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July 2021

Trends in Production Practices and Costs of the U.S. Corn Sector

Monica Saavoss, Tom Capehart, William McBride, and Anne Effland

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Abstract

Corn for grain is a major field crop in the United States, with wide-ranging uses including animal feed, ethanol, food, beverages, industrial products, and exports. The costs and returns for corn for grain production in the United States have undergone numerous changes over the past several decades. Nationally representative data covering 1996–2018 reveals that over the roughly 20-year period, the U.S. corn industry has increased acreage planted to corn, achieved higher yields except during drought years, and increased overall productivity per planted acre. Concurrently, the real price of corn decreased from 1996 through 2005, climbed through 2012, and then declined again, leading to fluctuating net returns, which peaked in 2011. A combination of long-term factors has influenced demand for corn, including growing demand for feed to meet rising global meat consumption and expanding biofuel production, as well as periodic weather-related international production shortfalls and declining stocks, while weather, seed technologies, precision agriculture technologies, and irrigation were major factors that influenced the supply and cost of production.

Keywords: corn, farm characteristics, agricultural production costs, agricultural production practices, cost and returns, organic corn, Agricultural Resource Management Survey (ARMS).

Acknowledgments

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Contents

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A report summary from the Economic Research Service

July 2021

Trends in Production Practices and Costs of the U.S. Corn Sector

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What Is the Issue?

Over the past several decades, the U.S. corn industry experienced developments in seed and precision farming technologies, farm consolidation, and changes in irrigation coverage, which impacted production. Corn accounted for over one-third of the planted acreage for the eight major row crops and was number one in value of production. Corn is a major source of livestock feed, fuel, exports, and a multitude of corn-derived products such as paper and advanced bioproducts such as plastics and cosmetics. This report describes the technological and structural changes in U.S. corn production and describes how these changes have affected farm expenditures, net returns, productivity, yields, and production costs.

What Did the Study Find?

In the last several decades, there was significant structural change in U.S. corn production:

- Over 88 million acres of corn were planted in the United States in 2018, an 11-percent increase from the 79 million acres planted in 1996. The average size of farms that planted corn followed an upward trend, with an average of 501 acres in 1997, 637 acres in 2007, and 725 acres in 2017. In the early part of the period, the average acres planted to corn per farm expanded nearly 50 percent, from 189 acres in 1996 to 280 acres in 2010. There was little change, however, beyond 2010; the average was 278 acres in 2016.
- Across regions, total net returns (value of production less total costs) for corn production fluctuated year to year, with the highest net returns in 2010 and the lowest in 2005 of the 1996-2016 period.

Technological changes in U.S. corn production between 1996 and 2016 (the most recent data available) included:

- Genetically engineered seed varieties. These appeared on the seed corn market in 1996 and, with the introduction of stacked trait seeds—those with genes to produce up to three different traits—became increasingly complex. Steadily, producers increased their adoption of Bt (corn borer)-resistant, corn root worm-resistant, and herbicide-tolerant seed varieties.

- Precision production technologies. Yield monitor and yield map adoption expanded, from 19 and 6 percent nationally (respectively) in 2001 to 52 and 31 percent in 2016. Over the 2001–2016 period, self-propelled machinery with guidance systems (from 3 to 39 percent), variable-rate fertilizer application (about 6 to 19 percent), variable-rate seeding (less than 1 to 15 percent), and variable-rate pesticide application (about 1 to 7 percent) were used on rising percentages of corn-planted acres, with rates of increase varying depending on the region.

- Irrigation. The share of irrigated corn acres declined. The most notable changes were in the Prairie Gateway region, where 77 percent of planted acres were irrigated in 1996 compared with 39 percent in 2017, and in the Northern Great Plains region, where irrigated corn acres dropped from 39 percent in 1996 to 10 percent in 2016.

The effects of structural and technological change in U.S. corn production can be seen in increased average corn yields. The Heartland bolstered the U.S average throughout most of the period with the highest yield of any region and increases in bushels per acre from 138 in 1996 to 197 in 2016, while the Southern Seaboard region had the lowest average yields across years, at 113 bushels per acre.

Average production costs per acre nearly doubled between 1996 and 2016, with seed, fertilizer, capital (buildings and equipment), and land costs as major drivers.

Corn farm productivity improved. Measured as the cost per bushel of corn a farm produced, adjusted by the cost of inputs, farms were considered more productive when the input-adjusted cost per bushel was lower. Productivity grew 28 percent over the period, at an average annual rate of 1.2 percent.

Cost per bushel of corn production decreased as farm size increased up to and including farms of 750 acres in 2016. However, economies of size appear to level out for farms between 750 and 1,500 acres. Since 58 percent of total planted corn acres were on farms of fewer than 750 acres, this suggests a significant capacity for corn farms to further exploit economies of size.

Higher productivity producers had higher yields, larger farms, lower irrigation rates, and lower per acre expenditures on chemicals, fuels, and fertilizer than lower productivity producers. Corn yields of the most productive producers in 2016 averaged 202 bushels per acre, more than 50 percent higher than the yields of low-productivity producers.

How Was the Study Conducted?

This study uses data from USDA, Economic Research Service (ERS) and USDA, National Agricultural Statistics Service's (NASS) Agricultural Resource Management Survey (ARMS) for corn from the years 1996, 2001, 2005, 2010, and 2016, and from the U.S. Census of Agriculture in 2002, 2007, 2012, and 2017. It also uses costs and returns estimates produced by USDA, ERS in each ARMS corn survey year, as well as 2018/2019 acreage and yield reports from USDA, NASS. These data are summarized for each year to describe changes in corn production practices and productivity. Technological and structural characteristics are summarized for each survey year. Corn export statistics from the ERS Feed Grains database are employed to provide context for production changes. For tractability reasons, figures for all summaries of regional outcomes over time include only a subset of regions. Regions are included either because they are major corn-producing regions or because they demonstrate a particularly notable trend in the outcome of interest (for example, a region that experiences the fastest growth in the outcome of interest may be included).

Trends in Production Practices and Costs in the U.S. Corn Sector

Introduction

This study examines changes in production patterns and market trends in U.S. corn production over the past two decades, particularly the growing productivity in corn farming. The study summarizes trends in yield, acreage, prices, input use, production practices, technological adoption, and production costs and returns.[1] It also analyzes the drivers of these changes and how they vary by region. For the purposes of this article, a corn farm refers to any farm that grows corn in a particular year and expects to sell, or would normally sell, at least $1,000 worth of agricultural products. This definition includes farms that also produce other agricultural commodities.

Data for this report are primarily from USDA's Agricultural Resource Management Survey (ARMS) of corn producers, conducted in 1996, 2001, 2005, 2010, and 2016. Data from USDA, National Agricultural Statistics Service (NASS) acreage and yield reports, NASS input price indices, and the costs and returns data product from USDA, Economic Research Service (ERS) are also used in the report.

This report examines farms by the ERS farm resource regions[2] (figure 1). Under this regional framework, the contiguous United States is divided into nine production regions based on production conditions, such as soil and climate, and on farm characteristics. These regions are identified as the Fruitful Rim, Basin and Range, Prairie Gateway, Northern Great Plains, Northern Crescent, Heartland, Eastern Uplands, Mississippi Portal, and Southern Seaboard (see Box: Corn Production in the United States).

Sixty-one percent of U.S. planted corn acres are in the Heartland. The Prairie Gateway is the second highest producing region, with 15 percent of all planted corn acres. The Northern Crescent follows, with 12 percent of planted acres. The Northern Great Plains is the fourth largest, followed by the Southern Seaboard, and finally the Eastern Uplands region.

[1] The focus of this study is dent corn, also known as field corn or Zea mays indentata, which accounts for the majority of corn grown in the United States.

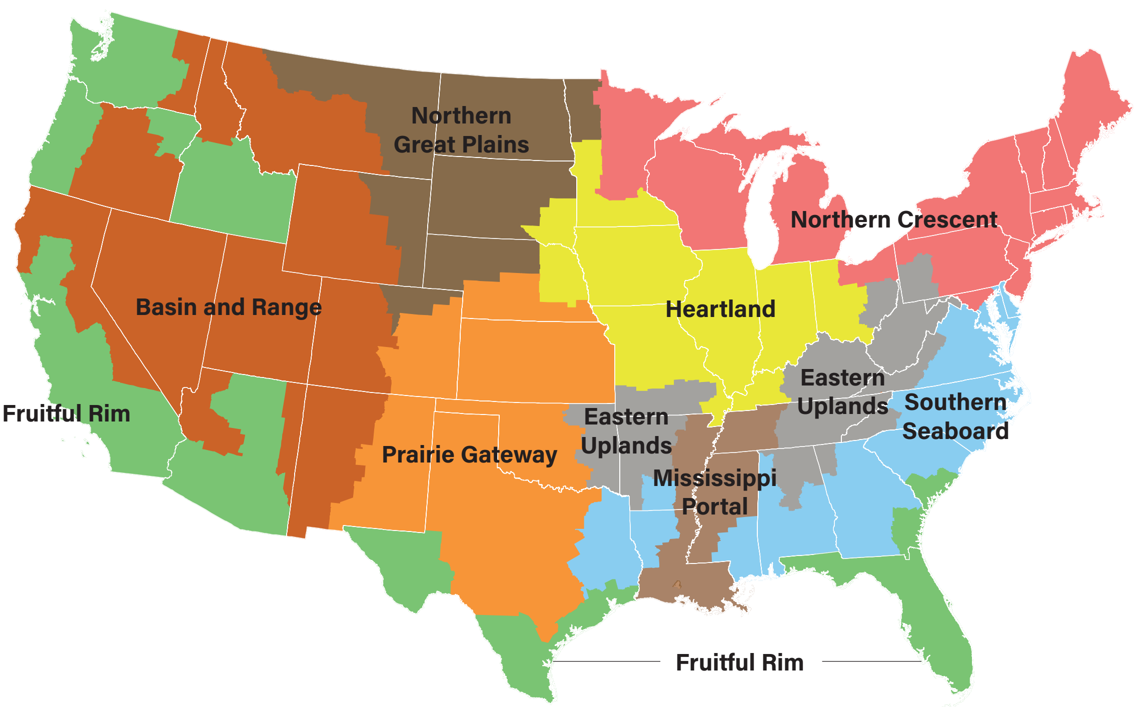
[2] For tractability reasons, figures for all summaries of regional outcomes over time include only a subset of regions. Regions are included either because they are major corn-producing regions or because they demonstrate a particularly notable trend in the outcome of interest (for example, a region that experiences the fastest growth in the outcome of interest may be included).

Corn Production in the United States

Corn is one of the most commonly grown crops worldwide, with the largest producers being the United States, China, Brazil, India, and Argentina (USDA, Foreign Agricultural Service, [FAS], 2019). Regional differences in soil and climate are major determinants of variation in yield and costs. Corn production thrives under a moderate climate with adequate sunshine and without extreme heat or frost. Corn also requires adequate water, drainage, and soil nutrients. Corn is best grown on flat land, which helps keep drainage even and runoff minimized. While corn acreage in the United States is concentrated in the Heartland, the range of regions that can support corn is wider than the ranges of regions that can support many other crops (Meade et al., 2016).

Corn is grown in rows, using a highly mechanized process, with seeding, fertilizer application, chemical application, and harvesting each typically done with a tractor or self-propelled machine. Land and equipment used for corn production are generally transferable to and from soybean production, allowing farmers to rotate between the two crops. Other field crops tend to compete for the same land, but some, such as peanuts and cotton in the Southeast, may require different equipment.

Figure 1
USDA, Economic Research Service, Farm Resource Regions



Source: USDA, Economic Research Service Farm Resource Regions.

Corn Acreage

Over 88 million acres of corn were planted in the United States in 2018, an 11-percent increase from the 79 million acres planted in 1996 (USDA, NASS, 2018). The total number of corn acres planted in the United States remained stable between 1996 and 2006 but increased substantially between 2006 and 2013 before leveling off through 2018 (figure 2). Planted corn acreage peaked at 97.3 million acres in 2012. The U.S. Census of Agriculture reports that the total number of U.S. corn farms (farms producing at least 1 acre of corn for grain with the intent to harvest) decreased between 1997 and 2017, with 450,520 farms in 1997; 348,590 farms in 2002; 347,760 farms in 2007; 348,530 farms in 2012; and 304,801 farms in 2017.

Much of the corn acreage growth has been concentrated in the Northern Great Plains and Prairie Gateway regions. North Dakota, South Dakota, Montana, and Nebraska (mostly in the Northern Great Plains region) experienced a combined growth of 37 percent (4.9 million acres) in planted acres between 1996 and 2018. Corn production also increased substantially in Texas, Colorado, Arizona, and Oklahoma (mostly in the Prairie Gateway) with a 21-percent (700,000 acres) combined increase in planted acres between 1996 and 2018.

In contrast, the number of acres planted in States of the Heartland (Iowa, Illinois, Indiana, Missouri, and Ohio) increased by only 1.6 million acres, or 4 percent, during this period. Planted corn acres in the Northern Crescent, Eastern Uplands, and Southern Seaboard have remained relatively stable.

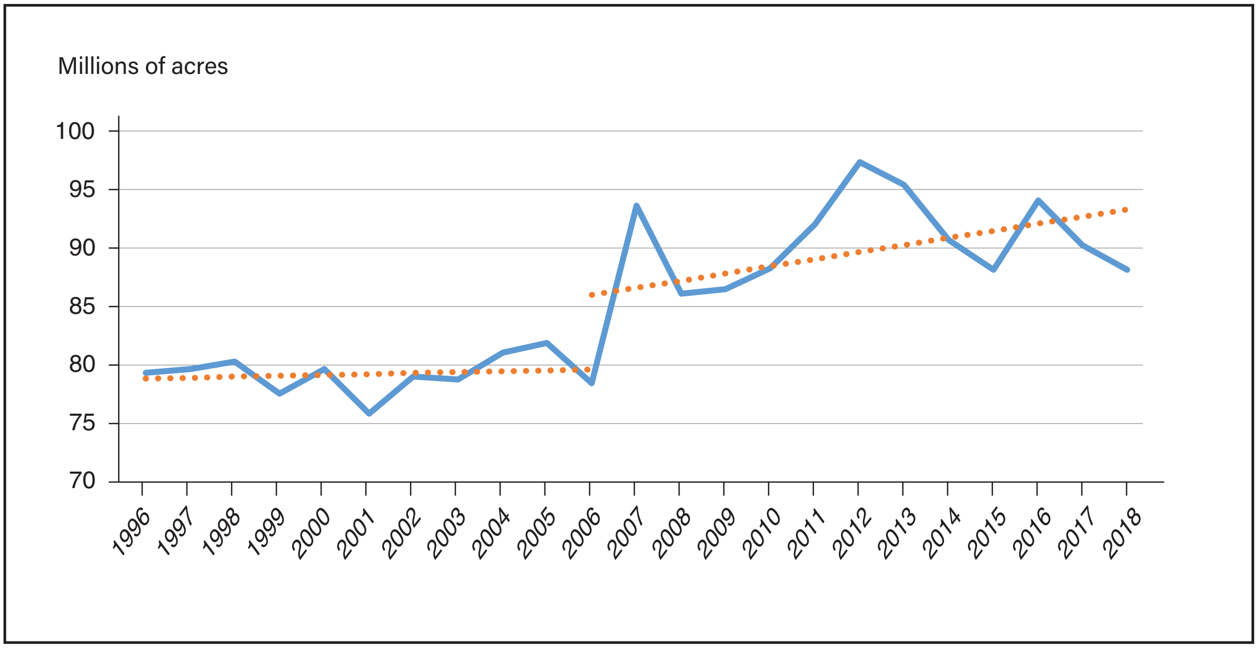
The expanded acreage during the period from 1996 to 2018 has been driven by both increased demand and new technologies. Demand has risen in response to a number of long-term factors such as rising feed demand to meet growing global meat consumption and increasing use of ethanol for fuel. (see Box: Corn Marketing and Use for Major Uses of Corn). The expansion has also been supported by new technologies, particularly genetically engineered seeds and precision farming techniques. Across regions, these technological changes have contributed to a decline in costs of production per bushel (USDA, ERS, *Costs and Returns*).

