United States Department of Agriculture

Economic Research Service

Economic Information Bulletin Number 163

November 2016

The Adoption of Genetically Engineered Alfalfa, Canola, and Sugarbeets in the United States

Jorge Fernandez-Cornejo, Seth Wechsler, and Daniel Milkove

United States Department of Agriculture

Economic Research Service
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Recommended citation format for this publication:

Jorge Fernandez-Cornejo, Seth Wechsler, and Daniel Milkove. *The Adoption of Genetically Engineered Alfalfa, Canola, and Sugarbeets in the United States,* EIB-163, U.S. Department of Agriculture, Economic Research Service, November 2016.

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Jorge Fernandez-Cornejo, Seth Wechsler, and Daniel Milkove

Abstract

After their commercial introduction in 1996, genetically engineered (GE), herbicide-tolerant (HT) varieties of corn, soybeans, and cotton were rapidly adopted by U.S. farmers. The success of these GE crops led to the deregulation that enabled the commercialization of HT canola in 1998 and of HT alfalfa and sugarbeets in 2005. Although legal/regulatory issues limited the spread of GE sugarbeets and GE alfalfa during the first decade of the 21st century, adoption rates for these crops have increased rapidly in recent years. This report uses data from USDA's 2013 Agricultural Resource Management Survey (ARMS) to analyze the adoption of GE alfalfa, canola, and sugarbeets in the United States. It also discusses legal/regulatory issues associated with the commercialization of these crops, trends in adoption rates, and the economic impacts of adoption. Some 95 percent of U.S. canola acres and over 99 percent of sugarbeet acres harvested in 2013 were planted with GE seeds containing HT traits. Only 13 percent of U.S. alfalfa acres were planted using GE seeds in 2013, but this slower adoption rate is expected because alfalfa is a perennial crop and only about one-seventh of the alfalfa acreage is newly seeded each year.

Keywords: Agricultural biotechnology, genetically engineered crops, herbicide tolerance, alfalfa, canola, sugarbeets.

Acknowledgments

The authors would like to thank James MacDonald and Cynthia Nickerson, U.S. Department of Agriculture (USDA), Economic Research Service for advice. They would also like to thank the following for technical peer reviews: Maria Bowman, USDA, Economic Research Service; George Frisvold, The University of Arizona; Neil Hoffman, USDA, Animal and Plant Health Inspection Service; Paul Mitchell, University of Wisconsin; and Michael Schechtman, USDA, Agricultural Research Service. We also thank Dale Simms and Ethiene Salgado-Rodriguez, USDA/ERS for editorial and design services.

About the Authors

Seth Wechsler and Daniel Milkove are economists with the USDA, Economic Research Service (ERS). Jorge Fernandez-Cornejo was formerly with ERS when this research was conducted.

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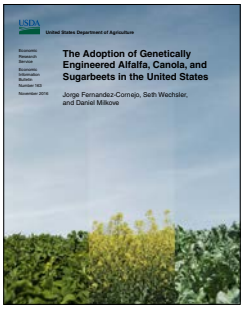

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The Adoption of Genetically Engineered Alfalfa, Canola, and Sugarbeets in the United States

Jorge Fernandez-Cornejo, Seth Wechsler, and Daniel Milkove

What Is the Issue?

Genetically engineered (GE) varieties of corn, soybeans, and cotton with herbicide-tolerant and/or insect-resistant traits were commercially introduced in the United States in 1996. Twenty years later, most corn, cotton, and soybean farmers use these varieties, and the impacts of adoption have been widely documented. By contrast, relatively little is known about the adoption of GE alfalfa, canola, and sugarbeets, crops that add substantial value to the U.S. agricultural sector. For instance, alfalfa is the fourth largest crop in the United States in terms of acreage and production value. It was also the first widely grown GE ***perennial*** to be commercialized. GE alfalfa and GE sugarbeets have been subjects of recent legal controversies.

What Did the Study Find?

Most GE varieties of alfalfa, canola, and sugarbeets have herbicide-tolerant (HT) traits. The most common of these varieties are resistant to glyphosate.

Alfalfa

- Approximately 18 million acres of alfalfa, with a production value of $10.7 billion, were harvested in the United States in 2013. Alfalfa is the fourth largest crop in the United States (in terms of acreage and production value). South Dakota, Montana, North Dakota, Idaho, and Wisconsin account for 42 percent of national acreage devoted to alfalfa.
- The first GE HT alfalfa varieties were deregulated by USDA in June 2005. Deregulation facilitates commercialization by allowing the introduction (importation, interstate movement, and environmental release) of the GE organism without further authorization from USDA. Following legal action from environmental groups in March 2007, plantings were temporarily suspended while USDA's Animal and Plant Health Inspection Service (APHIS) prepared an Environmental Impact Statement (EIS). Once the applicable regulatory requirements were satisfied, GE HT alfalfa was fully deregulated in February 2011. Planting resumed that spring.
- Alfalfa is a perennial crop with an average of 6-7 years between plantings. Approximately 3.5 million acres were newly seeded in 2013 (14 percent of the acres that were harvested that year). Nearly one-third of this newly seeded alfalfa acreage was GE HT.
- Data from USDA's Agricultural Resource Management Survey (ARMS) indicate that GE HT alfalfa constituted 13 percent of the alfalfa acres harvested in 2013.

ERS is a primary source of economic research and analysis from the U.S. Department of Agriculture, providing timely information on economic and policy issues related to agriculture, food, the environment, and rural America.

- GE HT alfalfa adoption rates were highest in New York, where approximately 37 percent of the acres that were harvested in 2013 were produced using GE HT. Adoption rates were also relatively high in Washington and Colorado.
- ARMS data from 2013 suggest that farmers who planted GE HT alfalfa had higher yields than farmers who planted conventional seeds. On average, adopters' yields were 0.53 ton per acre, approximately 17 percent higher than the yields of other farmers.

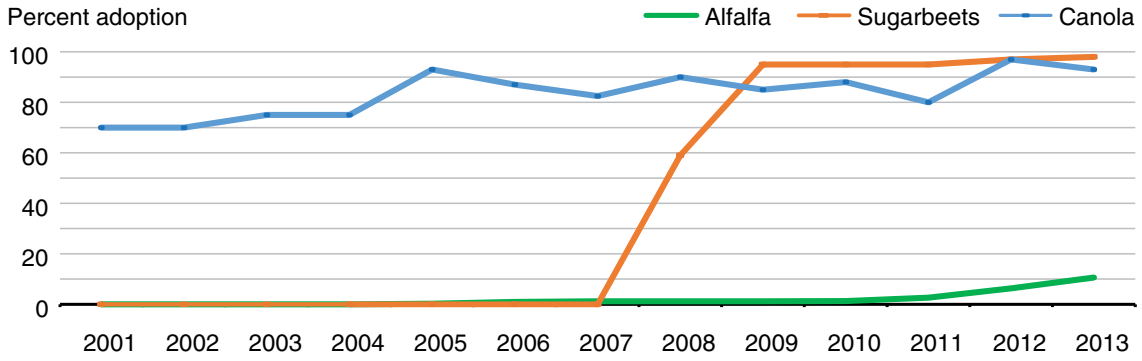
Canola

- Approximately 1.3 million acres of canola (an edible version of rapeseed), with a production value of $456 million, were harvested in the United States in 2013. North Dakota, Oklahoma, Montana, Idaho, and Washington accounted for 96 percent of U.S. canola production.
- GE HT canola varieties were deregulated in 1998. ARMS data indicate that GE HT canola accounted for 95 percent of U.S. canola acres that were harvested in 2013. While this result is based on a small sample, it is consistent with estimates obtained from other sources.

Sugarbeets

- Approximately 1.2 million acres of sugarbeets, with a production value of $1.6 billion, were harvested in 2013. Minnesota, North Dakota, Idaho, and Michigan accounted for over 80 percent of sugarbeet production in 2013.
- APHIS deregulated the first GE HT sugarbeets in 1998. Small amounts of these varieties were produced for testing and seed production in 2006 and 2007. GE HT sugarbeets were commercially introduced in 2008, and about 60 percent of total acreage was planted with GE HT seeds in that year. ARMS data indicate that over 99 percent of harvested acreage was produced using GE HT seeds in 2013.
- Previous studies suggest that using GE HT-based production systems increases sugarbeet root yields and reduces herbicide and labor costs.

