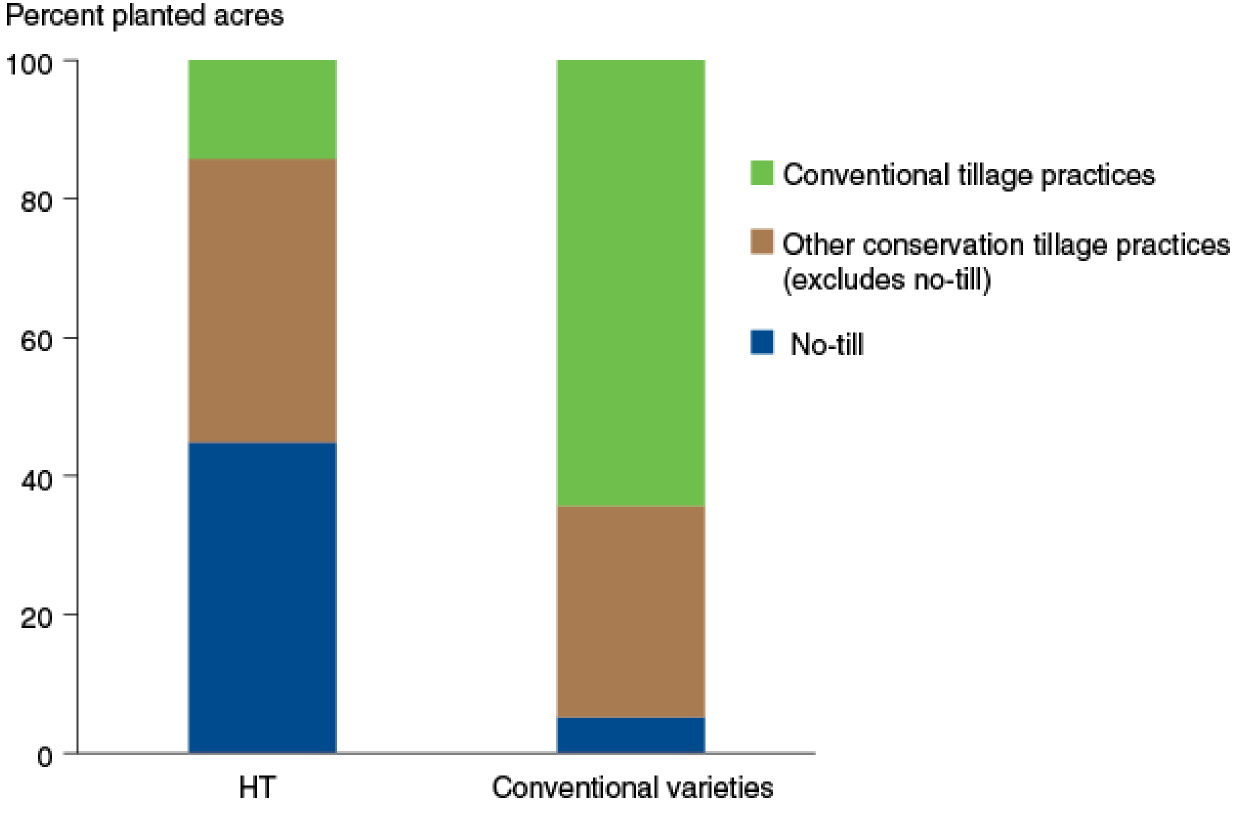
Herbicide use on corn, cotton and soybean acres (measured in pounds per planted acre) declined slightly in the first years following introduction of HT seeds in 1996, but increased modestly in later years. Despite the relatively minor effect HT crop adoption has had on overall herbicide usage, HT crop adoption has enabled farmers to substitute glyphosate (which many HT crops are designed to tolerate) for more traditional herbicides. Because glyphosate is significantly less toxic and less persistent than traditional herbicides, the net impact of HT crop adoption is an improvement in environmental quality and a reduction in health risks.

HT crops and conservation tillage

Conservation tillage (including no-till, ridge-till, and mulch-till) is known to provide environmental benefits and is facilitated by use of HT crops. By leaving at least 30 percent of crop residue covering the soil surface after all the tillage and planting operations, conservation tillage reduces soil erosion by wind and water, increases water retention, and reduces soil degradation and water/chemical runoff. In addition, conservation tillage reduces the carbon footprint of agriculture.