Corn Marketing and Use for Major Uses of Corn

In the United States, nearly 40 percent of corn disappearance goes to ethanol. The average share of corn used for ethanol increased from 4.9 percent in 1996 to an estimated 37.6 percent for 2018 (Feed Grains Yearbook, 2019). Another 38 percent of corn production goes to feed and residual uses. Feed and residual disappearance is the volume remaining of total supply after accounting for all other uses (food, seed and industrial, and exports) and ending stocks. The feed and residual category includes any reporting or estimating errors in the NASS surveys for production, stocks, industrial use, and trade. The share of corn used for feed and residual declined from 60 percent in 1996 to 38 percent in 2018. The magnitude of the residual component tends to increase with larger crop size. Exports are the third major use for corn (ERS Feed Grains Database). Since 1996, exports have declined in share of total disappearance from 20 to 14.5 percent; however, in absolute terms, export volume is up 15 percent. Total use increased 62.6 percent during the period from 1996 to 2018, from 8.8 billion bushels in 1996 to 14.3 billion for 2018.

Price is an important factor in determining grower profitability, and the correlation between price and the stocks-to-use ratio is significant. Since 1996, the stocks-to-use ratio on a marketing-year basis has averaged 13.5 percent, with a low of 7.4 percent in 2012, a drought year, and a high of 19.8 percent in 2004, when stocks exceeded 2 billion bushels. From 2013 to 2018, the stocks-to-use ratio has averaged 14.2 percent, which resulted in an average price of $3.53 per bushel.

Figure 2
U.S. corn acres planted



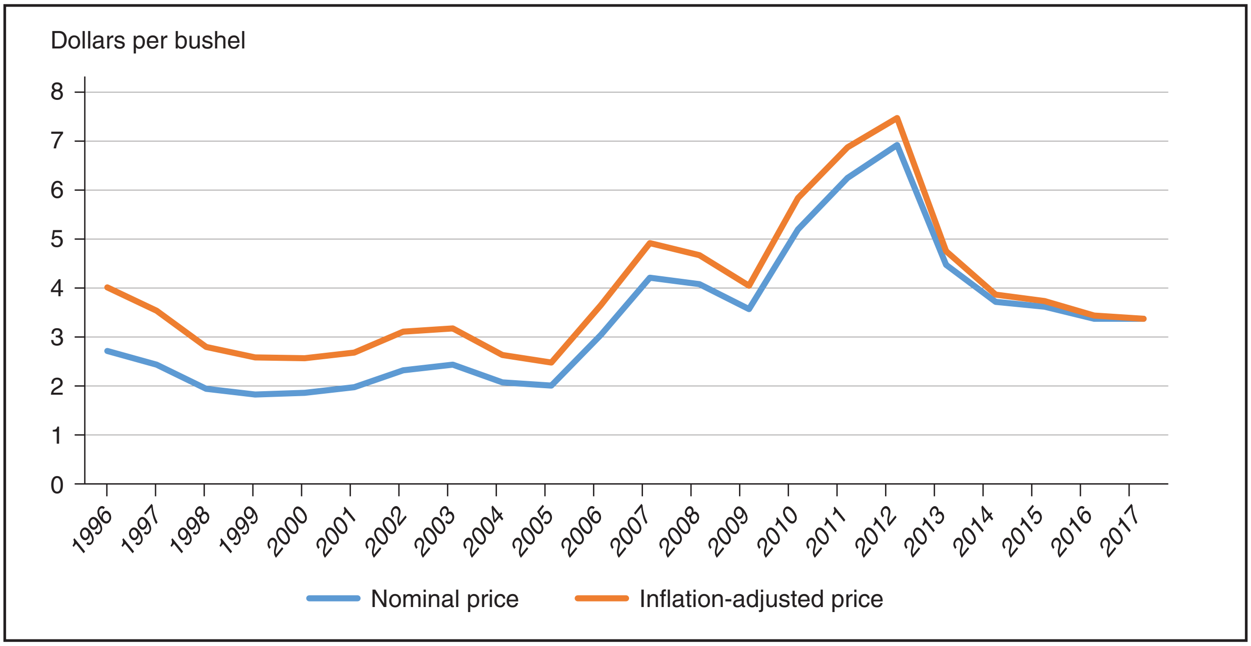
Note: Dashed lines are trends from 1996 to 2006, and from 2006 to 2018

Source: USDA, National Agricultural Statistics Service, *Acreage Report*, 2018.

Corn Prices

The season average corn price received by farmers climbed between 2005 and 2012, peaking during the 2012 marketing year at a national average of $6.89 per bushel, or $7.44 in inflation-adjusted 2017 dollars (figure 3). This rise in prices coincided with the 2012 drought, which lowered production by more than 25 percent from initial expectations, and rising ethanol blending requirements (see Box: The Energy Policy Act of 2005 and Corn Prices). Since 2012, production returned to trend levels, and prices have ranged between $3 to $4 per bushel. Corn prices correlate closely across the United States, with the Northern Great Plains typically expe-riencing the lowest prices and the Southern Seaboard typically experiencing the highest prices. Differences in price between regions are small and due to differences in local supply and demand conditions. For example, areas with more corn acreage may experience higher supply while areas with a larger livestock industry pres-ence may experience more demand.

Figure 3
U.S. corn marketing year average price per bushel



Note: Prices are adjusted for inflation using the Gross Domestic Product (GDP) Implicit Price Deflator to reflect 2017 dollars.
Source: USDA, National Agricultural Statistics Service, *Price Reports*.

Yield and Production

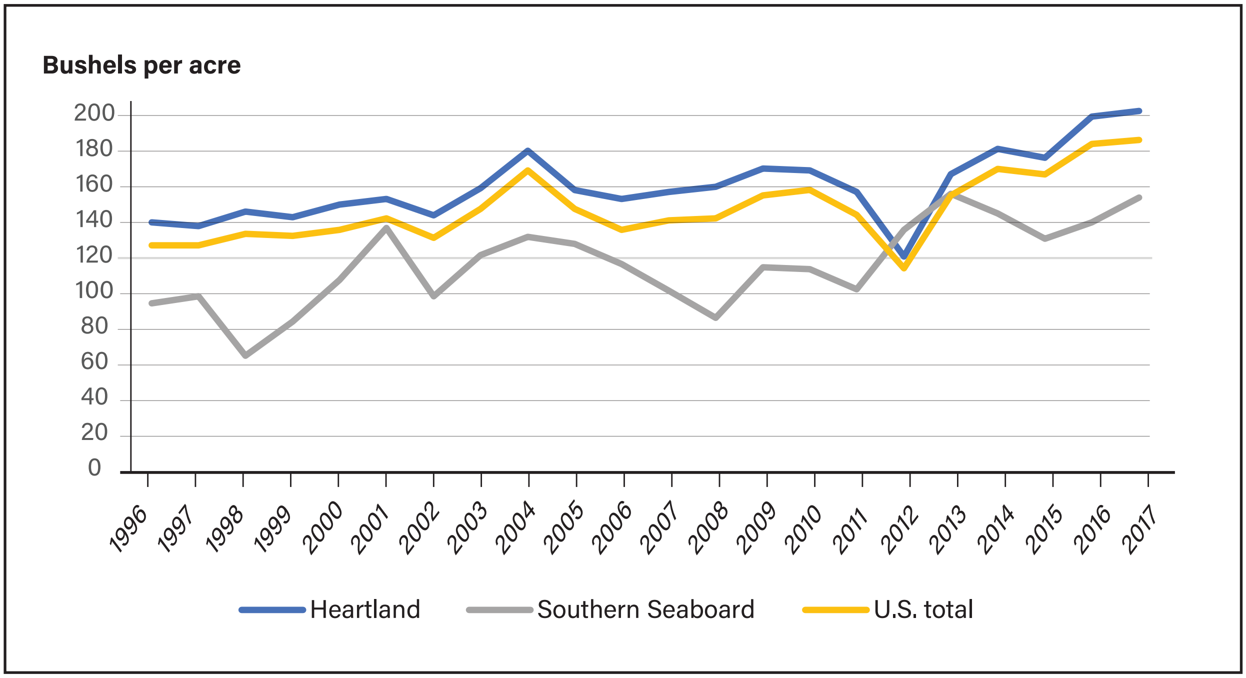
Between 1996 and 2017, average U.S. corn yields increased by 42 percent, from 130 bushels per acre in 1996 to 185 bushels per acre in 2017 (figure 4). Droughts in 2002, 2006, and, most significantly, in 2012, accounted for abnormally low yields in those years. Growth in yields has been consistent across regions, with yields highest in the Heartland (an average of 201 bushels per acre in 2017) and lowest in the Southern Seaboard (an average yield of 152 bushels per acre in 2017). Due to increases in both planted corn acreage and corn yield, total U.S. corn production grew from 9.2 billion bushels in 1996 to 14.6 billion bushels in 2017, an average of 2.2 percent per year[3] (figure 5). The increase in production has been fairly steady, except for the drought years. Production increases have been most pronounced in the Heartland, with just over 6 billion bushels produced in 1996, to just over 10 billion bushels in 2016 (figure 6). In relative terms, the Northern Great Plains experienced the highest growth in production, from 273 million bushels in 1996 to 1.2 billion bushels in 2016.

[3]Average annual growth rates were calculated by raising the total growth rate to the reciprocal of the number of years to account for compounding.

The Energy Policy Act of 2005 and Corn Prices

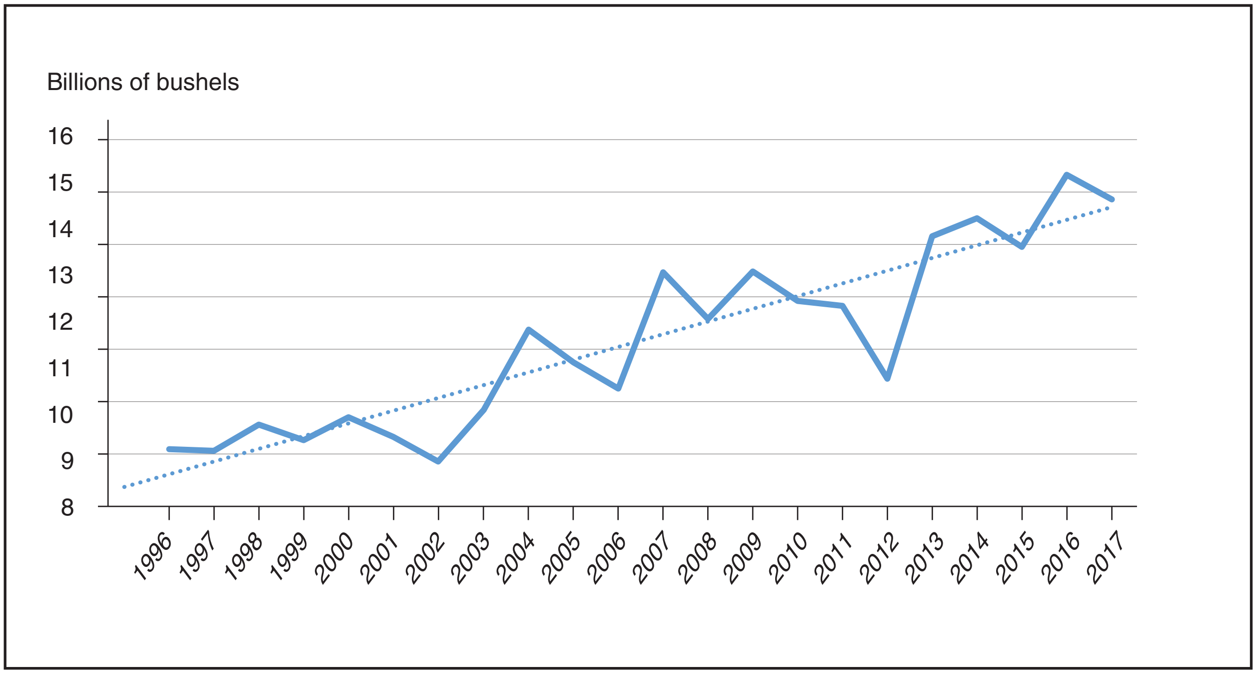
The Energy Policy Act of 2005 and its successor, the Energy Independence and Security Act of 2007, set the minimum amount of biofuel in transportation and heating fuel under the Renewable Fuels Standard (RFS). Under the Energy Policy Act of 2005, the required volume of biofuels mixed in with gasoline and diesel was gradually increased each year from 2006 through 2012. The requirement started at 4 billion gallons in 2006 and was set to move to 7.5 billion gallons by 2012. In 2007, however, the Energy Policy Act of 2005 was superseded by the Energy Independence and Security Act of 2007, which increased the required volume of biofuels present in gasoline sales starting in 2008, to continue through 2022, with new requirements of 9 billion gallons in 2008, 15.2 billion gallons in 2012, and 36 billion gallons in 2022 (Energy Policy Act, 2005; Energy Independence and Security Act, 2007). However, it also established requirements that specified portions of the required biofuel volume come, in increasing increments, from cellulosic biofuel rather than from corn-based biofuel. However, production of cellulosic ethanol did not meet the requirements of the mandate and demand for conventional corn-based ethanol grew. Although the contribution of corn-starch-based conventional ethanol to the RFS was capped at 15 billion gallons during the later years of the mandate, demand for corn was nonetheless strengthened by additional ethanol production outside the RFS, with the enhanced demand contributing to price increases (Roberts and Schlenker, 2013).