Adoption of genetically engineered herbicide-tolerant (GE HT) sugarbeet



Note: Because alfalfa is a perennial, new alfalfa seedings represent a small percent of the total GE alfalfa in production. Therefore, adoption rates for HT alfalfa were calculated as a percent of harvested acreage. Adoption rates for HT canola and HT sugarbeets were estimated as a percent of planted acreage.
Source: USDA, Economic Research Service using data from the International Service for the Acquisition of Agri-biotech Applications, Brookes and Barfoot (2014), Johnson et al. (2008), and National Agricultural Statistics Service (NASS).

How Was the Study Conducted?

This report uses simple statistical methods and information from secondary sources to analyze the adoption of genetically engineered alfalfa, canola, and sugarbeets. The primary source is USDA's 2013 Agricultural Resource Management Survey, which is jointly managed by USDA's Economic Research Service and USDA, National Agricultural Statistics Service. Other data sources include publications by the International Service for the Acquisition of Agri-Biotech Applications (ISAAA) and the 2012 Census of Agriculture.

The Adoption of Genetically Engineered Alfalfa, Canola, and Sugarbeets in the United States

Introduction

Twenty years after the commercial introduction of the first major crop varieties, more than 90 percent of U.S. corn, soybean, and cotton acreage is planted with genetically engineered (GE) seeds with herbicide-tolerant and/or insect-resistant traits, accounting for almost half of the land used to grow all U.S. crops in 2013 (Fernandez-Cornejo et al., 2014). While the widespread adoption of these crops has been extensively analyzed and reported, relatively little is known about the adoption of GE alfalfa, canola, and sugarbeets, crops that add substantial value to the U.S. agricultural sector.[1]

This report uses data from USDA's 2013 Agricultural Resource Management Survey (ARMS) to analyze the adoption of GE alfalfa, canola, and sugarbeets in the United States. It discusses trends in adoption of these crops, describes the legal/regulatory issues associated with their commercialization, and the economic impacts of adoption.

The mostly widely adopted GE crops have herbicide tolerance (GE HT) traits. These crops were developed to survive the application of specific herbicides that previously would have destroyed the crop along with the targeted weeds. GE HT-based production systems provide farmers with multiple options for effective weed control (Fernandez-Cornejo and McBride, 2002). The most common GE HT crops tolerate glyphosate, an herbicide first marketed in 1974 under the trade name Roundup. Glyphosate is effective on many species of grasses, broadleaf weeds, and sedges.[2] However, overreliance on glyphosate and a reduction in the diversity of weed management practices have contributed to the evolution of glyphosate resistance in some weed species (Livingston et al., 2015). Glyphosate tolerance has been incorporated into soybeans, corn, cotton, canola, sugarbeets, and, more recently, alfalfa.

USDA's annual Acreage reports provide estimates of planted and harvested acres for many major crops (USDA/NASS, 2015b). Since 2000, this publication has included survey estimates of the shares of acreage planted using GE corn, cotton, and soybeans with insect-resistant and herbicide-tolerant traits. ERS researchers added questions to the 2013 ARMS (see appendix 1) to support similar estimates for alfalfa, canola, and sugarbeets. ARMS is a nationally representative survey that provides an objective source of production data. However, ARMS surveys are administered to a relatively small number of canola and sugarbeet producers. This report, therefore, combines ARMS, NASS, and private-sector data to assess the adoption of GE seeds for alfalfa, canola, and sugarbeets.

[1]Alfalfa is the fourth largest crop in the United States in terms of acreage and production value. It is also the first widely grown GE perennial to be commercialized.

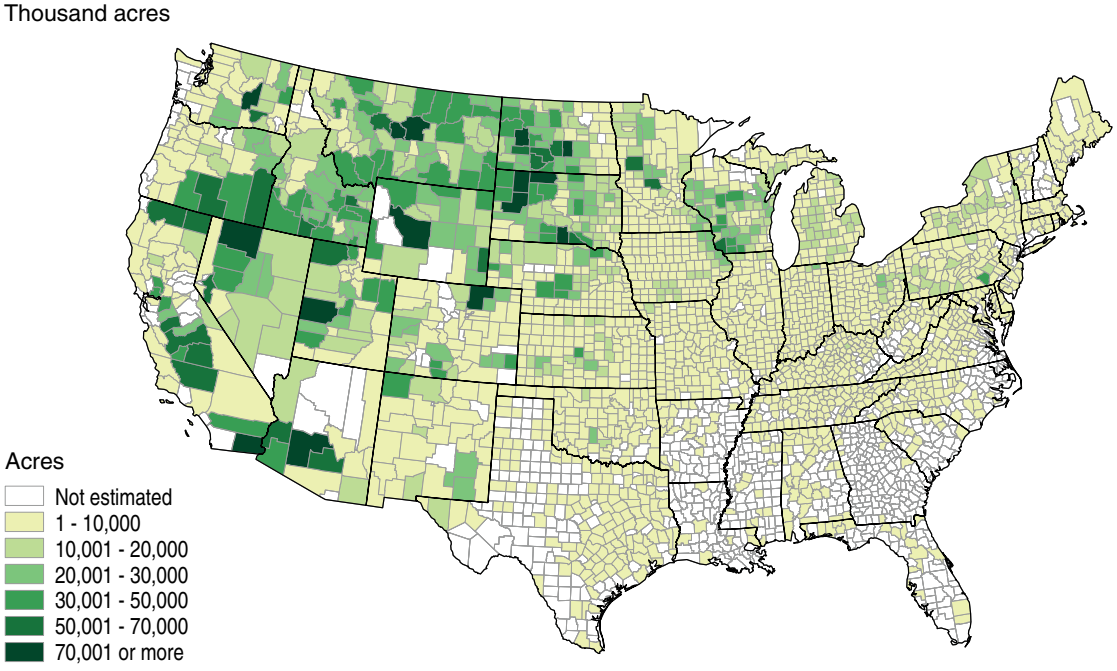
[2]Crops tolerant to the herbicide glyphosate were developed by the firm Monsanto under the name Roundup Ready. Under another GE herbicide-tolerant system, developed by Bayer CropScience with the trade name Liberty Link, crops tolerate the herbicide glufosinate. In addition, Pioneer (now part of DuPont) developed a system called Clearfield in which crops tolerate the herbicide imidazolinone. However, this system was developed using mutagenesis, not genetic engineering. This system is reported to be used for canola in Canada, but its use is much less prevalent than GE varieties in recent years. For example, 93 percent of the canola acres in Canada were grown with GE HT varieties, compared to 6 percent with non-GE HT varieties and 1 percent with conventional varieties (Canola Council of Canada, 2014).

Alfalfa

Alfalfa is a highly nutritious, perennial legume. In the United States, it is primarily used as feed for dairy cattle.[3] Though it has been grown domestically only since 1736, farmers have produced alfalfa for over 4,000 years (Yueago and Cash, 2009). Currently, it is cultivated on approximately 74 million acres worldwide, mainly in temperate countries such as the United States, Argentina, Canada, Russia, Italy, and China (Yueago and Cash, 2009).

In 2013, approximately 18 million acres of alfalfa (table 1), with a production value of $10.7 billion, were harvested in the United States. Only three crops (corn, soybeans, and wheat) are grown on more acreage or have more aggregate production value than alfalfa (USDA/NASS, 2014). In 2012, alfalfa was grown throughout the continental United States (figure 1). Because alfalfa yields are highly variable, the States that produce the most alfalfa are not always the ones with largest planted acreages (table 1).

Figure 1
Alfalfa hay, harvested acreage by county, 2012



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

The ratio of newly seeded (planted) alfalfa acres to harvested alfalfa acres was 0.14 (2,517/17,763) in 2013 (table 2). This implies that approximately 14 percent of the harvested area was newly seeded that year. It also suggests that U.S. alfalfa fields are seeded, on average, once every 7 years.