By 2006, approximately 86 percent of HT soybean planted acres were under conservation tillage, compared to only 36 percent of conventional soybean acres. Differences in the use of no-till were just as pronounced. While approximately 45 percent of HT soybean acres were cultivated using no-till technologies in 2006, only 5 percent of the acres planted with conventional seeds were cultivated using no-till techniques, which are often considered the most effective of all conservation tillage systems. Cotton and corn data exhibit similar though less pronounced patterns.

Adopters of HT soybeans had higher rates of adoption of conservation tillage relative to users of conventional varieties, 2006



Conservation tillage includes no-till, ridge-till and mulch-till.
Source: USDA Economic Research Service using data from 2006 ARMS Phase II soybean survey.

These trends suggest that HT crop adoption facilitates the use of conservation tillage practices. In addition, a review of several econometric studies points to a two-way causal relationship between the adoption of HT crops and conservation tillage. Thus, in addition to its direct effects on herbicide usage, adoption of herbicide-tolerant crops indirectly benefits the environment by encouraging the use of conservation tillage.

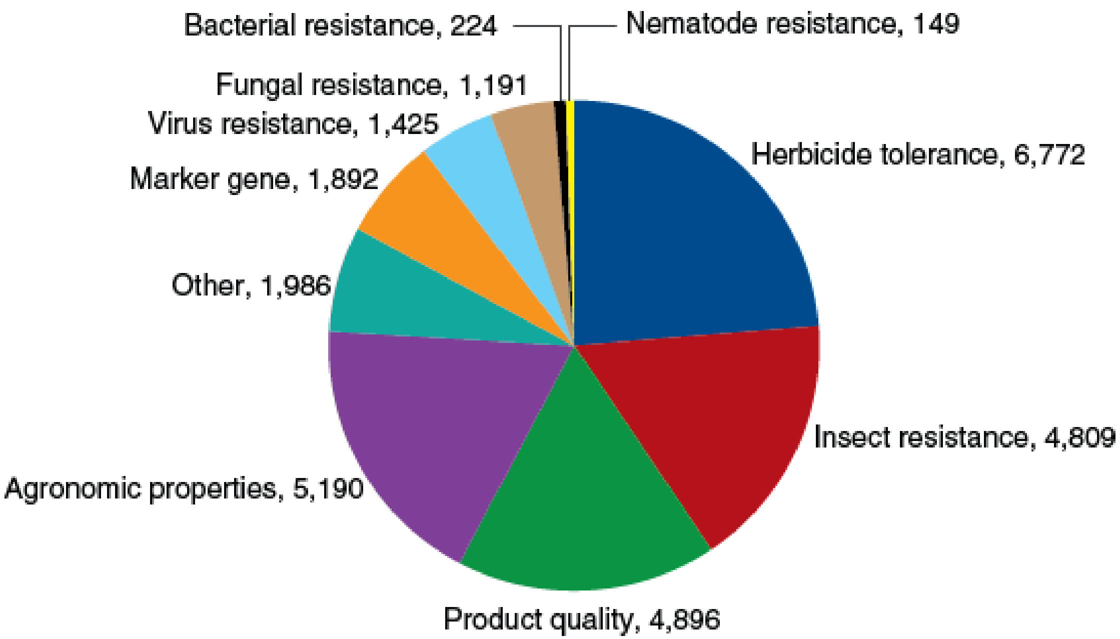
Future trends

The acceptance of GE crops by farmers has been due, in large part, to the pest management traits incorporated into GE seeds. Farmers were willing to adopt GE seeds because their benefits exceeded their costs, while domestic consumers were largely indifferent to these traits. But how long can farmers expect to benefit from the pest management traits engineered into the seeds currently commercially available? And, what other traits might be engineered into seeds that would attract farmer and consumer interest?