Figure 4
U.S. average corn yield



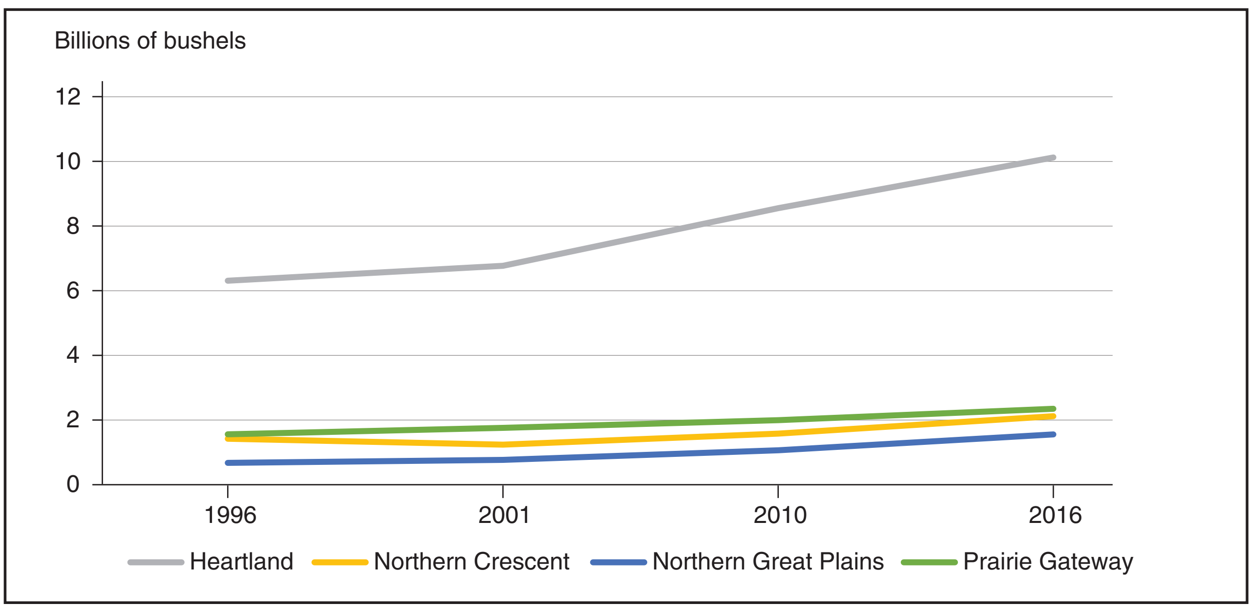
Source: USDA, Economic Research Service, *Costs and Returns*.

Figure 5
U.S. corn production



Note: The dashed line is a trend line.
Source: USDA, National Agricultural Statistics Service, County Agricultural Production Surveys.

Figure 6
U.S. corn production by region



Source: USDA, Economic Research Service, and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

USDA, Economic Research Service and USDA, National Agricultural Statistics Service Agricultural Resource Management Survey Data

The corn commodity-specific USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey (ARMS) is a nationally representative survey that targets the minimum number of States that represent 90 percent of all U.S. corn acreage. The survey is conducted in three phases. The first phase screens potential farms for eligibility. Farms are eligible if they are growing corn in the target year and they expect to sell or would normally sell at least $1,000 worth of agricultural products. The second phase of the survey asks detailed questions about the quantity of inputs used, production practices, and costs for a randomly chosen field of corn. The third phase collects farm-level information about farm finances. The Economic Research Service (ERS) uses the corn commodity-specific ARMS responses to estimate corn commodity costs and returns in survey years.

The corn-specific ARMS used in the costs and returns estimates were conducted for the years 1996, 2001, 2005, 2010, and 2016. Sample sizes of the field-level survey (Phase 2) were 1,379 in 1996; 2,930 in 2001; 1,617 in 2005; 2,654 in 2010; and 1,819 in 2016. In each of those 5 survey years, the survey included the States of Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Carolina, Ohio, South Dakota, and Wisconsin. Starting in 2001, Georgia, New York, North Dakota, Pennsylvania, and Texas were also included. Colorado was added in 2016.

Technological Change

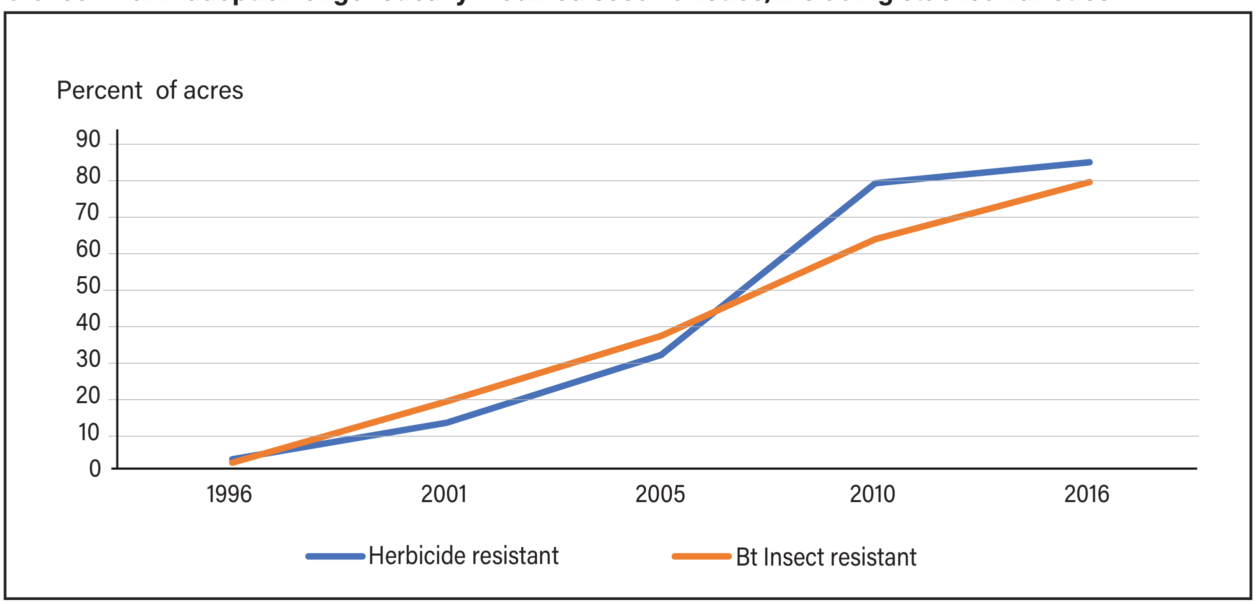
Major technological shifts in U.S. corn production over the past 20 years include the adoption of new seed varieties and precision farming technologies, and changes in irrigation practices. Tile drainage may have also played an important role in shifting corn production patterns. While historical data for tile drainage practices are not available, 33 percent of fields employed subsurface drainage systems in 2016.

Seed Varieties

Corn seed may be genetically engineered or selectively bred to resist damage from insects (using Bacillus thuringiensis bacteria, or Bt), herbicides, fungal diseases, or drought. Some genetically engineered Bt-variety seeds target a single genus of insects such as rootworms, earworms, armyworms, or corn borers, while others are stacked to target multiple genera. Similarly, some varieties of corn seed are stacked to resist multiple pathways of damage, such as from insect, herbicides, or drought. Adoption and development of genetically engineered seed varieties has increased significantly over the past two decades (figure 7).

Bt corn varieties were first commercially available in 1996 (Fernandez-Cornejo and McBride, 2002). In 1996, farmers planted Bt insect-resistant seed on only 2 percent of acres, and planted herbicide-tolerant seed on only 3 percent of acres. By 2001, those figures had increased to 21 percent and 16 percent, respectively. By 2016, farmers planted Bt insect-resistant seed on 78 percent of acres and planted herbicide-tolerant seed on 84 percent of acres. By 2016, 91 percent of corn acres were planted using some form of genetically engineered seed. The trend continued through 2018, with NASS reporting that 92 percent of 2018 corn acres were planted using genetically engineered seed.

Figure 7
U.S. corn farm adoption of genetically modified seed varieties, including stacked varieties



Source: Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

The two major insects Bt corn protects against are the European corn borer and the corn rootworm. European corn borers damage corn harvests by tunneling stalks, which results in broken stalks and drooped ears, leading in turn to reduced yields (Cullen and Wedberg, 2005). Corn rootworms damage corn harvests by eating the root, which reduces the water and nutrient uptake and causes misshapen plants, leading to reduced yields. The entry sites of corn rootworms also serve as entrances to pathogens (Purdue University,

Specialty Markets

In recent years, the market for organic and non-genetically engineered corn has increased, with organic corn prices generally two to three times higher than prices for conventional varieties (Greene et al., 2016). USDA released regulatory standards for certifying agricultural products as organic under the National Organic Program. These standards prohibit certified organic farms from using synthetic fertilizers, genetically engineered seeds, and certain synthetic pesticides. Beginning in 2005, the Agricultural Resource Management Survey has asked whether corn acres are certified as organic. In that year, the percentage of corn acres that were certified as organic was 0.16 percent. In 2010, the percentage of corn acres that were certified was 0.10 percent. For the 2016 survey year, that figure rose to 2 percent, an increase from the previous survey year, but still a small portion of the overall corn market.

While there is no government-sanctioned certification for non-genetically engineered (non-ge) corn, some farmers using non-ge seed receive certification through private organizations. Becoming certified as non-ge is a lower burden for farmers than becoming certified as organic; all organic corn must be non-ge, but non-ge corn does not have to adhere to the other requirements of organic certification. In 2016, excluding certified organic acres, 2 percent of corn acres were grown with the intention of selling in a market specifically for identity-preserved non-ge corn.

2009). Starting in 2010, the ARMS asked whether corn farmers used Bt seeds that targeted European corn borers, corn rootworm, or both. In 2010, 55 percent of corn-planted acres had seeds that targeted the European corn borer, compared with 76 percent in 2016. The adoption of seeds targeting the corn rootworm exhibited similar growth, with 41 percent of corn-planted acres targeting corn rootworm in 2010 and 62 percent in 2016.

A widening variety of seeds has become available on the market. In 1996, when stacked varieties of corn seed were not yet available, farmers who wanted to plant genetically engineered seed had to choose between targeting a specific pest or using an herbicide-tolerant seed variety. In contrast, by 2016, the seed market offered multiple varieties of corn that protected the crop against three or more pathways to potential damage. Organic and non-genetically engineered markets exclude the use of genetically engineered seeds (see Box: Specialty Markets).

New seed technologies may also have bolstered some of the acreage expansion and some of the changes in production practices seen over the past two decades. Drought-tolerant seed varieties, for example, became commercially available in 2011 and have facilitated the growing of corn in a widened range of climates, increasing yields in the water-limited environments of the Prairie Gateway and Northern Great Plains regions without penalizing yield in more water-favorable environments (Gaffney et al., 2015; McFadden et al., 2019). As expected, adoption of drought-tolerant seeds has been disproportionally high in drought-prone regions (McFadden et al., 2019). Insect-resistant and herbicide-tolerant seed varieties have expanded farmers' options for pest management, allowing farmers to plant in areas where pest management had been more difficult. In addition to supporting expanded acreage, the introduction of new seed varieties has altered production practices. The adoption of drought-tolerant seed varieties coincided with a slight decline in irrigated acreage, suggesting that farms may use new seeds as a substitute for irrigation (see McFadden et al., 2019, for more information on drought-tolerant corn seeds). The adoption of insect-resistant seed varieties has coincided with shifts in chemical use (Benbrook, 2012), and the adoption of all genetically engineered seed varieties coincided with an increase in the seeding rate for corn (Butzen, 2011).

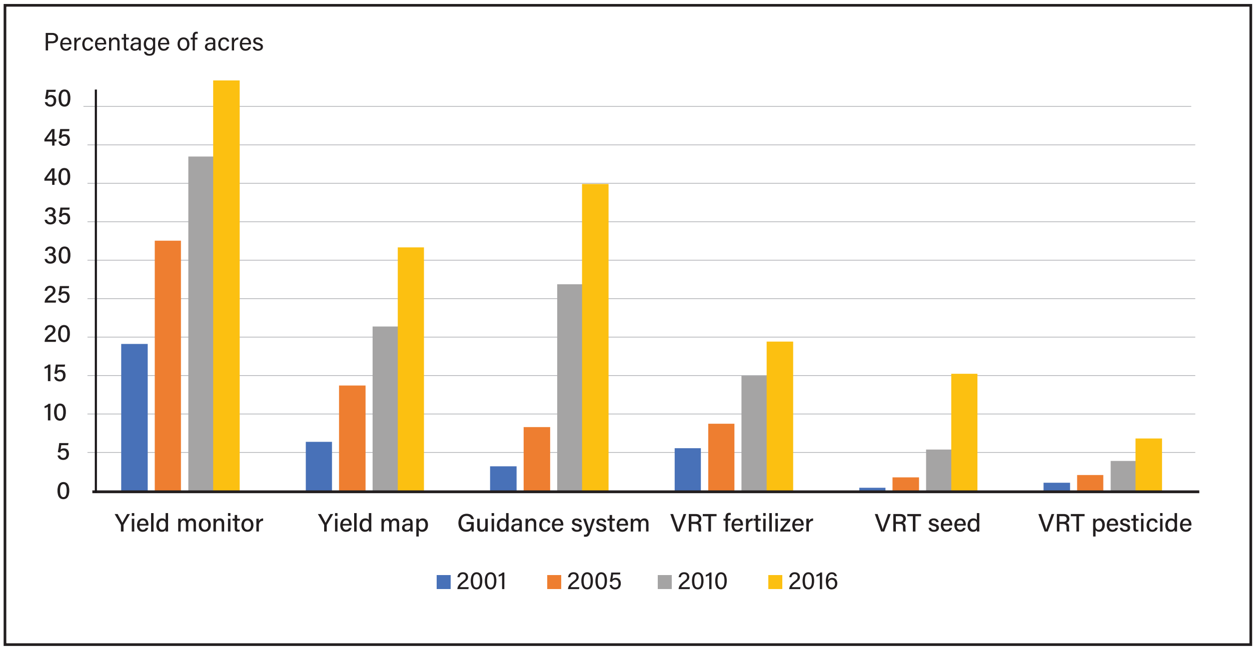
Kucharik (2006) and Kucharik (2008) documented a gradual shift, from the 1970s to the early 2000s, toward earlier planting dates. These earlier planting dates were enabled first by advances in mechanization, then by improvements in pesticides, and finally by the introduction of genetically engineered seeds. Kucharik (2006) and Kucharik (2008) argued that by allowing a lengthened growing season, these earlier planting dates contributed to increased yields. Kucharik (2008) noted that earlier planting dates were particularly beneficial to northern regions in the United States since a long growing season had already been possible in southern regions.