[3]Alfalfa is a perennial crop and produces its highest yields during the second year of growth. In climates with mild winters, alfalfa is grown for 3 to 4 years continuously, but in climates with cold winters, it is grown for 6 to 9 years, with a dormant period in winter (FAO, 2013).

Approximately 4 percent of U.S. alfalfa production was exported in 2012, mainly to Japan, United Arab Emirates, China, Korea, and Taiwan (Putman et al., 2013, using data from the U.S. Department of Commerce and USDA).

Table 1
Top 10 States growing alfalfa by acres harvested and production, 2013

State	Area harvested (1,000 acres)	Percent of total	State	Production (1,000 tons)	Percent of total
Montana	1,800	10.1	California	6,120	10.6
South Dakota	1,800	10.1	Idaho	4,256	7.4
North Dakota	1,620	9.1	Montana	3,960	6.9
Idaho	1,120	6.3	South Dakota	3,780	6.6
Wisconsin	1,100	6.2	North Dakota	3,240	5.6
Minnesota	950	5.3	Wisconsin	2,860	5.0
California	900	5.1	Minnesota	2,470	4.3
Iowa	730	4.1	Nebraska	2,415	4.2
Nebraska	700	3.9	Iowa	2,409	4.2
Colorado	650	3.7	Utah	2,310	4.0
United States	**17,763**	**100.00**	**United States**	**57,581**	**100.00**

Source: USDA, Economic Research Service using data from USDA's Crop Production report (USDA/NASS, 2014b).

Table 2
Total acres, yields, and production: alfalfa, canola, and sugarbeets, 2011-13

Crop	Acres planted (1,000)	Acres harvested (1,000)	Yield, tons/ harvested acre	Total production (1,000 tons)
Alfalfa				
2013	2,5171	17,763	3.24	57,581
2012	2,3891	17,292	3.01	52,049
2011	2,3211	19,213	3.40	67,829
Canola				
2013	1,348	1,265	0.87	1,105
2012	1,765	1,729	0.71	1,224
2011	1,072	1,043	0.74	769
Sugarbeets				
2013	1,198	1,154	28.5	32,813
2012	1,230	1,204	29.3	35,236
2011	1,233	1,213	23.8	28,828

Source: USDA, Economic Research Service using data from the Crop Production report (USDA/NASS, 2014b).
1 Alfalfa is a perennial crop. These data refer to the area newly seeded with alfalfa, which is much smaller than acres harvested.

Approval of GE Alfalfa: Regulatory Issues

USDA's Animal and Plant Health Inspection Service (APHIS) issued the first permit for field testing GE alfalfa to the Northrup King Company in June 1989 (see box, "Regulatory Oversight of GE Crops"). A glufosinate-tolerant varietal was field tested in Woodland, California, later that year (Information Systems for Biotechnology, 2015). In 1998, the first field tests of genetically engineered, glyphosate-tolerant alfalfa were authorized in Iowa, Idaho, Indiana, and Wisconsin (ISB, 2015).[4]

In the spring of 2004, APHIS received a petition from Monsanto Company and Forage Genetics International to deregulate two glyphosate-tolerant alfalfa lines. After assessing the plant pest risks and preparing an Environmental Assessment (EA), APHIS determined that these lines (J101 and J163) did not pose a plant pest risk (USDA/APHIS, 2010a).[5] In June 2005, the GE HT lines were deregulated and full-scale commercialization was permitted (Cowan and Alexander, 2013).

In 2006, the Center for Food Safety and other organizations sued USDA-APHIS. The plaintiffs argued that APHIS's Environmental Assessment of GE HT alfalfa was not sufficiently comprehensive and that an indepth Environmental Impact Statement (EIS) should be conducted. On February 13, 2007, the U.S. District Court for the Northern District of California ruled that APHIS had not adequately assessed the environmental and economic impacts of GE HT alfalfa, as required by the National Environmental Policy Act (NEPA). Consequently, the Court vacated APHIS' deregulation decision and ordered that a NEPA-compliant EIS be prepared (USDA/APHIS, 2010a). The Court determined that growers who had already planted GE HT alfalfa would be permitted to harvest, use, and sell it. However, new seed sales and new planting were no longer permitted under the court injunction (USDA/APHIS, 2010a).[6]

APHIS released the EIS for glyphosate-tolerant alfalfa in December 2010. On January 27, 2011, under the authority of the Plant Protection Act of 2000, glyphosate-tolerant alfalfa was fully deregulated.[7] Planting resumed in February 2011 (Cowan, 2011).

Though the legal actions described above did not prevent the deregulation of GE HT alfalfa, they did slow its adoption. Plantings of GE HT alfalfa were suspended from 2007 to 2010.

Alfalfa that has been genetically engineered to have low lignin content was deregulated in November 2014 after a petition from Monsanto Company and Forage Genetics International. This

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[4]In total, APHIS authorized 473 field tests of GE alfalfa between 1989 and April 2015 through either a permit or a notification.

[5]Under title 7 of the Code of Federal Regulations (CFR) part 340, USDA's Animal and Plant Health Inspection Service (APHIS) regulates the "introduction (importation, interstate movement, or release into the environment) of organisms and products altered or produced through genetic engineering that are plant pests or that there is reason to believe are plant pests. (USDA/APHIS, 2010a). APHIS' EIS also states that "The regulations in § 340.6(a) provide that any person may submit a petition to APHIS seeking a determination that an article does not pose a plant pest risk and should therefore not be regulated under 7 CFR part 340. Paragraphs (b) and (c) of § 340.6 describe the form that a petition for a determination of nonregulated status must take and the information that must be included in the petition."

[6]In the two growing seasons that GE HT alfalfa was on the market (2005 and 2006), approximately 200,000 acres of GE alfalfa were planted in the continental United States (USDA/APHIS, 2010a).

[7]Soon after, the Center for Food Safety filed suit in March 2011 claiming that the deregulation violated both NEPA and the Plant Protection Act. The claims were rejected by a District Judge on January 2012, and this decision was affirmed by the Ninth Circuit Court of Appeals on May 17, 2013.

trait increases the digestibility of the alfalfa, thereby enhancing the nutritional quality of the derived feed and directly benefiting the consumer (as opposed to herbicide-tolerance traits that benefit the producer). This alfalfa varietal has been reported to increase yields by 10-20 percent (ISAAA, 2014b), which may lead to further adoption of GE alfalfa in the near future.

Table 3
APHIS' deregulation of genetically enginereed (GE) alfalfa

Petitioner	Event	GE trait	Date deregulated
Monsanto & Forage Genetics	J101, J163	Glyphosate tolerant	June 14, 2005
Monsanto & Forage Genetics	J101, J163	Glyphosate tolerant	January 28, 2011
Monsanto & Forage Genetics	KK179	Reduced lignin	November 10, 2014

Source: USDA, Animal and Plant Health Inspection Service, 2015. Petitions for determination of nonregulated status, http://www.aphis.usda.gov/biotechnology/petitions_table_pending.shtml

Regulatory Oversight of GE Crops

Before commercial introduction, genetically engineered crops must conform to standards set by State and Federal statutes (Fernandez-Cornejo et al., 2014; USDA/APHIS, 2013). Under the Coordinated Framework for the Regulation of Biotechnology, Federal oversight is shared by the U.S. Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA), and the U.S. Food and Drug Administration (FDA).

USDA's Animal and Plant Health Inspection Service (APHIS) plays a central role in regulating field testing of agricultural biotechnology products. Through either a notification or permit procedure, such products—which include certain genetically engineered plants, microorganisms, and invertebrates—are considered "regulated articles." APHIS issues authorizations for field releases of those GE organisms (mostly GE plants) that are categorized as "regulated articles" to allow technology providers to conduct field testing.

GE plants that meet six specific criteria (described in the regulations) undergo an administratively streamlined process, known as a ***notification***. Under a notification, applicants provide information on the nature of the plant and introduced genes, exact genetic modifications, size/scope of the introduction, and origin/destinations for movement or the location of a field test.