As with other efforts to control agricultural pests, pests will inevitably develop resistance to the pest management traits incorporated in GE seeds. Prior to the commercial introduction of Bt crops, entomologists and other scientists persuasively argued that mandatory minimum refuge requirements (planting sufficient acres of the non-Bt crop near the Bt crop) were needed to reduce the rate at which targeted insect pests evolved resistance. Analysis of more than a decade of monitoring data suggests that minimum refuge requirements and natural refuges have indeed helped delay the evolution of Bt resistance in some insect pests. However, Bt resistance in western corn rootworm, cotton bollworm, and fall armyworm populations leading to reduced efficacy of Bt corn and Bt cotton has been recently documented in some U.S. crop fields.

Likewise, an overreliance on glyphosate and a reduction in the diversity of weed management practices by HT crop producers contributed to the evolution of glyphosate resistance in 14 weed species in the United States. Because no new major classes of herbicides have been made commercially available in the last 20 years, and because few new ones are expected to be available soon, growing resistance to glyphosate is expected to reduce the benefit farmers derive from using the most widely available HT seed varieties. Furthermore, the weed management practices needed to slow the spread of glyphosate-resistant weeds may themselves reduce the short-term benefits of planting glyphosate-tolerant (i.e., HT) seeds. As a result, their benefits may erode over time in the absence of further developments affecting HT seeds and their associated herbicides and/or improvements in weed management practices. One such development is the introduction of crops tolerant to the herbicides dicamba and 2, 4-D if used in the context of a diversified approach to weed management.

About half of the releases approved by APHIS for field testing (including permits and notifications) are for pest management traits*



*As of September, 2013. Authorizations for field releases of GE plant varieties are issued by USDA's Animal and Plant Health Inspection Service (APHIS) to allow technology providers to pursue field testing of GE varieties. Counts refer to the actual number of approved release locations (states) per phenotype category.

Source: USDA, Economic Research Service using data from Information Systems for Biotechnology (ISB, 2013).

While relatively few GE traits are currently commercially available, the number of field releases to test GE varieties approved by USDA's Animal and Plant Health Inspection Service indicates continued GE-related R&D activities since field testing is a critical part of seed development. The number of field releases grew from 4 in 1985 to 1,194 in 2002 and has since averaged around 800 per year. Other measures suggest that GE-related R&D activity has increased dramatically since 2005.

Field releases approved for GE varieties continue to focus heavily on herbicide tolerance and insect resistance, but other traits are being developed and tested in large numbers as well. These include traits that provide favorable agronomic properties (resistance to cold/drought/frost/salinity, more efficient use of nitrogen, increased yield); enhanced product quality, such as delayed ripening, flavor and texture (fruits and vegetables); increased protein or carbohydrate content, fatty acid content, or micronutrient content; modified starch, color (cotton, flowers), fiber properties (cotton), or gluten content (wheat); naturally decaffeinated (coffee); and nutraceuticals (added vitamins, iron, antioxidants such as beta-carotene).

New HT and insect resistance traits may give farmers more pest management options and slow the spread of pesticide resistance among pest populations. Approval of other “first generation” traits that improve yields or reduce yield losses could result in further adoption of GE varieties. Farmer response to the approval of “second generation” traits that alter end product quality may be more cautious. Farmers can expect to benefit from the adoption of these GE traits only if consumer acceptance is assured. In short, the future of GE seed use depends on the ability of farmers to adopt best management practices, the ability of biotech companies to develop new GE varieties, and consumer acceptance of products from GE sources.

This article is drawn from...

Genetically Engineered Crops in the United States, by Jorge Fernandez-Cornejo, Seth James Wechsler, Michael Livingston, and Lorraine Mitchell, USDA, Economic Research Service, February 2014

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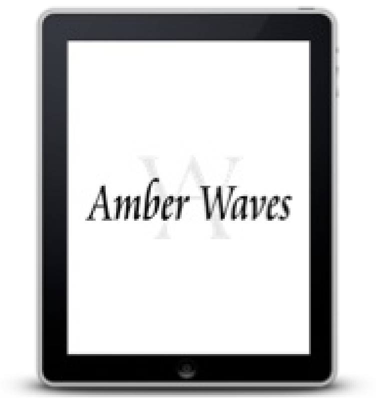
The Impact of Genetically Engineered Crops on Farm Sustainability in the United States, National Research Council, National Academies Press, Washington, DC, 2010



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