Precision Farming

"Precision farming" refers to a set of technologies that allow farmers to make operating decisions on a site-specific basis, considering variability within and between fields. Over the past 20 years, precision farming has grown from a niche production technique to a widespread adoption of some technologies (Schimmelpfennig, 2016). Widely adopted technologies include yield monitors, yield maps, variable-rate applicators, and guidance systems. Yield monitors use a sensor on the harvester and Global Positioning System (GPS) tracking technology to keep track of how much corn is harvested from each part, or management zone, of the field. This information can be put into a yield map, which visualizes the data from the monitor and allows farmers to address site-specific issues such as poor drainage or low nutrient levels in low-yield areas of the field. Soil maps provide similar site-specific information about soil type and soil quality throughout the field, highlighting differences in pH level and nutrient content. Variable-rate applicators allow farmers to apply varying amounts of inputs throughout the field. They can be used for seed, fertilizer, or pesticides. Farmers base variable-rate application decisions on yield maps or soil maps. Guidance systems use GPS technologies to provide tractor operators with visual directions toward rows, or in some instances, automatically steer the tractor to drive directly over rows. This can reduce the number of passes required over the field.

Over the past two decades, the adoption of precision-farming technologies has increased. Since 2001, the portion of acres covered by yield monitors, yield maps, guidance systems, variable-rate seeders, variable-rate fertilizer applicators, and variable-rate pesticide applicators has increased with each subsequent corn survey (figure 8). For example, yield monitor adoption more than doubled from 19 percent of corn acres in 2001 to 52 percent of acres in 2016. The use of yield maps grew even more sharply, from 6 percent of acres in 2001 to 31 percent of acres in 2016. Adoption of guidance systems increased more than tenfold, from 3 percent of acres in 2001 to 39 percent of acres in 2016. Across time, the use of all three forms of variable-rate applicators increased, although adoption of fertilizer variable-rate applicators was consistently more widespread than adoption of seeding variable-rate applicators, which in turn was more widespread than adoption of pesticide variable-rate applicators. Adoption rates for corn of yield mapping, soil mapping, and variable-rate applicators have been comparable to adoption rates for soybeans and higher than for peanuts, cotton, rice, and spring wheat (Schimmelpfennig, 2016). Adoption rates for guidance systems have been increasing across crops, with the highest rates of adoption on spring wheat and rice farms (Schimmelpfennig, 2016).

Figure 8
Use of precision farming technologies on U.S. corn acreage



Note: VRT is Variable Rate Technology.

Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

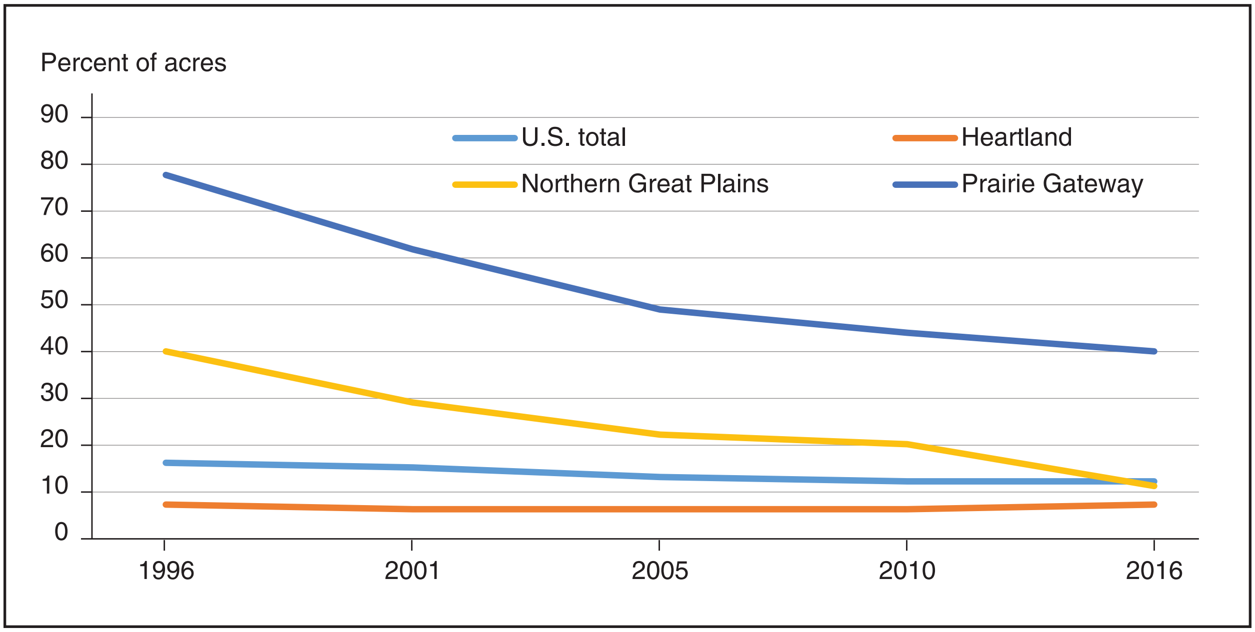
The adoption of precision farming technologies has varied by region. Yield monitors were used on 62 percent of corn acres in the Heartland in 2016, for example, compared with 72 percent of acres in the Northern Great Plains. A yield map was developed for 39 percent of corn acres in the Heartland, and 36 percent of corn acres in the Northern Great Plains. The two highest-adopting regions for guidance systems were the Northern Great Plains at 70 percent of acres and the Prairie Gateway at 57 percent of corn acres. The adoption rate for guidance systems in the Heartland was 48 percent of corn acres. The Heartland had the highest adoption rate of variable-rate fertilizer applicators, at 26 percent of corn acres, followed by the Northern Great Plains at 20 percent of acres. The Northern Great Plains had the highest adoption rate of variable-rate seeders, at 23 percent of corn acres, followed by the Heartland at 20 percent of corn acres. The Southern Seaboard had the highest adoption rate of variable-rate pesticide applicators, at 12 percent of corn acres, followed by the Heartland at 9 percent.

In the 2016 ARMS, producers were asked about their use of additional information-gathering technologies that were newer to the market, including soil tests, soil sensors, hardwire and wireless crop-condition sensors, and aircraft, satellites, and drones. Each of these technologies had relatively low adoption rates, with soil tests, soil sensors, and each type of crop-condition sensor used on just over 1 percent of all corn acres. Aircraft, satellites, and drones had slightly higher adoption rates, each used on 4 percent of all corn acres.

Irrigation

Irrigated acreage as a percentage of total corn acreage has declined steadily since 1996, from 15 percent of corn acres irrigated in 1996 to 11 percent of acres irrigated in 2016 (figure 9 and table 1). Irrigation trends have varied significantly by region. The Prairie Gateway has seen a sharp decline in irrigation rates, from 77 percent of all corn acres irrigated in 1996 to 39 percent in 2016. This decline coincided with a decrease in the absolute number of irrigated acres in the region, from 6.4 million planted acres in 1996 to 5.0 million acres in 2016. This may be due in part to the depletion of the Ogallala Aquifer having driven up irrigation pumping costs (Colaizzi et al., 2009). In recent years, many aquifers have undergone severe overdraft, with overdraft leading to a reduction in the availability of groundwater (Hellerstein et al., 2019). Such depletion may make irrigating more costly, especially when farmers must invest in new irrigation equipment and less likely where farmers anticipate a lower return on that investment. Availability of drought-tolerant varieties of corn may also play a role in the decline of irrigation rates.

Figure 9
Percent of U.S. corn acres irrigated



Source: USDA, Economic Resource Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

The decline in irrigated corn acres in the Prairie Gateway mirrors a regional trend away from irrigation, with net decreases in total irrigated acres occurring across all crops between the 2007 and 2012 Census of Agriculture (USDA, National Agricultural Statistics Service, 2009; USDA, National Agricultural Statistics Service, 2014). Similarly, irrigation of corn in the Northern Great Plains region declined from 39 percent of corn acres in 1996 to 10 percent in 2016. The absolute number of irrigated acres in the Northern Great Plains declined by 33 percent, from 1.1 million acres in 1996 to 720,911 in 2016.

Corn irrigation in the Southern Seaboard region increased in percent of acres irrigated from virtually zero in 1996 to a peak of 21 percent in the 2001 ARMS survey year, holding at 18 percent by 2016. The absolute number of irrigated acres in the Southern Seaboard increased almost 20-fold between 1996 and 2016, from 12,687 irrigated planted acres in 1996 to 248,248 irrigated planted acres in 2016.The 1996–2010 increase in irrigated acres in the Southern Seaboard mirrored trends across crops in Eastern States, which were driven by increased commodity prices and yields, access to relatively low-cost groundwater, and increased risk-avoidance due to drought conditions (Schaible and Aillery, 2012).

Rates of irrigation usage in the Heartland have been relatively stable, ranging from 5 percent to 6 percent over the period from 1996 to 2016. The absolute number of irrigated acres in the Heartland decreased between 1996 and 2001 before increasing from 2.3 million planted acres in 2001 to 3.3 million planted acres in 2016, mirroring trends in overall planted acres.

While overall irrigation rates have declined, the portion of irrigated corn acres with pressure systems has increased steadily. In 1996, 63 percent of all irrigated acres used a pressure system.[4] That number remained steady through 2001, and then increased to 67 percent in 2005, 74 percent in 2010, and 77 percent in 2016. At the same time, the portion of irrigated acres that used gravity systems using unlined ditches[5] (such as siphon tubes from unlined ditches or portal systems from unlined ditches) declined from 9 percent in 1996 to 5 percent in 2001, 3 percent in 2005, 2 percent in 2010, and was at 3 percent in 2016. Unlined ditches tend to lose water through leaching into the ground.

In 2016, the distribution of irrigation technologies varied by region. Irrigated acres in the Southern Seaboard, Eastern Uplands, and Northern Crescent regions used pressure systems almost exclusively, while 41 percent of irrigated acres in the Northern Great Plains region employed gravity systems. Other regions had more mixed adoption of each type of system, with 25 percent of corn acres in the Heartland and 22 percent in the Prairie Gateway employing gravity systems.

Table 1

U.S. corn percent of acres irrigated

	U.S. total	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Eastern Uplands	Southern Seaboard
	Percent of acres						
1996	15	6	2	39	77	0	0
2001	14	5	4	28	61	1	21
2005	12	5	5	21	48	2	13
2010	11	5	0	19	43	0	15
2016	11	6	2	10	39	0	18

Source: USDA, Economic Research Service, *Costs and Returns*.

[4]Irrigation systems are either pressure or gravity systems. Pressure systems use water from sprinklers or low-flow or drip/trickle systems whereas gravity systems use water from flood or furrow irrigation systems or from sub-irrigation systems (USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey, 2018 Phase 2 Interviewer's Manual*)*.

[5]Lined ditches are lined with concrete, plastic, clay, or other nonporous material to prevent water loss, where unlined ditches have no lining (USDA, Economic Research Service and USDA, National Agricultural Statistics Service, *Agricultural Resource Management Survey 2018 Phase 2 Interviewer's Manual)*.

Input Use and Costs

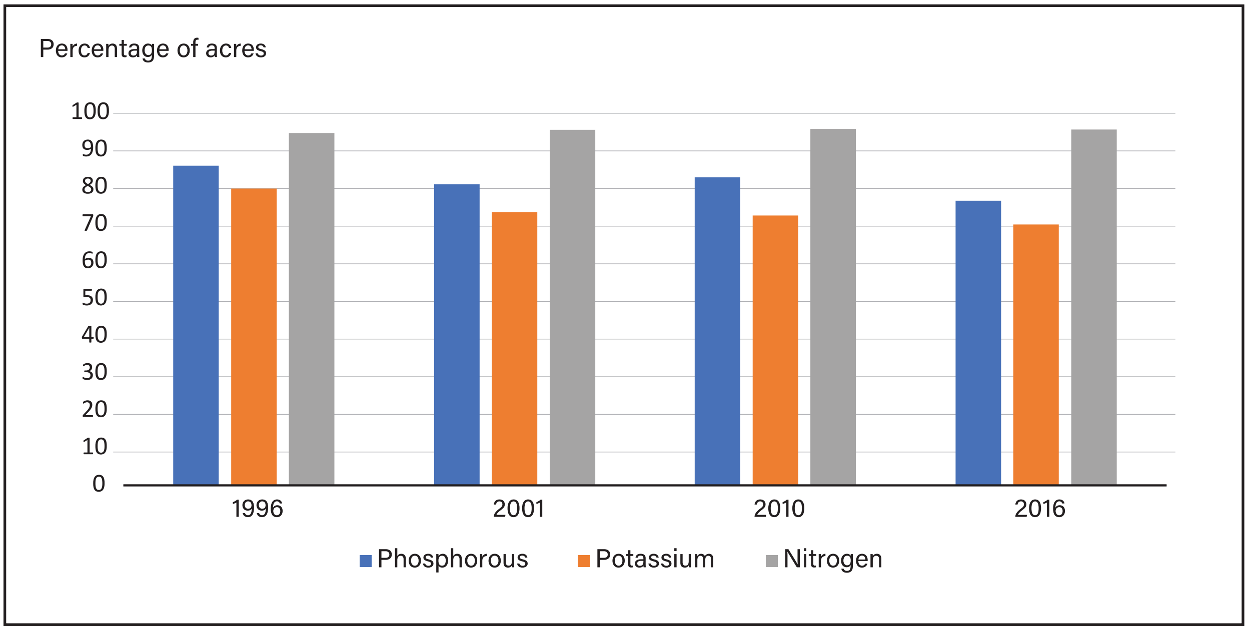
Inputs

The adoption of genetically engineered and new hybrid seed varieties during the past two decades has facilitated an increase in seeding rates from an average of 27,328 seeds per acre in 1996 to 31,358 seeds per acre in 2016. With features such as upright leaves that can capture sunlight without requiring the amount of space traditional varieties do, new seed varieties enable higher planting densities (Mansfield and Mumm, 2014). Additionally, the increased adoption of variable-rate seeding technology allows farmers to customize their seeding rates in order to maximize efficiency.