For GE plants that do not meet the criteria for a notification, an APHIS ***permit*** is required. This process involves a more comprehensive review. In addition to the data required for notification, permit applicants must describe how they will perform the test, including specific measures to reduce the risk of harm to other plants, so that the tested organisms remain confined and do not persist after completion of the field test.

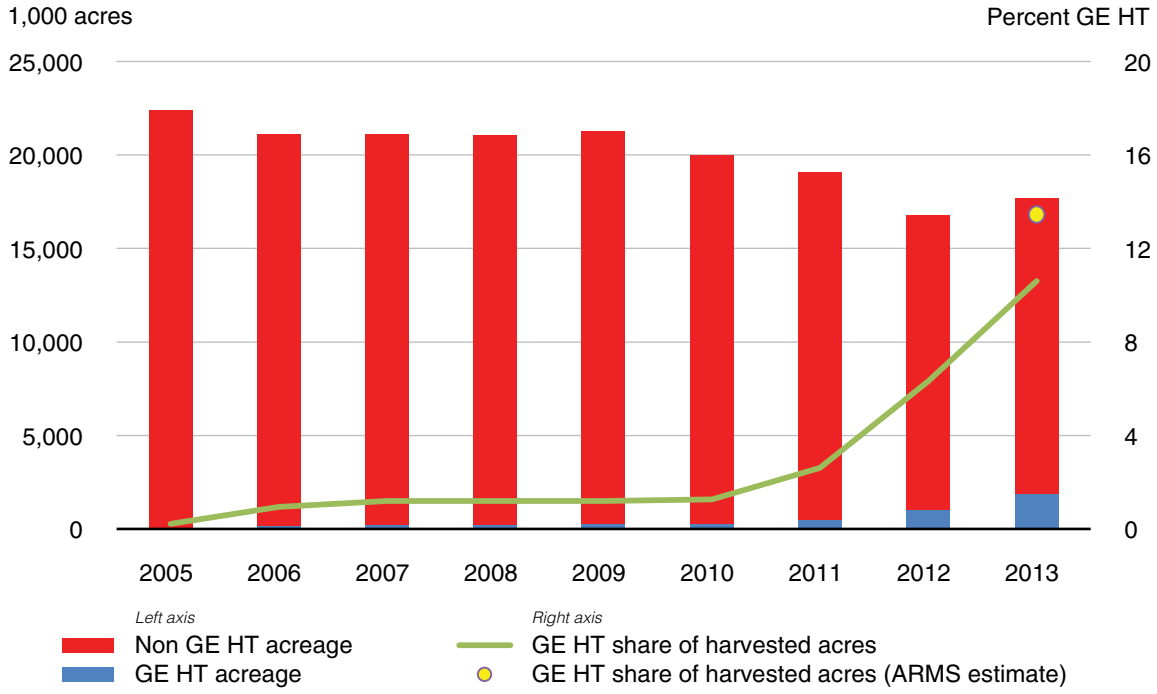
After years of field tests, an applicant may petition APHIS for a determination of ***nonregulated status*** in order to facilitate commercialization of the product. If, after extensive review, APHIS determines that the GE organism is unlikely to pose a plant pest risk, the organism is issued a "determination of nonregulated status." At this point, the organism is no longer considered a regulated article and can be moved and planted without APHIS oversight under the biotechnology regulations. More details on the regulations of GE products may be found in USEPA, 2003; Belson, 2000; USDA/APHIS, 2010a, 2015; and Fernandez-Cornejo et al., 2014.

The Adoption of GE HT alfalfa

The International Service for the Acquisition of Agri-biotech Applications (ISAAA) reports that 50,000 acres of GE HT alfalfa were planted in the United States in 2005 (ISAAA 2013a, b; 2014a, b). Approximately 150,000 acres were planted in 2006, and 55,000 acres were planted in 2007 (before the U.S. District Court vacated the GE HT alfalfa's deregulation). Therefore, there were approximately 255,000 acres of GE HT alfalfa in the United States by 2007. After a 3-year moratorium (during which planting GE HT alfalfa was prohibited), GE HT planting resumed in 2011. Approximately 245,000 acres of GE HT were planted during that year. Newly seeded GE HT alfalfa acreage increased to 560,000 acres in 2012 and 810,000 acres in 2013.

By 2013, total GE HT acreage (including GE HT acreage that was planted in previous years) had reached 1.87 million acres (figure 2),[8] representing 11 percent of U.S. alfalfa acreage. USDA's 2013 ARMS, by contrast, indicates that 13 percent of U.S. alfalfa acreage harvested in 2013 was produced using genetically engineered seeds with herbicide tolerance (table 4).[9] This estimate is slightly higher, but not statistically different from the 11 percent reported by ISAAA (2013b, 2014a).[10]

Figure 2
Adoption of genetically engineered herbicide-tolerant (GE HT) alfalfa, 2005-13



Source: USDA, Economic Research Service using data for acreage with GE HT alfalfa from ISAAA (2006, 2013a, 2014b) and ARMS for 2013. Data for harvested acres from NASS.

[8]ISAAA (2014a, b) reported that about 810,000 acres were newly seeded with GE HT alfalfa in 2013, representing 32 percent of the total area newly seeded with alfalfa in 2013.

[9]The ERS estimate includes the area newly seeded with GE HT alfalfa in 2013 and GE HT acreage that was planted in previous years.

[10]The 95-percent confidence interval for the ERS estimate is bounded by 9 and 18 percent.

The 2013 ARMS data show that adoption rates for GE HT alfalfa are fairly low in States with substantial alfalfa acreage, like Montana.[11] Other States with large alfalfa acreages and low GE HT adoption rates include Nebraska (5.1 percent of alfalfa was GE HT in 2013) and Iowa (5.6 percent). Adoption rates tend to be higher in States with less alfalfa acreage. For instance, 37 percent of alfalfa in New York was GE HT in 2013 (appendix table 1).[12]

Table 4
Estimated adoption rates for genetically engineered herbicide-tolerant (GE HT) alfalfa, canola, and sugarbeets, 2013*

	Percent of harvested acres	Standard error	Lower bound	Upper bound	Number of observations
Alfalfa					
GE HT	13	2	9	18	1411
Non-GE HT	87	2	82	91	
Sugarbeets					
GE HT	100	0	100	100	44
Non-GE HT	0	0	0	0	
Canola					
GE HT	95	4	88	100	22
Non-GE HT	5	4	0	12	

*Using jackknifed standard errors and 95% confidence intervals.
Source: USDA, Economic Research Service using data from 2013 ARMS Phase III.

Economic Effects of Adopting GE HT Alfalfa

The 2013 ARMS data suggest that farmers who plant their acreage to GE HT alfalfa (adopters) enjoy higher yields than farmers who plant all of their acreage with conventional alfalfa seeds (table 5). The difference in average yields between adopters and non-adopters was 0.53 ton per acre, or approximately 17 percent (table 6).[13] However, this comparison does not control for variations in production practices or other systematic differences between farmers (and fields) that use GE seeds and those that do not use them. For instance, alfalfa yields are influenced by many factors such as seed variety (there are hundreds of alfalfa varieties), weather and soil conditions, water availability, the severity of pest infestations, fertilizer use, and method of weed/insect control (Dixon et al., 2005). In other words, though the mean comparisons suggest that yields tend to be higher on fields

[11]A negligible percentage of alfalfa was planted with GE HT seeds in Montana. Montana is a very large cow-calf State with high demand for "cowboy mix" (alfalfa hay mixed with grasses with the intention of being grazed or fed on cow-calf operations). Producers use the grasses to keep the hay from being too rich, which can cause serious problems with digestion. Producers using the cowboy mix would defeat the intent of the mix if they sprayed their fields with glyphosate because it would kill the grasses. Commercial growers may also be wary of using GE HT alfalfa due to export restrictions on the hay.

[12]According to the alfalfa Environmental Impact Statement (USDA/APHIS, 2010a), the counties that are likely to benefit more from adoption of GE HT alfalfa are those in which weeds are a problem in need of management and where GE HT weed control is cheaper. Also, counties are likely to benefit more from adoption of GE HT where the markets demand cleaner alfalfa since GE HT alfalfa leads to alfalfa hay with a lower weed content.