Nitrogen, phosphorus, and potassium are important nutrients for corn, with nitrogen the most widely used in terms of both prevalence and amount. In 2016, farmers applied nitrogen to 96 percent of all corn acres, a figure that has remained relatively stable since 1996 (figure 10). During this period, the average amount of nitrogen used, including untreated acres, increased from 107 pounds per acre in 1996 to 125 pounds per acre in 2016. The percentage of corn acres that had soil tested for nitrogen levels increased from 13 percent in 1996 to 18 percent in 2001 but has remained relatively steady since then at 21 percent in 2005, 18 percent in 2010, and 21 percent in 2016.

In contrast to nitrogen, farmers applied phosphorus on 76 percent of all corn acres in 2016, a decrease from 86 percent in 1996. The average amount of phosphorus applied has been steady since 1996, when an average of 45 pounds of phosphorus was applied per corn-planted acre, to 2016, when the average was 44 pounds per corn-planted acre. Meanwhile, the percentage of farmers who soil tested for phosphorus remained relatively stable. The ARMS did not ask about phosphorus testing in 1996, but in 2001, 27 percent of all farmers tested for phosphorus, compared with 30 percent in 2016.

Figure 10
U.S. corn acres receiving nitrogen, phosphorus, and potassium



Source: USDA, Economic Research Service, and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Like the trends in phosphorus, the percentage of corn acres on which farmers applied potassium decreased from 80 percent in 1996 to 70 percent in 2016; however, average rates of potassium usage remained stable, from 57 pounds per acre in 1996 to 55 pounds per acre in 2016, with lower levels in the intervening years. Considering the reduction in the percentage of farmers applying potassium to corn, rates of potassium application per treated acre increased.

The use of chemicals for weed and pest control has changed substantially over the past two decades in conjunction with the adoption of the new seed varieties designed to aid in pest management. Across both treated and untreated acres, the average number of herbicide treatments per acre[6] increased from 2.5 in 1996 to 2.9 in 2001, dipped in 2010 to 2.6 treatments per acre, and increased in 2016 to 3.6. The large increase between 2010 and 2016 coincided with a growth in herbicide-resistant weeds. Resistance to Glyphosate, for example, is widespread and is documented for 14 different species of weeds (Livingston et al., 2015).

Insecticide use decreased from 0.31 treatments per acre in 1996 to 0.28 in 2001 and 0.13 treatments per acre in 2016, with a dip to 0.08 treatments per acre in 2010. This decrease coincided with increasing adoption of Bt insect-resistant seed varieties. Corn borer varieties came on the market in 1996 and rootworm varieties came on the market in 2003 (Magnier et al., 2010). Finally, the use of fungicide has been increasing. In the 1996 ARMS, no respondents reported using fungicides. That figure climbed to 0.07 treatments per acre in 2010, and to 0.13 treatments per acre in 2016. Paul et al. (2011) suggest this increase may be due to claims of increased yield in hybrid corn response to foliar fungicides as well as to the availability of new active ingredients such as quinone outside inhibitors (QoI).

Corn farmers till soil in order to incorporate fertilizer and crop residue into the soil, to prepare the soil for planting, and to control weeds (Claassen et al., 2018). Farmers use no-till farming and conservation tillage farming[7] for a variety of reasons including soil and water conservation, and production-cost reduction (Claassen et al., 2018).

Claassen et al. (2018) analyzed the field operations data from the ARMS to identify farms that met USDA, Natural Resources Conservation Service (NRCS) standards for conservation tillage, based on the Soil Tillage Intensity Rating (STIR), a measure of soil disturbance based on type of tillage equipment used, tillage depth, speed, and percent of soil surface disturbed. A tillage practice is considered conservation tillage if it has a STIR rating of less than 80 and does not use a moldboard plow. The percentage of corn-planted acres that used no-tillage or conservation tillage changed slightly, from just over 60 percent in 2005, to 65 percent in 2016. Claassen et al. found that adoption rates of no-tillage in corn farming were higher in drier climates (the Northern Great Plains and the Prairie Gateway) and warmer climates (the Prairie Gateway, the Southern Seaboard, and the Eastern Uplands), possibly due to the water-conserving effects of no-till methods and because in warmer climates, tillage is less necessary for warming the soil.

Production Costs

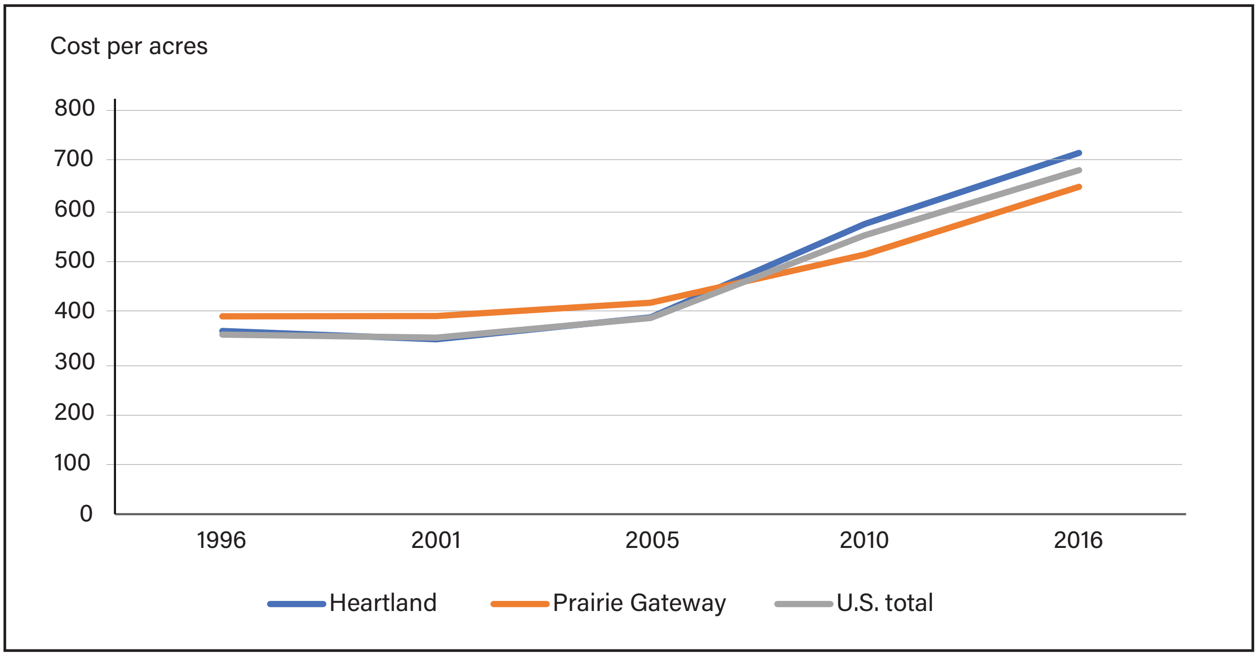
The total production cost per acre for U.S. corn increased from $354 in 1996 to $678 in 2016 in nominal terms (table 2; Box: Economic Research Service [ERS] Commodity Costs and Returns Methodology). While the total costs per acre by region were highly correlated over time, the Heartland and Prairie Gateway tended to have higher costs per acre over the 1996–2016 period (figure 11, table 3). In 2016, there was a $147 difference in per-acre costs between the highest cost region (the Heartland at $712) and the lowest cost region (the

[6]Treatments per acre are the total number of treatments times the acres treated each time over the total number of field acres on each field. For example, if the entire field was treated twice, the treatments per acre would be equal to two

[7]Conservation tillage is a tillage system that disturbs the soil less than conventional tillage

Northern Great Plains region at $565). Total gross value of production increased from $370 per acre in 1996 to $602 per acre in 2016.

Figure 11
U.S. average nominal total costs per acre on corn farms



Source: USDA, Economic Research Service, *Costs and Returns*.

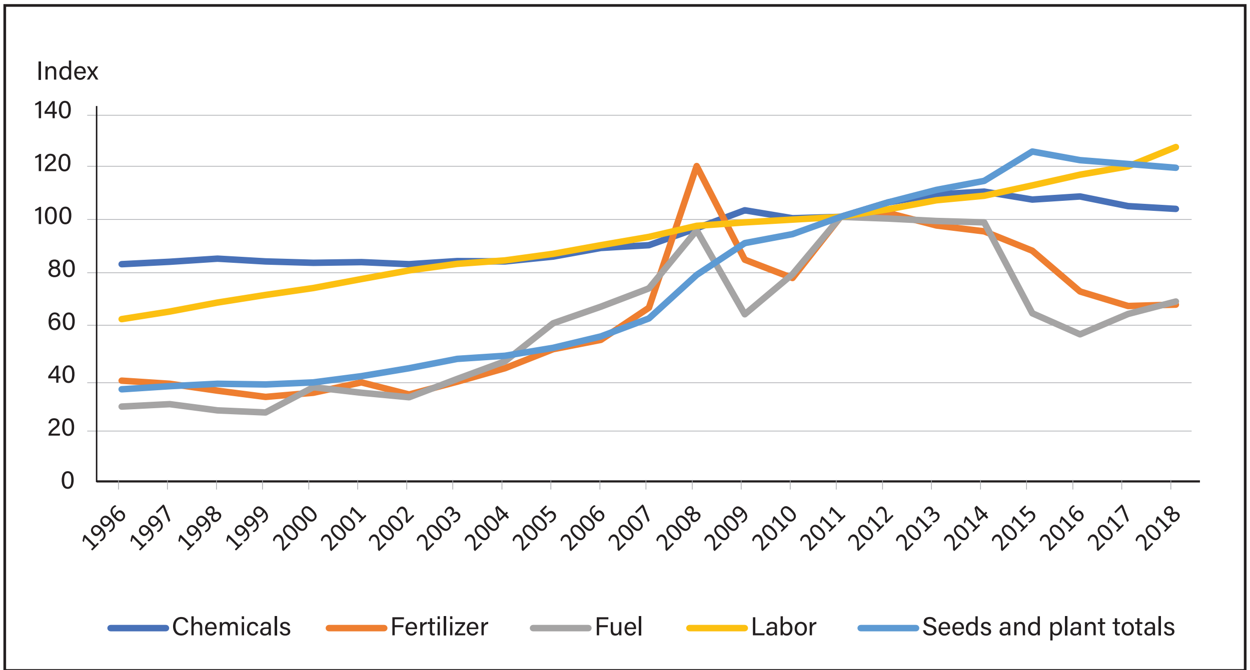
Table 3 includes a summary of the nominal U.S. average costs and returns for corn by input for the survey years 1996, 2001, 2005, 2010, and 2016. For each year in that period, NASS provides a price index for most major inputs to reflect how the per-unit input price changed relative to 2011. Figure 12 provides these indices, standardized such that the price of a unit of each input in 2011 is equal to 100. This figure assists in visualizing how various input prices changed over the period.

Over the study period, operating costs more than doubled, from $161 per acre in 1996 to $341 per acre in 2016. The largest percentage increase was from seed, which increased 263 percent from $27 per acre in 1996 to $98 per acre in 2016, with a steady upward trend mirroring the adoption of increasingly costly genetically engineered seeds. Between 1996 and 2016, fertilizer costs steadily increased by a total of 149 percent, from an average of $51 per acre in 1996 to $127 per acre in 2016. The price index for fertilizer increased by 111 percent during that same period, indicating that the cost increase was due to changes in both price and quantity of fertilizer used.

Fuel, lube, and electricity expenditures per acre remained steady in nominal terms over the time period, at $24 in 1996 and in 2016, with some fluctuations in between. Between 1996 and 2016, the price index for fuel increased by 97 percent, indicating average energy use per acre declined by nearly half. This decline may be due to the decline in irrigation rates, to the increased efficiency of tractors, and to no-tillage or conservation-tillage practices, which require fewer passes over the field (Hitaj and Suttles, 2016). Chemical costs increased by only 30 percent in nominal terms, from $27 per acre in 1996 to $36 per acre in 2016, in line with the chemical price index, which increased 31 percent.

Between 1996 and 2016, nominal total allocated overhead costs per acre rose by 73 percent. The largest increase was in the opportunity cost of land, which is an estimate of how much money the farmer paid for rent per acre, or, if the farmer owns the land, how much money the farmer could get from renting the land out for

Figure 12
Input price indices (2011 base year)



Source: USDA, National Agricultural Statistics Service, *Producer Price Indices*.

other purposes. This increase reflects the increased productivity of corn production. As productivity increases, the rental value of the land increases as well. The opportunity cost of land increased by 98 percent, from $81 in 1996 to $160 in 2016. The increase in the opportunity cost of land mirrored an overall increase in agricultural land values over that period. Between 1998 (the earliest year for which NASS documented crop cash rental rates) and 2016, the cash rental rate of cropland more than doubled, from $66.50 per acre in 1998 to $136 per acre in 2016. Although ERS accounts for land as a cost to farmers, many farmers own the land that they farm, which can be considered an asset that has substantially increased in value over the study period. In contrast, the opportunity cost of unpaid labor, an estimate of the wages a farm operator could have earned working off-farm. decreased in nominal terms, from $29 in 1996 to $26 per acre in 2016.

While the nominal cost of hired labor increased by 59 percent between 1996 and 2016, the price index for agricultural labor increased by 89 percent, suggesting farmers decreased their reliance on hired labor. Across years, hired labor accounts for a relatively small portion of total labor costs, with the opportunity cost of unpaid labor accounting for 91 percent of the cost of labor in 1996 and 85 percent in 2016. The sum of expenditures on paid labor and the opportunity cost of unpaid labor remained relatively stable in nominal terms, from $31.82 in 1996 to $30.25 in 2016.

Table 2

Average nominal costs and returns per acre for U.S. corn producers

	1996	2001	2005	2010	2016
Gross value of production	Dollars per planted acre				
Primary product grain	366.46	264.96	259.26	688.47	602.07
Secondary product silage	3.47	1.96	1.17	0.92	1.85
Total, gross value of production	369.93	266.92	260.43	689.39	603.92
Operating costs					
Seed	26.65	32.34	40.47	81.58	98.36
Fertilizer	51.21	55.12	69.35	112.03	126.53
Chemicals	27.42	26.44	22.84	26.29	35.65
Custom services	11.30	10.94	9.97	16.36	22.69
Fuel, lube, and electricity	24.43	20.88	26.50	25.80	24.08
Repairs	15.78	13.76	14.00	23.96	32.20
Purchased irrigation water	0.30	0.22	0.12	0.11	0.26
Interest on operating capital	3.86	2.60	3.12	0.28	0.78
Total, operating costs	160.95	162.30	186.37	286.41	340.55
Allocated overhead					
Hired labor	2.83	2.92	2.08	2.96	4.49
Opportunity cost of unpaid labor	28.99	24.96	22.02	22.54	25.76
Capital recovery of machinery and equipment	63.02	54.69	64.02	84.40	117.96
Opportunity cost of land	80.79	86.50	93.27	127.33	160.42
Taxes and insurance	6.98	5.49	6.51	8.46	11.56
General farm overhead	10.38	11.67	12.61	18.10	17.74
Total, allocated overhead	192.99	186.23	200.51	263.79	345.72
Costs listed					
Total, costs listed	353.94	348.53	386.88	550.20	678.48
Net					
Value of production less total costs listed1	15.99	(81.61)	(126.45)	139.19	(74.56)
Value of production less operating costs	208.98	104.62	74.06	402.98	263.37
Supporting information					
Yield (bushels per planted acre)	130.00	144.00	149.00	159.00	183.00
Price (dollars per bushel at harvest)	2.82	1.84	1.74	4.33	3.29
Enterprise size (planted acres)	189.00	236.00	250.00	280.00	278.00
Production practices					
Dryland (percent of acres)	85.00	86.00	88.00	89.00	89.00
Irrigated (percent of acres)	15.00	14.00	12.00	11.00	11.00

Note: [1] Total costs include non-cash economic costs like the value of unpaid labor and rental value of owned land.

Source: USDA, Economic Research Service, *Costs and Returns.*

USDA, Economic Research Service Commodity Costs and Returns Methodology

The Economic Research Service (ERS) estimates the commodity costs and returns per planted acre for each farm in the Agricultural Resource Management Survey (ARMS) data, and reports averages of the costs and returns, enterprise size, crop yield and price, and portion of acres irrigated of major crop commodity for the United States and by region. The ARMS is the primary source for the ERS Costs and Returns estimates. Survey data are supplemented by supporting information from the USDA, National Agricultural Statistics Service (NASS). Between survey years, costs are updated based on annual input price indices, output price estimates, yield estimates, and acreage estimates from NASS.

The estimates itemize costs per planted acre into operating and allocated overhead costs. Operating costs include seed; fertilizer; chemicals; custom services; fuel, lubricant, and electricity; repairs; purchased irrigation water; and interest on the operating capital. Allocated overhead costs include hired labor, opportunity cost of unpaid labor, capital recovery of machinery and equipment, opportunity cost of land, taxes and insurance, and general farm overhead. The ERS calculates gross returns using the product of the per-bushel yield and the per-bushel harvest-period price of corn. Government payments are not included in the calculation of returns.

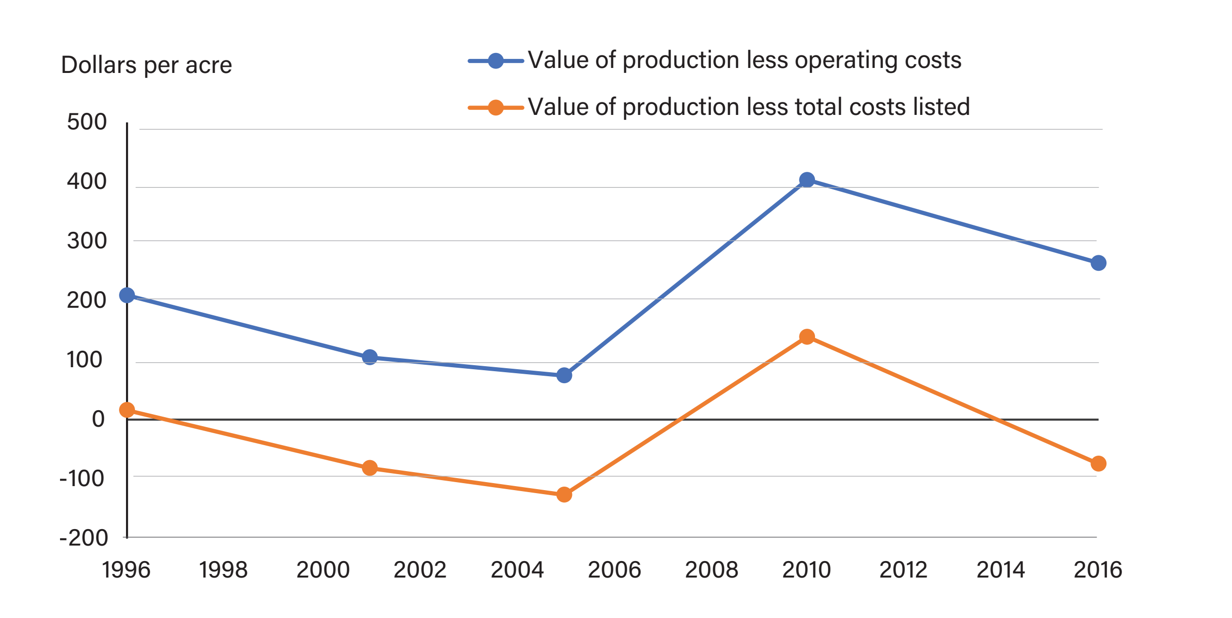
This report includes estimates of economic net returns, or net total returns, in addition to accounting net returns, or net operating returns. For economic net returns items such as the opportunity cost of the land are included as a cost, even if the farmer does not actually pay any rent on it. The amortized costs of depreciation for the machinery are included, even if the farmer already owns the machines and does not pay any marginal costs for their use. Similarly, the opportunity cost of the farmer's own labor is included as a cost, even if the farmer is not directly paying wage costs for their own hours worked. For this reason, zero or negative economic net returns do not imply that the farm is losing money.

Table 3
U.S. total nominal corn costs per acre by region

	Heartland	Northern Great Plains	Eastern Uplands	Northern Crescent	Prairie Gateway	Southern Seaboard	U.S. total
	Dollars per acre						
1996	361	279	350	316	390	344	354
2001	345	286	315	350	391	341	349
2005	388	322	364	394	417	358	387
2010	572	492	475	514	512	539	550
2016	712	565	578	652	646	697	678

Source: USDA, Economic Research Service, *Costs and Returns.*

Figure 13
U.S. corn net returns per acre



Note: Total costs include non-cash economic costs like the value of unpaid labor and rental value of owned land.
Source: USDA, Economic Research Service, *Costs and Returns*.

Net Returns

ERS reports the net costs and returns of corn production on a per-acre basis. ERS net returns estimates represent averages across a wide variety of farms. Actual net returns to individual farms vary widely as a result of differences in farm size, specialization, and other characteristics that affect operating costs, marketing opportunities, and efficiency. Average net returns are reported in terms of both net operating returns and net total returns (see Box: Agricultural Resources Management Survey (ARMS) Data, and Box: Economic Research Service (ERS) Commodity Costs and Returns Methodology). Net operating returns are calculated as the per-acre value of production less the per-acre operating costs, which include purchased inputs, energy costs, repairs, and interest on operating capital. Net total returns are calculated as the per-acre value of production less the per-acre total costs, which, in addition to operating costs, include hired labor, capital recovery of machinery and equipment, opportunity cost of land, taxes and insurance, and general farm overhead. Total costs includes some items, like opportunity costs of owned farmland and unpaid labor, that do not reflect actual cash expenditures.

Similarly, capital expenditures on machinery and equipment are smoothed over multiple years, although actual purchases may be made from returns in a high-income year. Operating costs require annual expenditures from revenue, so if net operating returns are negative, those expenditures must come from savings or credit. Non-cash total costs, on the other hand, do not involve annual outlays, so if net total returns are negative, while they will likely enter into farming decisions over the longer term, in the short-term they may not.

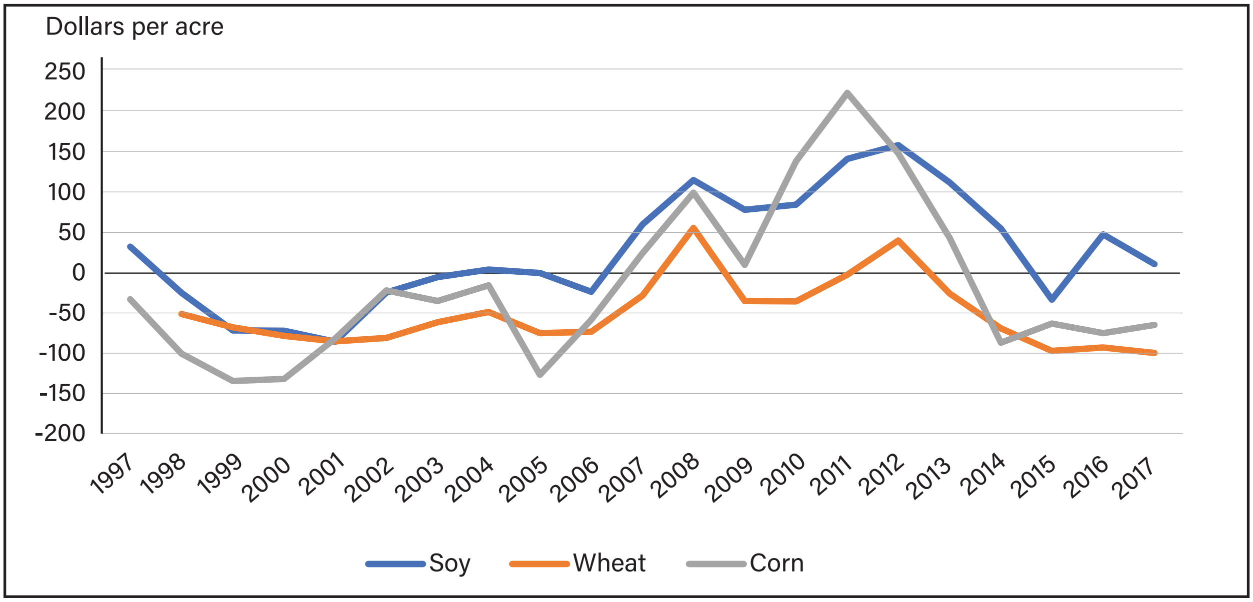
Across regions, both net operating returns and net total returns per acre for corn were highest in 2010 and lowest in 2005 (figure 13; table 4). The variation in the nominal price of corn accounted for more variation in the net operating returns and the net total returns than the variation in price of inputs. This was due primarily to the unusually high nominal price of corn between 2010 and 2012. While no single region consistently had the highest or lowest net returns across every year, the Heartland had the highest average of net operating returns ($231.08 per acre) and the average of net total returns across survey years (-$16.21 per acre). Conversely, the Southern Seaboard had the lowest cross-survey-year average net operating returns ($140.96 per acre) and the lowest average net total returns (-$65.78 per acre).

Table 4
U.S. corn average net returns per acre

	Eastern Uplands	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Southern Seaboard	U.S. total
1996							
Value of production less operating costs	196.31	224.12	148.92	133.30	244.57	171.12	208.98
Value of production less total costs listed	14.03	24.98	-18.79	-11.26	39.36	-8.06	15.99
2001							
Value of production less operating costs	54.11	116.35	54.86	60.59	103.26	128.67	104.62
Value of production less total costs listed	-111.48	-71.76	-128.79	-88.58	-92.77	-43.15	-81.61
2005							
Value of production less operating costs	20.75	84.10	67.22	70.82	29.40	40.07	74.06
Value of production less total costs listed	-153.42	-120.63	-131.94	-95.89	-171.93	-133.76	-126.45
2010							
Value of production less operating costs	379.07	431.1	406.70	311.71	348.13	241.77	402.98
Value of production less total costs listed	164.11	151.43	183.62	83.71	105.63	18.91	139.19
2016							
Value of production less operating costs	238.50	299.71	231.00	210.99	187.08	123.16	263.37
Value of production less total costs listed	-9.98	-65.05	-70.65	-62.31	-127.95	-162.85	-74.56

Note: Total costs include non-cash economic costs such as the value of unpaid labor and rental value of owned land.
Source: USDA, Economic Research Service, *Costs and Returns*.

Figure 14
U.S. net returns per acre for major field crops

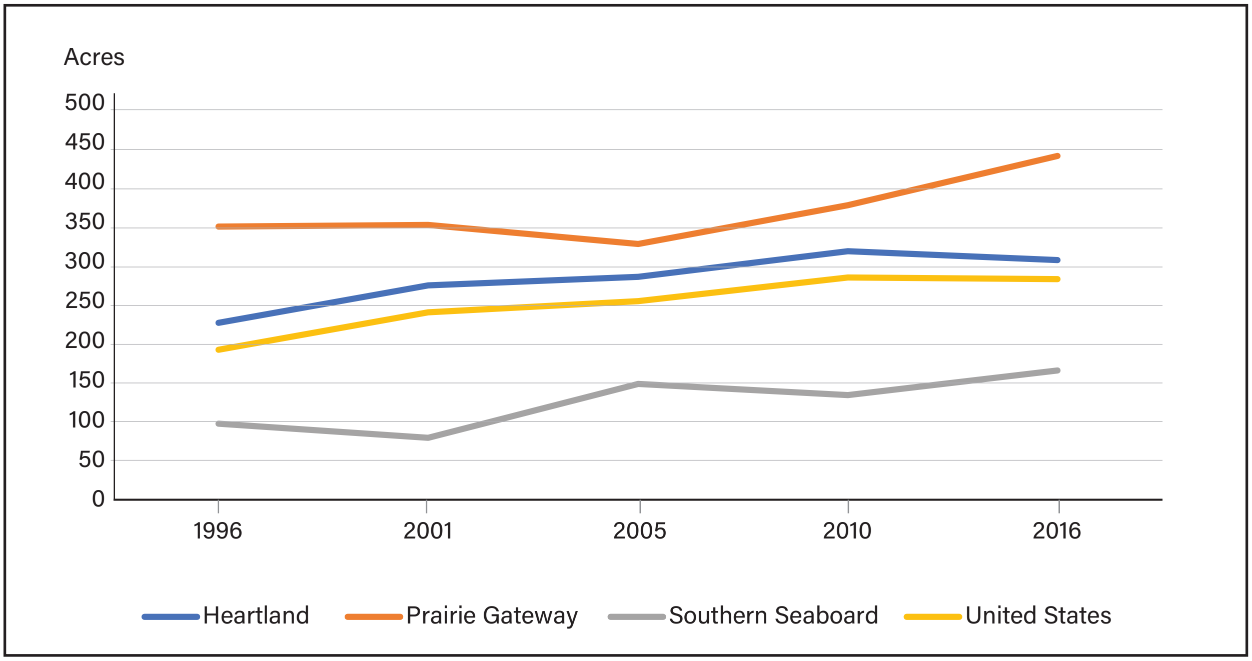


Note: Net returns are determined as the annual gross value of production less total production costs, which include non-cash economic costs like the value of unpaid labor and rental value of owned.

Source: Source: USDA, Economic Research Service, *Costs and Returns*.