[13]A t-test was used to determine whether the average difference between the yields of adopters and non-adopters was statistically significant. The delete-a-group jackknife procedure described in Dubman (2000) was used to account for the complexity of the survey design. Robustness checks suggest that unobserved, systematic differences in time-invariant variables (such as soil quality) may partially account for yield differences between HT adopters and non-adopters. Future work will explore this possibility.

where farmers have planted GE seeds, they do not demonstrate that these increases were *caused* by GE HT adoption.

Experimental field studies of GE HT alfalfa in several U.S. locations have produced mixed results (USDA/APHIS, 2010b; Van Deynze et al., 2004). Wilson (2007) found that GE HT alfalfa in Nebraska provided slightly higher forage yields and better weed control than conventional production systems.[14] However, D. Putnam, a plant and soil scientist at the University of California, Davis, who has field tested GE alfalfa and other alfalfa cultivars in California concluded (as reported by USDA/APHIS, 2010b) that the yields of herbicide-tolerant alfalfa as a group "are no different than what could be expected from similar conventional lines..."

Regardless of whether adoption increases yields, there appear to be benefits associated with GE HT alfalfa use. In its Final Environmental Impact Statement, APHIS reported that GE HT adoption increased forage quality and reduced herbicide costs (USDA/APHIS, 2010b). That report suggests that changes in yields and/or in forage prices are likely to have a greater impact on returns than comparable changes in costs.

Table 5
Acres, tons, and weighted yields for adopters and non-adopters of GE HT alfalfa, 2013

	Acres harvested per farm	Total production per farm, in tons (dry)	Implied yield, tons/ acre	Observations
Full adopters	68.29	249.89	3.66	198
Non-adopters	83.23	260.47	3.13	1178

Note: Thirty-five farmers in the ARMS sample planted some, but not all, of their acreage to GE HT alfalfa. Because this is a small number of observations, and because outliers appeared to be distorting the estimates, these observations are not included in tables 5 or 6, or discussed in this section.
Sources: USDA, Economic Research Service using data from the 2013 Agricultural Resource Management Survey (ARMS) Phase III.

Table 6
Yield difference (tons/acre) between adopters and non-adopters of GE HT alfalfa, 2013

Difference in means between adopters and….

	Difference in means	Standard error	T-Stat	P-value
Non-adopters	0.53	0.17	3.11	0.004

Note: Standard errors were estimated using the delete-a-group jackknife method described in Dubman (2000).
Sources: USDA, Economic Research Service using data from the 2013 Agricultural Resource Management Survey (ARMS) Phase III.

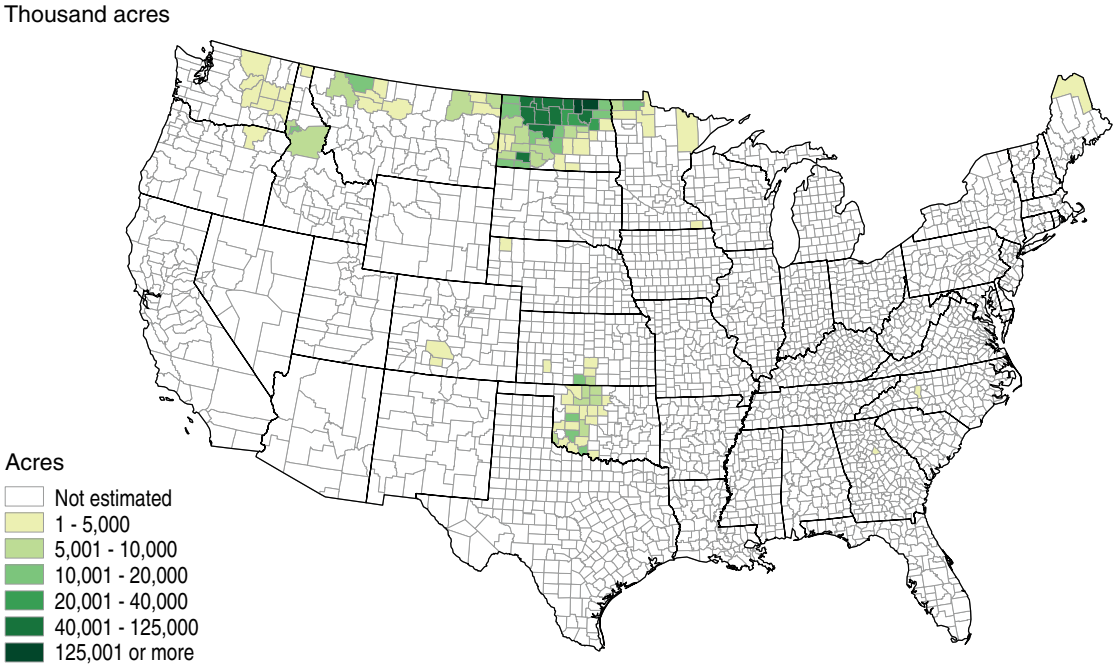
[14] Forage yields were 4.3 to 4.4 tons per acre in a Roundup Ready system that achieved 94 to 97 percent weed control. Yields were 3.8 to 4.2 tons per acre in a conventional weed control system that provided 87 percent weed control (Wilson, 2007).

Canola

Prior to 1980, rapeseed oil was largely used as an industrial lubricant. Undesirable byproducts, such as erucic acid, made it unsuitable for human or animal consumption. Canadian scientists solved both of these problems using modern (but not GE) plant breeding methods. Canada labeled the modified, edible rapeseed plants "canola" in 1979.[15] This distinction was formalized in 1985, when the U.S. Food and Drug Administration deemed rapeseed and canola to be separate crops. Though it is referred to as canola in North America only, edible versions of rapeseed have been commercialized in Australia, China, Europe, and India.

In the United States, 1.26 million acres of canola, with a production value of $456 million, were harvested in 2013 (USDA/NASS, 2014b and 2015a).[16] Canola production is concentrated in North Dakota, where 1.7 billion pounds were grown on 915,000 acres in 2013 (figure 3 depicts harvested acreage in 2012).

Figure 3
Canola, harvested acreage by county, 2012



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

[15]The name canola was created by combining "Canada" and "Oil" (Canola Council of Canada, 2016).

[16]The 2012 Census of Agriculture found that 32 farms harvested a total of 2,759 acres to produce 4.24 million pounds of industrial rapeseed in the United States. Because industrial rapeseed constitutes less than 1 percent of the 2.5 billion pounds of rapeseed produced in 2012, this report restricts its analysis to edible rapeseed, or canola.

Approval of GE Canola: – Regulatory Issues

The first genetically engineered, herbicide-tolerant (GE HT) canola plant was deregulated in January 1998 in response to a petition received from AgrEvo.[17] It was tolerant to the herbicide phosphinothricin (glufosinate ammonium). In January 1999, APHIS deregulated the first glyphosate-tolerant canola variety. Other glufosinate-tolerant varieties were deregulated in 1999 and 2002 (table 7).

Table 7
APHIS' deregulation of GE canola/rapeseed

Petitioner	Event(s)	GE Trait	Date Deregulated
Calgene	pCGN3828-212/86-18 and pCGN3828-212/86-23	Oil profile altered	October 31, 1994
AgrEvo	T45	Glufosinate tolerant	January 29, 1998
Monsanto	RT73	Glyphosate tolerant	January 27, 1999
AgrEvo	MS8, RF3	Glufosinate tolerant and pollination control	March 22, 1999
Aventis	MS1	Glufosinate tolerant	December 23, 2002
Aventis	Topas 19/2	Glufosinate tolerant and pollination control	December 23, 2002
Monsanto	GT200	Glyphosate tolerant	January 2, 2003
Pioneer	73496	Glyphosate tolerant	July 18, 2013
Monsanto	MON 88303	Glyphosate tolerant	September 25, 2013

Source: USDA, Economic Research Service using data from USDA, Animal and Plant Health Inspection Service (2015).