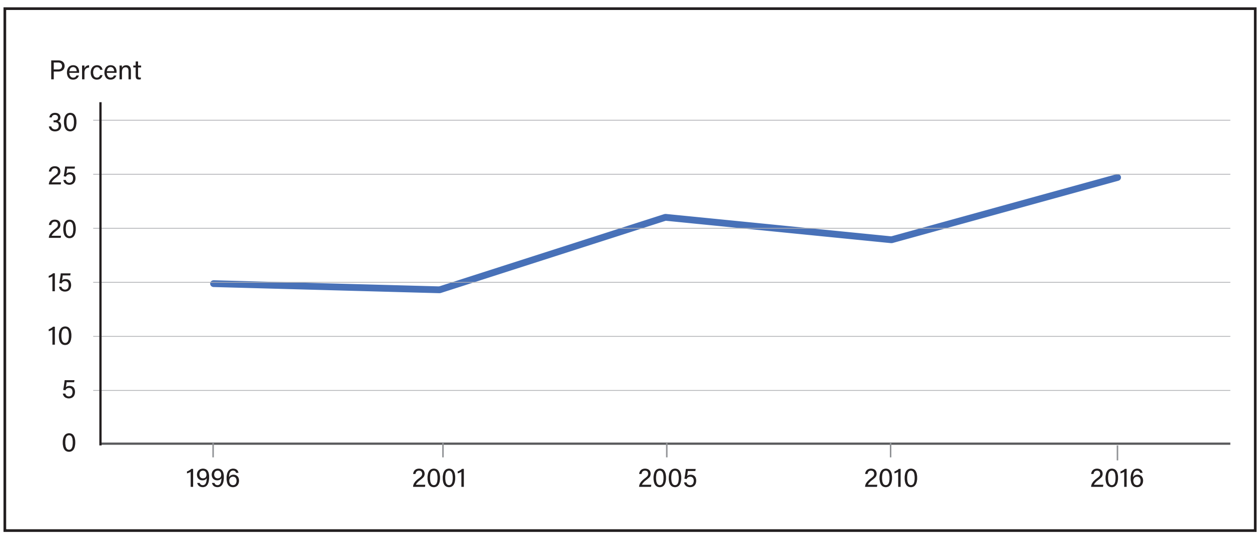
Between 1997 and 2016, during most years, U.S. net total returns per acre of corn were higher than those per acre of wheat, but lower than the net total returns for soybeans. Figure 14 displays the average U.S. net returns for corn, wheat, and soybeans—three crops that compete for acreage in the primary corn production regions—between 1997 and 2016. Soybeans generated higher net total returns per acre than corn in most years, except in 2001 and 2002, when net returns for corn and soybeans were almost identical, and in 2010 and 2011 when corn prices were at their highest. In most years from 1997 to 2016, net total returns for wheat were less than for corn and soybeans. Corn was the highest-acreage crop between 1996 and 2016, but was overtaken by soybeans in 2017, perhaps due to higher net returns from soybeans since 2012. Wheat has had the lowest acreage of the three crops, with acreage declining steadily.

Figure 15
U.S. corn acres per farm



Source: USDA, EconomicResearch Service, *Costs and Returns*.

Figure 16
Percent of U.S. corn farmers with a 4-year college degree



Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Farm Structure

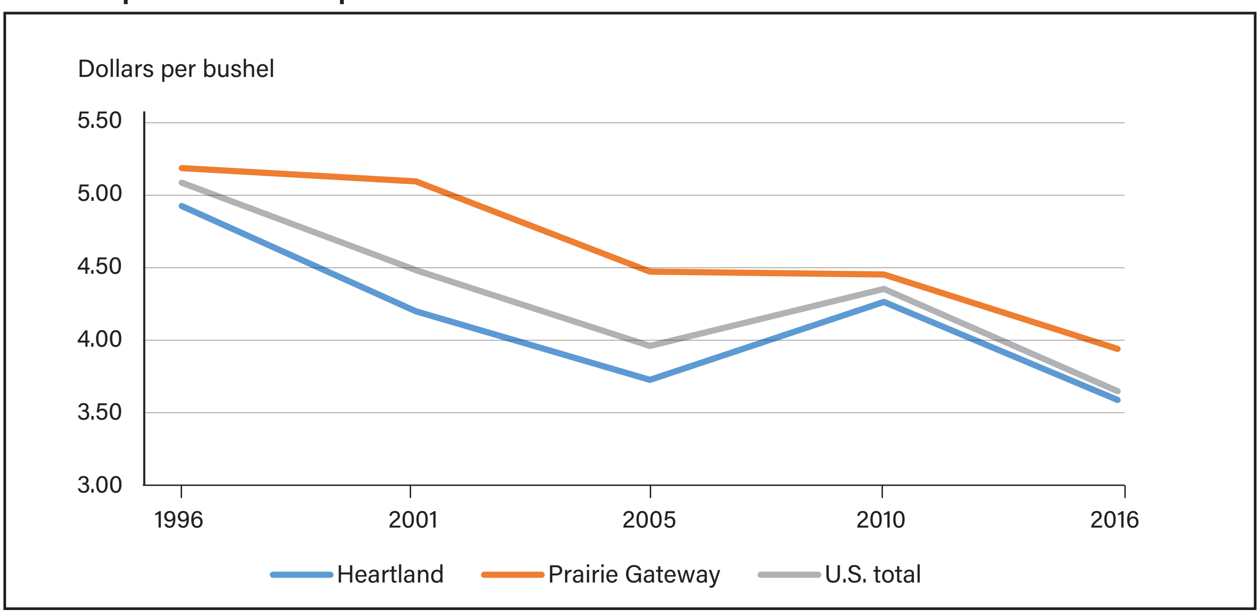
Farm Characteristics

Between 1997 and 2017, whole-farm acreage for farms that planted corn followed an upward trend, with an average of 501 acres in 1997, 639 acres in 2002, 637 acres in 2007, 641 acres in 2012, and 725 acres in 2017 (U.S. Census of Agriculture). U.S. average corn acres per farm followed a similar pattern, increasing steadily from 189 in 1996 to 280 in 2010, up nearly 50 percent (USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey). However, between 2010 and 2016, average corn acres per farm changed little (figure 15 and table 5). The increase through 2010 may have been related to rising corn prices and net returns that encouraged more farmers to expand corn acreage, while the subsequent plateau corresponds to the decline in corn prices and net returns between 2010 and 2016.

The increased average size of the corn enterprise has been particularly pronounced in the Northern Great Plains, on both absolute and percentage bases. Average corn acreage per farm in the Northern Great Plains increased by 96 percent, from 301 planted acres in 1996 to 589 planted acres in 2016. The Eastern Uplands experienced the highest percentage growth in size, with average corn acreage per farm more than doubling, from 42 planted acres in 1996 to 98 planted acres in 2016, although this region had by far the smallest corn farms. In contrast, the Prairie Gateway experienced only a 26-percent increase in planted acres per farm, from 344 acres in 1996 to 433 acres in 2016. The plateau in average U.S. corn acres per farm between 2010 and 2016 resulted from average corn acres on farms in the Heartland, the largest region, having fallen slightly between 2010 and 2016 (313 to 302 acres). In most other regions, corn acres per farm increased significantly between 2010 and 2016, up more than 50 percent in the Northern Great Plains and Eastern Uplands regions.

As farms planting corn increased the share of corn acres over other crops, a higher portion of their earnings came from corn production. On average, the percent of the gross value of production from corn increased from 37 percent in 1996 to 41 percent in 2016, after having declined to 28 percent in 2001 and having rebounded to 41 percent in 2010. The portion of the total farm acreage where either corn grain or corn silage was harvested has remained fairly steady, at around one-third in each year.

Figure 17
U.S. corn production costs per bushel



Note: Deflated by USDA, National Agricultural Statistics Service, *Production Inputs Index*.
Source: USDA, Economic Resource Service, *Costs and Returns*.

Table 5
U.S. corn average enterprise size per farm

	Eastern Uplands	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Southern Seaboard	U.S. total
Year	Acres						
1996	42	223	113	301	344	96	189
2001	72	270	138	281	346	78	236
2005	77	281	128	341	322	146	250
2010	63	313	146	390	371	132	280
2016	98	302	142	589	433	163	278

Source: USDA, Economic Research Service, *Costs and Returns*.

Farm Ownership and Operators

In 2016, 47 percent of all U.S. acres planted to corn were rented. This percentage has remained fairly stable since 1996, when 43 percent of acres were rented. It peaked in 2001, when 50 percent of corn-planted acres were rented. The proportion of corn acreage rented varied by region. In 2016, in the Heartland, 51 percent of corn acres were rented, while in the Northern Great Plains, 57 percent were rented, and in the Northern Crescent, 39 percent were rented.

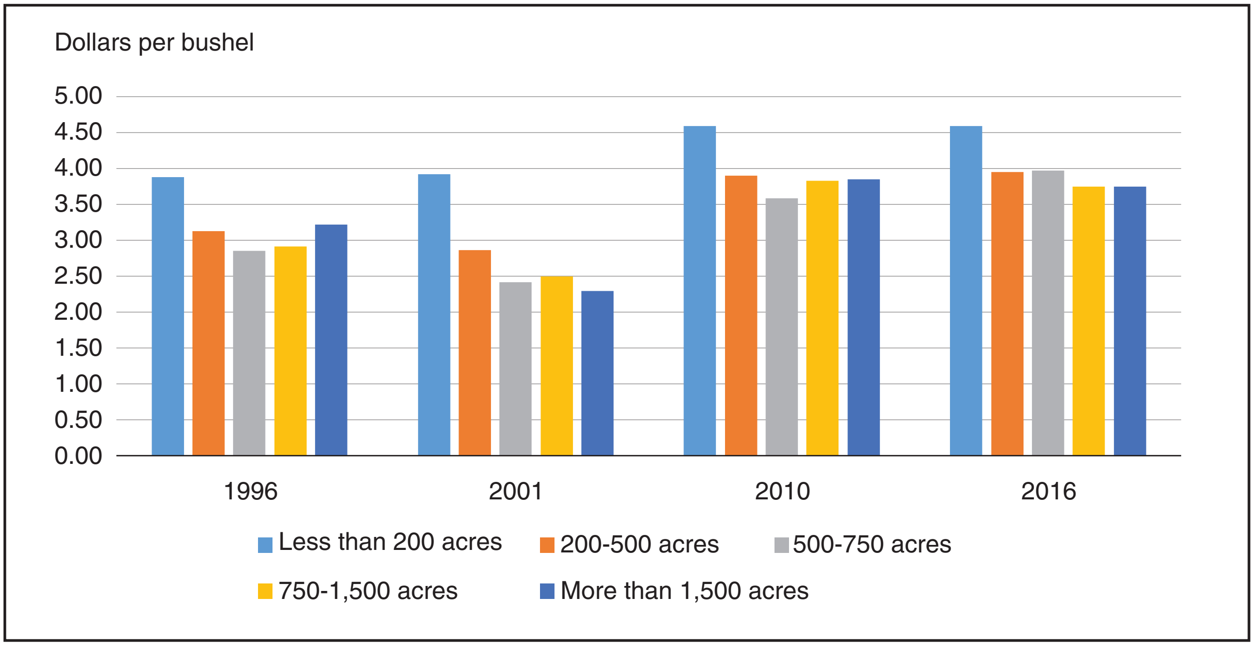
Education levels of corn farm operators trended upward, along with education levels of the general population (Camille and Bauman, 2016). In 1996, 15 percent of all corn farmers held a 4-year college degree. That figure rose to 21 percent in 2005 and to 25 percent in 2016 (figure 16). In 2016, 24 percent of farmers in the Heartland held college degrees, compared with 20 percent in the Northern Crescent, 28 percent in the Northern Great Plains, and 28 percent in the Prairie Gateway.

The average age of corn farm operators increased from 52 years in 1996 to 55 years in 2016 and was similar across regions. This trend mirrors the rising age of farmers across crops (Census of Agriculture, 2007, 2012, and 2017).

Productivity Changes

Productivity of corn farms can be measured as the quantity of resources required to produce a bushel of corn. Corn productivity can be increased by higher yields per acre, more efficient input use per acre, or a combination of both. One measure of productivity is the unit cost of producing corn. To calculate the average unit cost in a region, the total cost of all production expenses is divided by the average yield. Since prices of inputs change over time, total costs are deflated using the NASS production input prices index for 2011 (McBride et al., 2019). This index is based on sector-wide agricultural production prices.

Figure 18
U.S. corn production costs per bushel by operation size and year



Sources: USDA, Economic Research Service and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey and USDA, Economic Research Service, *Cost and Returns*.

In order to minimize the effect of year-to-year variation in yield and costs on the productivity change estimates, a 5-year moving average yield (the target year, the 2 previous years, and the 2 following years are used, except for the 1996 and 2016 estimates[8]). The 1996 yield estimate includes the 3-year average of 1996–1998, and the 2016 estimate includes the 4-year average of 2014–2017. Yield and costs per acre are estimated on a regional level.

Across the United States, annual corn yields trended up, from 130 bushels per acre in 1996 to 183 bushels per acre in 2016, averaging an annual growth rate of 1.7 percent. Yield growth rates were higher in the Northern Great Plains, with an average annual growth rate of 2.5 percent, rising from 99 bushels per acre in 1996 to 164 bushels per acre in 2016. The Heartland also experienced high growth in yield, averaging a 1.9-percent increase per year, from 138 bushels per acre in 1996 to 200 bushels in 2016. Yields in the Prairie Gateway increased substantially more slowly, from 143 bushels per acre in 1996 to 157 bushels per acre in 2016, averaging a 0.4-percent increase per year.

[8]The 1996 estimate used a 3-year average and the 2016 estimates used a 4-year average because there was no regional-level yield data available for 1994–1995 and 2018.

Between 1996 and 2016, while nominal total production costs per acre for corn doubled, the U.S. inflation-adjusted average total production costs per bushel decreased from $5.07 per bushel in 1996 in 2017 dollars to $3.64 per bushel in 2016 (figure 17, table 6). The spike in production costs per bushel in 2010 coincided with increases in average U.S. corn prices. With corn prices well above production costs in 2010, producers may have been less sensitive than they were in other years to input prices when deciding to expand acreage or make yield-increasing production decisions (Foreman, 2014).

Table 6
Inflation-adjusted average U.S. corn total costs per bushel

	Eastern Uplands	Heartland	Northern Crescent	Northern Great Plains	Prairie Gateway	Southern Seaboard	U.S. total
Years	Dollars per acre, deflated to 2017 dollars using USDA, National Agricultural Statistics Service, *Production Prices Index*						
1996	5.87	4.91	5.27	5.33	5.17	6.74	5.07
2001	5.83	4.19	4.95	4.97	5.08	5.66	4.47
2005	4.81	3.72	4.64	4.18	4.46	4.63	3.95
2010	4.26	4.25	4.34	4.40	4.44	5.64	4.34
2016	3.33	3.58	3.74	3.59	3.92	4.83	3.64

Due to data constraints, calculations are based on 5-year average yields for 2001–2016, and 3-year average yields for 1996.