Adoption of GE HT Canola

Canada became the first country to authorize the commercialization of GE canola in 1996.[18] USDA's APHIS deregulated glufosinate-tolerant and glyphosate-tolerant varieties of canola in 1998 and 1999, respectively. By 2002, approximately 70 percent of U.S. canola acreage was GE HT (figure 4). ARMS data show that 95 percent of the canola acres harvested in 2013 were planted using GE HT seeds (table 4, figure 4).[19] This result is consistent with ISAAA's estimate of 93 percent (ISAAA, 2013b).[20]

[17]A non-edible GE variety of rapeseed developed by Calgene was deregulated even earlier, in 1994. Its high-laurate oil trait gave it many industrial uses, but high prices and other undesirable production characteristics limited its profitability (Cornell Cooperative Extension, 2002).

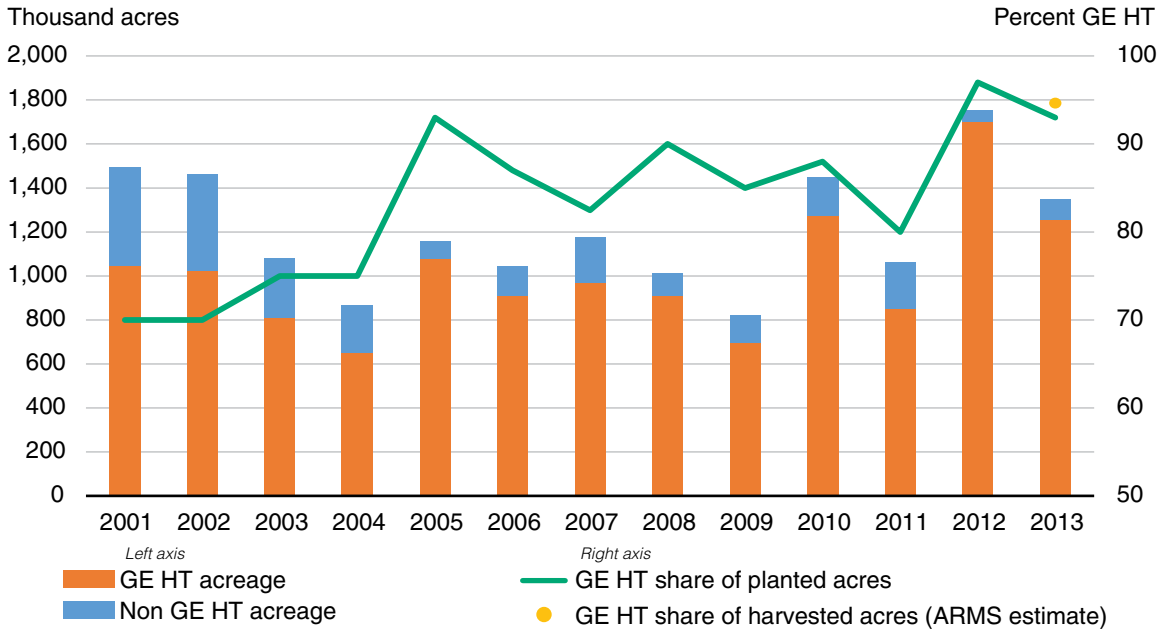
[18]GE HT canola was first grown commercially in Canada in 1996 on 4 percent of that country's canola acres. GE HT canola acreage increased to 12 percent in 1997, 35 percent in 1998, 53 percent in 1999, 55 percent in 2000, 79 percent in 2005, and 93 percent in 2010 (Canola Council of Canada, 2014). Non-GE HT canola (herbicide tolerant through conventional breeding techniques) started with 6 percent in 1996, peaked at 25 percent in 2000 and fell to 6 percent in 2010 (Canola Council of Canada, 2014). GE HT canola in Canada reached a peak of 96 percent in 2013 (ISAAA, 2014b).

[19]This estimate is based on a small sample size. See Appendix 1 for additional details.

[20]Canada grows much more canola than the United States, commercialized GE HT canola 3 years earlier (Canola Council of Canada, 2014), and typically has higher adoption rates for GE HT canola. Moreover, Canada also grows an herbicide-tolerant variety of canola that was not genetically engineered.

Figure 4

Adoption of genetically engineered herbicide-tolerant (GE HT) canola



Sources: USDA, Economic Research Service using data from the following. Planted acres for all years are from USDA, National Agricultural Statistics Service, "Crop Production Historical Track Records, April 2015. GE HT acres planted are calculated by multiplying the adoption share by total acres planted. GE HT adoption rates for 2001 and 2003-06 are from Johnson et al. (2008). (We repeated the 2001 value in 2002 because Johnson lacked 2002 data.) Rates for 2007-13 are from ISAAA Briefs (ISAAA, 2006, 2007, 2011, 2013b, 2014b). Harvested data for 2013 are from USDA's ARMS.

Economic Effects of Adopting GE HT Canola

Though HT canola seeds are more expensive than conventional seeds, most U.S. canola farmers use GE HT-based production systems. Apparently other cost savings, time savings from easier weed control, and/or revenue gains must outweigh the additional seed costs. Small savings also accrue from less dockage since fewer weeds are mixed in with the canola when it is sold (ISAAA, 2007).

Johnson, Grillo, and Strom (2008) report that HT canola reduced pesticide use in the United States by 600,000 pounds in 2006, a cost savings of $9.5 million. Brookes and Barfoot (2014) report that average yields increased by about 6 percent in the early years of GE HT adoption. Recently, improvements in conventional varieties have narrowed the gap in yields.

The premium paid for GE, glufosinate-tolerant varieties tends to range between $5-$7 per acre while the premium paid for glyphosate tolerant varieties ranges between $5 and $13 per acre (Brookes and Barfoot, 2014). Cost savings (before inclusion of the technology costs) are an estimated $7-$18 per acre for glufosinate-tolerant canola and $12-$32 per acre for glyphosate-tolerant canola.

On average, using glufosinate-tolerant canola-based production systems increased gross margins by $24 per acre in 2012 (impacts ranged from $9 per acre to $36 per acre).[21] Using a glyphosate-

[21]Brookes and Barfoot use the term "gross margin" to measure the "impact on gross revenue less variable costs of production rather than a full net cost of production assessment." Costs include seed cost and crop protection expenditures, as well as fuel and labor costs. The (annual) farm income benefits are gross margins ($ per acre) times the acres where GE HT was adopted in a given year.

tolerant canola-based production system increased gross margins between $11 and $25 per acre. Brookes and Barfoot estimate that at the national level, the total farm income benefit from GE HT canola was $26.8 million in 2012, with a cumulative benefit from 1999 to 2012 exceeding $268 million.[22]

[22]The sum of annual farm income benefits (expressed in nominal dollars).

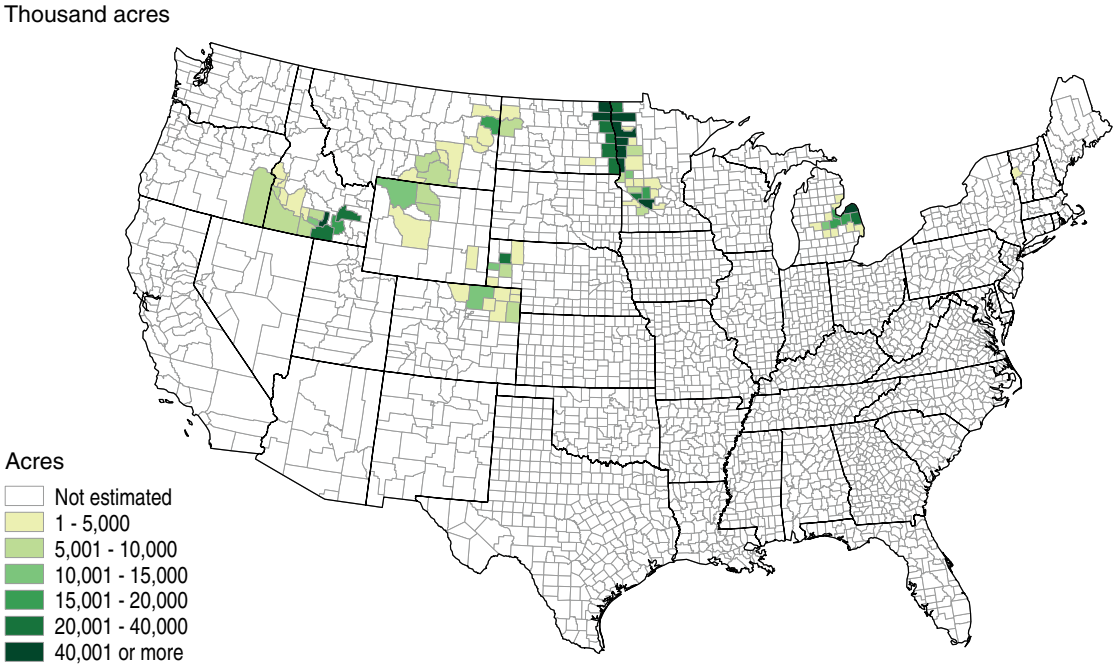
Sugarbeets

U.S. processers produced approximately 8 million metric tons of sugar in 2013. Though this accounts for over half of the sugar produced in North America, it is less than 5 percent of the 176 million metric tons produced worldwide (USDA ERS, 2016a). Currently, Brazil, India, and China dominate the global market. Approximately 55 percent of the domestic sugar supply was produced using sugarbeets in 2013; approximately 45 percent was produced using sugarcane (ERS, 2016b).

Sugarbeets can be grown in a wide variety of climates but prefer cool weather. Approximately 1.2 million acres of sugarbeets, with a production value of $1.6 billion, were harvested in 2013. Minnesota, North Dakota, Idaho, and Michigan accounted for over 80 percent of sugarbeet production in 2013 (ERS, 2016b; figure 5).

The first genetically engineered, herbicide-tolerant (GE HT) sugarbeets were deregulated in 1998 (table 8). Small amounts of these varieties were produced for testing and seed production in 2006 and 2007. Adoption rates rose very rapidly from 2008 to 2013 (figure 6).

Figure 5
Sugarbeets, harvested acreage by county, 2012



Source: USDA, Economic Research Service using data from USDA, National Agricultural Statistics Service, 2012 Census of Agriculture.

Approval of GE Sugarbeets: Regulatory Issues

Novartis Seeds and Monsanto Company submitted a petition for the deregulation of a genetically engineered, glyphosate-tolerant sugarbeet in August 1998 (USDA APHIS, 1999). After conducting an Environmental Assessment, APHIS determined that the GE sugarbeets were not a plant pest risk and the petition for deregulation was granted in December of that year.

Arguing that an Environmental Impact Statement (EIS) had not been prepared for GE HT sugarbeets, the Sierra Club, the Center for Food Safety, High Mowing Organic Seeds, and the Organic Seed Alliance filed suit against the U.S. Government in 2008 (Center for Food Safety et al. v Vilsack and Smith, 2013). In 2009, the U.S. District Court of California found that an EIS should have been conducted, but that it was not in the public interest to (1) issue an injunction on GE HT sugarbeet use, or (2) void the USDA's deregulation decision (Cowan and Alexander, 2013). Because APHIS had not initiated an EIS when the U.S. District Court reconvened in August, 2010, APHIS's deregulation decision was vacated (Cowan and Alexander, 2013). Though GE sugarbeets planted prior to the ruling were not affected, the Court warned growers that they should be prepared to plant conventional seeds in 2011 (Oeschger et al., 2011).

In the fall of 2010, APHIS issued permits to seed producers that authorized seedling production of GE HT sugarbeets. Though these permits were initially contested, the U.S. Court of Appeals for the Ninth Circuit found that there was no risk of cross-species pollination (Cowan and Alexander, 2013).[23]

In 2011, APHIS announced that GE HT sugarbeets would be partially deregulated (Oeschger et al., 2011). Root crop production would be deregulated but not the seed crop production. This was announced as an interim measure effective through December 31, 2012, while APHIS completed the EIS. Though the U.S. District Court for the Northern District of California issued a preliminary injunction ordering the destruction of any GE HT beets planted in 2011, this motion was successfully appealed (Center for Food Safety et al. v Vilsack and Smith, 2013). APHIS finished the environmental impact statement for GE HT sugarbeets in June and deregulated them in July 2012 (USDA/APHIS, 2015). Virtually all U.S. sugarbeet farmers currently cultivate GE HT sugarbeets.

Table 8
Deregulation of GE HT sugarbeets

Petitioner	Event	GE Trait	Date Deregulated
AgrEvo	T120-7	Phosphinothricin tolerant	April 28, 1998
Novartis Seeds and Monsanto	GTSB77	Glyphosate tolerant	Decemeber 23, 1998
Monsanto and KWS SAAT AG	H7-1	Glyphosate tolerant	March 04, 2005
Monsanto and KWS SAAT AG	H7-1	Glyphosate tolerant	Febreary 8, 2011 (Partial)
Monsanto and KWS SAAT AG	H7-1	Glyphosate tolerant	July 20, 2012

Source: USDA, Economic Research Service with data from APHIS (USDA/APHIS, 2015)

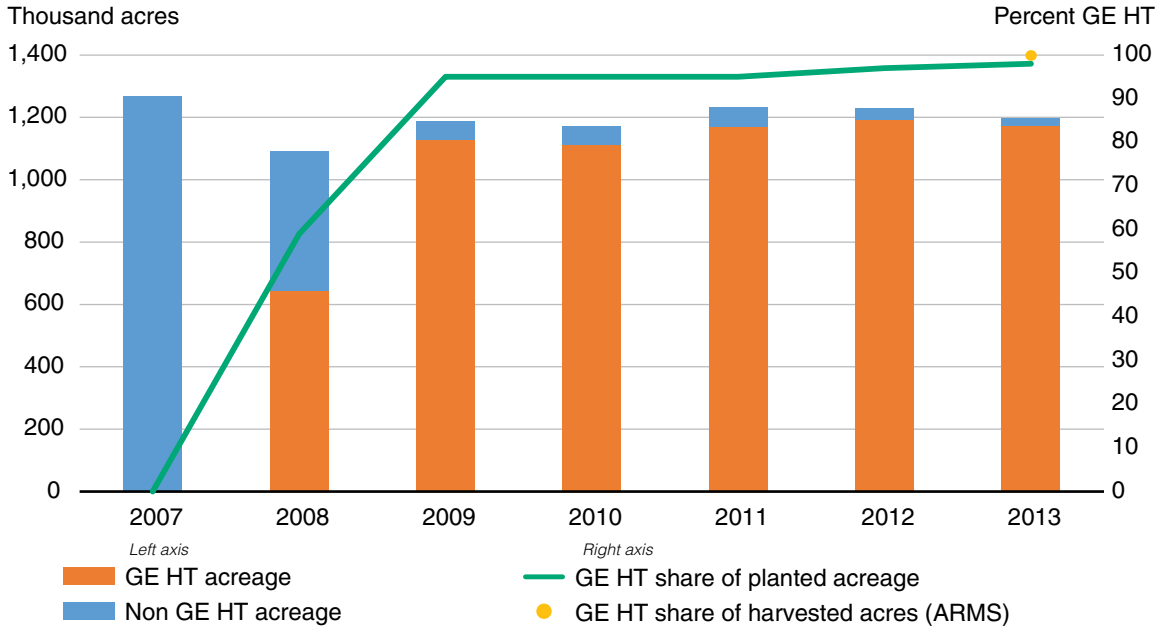
[23]Sugarbeets do not flower until the second year of their life-cycle. Under the conditions of the partial deregulation decision, all GE sugarbeets would be harvested after the first year of production.

Adoption of GE HT Sugarbeets

Demand for GE HT sugarbeets was very low immediately following their deregulation in 1998 (Cowan and Alexander, 2013). In 2006, large-scale field trials were conducted in Idaho to demonstrate the effectiveness of GE HT sugarbeet-based production systems (ISAAA, 2007). Additional demonstrations were held in Wyoming and Michigan in 2007. The success of these demonstrations encouraged producers to mass-produce GE HT sugarbeet seedlings. In 2008, over 60 percent of harvested sugarbeet acreage was planted with GE HT seeds. By 2009, adoption rates had risen to 95 percent (figure 6).