Source: USDA, Economic Research Service, *Costs and Returns*.

For most of the study period, the Southern Seaboard region had the highest costs per bushel, starting at $6.74 in 1996 and declining to $4.83 in 2016. While the Heartland had the lowest total costs per bushel in the beginning of the study period, production costs in the Eastern Uplands region were lower in 2016. The Eastern Uplands had the largest relative decline in total production costs per bushel, going from the second highest cost region in 1996, at $5.87, to becoming the lowest cost region in 2016. That the Heartland has consistently lower production costs per bushel may be due to its deep rich soils, flat lands, and good drainage. Across the United States, corn farm productivity has increased substantially over the past two decades.

Economies of Size

Economies of size exist if unit costs decline as the size of operation increases. The existence of economies of size has been shown to be a driving force behind changes in operation size and productivity over time (McBride and Key, 2013). To evaluate the economies of size associated with U.S. corn production, the total costs per bushel were averaged across operation size groups (figure 18, table 7). Operation size was measured using the total number of corn acres planted on the farm. Nationally, total costs per bushel were higher for smaller farms and declined as farm size increased.

Total costs per bushel ranged from $4.66 per bushel for farms with under 200 planted acres of corn to a low of $3.75 per bushel for farms with more than 1,500 planted acres of corn.

One measure of the change in economies of size over time is the ratio of total costs per bushel of the lowest farm size category (under 200 acres) to the total costs per bushel in the highest size category.[9] By this metric, economies of size were greatest in 2001, with a ratio of 1.71 to 1 for total costs per bushel of farms less than 200 corn acres to total costs per bushel of farms greater than 1,500 corn acres. Aside from the spike in 2001,

[9]Costs per bushel are available on the individual farm level only for the survey years of 1996, 2001, 2010, and 2016.

the economies of size were steady across the other years, with a ratio of 1.20 to 1 in 1996, 1.19 to 1 in 2010, and 1.24 to 1 in 2016.

The 2001 spike may be attributable to larger farms having disproportionately adopted genetically engineered seeds when they first came on the market, though this discrepancy had evened out by the time of the 2005 survey (Fernandez-Cornejo and McBride, 2002). In 2001, 13 percent of acres on farms with less than the median planted corn acres used insect-resistant seed varieties compared with 24 percent of acres on farms with above the median number of planted acres. By 2005, the farms below the median number of corn-planted acres still had a lower adoption rate, at 33 percent of acres versus 40 percent of acres for farms above the median number of planted acres, though in both absolute and percentage terms, this discrepancy was less than it was in 2001.

On a national level in 2016, the spread of corn acres between size groups was fairly even, with 20 percent of corn acres on farms with over 1,500 acres of corn, 23 percent on farms with 750 to 1,500 acres, 16 percent on farms with 500 to 700 acres, 26 percent on farms with 200 to 500 acres, and 15 percent on farms with fewer than 200 planted corn acres. With the majority of corn farms in the smaller size groups (less than 750 acres), there is substantial room for corn farms to take further advantage of economies of size.

Table 7

U.S. average corn cost per bushel by operation size

	1996	2001	2010	2016
Size group	Total ($) cost per bushel	Total ($) cost per bushel	Total ($) cost per bushel	Total ($) cost per bushel
Less than 200 acres	3.87	3.91	4.58	4.66
200–500 acres	3.12	2.85	3.89	3.98
500–750 acres	2.84	2.41	3.57	3.99
750–1,500 acres	2.91	2.49	3.82	3.76
More than 1,500 acres	3.21	2.28	3.83	3.75

Sources: USDA, Economic Research Service (ERS), *Costs and Returns*; and USDA, ERS and USDA, National Agricultural Statistics Service, Agricultural Resource Management Survey.

Characteristics of High-Productivity and Low-Productivity Farms

To determine the distinguishing characteristics of high- and low-productivity farms, respondents were divided into quartiles by their total costs per bushel, with key production characteristics reported for each quartile from the 2016 survey (table 8). The highest productivity quartile (lowest cost per unit) had an average total cost per bushel of $2.83, and the lowest productivity quartile had an average cost per bushel of $6.32.

The three highest productivity (lowest cost) quartiles had higher average whole-farm acreage than the lowest productivity quartile, with per-farm corn acreage mostly the same for the three highest productivity quartiles. This suggests farm size was not the sole determinant of productivity. Irrigation was consistently correlated with lower productivity farms, with 2 percent of the highest productivity farms irrigating, 6 percent of the

Table 8
Characteristics of high- and low-productivity operations, by quartile, *2016 Agricultural Resource Management Survey*, corn survey

	Lowest cost, highest productivity top 25 percent	Upper middle 25 percent	Lower middle 25 percent	Highest cost, lowest productivity lower 25 percent
Costs per bushel	$2.83	$3.46	$4.04	$6.32
Acres on farm	688	705	663	482
Yield	184	191	174	133
Yield goal	187	183	178	159
Percentage of acres irrigated	2	6	16	27
Chemical costs per acre	$28.88	$35.38	$36.67	$41.01
Fertilizer costs per acre	$106.74	$124.49	$137.61	$157.97
Custom services costs per acre	$26.86	$29.50	$24.13	$23.98
Fuel costs per acre	$18.58	$19.33	$24.22	$30.40
Repairs costs per acre	$24.34	$27.57	$31.20	$36.62
Paid labor costs per acre	$3.06	$3.63	$3.39	$5.70
Unpaid labor costs per acre	$25.56	$27.55	$34.42	$69.26
Land costs per acre	$121.00	$154.35	$155.21	$126.24
Allocated overhead costs per acre	$272.25	$321.36	$346.61	$370.54
Taxes and insurance costs per acre	$11.47	$11.08	$13.31	$14.82
Operating costs per acre	$299.55	$338.75	$353.93	$383.79
Total costs per acre	$571.80	$660.11	$700.54	$754.33

Sources: USDA, Economic Research Service (ERS), *Costs and Returns*; and USDA, ERS and USDA, National Agricultural Statistics Service, *Agricultural Resource Management Survey*.

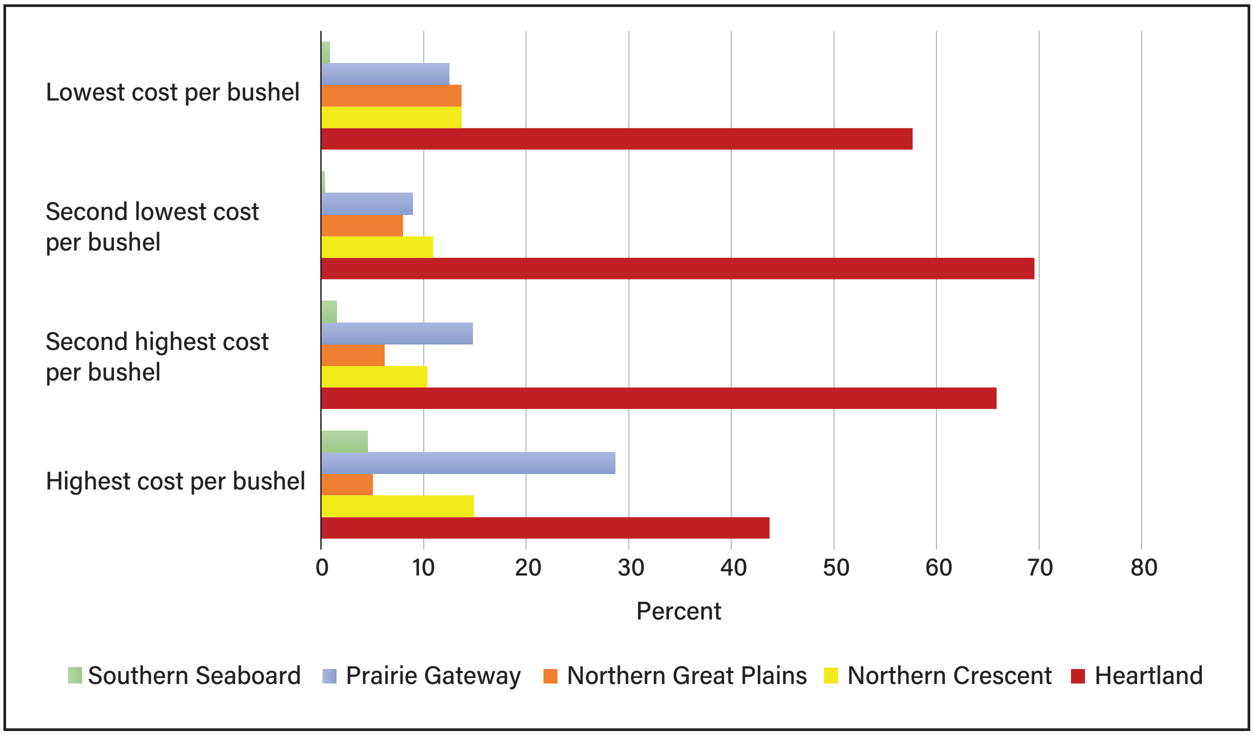
second highest productivity farms irrigating, 16 percent for the third highest, and 27 percent of the lowest productivity farms irrigating. The correlation between low productivity and high irrigation rates may be attributable to farmers using irrigation to compensate for lower productivity land.

Higher productivity farms also had lower per-acre operating costs and lower per-acre total costs, although the distribution of costs of inputs between high- and low-cost farms varied by input. The highest productivity quartile averaged $572 in total costs per acre while the lowest productivity quartile averaged $754 in total costs per acre. Similarly, the highest productivity quartile averaged $300 in operating costs per acre while the lowest productivity quartile averaged $384 in operating costs per acre. In addition to lower operating costs, higher productivity farms experienced higher yields, with the highest productivity quartile averaging 184 bushels per acre versus 133 bushels per acre for the lowest productivity quartile. Lower productivity farms had consistently higher per-acre expenditures on chemicals, fertilizers, fuel, repairs, labor, and overhead. However, there was no consistent relationship between productivity and per-acre expenditures on custom services, land costs, or taxes and insurance.

The high-cost producers had a significantly lower average yield than the low-cost producers, but their yield goal was also lower. The yield goal is the yield that the operator uses in planning input application. It is often based on historical yields (ARMS Interviewer's Manual, 2015). The lowest cost producers had a yield goal of 187 bushels per acre, followed by 183 bushels per acre for the second quartile, 178 bushels per acre for the third quartile, and 159 bushels per acre for the highest cost producers. This relationship suggests that low-productivity producers may have had chronic lower yields compared with other producers, and not just in 2016. The average corn yield of farms in the top, third, and fourth productivity quartiles in 2016 fell below the average yield goal of those quartiles, with only the second-most productive quartile surpassing the yield goal.

The Heartland accounted for the largest percentage of acres in all quartiles but accounted for a disproportionately low number of acres in the lowest quartile (figure 19). The Heartland accounted for 58 percent of acres in the highest productivity quartile, 70 percent in the second highest productivity quartile, 66 percent in the third-highest productivity quartile, and 44 percent in the lowest productivity quartile. The Northern Great Plains accounted for more high-productivity acres than low-productivity acres, making up 14 percent of the highest productivity acres, 8 percent of the second highest, 6 percent of the third highest, and 5 percent of the lowest productivity acres. The Prairie Gateway and the Southern Seaboard regions had disproportionately high numbers of acres in the lowest productivity quartile, with the Prairie Gateway accounting for 29 percent of all acres in the lowest productivity quartile versus 13 percent in the highest productivity quartile, and the Southern Seaboard accounting for less than 1 percent of acres in the highest and second highest productivity quartiles, 2 percent of acres in the second lowest-productivity quartile, and 5 percent of acres in the lowest productivity quartile. The Northern Crescent region accounted for a similar percentage of acres among all quartiles.

Figure 19
Percentage distribution of acres by region and cost per bushel quartiles



Source: USDA, Economic Research Service and USDA, National Agricultural Statistics Service

Conclusion

Inflation-adjusted costs per bushel of U.S. corn production have decreased substantially over the last 20 years. This indicates productivity growth in corn production, which may have been driven by technological change.

Genetically engineered seeds entered the market in 1996, and now have near-universal adoption. These seeds include Bt varieties that are insect-resistant, as well as herbicide-tolerant and drought-resistant varieties. These new varieties enabled the growing of corn in a widened variety of climates, and corn production expanded into new areas.

The adoption of genetically engineered seeds may have also spurred changes in other production practices, such as chemical use and irrigation. Overall, irrigation rates declined from 15 percent of corn acres in 1996 to 11 percent of corn acres in 2016, reflecting both regional shifts and substitution with drought-tolerant seeds. Genetically engineered seeds have served as a substitute for insecticides, reducing the need for insecticide applications. While insecticide applications decreased, herbicide and fungicide treatments increased, due to factors such as increased resistance to herbicide and new fungicide active ingredients on the market.

Adoption of precision agriculture technologies greatly increased between 1996 and 2016. Guidance systems, yield monitors, yield maps, and variable-rate applicators all proliferated, reflecting trends in other major field crops. The combination of precision agriculture, developments in chemical active ingredients, and genetically engineered seeds led to a decrease in overall production costs per bushel between 1996 and 2016.

The decrease in per-bushel production costs, in combination with seed innovations and to some extent the siting of new ethanol production plants, has supported the expansion of corn production to new areas. Despite this expansion, the Heartland region continues to lead in terms of overall acreage and yield, and lowest costs of production per bushel. The combination of higher yields and more acres has led to an overall increase in U.S. corn production.

Meanwhile, corn acreage per farm has increased as more farms take advantage of economies of size. Larger corn farms tended to have lower production costs per bushel up to around 750 acres, where the economies of size leveled off. With the average corn acreage per farm in 2016 at 278 acres, this leaves substantial room for more farms to take advantage of economies of size.

Corn farms that were more productive, as measured by having lower costs per bushel, had several differences from less productive corn farms. Higher productivity farms were larger and were less likely to irrigate. Higher productivity farms also had higher yields, higher yield goals, and lower costs per acre.

Yield, productivity, and costs varied across regions. Between 1996 and 2016, the Heartland region averaged the highest yields and the Southern Seaboard region averaged the lowest yields. In 2016, the Eastern Uplands and the Heartland had the highest productivity, with productivity growth strongest in those regions throughout the study period. The Eastern Uplands, the Northern Great Plains, and the Heartland experienced the highest net returns in 2016.

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