ARMS data indicate that 99.9 percent of harvested sugarbeet acres were planted using GE HT seeds in 2013.[24] This is consistent with ISAAA's estimate of 98.5 percent (ISAAA, 2014b).

Figure 6
Adoption of genetically engineered herbicide-tolerant (GE HT) sugarbeet



Sources: USDA, Economic Research Service using data from USDA's Agricultural Statistics (USDA/NASS 2012) and Acreage (USDA/NASS, 2013, 2014) for total planted and harvested acres. Data for GE HT share of planted acreage are from ISAAA (2007, 2011, 2013b), Brookes and Barfoot (2014), and Johnson et al. (2008). Data for GE HT share of harvested acreage (for 2013) are from the 2013 phase III of the Agricultural Resource Management Survey (ARMS).

Economic Effects of Adopting GE HT Sugarbeets

HT sugarbeet adoption has been reported to increase root yields by 4-18 percent (Kniss, 2010; Nichterlein et al., 2013). Adoption appears to reduce herbicide and labor costs by approximately $43/acre and $95/acre, respectively. The net impact of these benefits is an estimated $96 to $224/acre (Kniss, 2010; Lee, 2014).

[24]The lower bound on a 95% confidence interval is 99.59%; the upper bound is 100%.

Conclusions

Rapeseed did not become a widespread food source for humans and animals until Canadian scientists developed edible varieties of rapeseed, known as canola, using conventional breeding techniques in the 1970s. Genetically engineered, herbicide-tolerant canola was adopted rapidly after it was commercialized in 1999. Data from the 2013 ARMS show that approximately 95 percent of the 1.3 million acres of canola grown in the United States consists of GE HT varieties.

Despite legal challenges that delayed the commercialization of GE HT alfalfa and sugarbeets, U.S. farmers have adopted these seeds rapidly in recent years. GE HT sugarbeets were deregulated in 1998. However, these seeds were not widely distributed until 2007. By 2008, over 60 percent of sugarbeet acreage was produced using GE HT seeds. An analysis of 2013 ARMS data suggests that over 99 percent of the 1.2 million acres of sugarbeets harvested in 2013 were planted using GE HT seeds.

Approximately 13 percent of U.S. alfalfa acreage was planted (including newly seeded acres plus acres planted in previous years) using GE seeds in 2013. Since alfalfa is a perennial that is seeded approximately once every 7 years, only a fraction (about one-seventh) of the alfalfa acreage is newly seeded each year. There were about 810,000 acres newly seeded with GE HT alfalfa in 2013 out of a total of 2.5 million newly seeded alfalfa acres (table 2). This implies that nearly one-third of newly seeded alfalfa acreage was genetically engineered in 2013. Our analysis of the ARMS data suggests that farmers who planted GE HT alfalfa seeds had higher yields than farmers who planted conventional seeds. On average, adopters' yields were 0.53 ton per acre (approximately 17 percent) higher than the yields of other farmers.

Adoption rates for the first GE crops (corn, cotton, and soybeans) were rapid, and the adoption rates for GE canola and sugarbeets increased just as quickly. As of 2013, 90 percent of corn, 90 percent of cotton, 93 percent of soybeans, 93 percent of canola, and 98 percent of sugarbeets were produced using genetically engineered seeds. Adoption rates for GE HT alfalfa appear to be increasing quickly, but it is unclear if this trend will persist.

Currently, seed companies are conducting research to produce new varieties of genetically engineered corn, soybeans, cotton, alfalfa, canola, sugarbeets, wheat, sorghum, cucumbers, tomatoes, potatoes, and many other grains, fruits, and vegetables. If this trend continues, it seems likely that many crops will eventually be produced using seeds that have been genetically engineered.

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Appendix: Data

Primary data source

The primary source of data for this report was Phase III of USDA's 2013 Agricultural Resource Management Survey (ARMS). This multiphase, multiframe, stratified, probability-weighted survey is managed jointly by USDA's Economic Research Service and the National Agricultural Statistics Service (NASS). Surveys of farmers are conducted in three phases. Phase I is a screening questionnaire used to verify that respondents meet certain criteria. Phase II, which is conducted during the fall of the reference year, is a field-level survey that solicits information about a few specific major crops. Phase III, which is conducted in the winter following the reference year, is a whole farm-level survey that solicits information about revenues and expenses, as well as other financial and demographic information. Data from the Phase III survey were used here to estimate adoption rates for GE alfalfa, canola, and sugarbeets.

NASS uses a stratified sampling strategy to improve the reliability of estimates based on ARMS. Sample-selection probabilities vary by farm size, geographic area, and the commodities produced. For example, larger operations are more likely to be sampled than smaller operations. Population estimates are produced by weighting sample observations to account for their probability of selection in the sample. Weights support estimates of national totals of farm assets, debt, expense, and income.

Phase II of ARMS does not cover alfalfa, canola, or sugarbeets. Phase III solicits information about the number of harvested acres for various major crops (including alfalfa, canola, and sugarbeets), but it normally does not distinguish whether the crops were grown from conventional or GE seeds. For this reason, ERS researchers added questions to the 2013 Phase III survey that asked respondents how many acres had been harvested from acres planted using genetically engineered (GE) herbicide-tolerant (HT) seed varieties for alfalfa, canola, and sugarbeets.

ARMS weights are calibrated for some crops (including harvested acres of corn, cotton, soybeans, and wheat). However, the weights are not calibrated for alfalfa, canola, or sugarbeets. Therefore, estimates for these crops may not necessarily match the underlying population.

Several empirical issues had to be resolved before the ARMS data could be analyzed. For instance, some producers chose not to respond to questions about GE harvested acreage even though they reported total harvested acres. A few others indicated that they used seeds that had not been commercially introduced or entered values in two or more cells that did not sum to total acres reported on the harvested acres table. In these cases, we took a conservative approach and dropped the observations that contained problematic data. After applying this selection criteria, there were 1,411 observations for alfalfa (appendix table 1), 22 for canola, and 44 for sugarbeets. Our estimates of GE adoption rates for alfalfa, canola, and sugarbeets are consistent with estimates produced using other sources.

Other data sources

Other data sources include publications by the International Service for the Acquisition of Agri-Biotech Applications (ISAAA, 2006, 2007, 2011, 2013a,b, 2014a,b), the 2012 Census of Agriculture (USDA, 2012), and other USDA data sources (USDA/NASS, 2014, 2014a, 2015, 2015a).[25] Additional details on these data sources are provided under each of the figures and tables.

Appendix table 1
Share of U.S. acreage that is genetically engineered, herbicide-tolerant (GE HT) alfalfa, by State, 2013

State	Percent GE HT	Percent Non-GE HT	Observations
California	13.6%	86.4%	52
Colorado	28.5%	71.5%	17
Idaho	13.5%	86.5%	18
Illinois	17.2%	82.8%	55
Indiana	10.6%	89.4%	86
Iowa	5.6%	94.4%	125
Kansas	22.4%	77.6%	74
Michigan	10.6%	89.4%	54
Minnesota	11.2%	88.8%	143
Missouri	14.8%	85.2%	43
Montana	0.1%	99.9%	45
Nebraska	5.1%	94.9%	92
Nevada	22.1%	77.9%	20
New York	37.2%	62.8%	18
Ohio	16.2%	83.8%	23
Pennsylvania	10.4%	89.6%	36
South Dakota	15.2%	84.8%	31
Utah	6.3%	93.7%	34
Washington	30.0%	70.0%	40
Wisconsin	11.9%	88.1%	325
Other States			80
National	13.5%	86.5%	1411

Source: USDA, Economic Research Service with data from 2013 ARMS

[25]ISAAA is a non-profit organization whose donors include: Cornell University, the International Food Policy Research Institute, the US Department of Agriculture, the US Department of State, and the US Agency for International Development.